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Supply Chain Management of Tri-modal Sensor

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Supply Chain Management of Tri-modal Sensor

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Abstract

The objective of this project is to analyze a supply chain designed to provide a prototype electronic system with multiple companies involved. The rationale for this project is that integrating multiple companies' products and intellectual property to produce a new prototype which produces a new set of functionalities incorporates many types of risk. These risks include, but are not limited to, compatibility of technology, scheduling, cost overrun, and viability of the delivered prototype system. The methods used to analyze the supply chain include Axiomatic Design, critical path, Gantt chart, and qualitative risk assessment. Results indicate that the risks can be managed to ensure successful fulfilment of the prototype production. A main conclusion is that project management that includes scheduling and risk analysis greatly reduces the risk of prototype delivery failure.

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Introduction

Members of the armed forces are exposed often to incoming hostile gunfire. Soldiers face many different kinds of threats, and currently, there are less than optimal solutions to address the identities of various gunfire threats in real time. The project sponsor proposes a solution that embodies: low-cost, low weight, multi-modal, portable, and low false alarm rate. This will be accomplished using three sensor technologies: Electro-Optical/Infrared (EO/IR), Radar, and acoustics. The three technologies, when working in unison, will provide a range of threat detection, encompassing small arms fire, rocket-propelled grenades (RPGs), and Air to Ground Missiles (ATGMs).

The US Government has a budget for such technologies that it wishes to see rapidly developed by industry, called the Rapid Innovation Fund (RIF). From the Department of Defense website,

> "The Rapid Innovation Fund provides a collaborative vehicle for small businesses to provide the department with innovative technologies that can be rapidly inserted into acquisition programs that meet specific defense needs." (Rapid Innovation Fund, 2014)

Keeping an eye toward pioneering strategic advances in technology, the DoD has entertained a proposal from Biomimetic Systems (BMS), the sponsor of this Major Qualifying Project, but prior to awarding the contract, the DoD wants to see a plan of action. As the sole company being awarded the grant money, BMS feels there are elements of risk in accepting the government proposal without analyzing the different steps in the supply chain.

The responsibility of assembling the components of the prototype falls to BMS. With this responsibility comes a number of potential issues, including physical components not matching, software incompatibility, and conflicting data output.

Rationale

The rationale for this project is that integrating several different companies' proprietary technologies into one physical unit brings unique risks associated with it. With so many diverse methods of collaborating the businesses' properties, it is crucial to analyze the risks associated with each to determine the best technique to move forward.

Supply chains offer opportunities to streamline and optimize the production of goods. With such a vast number of different components that combine into the final product, it's possible for small problems to detract from the goal of satisfying the customer's requirements. It is of utmost importance that companies seek to integrate existing processes with supply chain principles in order to maximize the benefit of value added activities.

According to Designing and Managing the Supply Chain, a textbook on supply chain management and design:

> Supply chains encompass the companies and the business activities needed to design, make, deliver, and use a product or service. Businesses depend on their supply chains to provide them with what they need to survive and thrive. Every business fits into one or more supply chains and has a role to play in each of them. (Simchi-Levi, 2005)

Businesses are often part of a global network of other businesses that rely upon one another in order to satisfy their customers. For example, a large company on Wall St. depends on its custodial service to present a clean and workable environment, while the custodial service depends on the manufacturers of the chemicals it uses to perform its duties, and the chemical manufacturer depends on the transportation service to ship its goods, and so on. Everyone plays a part in the global economy, and that keeps the world spinning. If one of the "cogs" in the machine breaks down, it can have rippling effects throughout the country, or possibly the world.

With such far reaching consequences, it is important for businesses to strive for optimization of practices. Supply chains offer large opportunities for companies to use dedicated suppliers to receive goods and materials for use in their processes, which then allow for resources that would otherwise be spent searching for such suppliers in other locations.

> The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole. (Mentzer, et al., 2001)

Companies that seek to remain competitive in today’s economy would be well served by optimizing supply chain operations.

Prototyping operations present the opportunity to process several iterations of a product before committing to a final design. From the proceedings of the 42nd Hawaii International Conference on System Sciences (HICSS):

> Prototyping is often presented as a universal solution to many intractable information systems project problems. Prototyping is known to offer at least three advantages (1) provide users with a concrete understanding, (2) eliminate the confusion, (3) cope with uncertainty. (Granlien, 2009)

Manufacturing a prototype of a product brings inherent challenges unique from mass production. It often occurs that a prototype will require original machine tooling, which must be purchased and tested before even the first unit is created. Sometimes, the initial prototype does not meet the design specifications, and must be redrawn and recreated in order to satisfy customer expectations. These obstacles present opportunities where proper planning and design work help formulate a workable solution to solve the customer’s needs.

According to Wenwen Jiang and Zhibin Xie:

> In the process of analytical model building, the designer's lack of understanding of the internal structure of products, product functional layout has not been fully established early in the design, the technology which make productions relied on is in a state of change. All of the above factors will make the product analytical model [cannot] fully meet the changing constraints, consequently, after the analytical model is made into the solid model, it [cannot] achieve the design tasks required indicators, such as function, technology, and modeling. (W. Jiang, 2011)

The authors reiterate that that the model (prototype) needs to be fully in line with the design parameters of the project in order to produce a functional solution for the customer. Failure to accomplish this can, and most likely will, result in a failure to complete a contract as described, affecting the likelihood of future agreements.

Methods

With any project, a roadmap must be constructed. One method to accomplish this is through the Axiomatic Design, a design framework created by MIT professor Nam Suh.

Axiomatic Design is based upon two axioms: the Independence Axiom and the Information Axiom. The Independence Axiom is satisfied by maximizing the extent to which the individual requirements of the system are independent. This allows alterations and other changes to be made on specific portions of the project while minimizing the impact on everything else. As described by Professor Suh, "Axiom 1 is named the *independence axiom*. An optimal design always maintains the independence of the functional requirements of the design. Axiom 2 is the *Information axiom:* The best design is a functionally uncoupled design that has the minimum information content." (Suh, 2001)

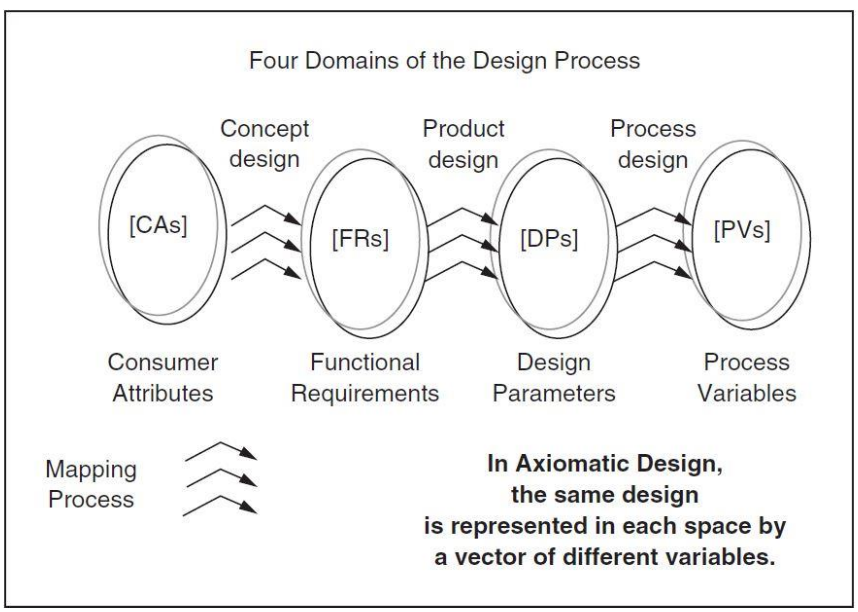

Figure 1 - Axiomatic Design's Four Domains

The Four Domains of Axiomatic Design (Figure 1) are the Customer Attributes, Functional Requirements, Design Parameters, and the Process Variables. The CAs characterize the consumer's needs and serve as the catalyst for the project. The FRs and DPs reflect different methods through which the design solves the CAs, as explained below. From *The Principles of Design*, "PVs are the variables of the processes that will result in the physical design described by the set of DPs," (Suh, 1990).

The high level Functional Requirements (FRs) are the "wave tops" that the project hopes to accomplish; without them, there would be no reason to do the project. In this case, the first FR (FR_0) is to deliver a prototype of the fused sensors on time and under budget. Underneath this overarching goal are the lower level FRs of "Ensure prototype functions properly," "Deliver prototype on time," and "Ensure the prototype is under budget."

To accompany these FRs are Design Parameters (DPs), which seek to describe the method by which the FRs are completed. The two categories match up at a minimum of 1:1, but in order to remain in control, previously completed FRs cannot be altered by newly added DPs.

Equation 1 - Axiomatic Design relational equation

$$\{FR\} = [A]\{DP\}$$

The square matrix [A] is such that for each FR, there is one DP that controls it. This is vital to ensure that previously accomplished FRs aren't changed by newly added DPs.

Figure 2 shows additional FRs:

	DP0: Construct appropriate budget and schedules	DP1: Stick to proposed budget	DP1.1: Utilize financial risk assessment tool	DP2: Outline testing schedule	DP2.1: Come up with schedule to assemble technologies	DP2.2: Outline testing schedule	DP3: Construct timeline	DP3.1: Develop system to manage risk
FR0: Deliver functional prototype on time and under budget	X							
FR1: Project is under budget		X		O	O	O	O	O
FR1.1: Manage financial risk			X	O	O	O	O	O
FR2: Product functions properly		O	O	X			O	O
FR2.1: Integrate functions		O	O		X	O	O	O
FR2.2: Test functionality		O	O		O	X	O	O
FR3: Project is on time		O	O	X	X	X	X	
FR3.1: Manage risks in schedule		O	O	O	X	O		X

Figure 2 - Axiomatic Design decomposition

Because FR_0 is to deliver a functional product that is both on time and under budget, a priority must be made between these three requirements. The hierarchy of these is as follows: number one is that the product functions, regardless of budget and time concerns. It is unlikely that the government will purchase a non-functioning product. If more time or money is required to achieve functionality, the government will wait. Second on this list is to ensure that the product is under budget. Given that functionality is achieved, money is the next most important concern. The government will wait for a product that works and is under budget, within reason, of course. This leaves the third level of importance to time. The aim of the RIF program is to obtain functional technology at an accelerated pace, but because in some cases new ground is being broken, complications arise that extend the initial time and money budgets allotted.

The FR that is linked with the most DPs is "Project is on time." Many of the other functionalities come before, but still affect, the "on time" requirement. Within the Axiomatic Design matrix, the DPs to which FR_3 is linked deal with schedules and other time requirements not directly linked to the project timeline. In this way, these DPs hold influence over the total timeline, but not directly.

An effective way to manage time is to establish project milestones. Utilizing a time table allows the project managers, at a glance, to determine very quickly whether the project is flowing smoothly, or if more resources must be allocated to overcome roadblocks that occur during the project lifecycle.

An example of a roadblock is unexpected supplier constraints. If different phases of the project cannot proceed without accomplishing prior steps, any holdup in the initial phases has the potential to affect many different steps further down the line. If one of the manufacturers experiences a supply shortage, for example, and needs another month to obtain the part they promised delivered, this will adversely affect the start date of the step involving that part once it arrives. Many companies allot for these types of occurrences by adding extra "insurance" time to delivery dates. Without sacrificing *too* much efficiency, the companies allow suppliers a certain amount of "wiggle room" to settle hiccups on their end to ensure that their portion of the business deal is completed within the specified time constraints.

It's essential to plan in advance for potential pitfalls in supply chain processes. Creating a "critical path" allows project managers to expand the flow of materials from beginning stages to final product, charting and noting the time each step will take. In this manner, they can see the time it will take to reach certain milestones, and plan accordingly. Figure 3 shows the critical path for BMS's proposal.

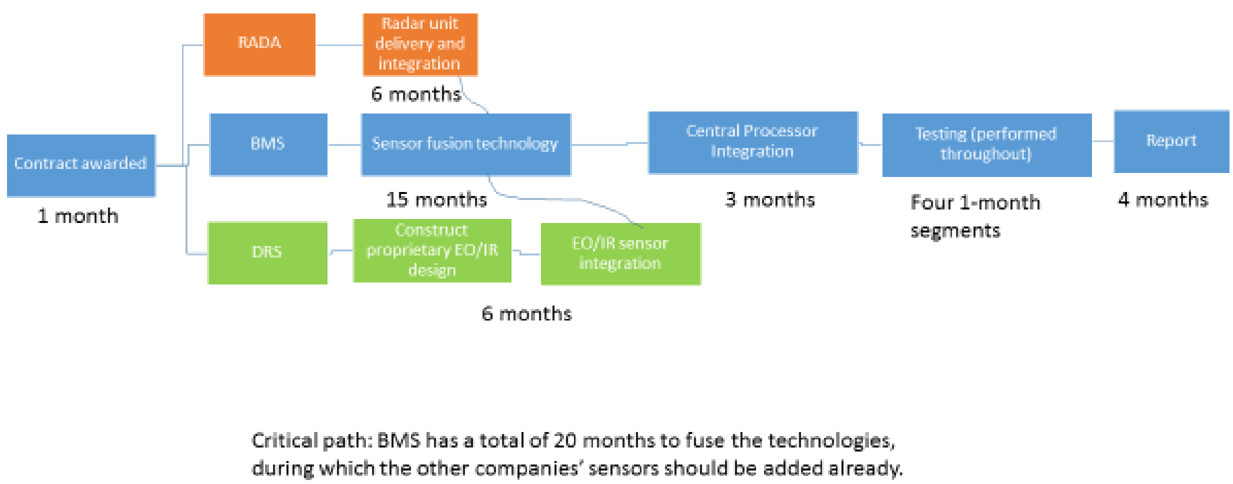

Figure 3 - BMS's Critical Path to completion

Gantt charts offer another way to visualize a scheduled timeline. Developed by Henry Gantt in the early 1900s, this chart displays every essential task, broken down by the time required to complete it, with relation to other tasks. "In their current primary application to projects [Gantt charts] provide an effective means for displaying important information." (Wilson, 2003)

Figure 4 shows a Gantt chart created for BMS's proposal to the government.

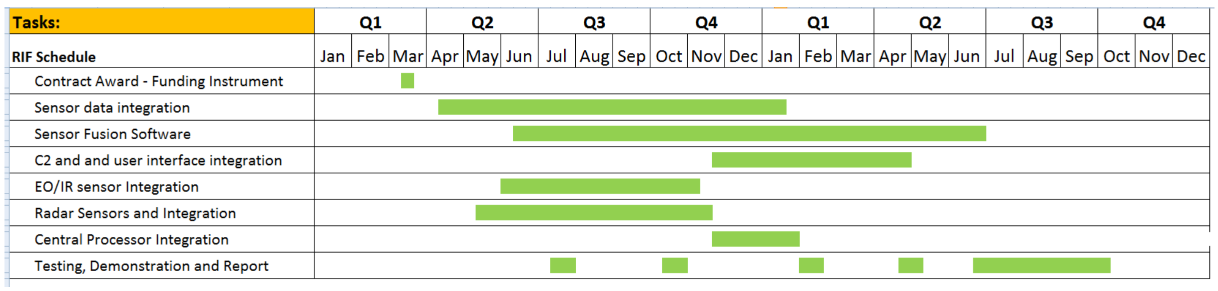

Figure 4 - BMS's proposed Gantt chart

The largest chunk of time will be spent by BMS integrating the sensors provided by the other two companies into its own. Developing this new software to synthesize and translate effectively the sensory input data is critical to proper functionality of the device. Without a rigidly designed testing cycle, it's easy for BMS to fall behind in their integration process.

As with any project, looking ahead for potential pitfalls is imperative. By qualitatively mapping strengths and weaknesses, one can attempt to preemptively overcome potential pitfalls before they hinder progress. Realizing your strengths and weaknesses enables you to identify snags that reasonably may occur along the way. Table 5 shows BMS's plan of attack for tackling the foreseen risks involved with the project:

Item	Risk	Risk Description	Mitigation	Mit. Risk
1	Med.	EO/IR sensor does not perform as advertised – embedded solution shows degraded performance.	A. Defined subcontract plan – statement of performance B. Use Optics 1 hardware in lieu of DRS C. Multiple algorithms required	Low
2	Med.	Sensor fusion software design iterations	Leverage BMS PinPoint and Cobham Individual Force Protection System (IFPS) sensor fusion software as core Linux compatible, code written in C /C++.	Low
3	Med.	BMS limited subcontracting experience	Cobham program management to mentor BMS on overall project. Cobham PM support included in Cobham hours.	Low
4	Med.	Test time may be too limited and live fire test costs too high	Piggy-back on existing Army-funded live fire tests and simulate RPG and ATGM live fire at Ft. Devens	Low
5	Med.	DRS EO/IR sensor cost may be too high to be tolerable for broad MIL Tactical Wheeled Vehicle use	Further due diligence with alternate suppliers or consider EO/IR only for certain vehicles (e.g., tanks)	Low
6	Med.	Development schedule limits demonstration time	Plan development for a 16 month duration, allowing 6 months for test and demonstration. Allows 2 mo. slack	Low

Note: An additional two months of slack has been added to the schedule for risk mitigation.

Figure 5 - Table of anticipated risks

Testing is a serious concern for any project, given that so much of the final deliverable relies upon the ability to perform to specification. Without a realistic testing schedule, it's possible to fall behind schedule and allow minor, easily solvable issues to mutate into much larger, budget consuming situations.

It's imperative that BMS not over-schedule its employees. This caution comes from Queuing Theory, the mathematical study of waiting lines. According to Harvard business Review:

> [The graph] shows that with variable processes, the amount of time projects spend on hold, waiting to be worked on, rises steeply as utilization of resources increases. Though the curve changes slightly depending on the project work, it always turns sharply upward as utilization nears 100%. (Stefan Thomke, 2012)

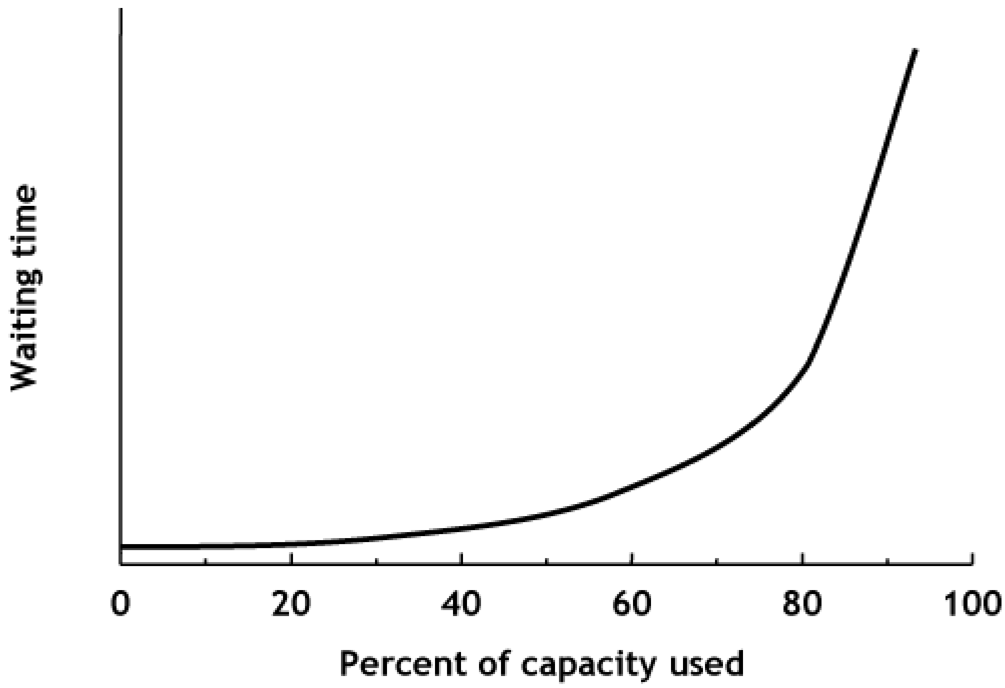

Figure 6 - Queuing Theory graph

Incorporating multiple companies' technology into a single product will inevitably result in at least one company waiting for another's work, information, or product to proceed to their next step, leading to increased wait times, which could result in missed deadlines.

A step in recognizing the proper level of capacity utilization is applying Little's Law, shown in Equation 2. Named after John Little, his law is a theorem that states:

> "Little's Law says that, under steady state conditions, the average number of items in a queuing system equals the average rate at which items arrive multiplied by the average time that an items spends in the system." (Chhajed, 2008)

Equation 2 - Little's Law

$$L = \lambda W$$

This allows for a quantifiable expression of task completion. With each new task that becomes available, as viewed from the proposed project completion timeline, BMS must make sure that the prerequisites for that task are finished before starting the next task. Checking with its business partners will permit BMS to ensure that the companies involved all adhere to the set production and testing schedule. This in turn will help alleviate potential bottlenecks that arise from overutilization of resources (in this case, people).

After analyzing the proposed risk mitigation strategy, we can see that BMS is in excellent shape to complete the contract on time with minimal risk.

Results

BioMimetic Systems utilized numerous methods to assemble their supply chain. Even after breaking down the risks involved with developing a prototype system, many different roadblocks appeared. DRS's IR/EO system was incredibly expensive to purchase, so a contract had to be developed in order to lease the technology to BMS to allow their project to proceed. This would work for the development purposes of the project, but if the DoD asked for delivery of a unit that they could use themselves, BMS would not be able to give them the unit without absorbing the prohibitive overhead cost of purchasing the IR unit from DRS. The lease agreement between BMS and DRS allows BMS to use the technology up to, but not including, physical delivery of the assembled unit to the government.

RADA had a much simpler contract; BMS bought two complete units for a set amount and would be able to turn them over to the government upon completion of the project. The contract with RADA made the integration of healthy supply chain practices easy, since much of the headache of product delivery was removed in the planning stages. More time and money could be invested in streamlining the development of the integration software and for testing the unit.

Discussion

It is of the utmost importance to have a road map before embarking on a journey such as this. Identifying the solution that greatest accomplishes the goals laid out in the Functional Requirements is at the heart of Axiomatic Design.

Having successfully fused the sensors into a single unit, the threat detection capabilities are enhanced several-fold.

One option that is still on the table is for the DoD to accept that the proposal from BMS is worthy of funding, but ultimately decide not to fund the project. This would be an unfortunate sentence for the company, given the possibility of falling into the "valley of death." As mentioned in the proceedings of a recent American Institute of Aeronautics and Astronautics:

> The "valley of death" has long been recognized as a symbolic barrier to government sponsored innovation, where technologies with military capability-enhancing potential perish for lack of funding from public and/or private sources. The negative consequences associated with the valley of death are substantial: without late stage technology development funding, government support of early stage research and development (R&D) will fail to positively impact economic growth and innovation. (John Avrett, 2014)

Even if the DoD decides not to fund the proposal, BMS still has the option to apply their research and collaborative efforts in the private sector. For example, an oil drilling company might be able to use the sound locating technology to determine precisely the location of a suspected leak or other noise-producing defect in a pipe.

Conclusion

The goal of outlining a schedule and a budget to ensure that BMS delivered their functional prototype on time and under budget was achieved. Using the principles of Axiomatic Design, BMS was able to accomplish their goal of providing the government with the promised product, solidifying their position in Department of Defense's contractor list.

Mapping the desired outcome to a set of measurable and well-defined goals is the best way to go about completing a project of this magnitude.

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