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"Real Options and Value Driven Design in Spiral Development"

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Abstract

The public and private sectors have undergone a number of failed programs over recent years. This paper proposes that many of these failures stem from the areas of requirements development, risk management, and design for spiral development. The tremendous growth in the complexity of our society has led to a proportional growth in the number of requirements and requirements changes for many systems. This paper proposes the use of the Real Options and Value Driven Design paradigms to the system engineering, design, and program management processes. The paper also discusses how the use of the Pareto frontier with the purpose of optimizing the performance/cost ratio may actually lead to many problems in fielding complex systems. This author has recently begun a research project in Real Options to determine the design tenets that make some systems flexible, adaptable, upgradeable, and scalable, while still reliable; thereby enabling these systems to last many more years than comparable systems. This paper also discusses the use of Real Options and Value Driven Design in providing an initial capability that is spirally developed throughout a system's lifetime. The latest research results will be discussed in a follow up paper provided at the 2007 conference.

Introduction

The majority of recent public projects have been over budget, taken far longer than originally scheduled, and frequently failed to meet the customers' requirements. While there have been some success stories, the failures greatly outnumber them. This paper proposes that three key paradigms, which, when incorporated into both the systems engineers' and the program managers' toolboxes, will decrease program risk, increase fielding of capabilities to the customers, and most likely decrease program costs. They are: Value Driven Design (VDD), Real Options (RO), and Spiral Development. This author believes the judicious use of these paradigms will increase program success and the intersection of these paradigms will have tremendous value to systems engineers on a variety of programs. Essentially, these three paradigms offer the chance to provide capability in an incremental manner, linking decisions more closely to the customers' required date of operation, thereby reducing program risk.

This paper represents a framework for research to take place within the 2006 - 2007 time period. As such, this paper does not promise a final solution and will be followed up on with a paper for the 2007 conference describing the results of the research up to that time.

The first paradigm is Value Driven Design (VDD). The American Institute for Aeronautics and Astronautics (AIAA) Systems Engineering (SE) Technical Committee (TC) has teamed up with the AIAA Economics TC and the Multidisciplinary Optimization TC to form a new group to be potentially called the VDD Program Committee. Since the AIAA has not determined the formal designation for this committee, it will herein be referred to as the VDD Committee. The purpose of this group is to answer the hypothetical question, "When told to decrease the weight of an aircraft by 100 pounds, how do the systems engineers and program managers determine the relative impact of decreasing 10 pounds from the landing gear as opposed to 10 pounds from the avionics system?" Though hypothetical, this scenario touches on analogous situations faced by most programs regarding a total system's weight, size, program funding, etc.

The Problems with Pareto Optimization

Systems engineers have used the Pareto frontier to determine an optimal system performance within the limits of available funding. The Pareto frontier's assumption that there is a single solution to a customer's requirements would seem possible if performance were based on a single requirement, or even a small number of requirements. However, in reality, systems can have hundreds of user related requirements and thousands of technical ones all summarized by Pareto optimization as a single point on a 2-dimensional graph. For the above mentioned sample system, a graph of Pareto optimization would need over 1,000 dimensions. Hitting a 2-dimensional target with perfect accuracy is difficult, hitting a specific location in a 1,000 dimension target is nearly impossible. The use of Pareto in this scenario highlights one of the reasons why most programs are failing. The proposed use of a solution space makes hitting the proposed target far easier and increasingly possible. The concept of Pareto optimization and how systems engineers have historically used it relates closely to the need to investigate the future use of Real Options and Value Driven Design to support initial design and spiral development.

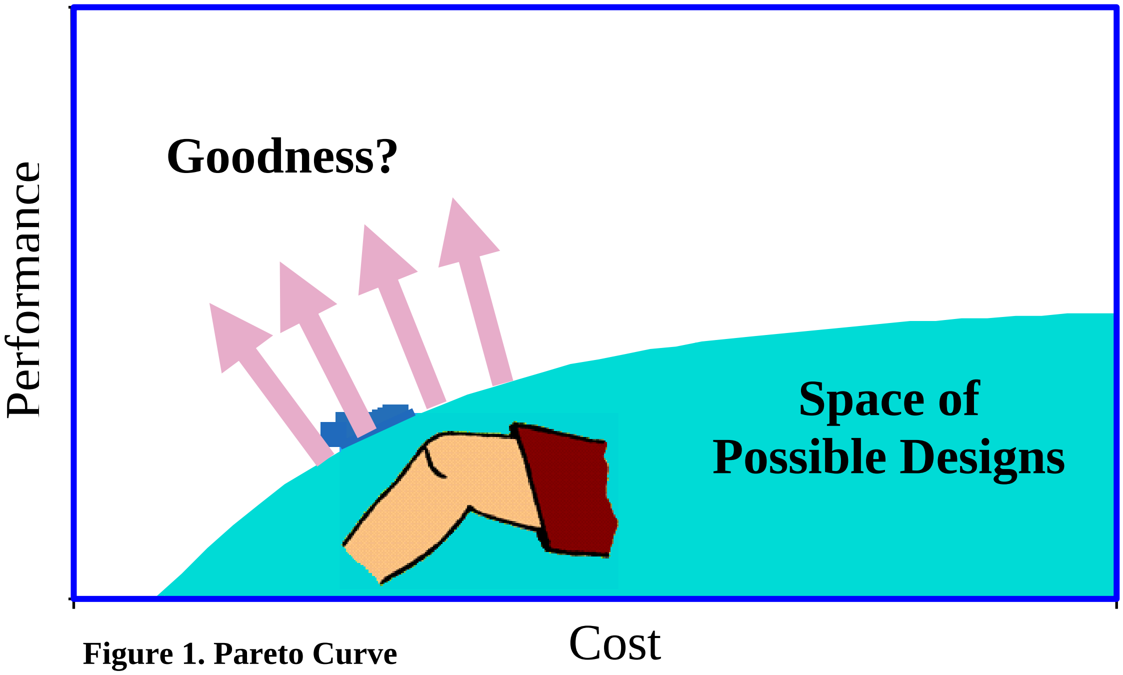

Figure 1. Pareto Curve

What is VDD?

The VDD Committee defines VDD as “A proposed improved design process that uses requirements flexibility, formal optimization, and a mathematical value model to balance performance, cost, schedule, and other measures important to the stakeholders to produce the best outcome possible.” VDD focuses on requirements flexibility and formal optimization across subsystems in order to allow system and component design engineers to discover the best design in the entire solution space. While traditional design focuses on a point solution to a wide variety of requirements, the goal of VDD is to open up an entire solution space for consideration by the designers, systems engineers, program managers, and customers in contrast to the current paradigm in which the performance of every subsystem is optimized in order to optimize the entire system (See Figure 2). Systems Engineers utilizing VDD will attempt to optimize total system performance, keeping in mind that it may not require the optimization of every subsystem. The committee will also need to consider at what point(s) extra capability for a subsystem ceases to add value to overall system performance and actually increases subsystem cost and complexity.

VDD will also use a mathematical value model to express all stakeholders’ (i.e. customer, business, society) values and their interactions into a single measure to communicate the needs of the project to every member of the design team. The best design obtained through VDD should demonstrate what is possible within a particular solution space. At this time, the mathematical model, which will be an important tool in determining not only the ordinal value of improving different subsystems, but ideally the cardinal value as well, has not been developed. Determining the cardinal value of changing subsystems will be essential in determining the true value of a subsystem and a benefit/cost ratio of subsystem improvements, thereby moving away from using cost avoidance as the main criteria in determining a subsystem’s value.

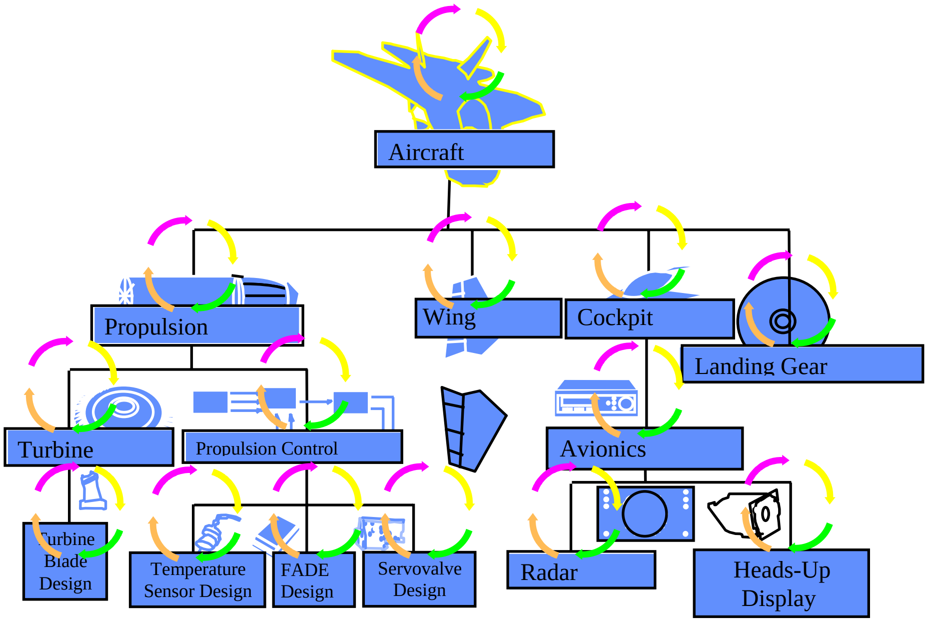

Figure 2. Hypothetical Distributed Optimal Design

VDD is intended to be a step past Traditional Systems Engineering (TSE) in which it is held that if each subsystem meets its requirements, the overall system will meet its requirements. VDD will attempt to optimize total system performance while giving a range of performance parameters to the subsystems. Measuring subsystems against a performance range instead of a specific point of performance opens up the trade space for both systems engineers and program managers to better weigh the impact of minimizing subsystem performance, which will hopefully decrease system costs and complexity. Just as VDD plans to optimize system performance, future research will attempt to prove that VDD can be used to optimize enterprise performance as well. Using TSE concepts, engineers have tried to assign specific performance values for each subsystem. However, increasing system complexity makes it next to impossible to integrate multiple subsystems of a system-of-systems, or major systems in an enterprise in such a specific manner. The concept of "loose coupling" whereby subsystems are not tightly integrated, but rather coupled in a manner allowing for at least semi-independent evolution, helps engineers design and evolve highly complex systems. Engineering an enterprise increases total complexity which engineers must work with to an incalculable level. The concept of a performance range for subsystems will likely lessen the number of hard technical requirements, enhance the opportunity for system evolution, decrease program risk, and improve the opportunity for major systems to be delivered within the overall performance, schedule, and budgetary constraints.

VDD also differs from TSE in its movement of the Cost As an Independent Variable (CAIV) process from, what in practice has often been the end of the acquisition process, towards the requirements definition phase. Under current situations, a user provides requirements; the engineers translate them into technical requirements; and a contract is awarded. Often times, the contractor cannot meet all of the requirements which then leads to negotiations between the users and contractors over what will not be provided or how much additional funding is needed to potentially meet the users' requirements. The current CAIV process, though not envisioned this way, has come to be represented by this final step. One of the proposed benefits of VDD's creation of a performance space (versus a single performance point) is to move those negotiations to the requirements development process , thereby providing the contractors with a more realistic target space and the users with a clearer vision of the system they will actually receive. The movement from a point solution to a solution space will enable systems engineers to work directly with customers to make system and performance trades prior to the initial design and throughout system spiral development.

VDD relates to Pareto by determining which subsystems and analogous operational and technical requirements have the greatest impact, and which other subsystems require the least optimization. Relating this back to the original scenario of cutting airplane weight by 100 pounds, using VDD to determine the cardinal impact of changing each subsystem combined with moving engineering subsystems and major systems to a solution space instead of a point solution, should aid program managers make wise decisions and enable systems engineers to optimize overall system performance.

What is Real Options (RO)?

RO is currently the study of how to design a system for flexibility and adaptability in order to allow for future system modifications and improvements as requirements become clearer and/or evolve. RO also investigates problems with the current TSE implementation of Pareto optimization in developing a system to meet a single solution point. RO differs from VDD by focusing on delivering a system that meets known initial requirements which can then be evolved as future requirements become clearer, as opposed to focusing on a large solution space. Whereas Pareto optimization under TSE focuses on the point where any change will either decrease performance or increase costs, RO intentionally focuses on a point where the minimal required capability is provided at a lower cost.

Professor Richard de Neufville from MIT's Engineering Systems Division (ESD), uses the example of a parking garage in a metropolitan area to explain the value of RO. In this example, the population projections for the next 10 years show the area growing to a point of needing a 7 story parking garage. Near term projections (next 2 years) show that a 3 story parking garage will be heavily utilized and meet the immediate needs of the community. Community planners and/or facility developers then have to decide what size garage to build. Current thinking would advise that the community either build a 3-story garage to meet current needs or a 7-story garage to meet long-term projected needs. Each of these choices offers significant monetary risks: the 3 story solution allows developers to minimize costs and optimize immediate revenue, while forgoing potentially significant future revenues; and the 7 story solution requires a significant initial outlay for construction to meet demand that may never materialize. Using RO offers a different solution that significantly reduces risks and maximizes potential revenue - build a 3 story garage with a reinforced foundation which allows for the addition of future stories as the population growth projections become much clearer. Admittedly, the RO solution incurs greater construction costs than the standard 3 story solution. However, the RO solution also incurs significantly less costs than building the 7 story garage. The key advantage of using RO in this example is that the risks are greatly reduced by satisfying immediate demands while, at the same time, laying the foundation for future growth without having to incur the total additional costs of enlarging the garage until future projections for demand become much clearer. One of the challenges of using RO is in determining when requirements definition (in this case population growth) has reached a sufficient level of maturity, thereby minimizing risk, while not waiting until the capability is absolutely needed at which time its absence causes hardship (i.e. loss of revenue, problems in the community, etc. etc). A simple mathematical formula illustrates this conundrum:

$P(x) \longrightarrow 1$ as $t \longrightarrow 0$
x = correctly predicting user demand or requirements
Waiting for t = 0 is not practical

How is this Like a Financial Option?

The additional cost of including the reinforced structure on the 3 story parking garage represents the purchase of an option on enlarging the garage to meet future demand. A financial option represents a right, but not an obligation, to purchase some item (often a commodity) at a given price in the future. The purchase of a “call” option offers a good example. Hypothetically, a purchaser, speculating that the price of lumber may increase in the coming 3-6 months above the current price of $5 per board-foot, may decide to purchase a call option allowing him to purchase lumber at $6.00 per board foot. Since this call option is considered to be “out of the money”, the hypothetical purchase price for the call might be low, say $0.50 per board foot. In the real-world, the price of the call option will vary with the current price of the underlying asset and the time left to exercise the option. If the price of lumber were to increase above $6 per board foot, the purchaser can exercise his call option to buy the lumber at $6 per board foot and make a profit by selling the lumber for the greater market value.

The use of options has evolved over the years from strictly buying and selling commodities to taking out options on such things as the purchase of real estate, the renting of office buildings, or the right to extract oil or other minerals from the land. Options on real estate or the use of mineral rights represent all or nothing decisions and are often referred to as options “on” a property or activity. Like the financial community example, the time frame for the option is usually a relatively short time period.

RO differs from the above two examples in a number of ways. As de Neufville’s work explains, RO represents an option “in” a system as opposed to “on” a system, which is a fundamentally different paradigm that provides systems engineers with a much more interesting problem to solve, while providing financial analysts with a more difficult problem to solve. A real option is not a commodity that can be interchanged with another similar item such as a piece of lumber. Many different subsystems in a major system can be candidates for the inclusion and future exercise of a real option, but all of these options will vary in their impact to the system, and therefore their value to the program manager. Additionally, a real option can be exercised anytime over the system’s life, whereas a financial option has a much shorter time period.

What Defines Good Design Tenets?

A combined MITRE and MIT team has undertaken a research project to look into how RO concepts can be applied to original system designs. Though this research has recently begun, this paper describes how it may provide insight into this design problem by focusing on determining the design tenets that have historically made some systems flexible, adaptable, upgradeable, scalable, and yet still reliable over many years. This research effort has been named Complex”ilities” to invoke the link between the need for these design considerations and the relationship to increasingly complex systems. An unfortunate, yet unavoidable, problem with this name is that many readers will see the “ilities” suffix and incorrectly relate it to maintenance concepts such as availability and maintainability. The research team has considered other definitions, such as those provided by IT Engineering System Division (ESD) Terms and Definitions White Paper (ESD-WP-2002-01). The team is not absolutely committed to the current definitions, and will spiral develop these definitions as our research demonstrates the need for such a change. The team is currently using the below definitions for “ilities”:

- Flexibility: The ability of a system to perform not only its original mission, but also additional missions which were not envisioned during the original design. This is done without changes to the system.
- Adaptability: The ability of a system to perform not only its original mission, but also additional missions which were not envisioned during the original design. This is done with changes to the system.
- Upgradeability: The ability of a system to be changed (or reconfigured) enabling it to perform additional missions.
- Reliability: The ability of a system to be flexible, adaptable, and/or upgradeable while still being able to operate for many years or even decades.
- Scalability: The ability of a system to perform its original mission to a much greater or smaller extent (i.e. serve an order of magnitude more or fewer customers, transactions, etc.).

The research has begun by looking into historical systems that have displayed some or all of the above capabilities, many of which resulted from design considerations meant to support another area. For instance, a certain type of aircraft may have evolved to support a variety of missions never envisioned during the initial design phase, but was nevertheless able to due to a design consideration in support of the original mission. After studying a variety of historical systems to determine a list of possible design tenets, the research will transition towards applying these design tenets to modern systems. Simultaneously, the team will attempt to determine a financial framework to determine the incremental costs of incorporating these design tenets into real world systems.

The team is researching systems such as mobile oil platforms, micro Unmanned Aerial Vehicles (UAVs), VISA International, and Global Positioning System (GPS). Other existing systems for potential study include the B-52 bomber, the Air and Space Operations Center (AOC), Google, and eBay. Konstantinos Kalligeros, a PhD student at MIT, is using design structure matrices to study platforming concepts and how system engineers can make wise platforming decisions in instances in which hundreds of thousands of systems will be produced, as well as in those where a relatively small number of systems (such as mobile oil platforms) will be produced. Capt Jason Bartolomei, another PhD student at MIT, is studying the concept of Hot and Cold spot analysis using Coupled Design Structure Matrices linked to changes in the system's Concept of Operations. A Cold spot includes a key component that may not change frequently or at all in a system's lifecycle, whereas a Hot spot is expected to change frequently. Both Konstantinos and Jason are using a bottom up analysis for their research. Mike Cokus of the MITRE Corporation (MITRE) is using a mixture of bottom up and top down to study VISA International. Mike has developed design structure matrices for the major components of VISA throughout the system's history. Michel-Alexandre Cardin, a master's student at MIT, and John Dahlgren of MITRE are using a top down approach to study GPS' relation to the "ilities" and Real Options opportunities. This research focuses on the "ilities" and real options from the standpoint of applying them to support higher level management decisions. This research will be reviewed and updated as other systems are also studied.

The above systems were intentionally chosen to represent a large range of unlikely correlated system types and related technologies. Choosing such a range of systems will enable the team to determine if common design tenets related to the "ilities" and Real Options are applicable across the design of most systems. The team realizes that not all of the "ilities" apply to every system. For instance, a mobile oil platform may prove to be upgradeable, whereas VISA International has already shown tremendous scalability. Other historical systems which may prove to scale up in the size of the number of customers or transactions they can serve, might prove cumbersome in situations calling for a great decrease in the number of transactions. Other systems to research in the future like the B-52 will not naturally correlate (in mission or design) with systems like mobile oil platforms or VISA International, but are expected to correlate with other air vehicles. Similarly, research of Google and eBay is expected to correlate in some ways with VISA International and the AOC. This variety of systems should provide the team with an adequate cross section of results for subsequent application to modern systems or enterprises.

The research may show positive and negative correlations between the above mentioned "ilities". For instance, while personal computers can be extremely flexible and adaptable, most users experience their significant lack of reliability. Conversely various tools for playing video games can be very reliable, but less flexible than a personal computer. While adaptability and reliability may be negatively correlated, the research may demonstrate that a system needs to be upgradeable to be adaptable, and those "ilities" would have a strong, positive correlation.

While focusing on design tenets that support good performance in the "ilities", each member has found that the impact of organizational and political considerations is nearly impossible to extract when determining why some previous design decisions were made. Members have also come to believe that the technical considerations they are finding with regard to system design will also apply to the design and spiral development of teams.

How do We Determine on which Subsystems to Exercise Real Options?

On a small system the use of RO may be relatively uncomplicated and ordinal values possible to determine through the available systems engineers' collective wisdom. However, as a system grows larger and more complex, this determination becomes much more difficult to make. Systems engineers and program managers will most likely require a tool enabling them to make these decisions in both an accurate and expeditious manner. The use of architecture products may serve as a starting point for the development of such a tool. While a product such as a System – System Matrix is valuable in determining which subsystems are directly linked, other architectural products may need to be consulted in order to take into account system functions, interface exchange requirements, and the types of required connections. This type of information will also be useful for the decisions discussed in the VDD section above. Essentially, systems engineers will need a tool, or at least a decision framework, with which to determine the operational impact of changing subsystems, make the design decisions enabling future system evolution, and ascertain the operational and financial impact of those technical decisions.

Spiral Development and its Intersection with VDD and RO:

In recent years our world has become more interconnected; subsequently various systems have come to rely more heavily on each other. At the same time, our government is facing increasing financial constraints at each level. The convergence of these two factors will necessitate the increased use of spiral development to provide increased capability to customers, instead of constantly developing brand new systems. RO offers a tool to transform spiral development from a concept into a value added process which decreases program risk and initial financial outlays. The use of RO concepts can be used to design an original system to meet the users' immediate needs, while also including the design considerations that facilitate spiral development. As in de Neufville's parking garage example, the use of RO will decrease the initial financial outlay and the time period between user need and system fielding, thereby reducing the risk resulting from a system not meeting user expectations. The ability to determine the cardinal value of implementing RO design decisions into specific subsystems will further reduce program risk and initial costs. The tool for determining these cardinal values may very well be a variant of the aforementioned tool used to make VDD decisions. Spiral development, RO, and VDD also offer an advantage to the careers of program managers. As system complexity increases, the time to field a system frequently increases as well, which can lead to the original program manager agreeing to certain requirements that may have initially seemed possible. Yet, as the system design and development evolves, these requirements prove to be unreachable. In this era in which program managers stay on a program for 3 years at best, the follow on program managers are often then mired in an unwinnable situation of explaining why initial requirements cannot be met, or why the system does not meet current requirements that have evolved over the years of design and development. The use of spiral development and RO enables the first program manager to promise delivery of capabilities that can be realistically fielded and design the system for future evolution, thereby affording succeeding program managers the opportunity to meet evolving customer requirements and reduce the risk that results when the fielded solution does not meet a customer's expectations.

CONCLUSION/RECOMMENDATION

The use of VDD, RO, and Spiral Development offers a significant advantage in decreasing program risk and aiding program managers and systems engineers to make wise, short-term and long-term decisions. The potential movement away from a Pareto optimization of a single point solution towards a solution space would reduce program risk and represent a significant departure from past systems engineering practices. The use of RO should decrease initial program costs, thereby lowering the impact of excessive funding requirements on programs and enable program managers to field capabilities in a much shorter time period. The tool being considered by the VDD Committee should aid in the determination of the relative value of implementing RO on a variety of subsystems, in addition to aiding in VDD related decisions. The intersection of VDD, RO, and Spiral Development should aid in the evolution of complex systems, especially at the enterprise level. This paper will be followed up on in 2007 to discuss research results at that time.

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