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STUDY OF COST OVERRUN AND DELAYS OF Department of Defense (DoD)'s SPACE ACQUISITION PROGRAM

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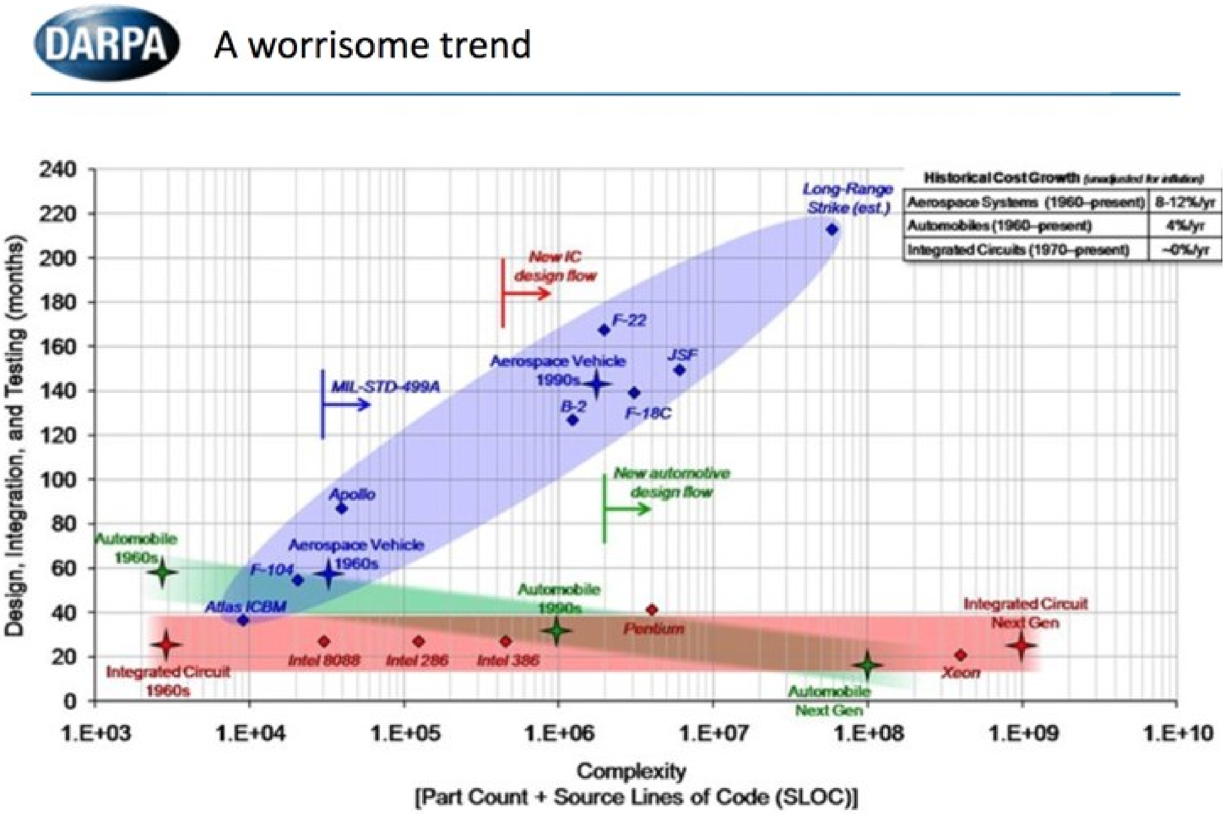
Abstract
Defense and Aerospace Systems Acquisition projects, just like any other Large-Scale Complex Engineered Systems (LSCES) experience delays and cost overrun during the acquisition process. Cost overrun and delays in LSCES are due, in part, to high complexity, size of the project, involvement of various stakeholders, organizations, political disruptions, changes in requirements and scope. These uncertainties, due to the exogenous factors, have cost the federal government billions of dollars and delays in completion of the programs. Cost estimation of federal programs is usually based on previous generations of systems produced and almost all the time the costs are underestimated. Underestimation of the cost of the programs is an endogenous factor, which results in cost overrun for any program, the behavior of the cost escalation is pre-forecasted to be normally distributed, but due to the cost overrun, the cost escalation curve may be skewed. In this paper, the authors will be studying the cost escalation and time delays of the Advanced Extremely High Frequency (AEHF), a DoD's space acquisition program. The distribution of the cost and time can aid in understanding the effects of endogenous factors influencing the cost overrun and the effect of change in requirements during the acquisition process. This data will serve as a foundation for further research to create a framework, which will be used, in better forecasting of the cost of the acquisition of the programs.

Keywords
Acquisition, DoD, Systems Engineering, Complex Systems, Cost Overruns

Introduction
A system, which in complex in nature with many stakeholders, interacting and coupled system is a Large-Scale Complex Engineered System (LSCES) (Deshmukh & Collopy, 2010). These systems are associated with high cost and high risk due the complexity and numerous interactions with people spanning across the world working in numerous geographic locations and organizations (Lewis & Collopy, 2012; Shapiro & Lorenz, 2000). One such system is the Defense weapon acquisition system or Major Defense Acquisition Programs (MDAP). There are various complexities in defense system such as technological complexity, managerial or organizational complexity, business system complexity, coupling of the systems, cognitive complexity, number of parts, lines of code and many more (Bloebaum, Collopy, & Hazelrigg, 2012) (Spero, Bloebaum, German, Pyster, & Ross, 2014).

The defense acquisition programs include weapons, aircrafts, ships, space acquisitions and so on. It is so often seen that such highly complex systems have higher costs and schedule overrun exceeding to more than 40% of their initial costs (Deshmukh & Collopy, 2010). For example, a comparison of complexity, in terms of number of parts and lines of code, with the schedule time in Exhibit 1 by former director of the DARPA Tactical technology office Paul Eremenko shows the escalation of schedule for aerospace industry (Eremenko, 2009). The exhibit also shows the escalation comparison of the aerospace industry with the automobile and integrated circuits industry. The aerospace industry's cost increases by 8-12% every year whereas the automobile industry and the integrated circuits industry's costs increase by 4% and 0.1% respectively. The increase of cost in the aerospace industry every year causes the cost to grow at least twice the estimated costs by the end of the program due to longer schedules and high complexity of the system produced (Eremenko, 2009).

Exhibit 1. Historical trend of Complexity and Schedule of Adaptive systems (Eremenko, 2009)



For any defense acquisitions, once the initial capabilities of the system are established, DoD calls out for proposals from participating contractors for their best offers for the program. Contracting is awarded by negotiating using tradeoffs and lowest price or performance-based contracting (G. V. Bhatia, 2016; G. V. Bhatia, Kannan, & Bloebaum, 2016) and have different contracting structures. The cost of acquisition systems is based on previous generations of similar systems and yet there seem to be cost overruns. The interpretation of such cost overrun is usually underestimation of the program, which is an exogenous factor. The cost overrun of the system is also dependent on various other factors like exogenous and endogenous. Exogenous factors are factors not belonging to the system and endogenous are factors which are within the realm of the program. Both factors play a major role in the cost and schedule overrun and this is validated by data of DoD programs (Collopy & Consulting, 2007; Deshmukh & Collopy, 2010; Maddox, Collopy, & Farrington, 2013). The authors in this paper try to prove the hypothesis that endogenous factors such as complexity, requirements and technical risks play an important role in the cost overrun of the program.

For a LSCES, the stakeholders present in the decision making of the system and numerous interactions between the different systems within the system, causes change scope. There are various reasons for the delays and cost overrun for a system with the major factor being the design errors, change in scope, complexity of the system, exogenous factors such as natural disasters, political dynamics, warfare, scientific world and other factors not related to the system. This is the same for Defense programs as well. In this paper the authors analyze a space program, Advanced Extremely High Frequency (AEHF) Satellite program, to find the different factors which lead to the cost and schedule overrun. The data will be used a background for further research to create a framework which will be used along with value-based modelling to reduce the cost and schedule overruns.

Department of Defense (DoD) Acquisition Process

All military goods, services from contractors, federal arsenals, ships, satellites, aircrafts and any system for military operations are acquired by the Department of Defense. Acquisition of a system can be defined as the purchase of an item or service for the system. Any system acquired by the DoD should undergo the acquisition process which involves the design, engineering, construction, testing, deployment, sustainment and disposal of the system and is highly complex (Schwartz, 2014).

For any weapon, information tech or advancement of previously used system or a new system, the DoD has three established organized systems to identify, plan, develop and dispose them. The systems with their responsibility are provided in Exhibit 2.

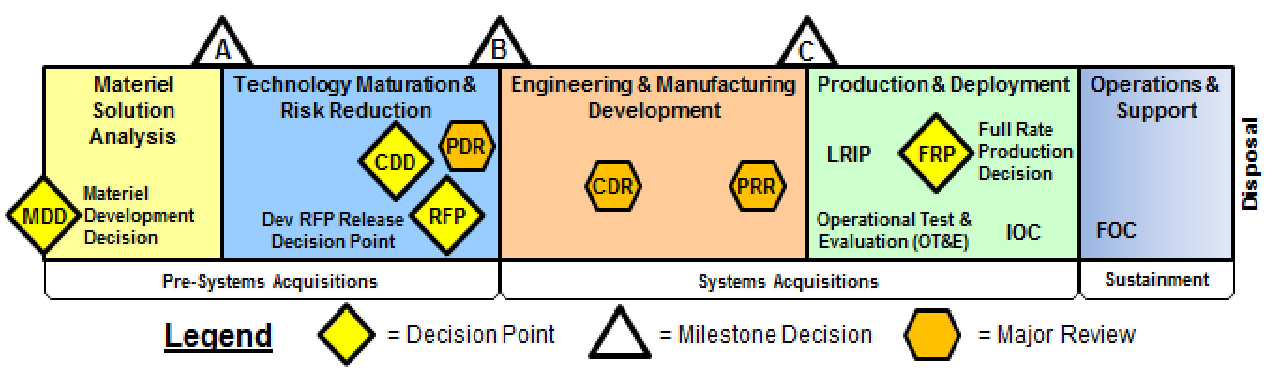
Exhibit 2. Systems involved in DoD Acquisition Process (Schwartz, 2016)

System	Acronym	Function
The Joint Capabilities Integration and Development System	JCIDS	Identifies the requirements
The Planning, Programming, Budgeting and Execution System	PPBE	Allocation of resources and budgeting
The Defense Acquisition System	DAS	Developing and buying an item

The first step for buying a system, say a weapon, is identifying the requirements for it. The Joint Capabilities Integration and Development System (JCIDS) achieve this requirement process and it identifies, assesses, and prioritizes what capabilities are required by the military. JCIDS ensures capabilities required by the joint warfare to be identified along with the requirements to successfully execute the mission. Budgeting and planning the process of development of the system is the next step toward the success of the program and it is monitored by the Planning, Programming, Budgeting and Execution System (PPBE). The next step is the acquisition process, which is the management part of the defense program. The Defense Acquisition System (DAS) oversees the acquisition process by using phases and milestones. At each milestone, the program should meet specific requirements before proceeding to the next phase of the acquisition process. There are five phases in DAS, and at the end of each phase is a milestone review and there are three milestone reviews A, B, C (Schwartz, 2014).

The first phase is the Material Solution Analysis (MSA) phase, which assesses different solutions for the required capability for the program. The second phase is the Technology Maturation & Risk Reduction (TMRR) phase where the technologies for the program is integrated into the system by reducing the technology risk and life cycle cost risk. The third phase is Engineering & Manufacturing Development (EMD) where the system undergoes design and development before going into production. The fourth phase is Production and Deployment (PD) where the system is produced and tested for the operational capability of the system in the program. The fifth phase is Operations and Support (O&S) which supports the use of the system in the field and maintains it until the end of the program. The Defense Acquisition process along with the phases and Milestone is shown in the exhibit 3 (Schwartz, 2014).

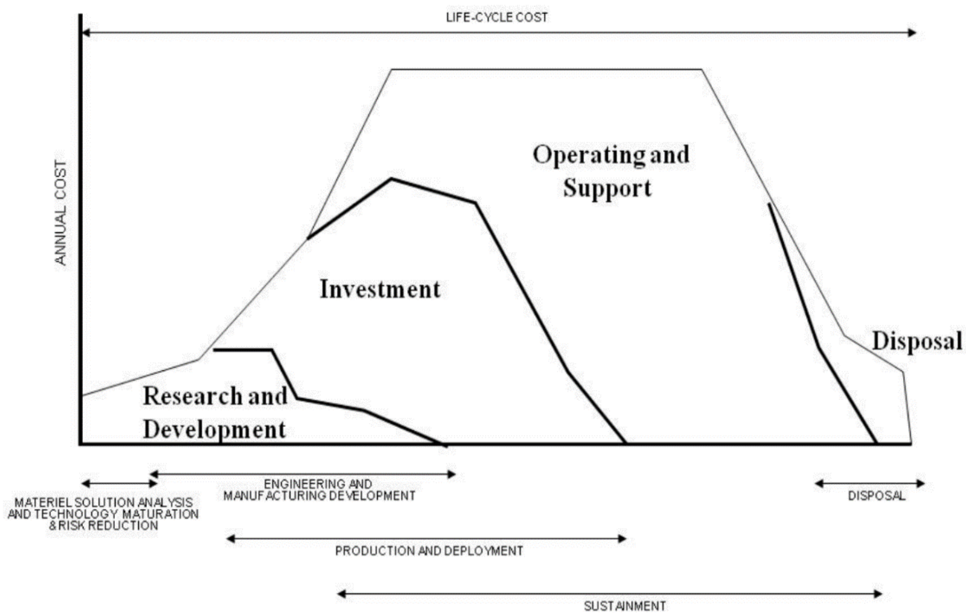
Exhibit 3. DoD Acquisition Process



DoD Cost Estimating Process

For any program to be completed within a given time, the program requires resources and funds, which need to be allocated. Estimation of the cost of a program is very important as it serves as constraint or a decision-making point to develop a project. Cost estimating involves collecting and analyzing historical data using quantitative models to predict the cost (McBride, 2010). For a DoD Acquisition program, cost estimation provides a basis for funding decision, annual budget requests, make key point decision, contracting the program to organizations, and many other reasons. The DoD has two main cost estimation categories namely, Life-Cycle Cost Estimate (LCCE) and Business Case Analysis (BCA). DoD uses the LCCE for a program to determine cost of categories and elements in the system. LCCE has four major cost categories: Research and development costs, investment costs, operations and support costs, and disposal costs. The profile of the costs for a DoD program is depicted in Exhibit 4. To avoid the cost overrun of the DoD programs to exceed excessively high, the government uses the Nunn McCurdy Act to report the cost overshoot to the congress to make necessary changes to the program.

Exhibit 4. LCCE of a DoD Program



Nunn McCurdy Amendment

The Nunn McCurdy Amendment, was introduced by Senator San Nunn and congressional representative Dave McCurdy, to reduce and control the cost overruns in the Major Defense Acquisition Program (MDAP). This amendment requires the DoD to report the cost overrun of the MDAP when it exceeds certain limits sets by the DoD (Schwartz, 2016). The cost increase is represented as breaches in the Nunn McCurdy Act. There are two breaches Significant Breach and Critical breach. The Significant Breach occurs when the cost overrun of MDAP is more than 15% of the current baseline or 30% of the original baseline estimate. The Critical Breach occur when the cost overrun of MDAP is 25% of the current baseline or 50% of the original baseline estimate

At the event of Significant breach, the program manger must notify Congress with report for unit cost and reasons for increase in cost, completion status of the program, changes in the projected cost and the actions to control the cost growth. Critical breach requires more justification of the costs as there is a possibility of the program being terminated. Root-Cause analysis is used to determine the different factors of the cost growth by the Secretary of the Defense and also asses the new estimated cost of the program with changes in requirement and reasonable alternatives. The program is not terminated if the programs meets certain requirements such as the program being essential for national security, new cost estimates are reasonable, the cost growth can be controlled by the management. The program should also be restructured in a manner that it adheres to address the root-cause analysis, change milestones and receive new milestone approvals (Schwartz, 2016).

DoD Space Acquisitions

The space systems provide critical capabilities, which support military and other government operations. Like any other LSCES, the space systems are highly complex and development and launching of it takes a long time. DoD follows the same process of Defense Acquisition system to acquire space programs (Maddox et al., 2013). Major DoD space programs have experienced momentous increases in cost and schedule resulting in the program to undergo Nunn McCurdy breaches. One such program is the Advanced Extremely High Frequency (AEHF) program, which had communication satellites for the Air force. The cost overrun for AEHF exceeded 118% of the initial costs estimated (Chaplain, 2017). The status of the Major defense Space Programs and their current and estimated costs are provided in Exhibit 5.

Exhibit 5. DoD Space Acquisition Programs (Chaplain, 2017)

DoD Space Acquisition	Status	Original Program Cost	Current Total Program Cost
Advanced Extremely High Frequency (AEHF)	Production & Deployment	$6.9 Billion	$15 Billion
Enhanced Polar System (EPS	Production & Deployment	$1.4 Billion	$ 1.4 Billion
Evolved Expendable Launch Vehicle	Production & Deployment	$18.8 Billion	$59.6 Billion
Family of Advanced Beyond Line-of - sight Terminals (FAB-T)	Production & Deployment	$1.7 Billion	$1.8 Billion
Global Positioning System (GPS) III	Production & Deployment	$4.3 Billion	$5.8 Billion
Global Positioning System Next Generation Operational Control System (GPS OCX)	Engineering & Manufacturing Development	$3.6 Billion	$5.5 Billion
Joint Space Operations Center Mission Systems (JMS) Increment 2	Engineering & Manufacturing Development	$320 Million	$469.9 Billion
Military GPS User Equipment (MGUE) Increment 1	Engineering & Manufacturing Development	$0.7 Billion	$1.1 Billion
Mobile User Objective System (MUOS)	Production & Deployment	$7.3 Billion	$7.4Billion
Space Based Infrared System (SBIRS)	Production & Deployment	$5.0 Billion	$19.2 Billion
Space Fence Ground – Based System Increment 1	Engineering & Manufacturing Development	$1.6 Billion	$1.6 Billion
Wideband Global SATCOM (WGS)	Production & Deployment	$1.3 Billion	$4.3 Billion

From the Exhibit, it is seen that the initial estimated cost of the program is lower than the current program. This can be due to numerous risk factors and uncertainty involved in the program. The data of the DoD space acquisition program will provide a background for further research on incorporating various complexity in terms of technical, organizational, couplings, parts, system to reduce the cost and schedule overrun in major space acquisition programs. In this paper the authors choose the AEHF satellite program to study the changes in costs, quantities and requirements from the start of the programs until the end of 2017 through the Selected Acquisition Reports (SAR) and Government Accountability Office Reports.

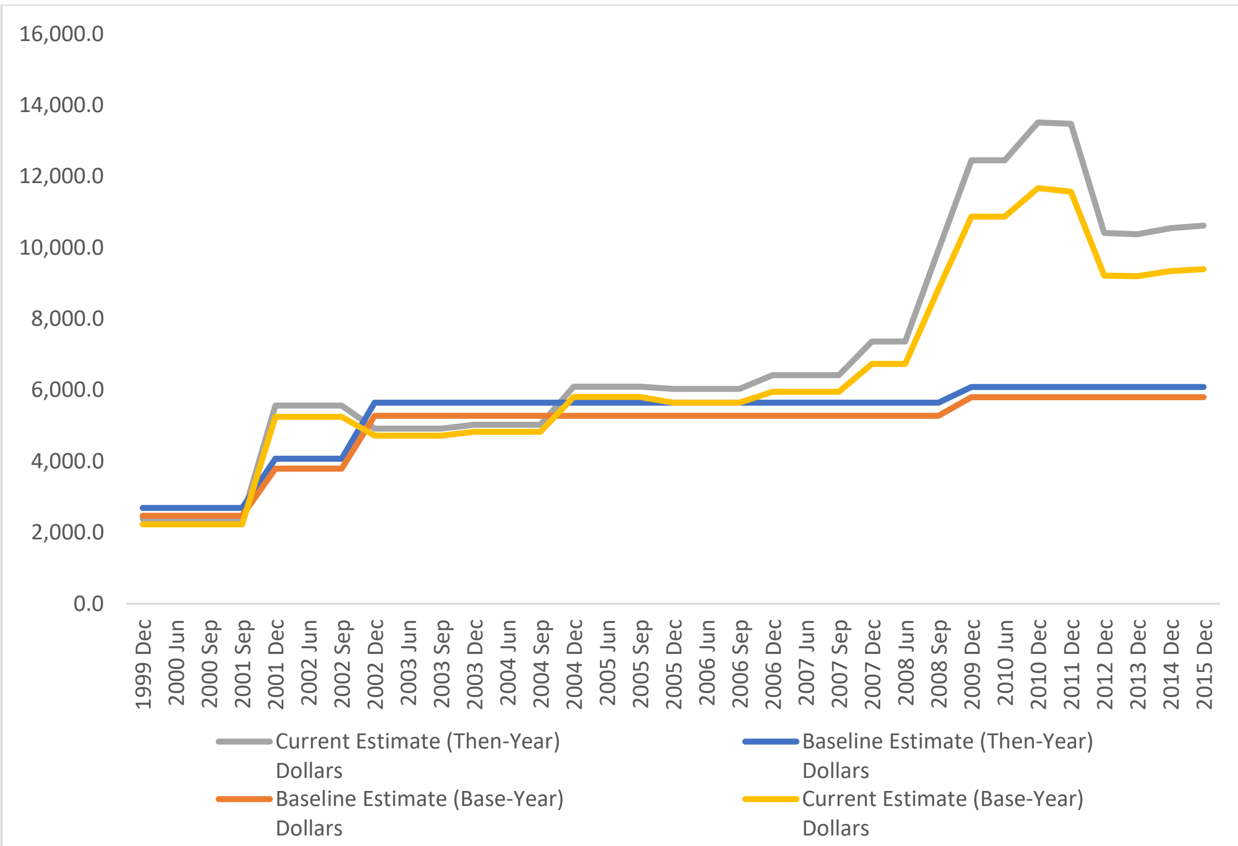
Advanced Extremely High Frequency (AEHF) Satellite

Advanced Extremely High Frequency Satellite program consists of communication satellites and it is operated by the United States Air Force Space Command to replace the Military Strategic and Tactical Relay (MILSTAR) satellite systems and to improve the tactical communication capabilities of the older version of MILSTAR satellite (Management, 2017). These communication satellites operate at extremely high frequency of 44GHz for Uplink and

20 GHz for downlink. The acquisition program was started in the year 1999, the contracts were awarded in 2001 to Lockheed Martin Space Systems and Northrop Grumman Space Technology, and the first launch of the satellites was expected to be in 2006.

The acquisition program is reported every year by the Government Accounting Office (GAO). This report states the different changes in the schedule, cost and requirement of the AEHF communications satellite. The costs are segregated in terms of research & development costs, procurement costs, total program costs and the unit cost along with the quantities. Initially the AEHF program was supposed to launch five satellites but due to the challenges in the technology, the number of satellites were reduced to 3 in 2002 (Acquisitions, 2003). The estimated costs of AEHF from the year of proposal till 2017 is provided in Exhibit 6 (Acquisitions, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017).

Exhibit 6. AEHF Estimated Costs (Base Year & Then Year) 1999- 2015



The change in costs during the development of AEHF are due to various requirement changes, technical errors, human errors and other factors. The different errors and changes occurred due to the various exogenous and endogenous factors of AEHF are listed below in the Exhibit 7 of the paper.

Exhibit 7. Change in AEHF from GAO Reports (Acquisitions, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012)

Year	Type of Change	Change	Reason
2002	Requirement	Quantity reduced to 3 from 5	Integration of new Transformational Satellite Communications System (TSAT)
2003	Technical	Cost growth & Schedule Delay	AEHF Comsec/Transec System (ACTS) architecture change and requirement change in the system

2003	Security	Separate Foundries to produce chips	Technically challenging fabrication process
2004	Technical	Cost growth & Schedule Delay & Nunn Mc Curdy Breach	Delay in ACTS delivery and concurrent development of two critical path items
2005	Schedule	Revised Dates	Significant Nunn McCurdy Breach
2006	Technical	Schedule Delay	Delay in delivery of Command Post Terminal
2007	Technical	Cost growth & Schedule Delay	Hardware components incomplete in payload
2008	Schedule	Revised Dates	Critical Nunn-McCurdy breach
2008	Requirement	Increase in quantity	3 satellites were added
2009	Requirement	TSAT Termination	Procurement of 3 additional satellites

The first satellite of AEHF program, AEHF-1 was launched 4 years behind the expected launch date in 2010 and the satellites 2 and 3 were launched in 2012 and 2013 respectively (Management, 2017). In 2008, the Defense Appropriations Act recommended a fourth satellite, but the cost of building was projected to $1.5 Billion which is almost twice the estimated cost of the third satellite $952 Million. From Exhibit 7, it is seen that endogenous factors such as technical changes and complexity in the satellite hardware has led to cost overrun and schedule delays. The AEHF program has undergone two Nunn McCurdy breaches in the year 2004 and 2008. The 2004 breach was due to the schedule and cost increase by 15% of the baseline and a critical breach in 2008 when the unit cost exceeded 130% of the initial costs (Management, 2017). From the above data the hypothesis that endogenous mechanisms are responsible to cost overrun than the exogenous cost overrun. This data will serve as a background for further research in terms of management complexity, decision making.

Summary

DoD acquisition of programs is prone to a lot of risk and uncertainty due to the complexity of the system, change in requirements and interactions between different organizations and governments. The consequences of risk and uncertainty leads to increase in cost and time of the acquisition of the program. The Nunn-McCurdy amendment keeps in check of the cost overrun and the acquisition program may or may not be terminated depending on the significance of it on the defense sector. It is believed that the cost and schedule overrun are due to the underestimation of the costs which is an exogenous factor. n this paper, the authors utilize the different unclassified data from SAR and GAO to understand the occurrence of cost overrun of AEHF, a space acquisition program. It is seen that endogenous factors such as lack of technical tests had led to the cost and schedule overrun of the AEHF.

Future Work

The AEHF show the technical risk, uncertainty in requirement which are endogenous to the system are responsible for cost overrun. The next step is finding other endogenous factors such as management type of the organization and the management of the acquisition. DoD uses Earned Value Method for cost estimation and is also used as management tool of the program. The authors will study the EVM process and find the factors which affect the acquisition program and also the different contracting method involve in it. Another government agency which acquires space systems is NASA. NASA's space acquisition program uses Joint Confidence Limits (JCL) to estimate the cost of the program. JCL will be used to compare the cost estimation of DoD's acquisition programs. The difference of using NASA's JCL to the DoD's cost estimating process will also be studied to understand the underlaying issues. These data will serve as a background to construct a new framework involving systems engineering, value-based modelling, decision analysis and microeconomics which will reduce the cost and schedule overrun of the system.

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About the Author(s)

Nazareen Sikkandar Basha is a doctoral student pursuing her PhD in the department of Aerospace Engineering at Iowa State University. Her research interests include the DoD Acquisition process, contracting methods and also the integration of Cynefin framework in the design and development of Large-Scale Complex Engineered Systems (LSCES) to aide in better decision making. She has a master's degree in Aerospace Engineering from Iowa State University and has a bachelor's degree in Mechatronics Engineering from Anna University, India.

Benjamin Kwasa is a Postdoctoral Research Associate in Aerospace Engineering at Iowa State University. His research focuses on the incorporation of Organization Design in the design of Large-Scale Complex Engineered Systems (LSCESs) in a value-driven approach to Multidisciplinary Design Optimization (MDO). He attained his bachelor's degree in Aerospace Engineering from Iowa State University as well. Benjamin's interests include systems design, heuristic optimization and organization design.

Professor Christina Bloebaum joined Iowa State as a Professor of Aerospace Engineering in August 2012. Previously, she was the Program Director for the Engineering and Systems Design and System Science programs at the NSF from 2009-2012. Prior to that, she was a faculty at University of Buffalo since 1991. Professor Bluebeam's present research area is in the design of large-scale complex engineered systems. She has spent her career looking at challenges in the Multidisciplinary Design Optimization (MDO) field – developing new optimization, visualization, and trade space methodologies for these systems. She has recently been developing approaches in which Decision Analysis, Game Theory, and Mechanism Design are applied to simulate end user interactions of complex system so as to represent these decisions early in the design process. She is also investigating new systems engineering frameworks that will enable holistic decision-making by bringing together Value Driven Design, MDO and Decision Analysis.