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Enhanced Acquisition Analysis in Support of The Aerospace Corporation's Decision Support Framework (DSF)

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Since its inception fifty years ago, The Aerospace Corporation has been supporting government decision making for many programs and at different levels. An objective technical analysis employing subject matter experts using many tools, models, and methodologies is the backbone of The Aerospace's Decision Support Framework. Strong customer demand for timely analysis and advances in modeling capabilities have enabled introduction of fast, concurrent, engineering processes into decision support. The Concept Design Center (CDC) and Concurrent Program Definition Environment (CPDE) engines were built to enhance timeliness of design and program definition processes. Increased complexity of space enterprise and associated decision-making are now creating demand for enterprise-level decision support that requires system-of-system analysis and cross-mission tradeoffs. This open-model decision support framework employs layered approach to capability evaluation that encompasses technical, programmatic, operational, enterprise, and national levels. This paper briefly describes current DSF modeling activities while focusing on the cost, schedule and risk analyses part of the framework. It will show how traditional space segment costing has been expanded into an acquisition strategy evaluation that supports our Air Force, NRO and other customers with an enhanced and needed program level assessment. Sample products from past studies are given to illustrate some of the current DSF capabilities.

Nomenclature

CET	=	Concept Evaluation Team
CDC	=	Concept Design Center
CPDE	=	Concurrent Program Definition Environment
DSF	=	Decision Support Framework

I. Introduction

FROM its inception fifty years ago, The Aerospace Corporation has been supporting government decision making in many programs and at different levels. Objective technical analysis by subject matter experts using many tools, models, and methodologies is the backbone of The Aerospace Corporation's capability to provide our customers this decision making support. Strong customer demand for timely analysis and advances in modeling capabilities have enabled the introduction of fast, concurrent, engineering processes into The Aerospace Corporation's Decision Support Framework (DSF). The Aerospace Corporation's CDC and CPDE capabilities were built to enhance timeliness of design and program definition processes. Increased complexity of space enterprise and associated decision-making are now creating demand for enterprise-level decision support that requires system-of-systems analysis and cross-mission tradeoffs. This paper describes the framework for evolution from traditional single-system analysis to concurrent, cross-mission, portfolio decision support at The Aerospace Corporation and shows how enhanced cost analysis leads to the acquisition strategy element of the DSF. Ongoing activities include development of mission analysis, enterprise architecting, utility analysis, cross-mission portfolio evaluation and selection and decision presentation modules to augment existing engineering engines. Sample products from past studies are given to illustrate some of the current DSF capabilities.

II. Decision Support at The Aerospace Corporation

A. Traditional Decision Support: Multiple Models

The Aerospace Corporation has extensive decision support involvement in many programs and at different levels ranging from architecture and concept studies for developmental planning and various milestone decision analyses. Also important are the utility, capability and performance analyses, risk evaluation and program acquisition planning, as well as portfolio assessment and strategic planning. Numerous tools, models, methodologies, and processes have been used for these efforts: SEAS (System Effectiveness Analysis Simulation), SuperSEAD (Super Suppression of Enemy Air Defense), STAMP (Strategies to Tasks to Architecture Measures of Performance), GAP (Generalized Availability Program), DyCAST (Dynamic Communications Architecture Study Tool), CASA (Communication Architecture System Assessor), MAST (Milsatcom Architecture Study Tool), GRIPS (Genetic Resources for Innovation and Problem Solving), SCT (Sand Chart Tool), a constellation-level, multi-platform/sensor, design trade and evaluation tool called TRADIX, SPET (System Performance Evaluation Tool), to name a few. The Decision Support Framework is an over-arching integrated approach to these capabilities and tools. The wide range of study types and customers dictates flexibility in the framework, such that maximum use can be made of the existing individual capabilities without undue constraints. The degree to which current tools and capabilities are linked together range from full integration in the concurrent environment such as the Concept Design Center (CDC) to passing of parameters serially from analyst to analyst.

B. Theoretical Foundations of the Decision Support Framework

"Decision-making is a process that uses analysis and persuasion stories to generate an interpretive story, which in turn generates action"[(1)]. Trends in modern decision science emphasize creativity and imaginativeness in thinking about the problem that is organized around command and control and networking, and modeled using ideas from systems dynamics and complex adaptive systems theory. Decision support flow encompasses imaginative problem definition, identification of system boundaries and interfaces, modeling and concept exploration in order to understand policy options and solution space, definition of evaluation measures and spanning scenarios, evaluation of alternative courses of action using models, games, and subject matter experts, integration of results and presentation of results and conclusions[(2)]. The scope of the integrated DSF process depicted in Figure 1 appears overwhelming at first glance. Closer examination of the framework reveals standard strategy-to-task mission analysis, system and program engineering, with options for portfolio and enterprise analyses. The flexible (open-tools) and evolutionary nature of the framework dictates that the flow and composition of the study process is not rigid but dynamic to meet the needs of each individual customer.

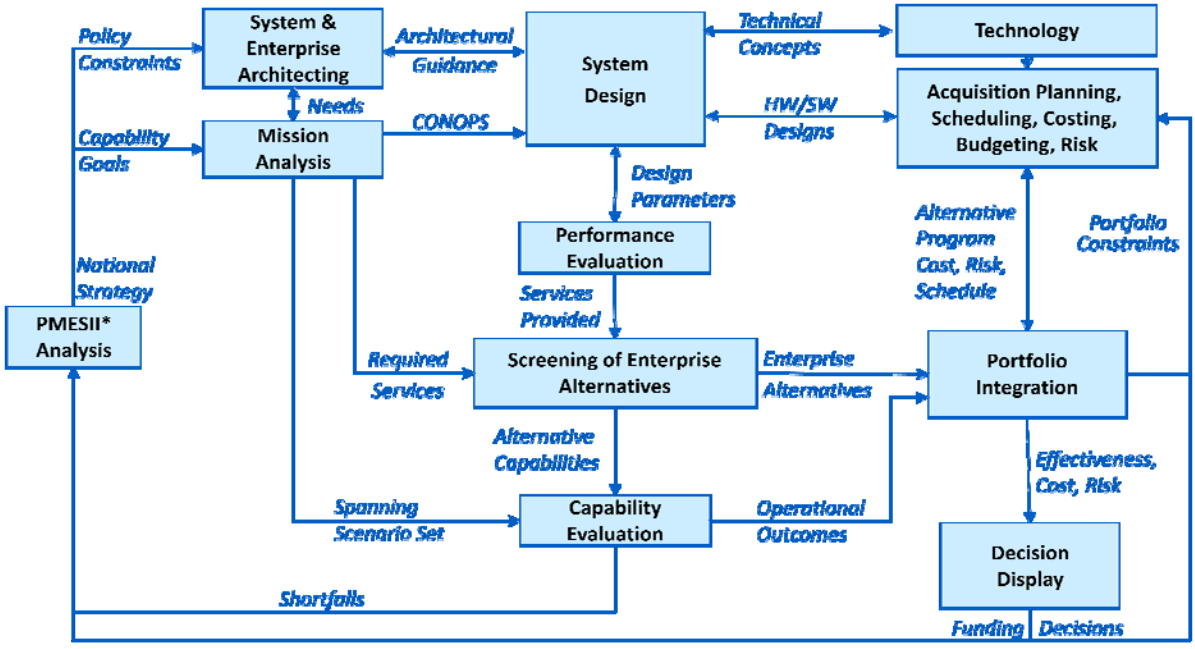

Figure 1. Scope of the integrated DSF.

Another important attribute of the framework is the need for such a system to capture and assess uncertainty via consideration of alternate scenarios and outcomes. A brief description of the main components of this framework follows. PMESII (Political, Military, Economic, Social, Infrastructure, and Information) analysis is performed to understand alternative futures and associated National Strategy goal priorities and policy constraints. The PMESII analysis provides the boundary conditions for mission analysis and Military Utility Analysis (MUA), which translates capability goals into mission needs and CONOPS for a set of specific conflict scenarios. The Spanning Scenario Set (SSS) provides the operational context for the use of agent-based simulation for dynamic execution of alternative architectures and system designs and comparison of end-user effects. Analysis of the large amount of data produced by simulation of the SSS requires pairing-down the list of alternative architectures, and systems to a smaller number of generically distinctive concepts. The critical contribution of MUA in the value-centric paradigm is not only to make relative assessments of operational outcomes for alternative architectures but also to identify the engineering Measures of Performance (MOP), which constitute the cost-driving key performance parameters and the human-in-the-loop command and control policies, which could relax the level of "how much is enough?" This becomes the enabler of more affordable, robust, and sustainable system acquisition. For further discussion of the relationship of C4ISR and MUA the reader is referred to Chapter 15 of the MORS textbook Methods for Conducting Military Operational Analysis[4].

Engineering concept development has long been established at The Aerospace Corporation as the concurrent engineering activity within the Concept Design Center (CDC). The CDC design parameters for individual systems are passed-on to a number of system performance evaluation tools to generate system-wide measures of performance. The MOPs are used to prescreen alternative concepts against the spanning scenario set to a smaller number of concepts for detailed utility evaluation. MOPs are also used to characterize individual system services and compare them to required services. Examples of ISR services are detect, track, identify, characterize capability, and determine intent. Communication services include protected, wide-band, and communications-on-the-move. Navigation services include position determination, navigation, and timing. The concept of services delivered to end-users/consumers of space capabilities is particularly powerful in portfolio evaluations of disparate systems with different measures of performance. It enables cross-mission comparison of contributions to end user success across unlike systems.

Design activities also generate parametric cost estimates and risk assessments that are passed to program definition activities for firmer anchoring in relevant historical data and specific program implementation context. The program definition activities are typically executed within the Concurrent Program Definition Environment (CPDE). The CPDE subject matter experts employ a variety of acquisition planning, cost, schedule, and risk evaluation tools and databases to produce a preliminary Acquisition Strategy Panel (ASP) for each down selected concept alternative. This methodology is discussed in detail in Section IV.

Finally, the effectiveness of system or enterprise alternatives is summarized in decision display using major categories of capability, cost, schedule, and risk, and possibly other measures of effectiveness (MOEs). One way effective communication of decision options is enabled is by side-by-side comparison of feasible solutions with all their MOEs evaluated. Examples of such matrices are given in Section IV. The credibility of the decision is enhanced with full visibility and traceability of analysis assumptions and methodologies, which is the focus of other DSF efforts.

C. Concurrent Decision Support: CDC and CPDE

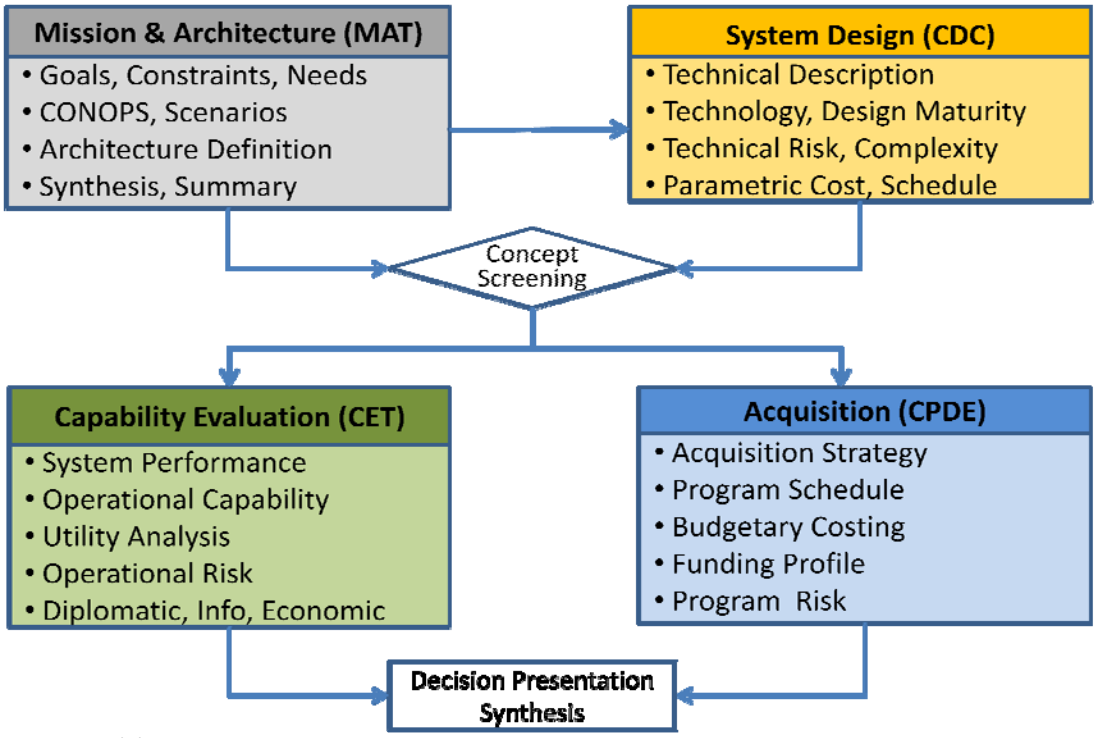

Figure 2. Decision Support Teams

The CDC and CPDE employ fully-transparent concurrent engineering processes, teams, and facilities to conduct decision support studies. The CDC and CPDE multi-disciplinary teams use an open modeling environment connecting individual models into common database tools that pass data over a network as determined by human-in-the-loop decision making at every level.

Members of the CDC meet in a design facility on an as-needed basis to create and evaluate conceptual space system designs. Seven CDC teams focus on different aspects of the conceptual design problem. Each team has developed tools and processes that allow for the conceptual design of an architecture or system at an appropriate level of detail. This provides insight and understanding of the technical issues involved from a multi-disciplinary perspective. The CDC teams provide expertise that range from system-of systems architecture analysis to the design of sensor components. To date, the CDC has performed around 260 studies. This is done in a synergistic and collaborative manner which leads to a better product in less time and lower cost than was possible with traditional methods. As can be seen in Figure 2, the mission/system requirements are converted into a useable design which contains literally thousands of parameters. Many of these parameters are passed from the CDC to CPDE.

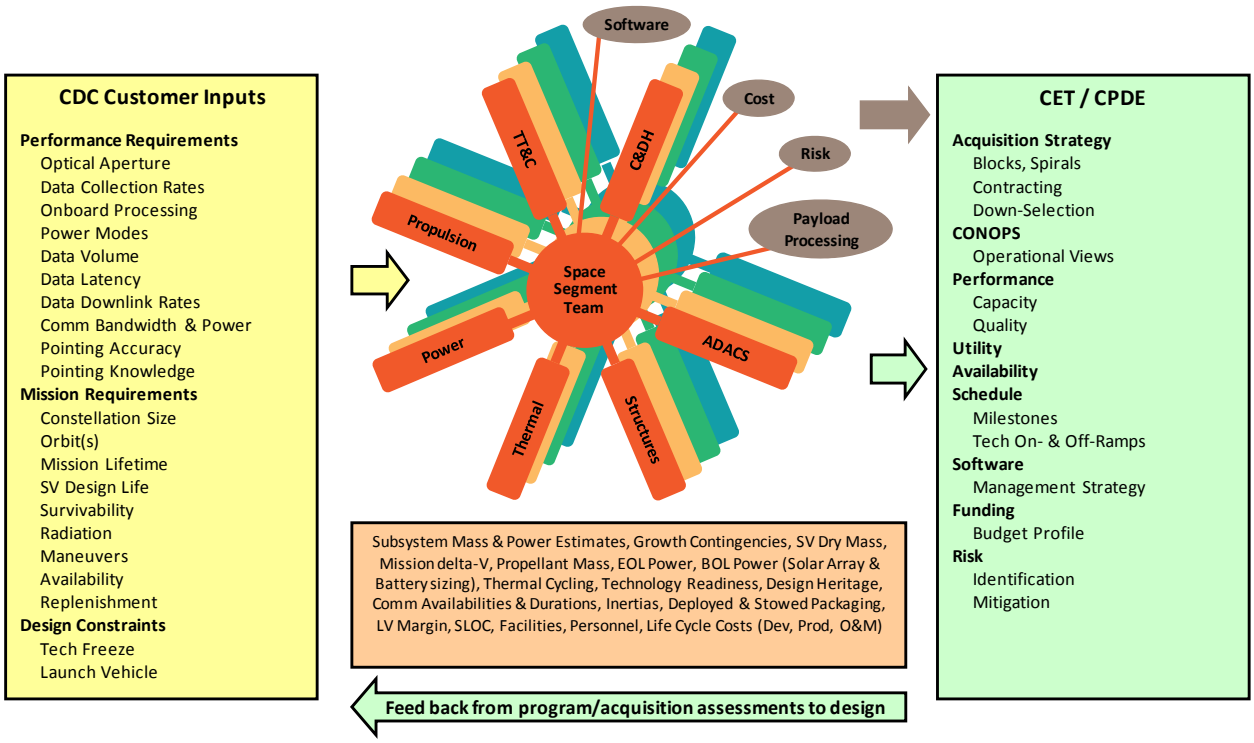

Figure 3. CDC and CET/CPDE process flow.

The CPDE quick turn-around programmatic and utility sessions using an enhanced CDC team and computer-aided modeling tools follow the initial iterations of CDC technical design sessions. Technical concepts designed in CDC sessions are passed on for program definition activities to anchor cost, schedule, and risk estimates with historical analogies, a draft Acquisition Strategy Panel (ASP) and evaluation of program executability. Past CPDE studies have addressed space-based radar tiers, Operationally Responsive Space (ORS) and SMC portfolios, and persistent Intelligence Surveillance Reconnaissance (ISR) system-of-systems. Portfolio and enterprise studies require that numerous disciplines come together to evaluate large amounts of data and cohesively combine them into decision quality information.

D. Decision Support Enhancements

The objective of a recently initiated Corporate Strategic Initiative (CSI) at The Aerospace Coporation is to develop a comprehensive and repeatable decision support framework that includes processes, teams, resources and tools. This is to be implemented by making existing Corporate best practices, knowledge bases, experts, tools more readily transparent and accessible for program offices and customers to use. New capabilities are to be developed as needed, and the focus is also on applying the framework to appropriate problems that extend the current set of tools. Areas of future emphasis to enhance integrated portfolio definition and analysis include programmatic issues (cost, risk, budgets, policy, and schedule), concurrent utility evaluation, enterprise plans and architectures.

Enhancements in the area of cost analysis include the ability to provide an integrated view of an architecture that includes the budget (reference 7) (Sandchart), schedule (Roadmap), capability, and operational states, among others. This approach emphasizes the important role that cost and budget constraints impose on any architectural or decision support activity. The Portfolio Decision Support Tool (PDST) shown in Figure 4 first serves a guideline or a ‘template’ to ensure that the full range of factors that go into characterizing an architecture or portfolio is captured by the study team. The tool also serves as a means by which the integrated architectural approach is maintained through the assessment process to capture evaluations of risk, policy, extensibility and other factors (not shown in the figure.) After population with the baseline (program of record) and alternatives, PDST is intended to be used to compare and contrast those competing alternatives in a selective (affordability, risk, performance, or any other measure of effectiveness) fashion, or across the board, considering all the major factors. And finally, PDST can be

used to consider the range of decision options and impacts as well as communicate the decision making thread of argument.

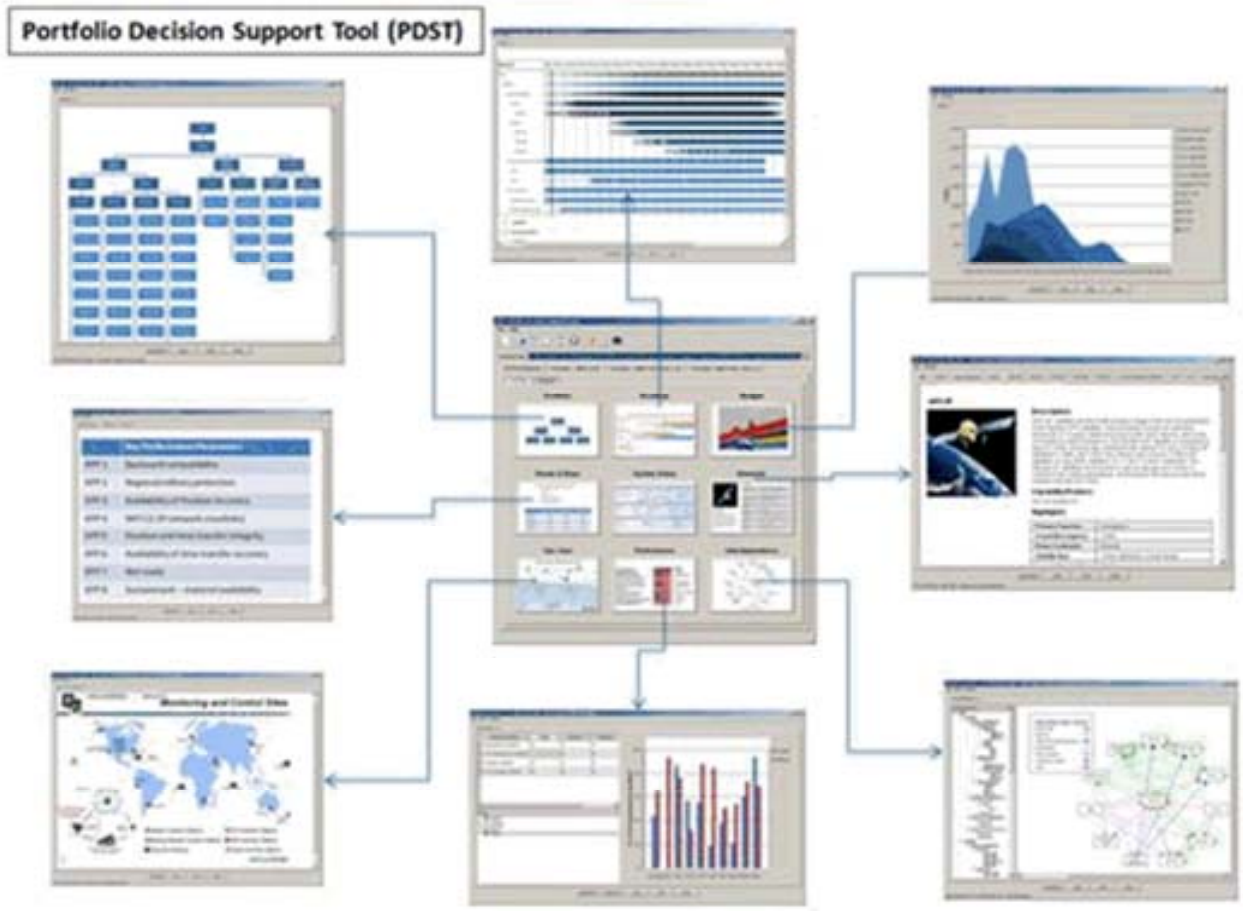

Figure 4. Portfolio decision support tool "Dashboard" and linked tools.

III. Risk, Acquisition Cost and Schedule

E. Acquisition

The objective of the CPDE acquisition planning activities is to produce a set of inputs that can be used in the creation of a preliminary Acquisition Strategy Panel (ASP) documentation. The ASP briefing is required by the Air Force for all programs needing to have contract approval by the milestone decision authority.

In an ongoing effort of collaboration with SMC/XR and AFIT, we are developing an acquisition planning tool for CPDE. The tool has two components. The front end component is an interface and information capture tool that helps the CPDE acquisition planner perform structured analysis of acquisition alternatives. The structured analysis tool will be used by the acquisition planner (the CPDE acquisition seat) to identify applicable guidance and program constraints, to formulate plausible assumptions, and to generate alternative acquisition strategies. Alternative acquisition strategies are subsequently evaluated using the second component of the CPDE acquisition tool: a discrete acquisition-event-simulation model. The model is based on research and methodology defined by Lt Col J. Robert Wirthlin [6] and historical data collected in ongoing studies by his graduate students. The simulation is hosted on the ExtendSim software application as shown in the lower half of Figure 5. The acquisition process follows the DoD 5000.02 regulations, called the Integrated Defense Acquisition, Technology and Logistics Life Cycle Cost Management System, illustrated in the DAU "wall chart" shown in the top portion of Figure 5. The simulation estimates approval process duration and probability of acquisition success of each acquisition strategy alternative. This provides guidance in choosing the best acquisition options to pursue.

The ExtendSim tool models the acquisition process through Milestone C based on inputs and control variables defined by the CPDE acquisition planner using a structured analysis tool and documented in the common data base. An input could be ACAT level or contract type. Control variables are "adjustment knobs" which affect the algorithms embedded in the discrete events. For example, the program office capability value would affect the time required to pass external reviews. The ExtendSim tool evaluates the outcomes of various acquisition approaches by estimating the length of time that the acquisition is likely to take and the chance of a successful procurement. The tool employs Monte Carlo simulation trials and provides the results as probability distributions. This process can be repeated to optimize the probability of success and time through milestone C.

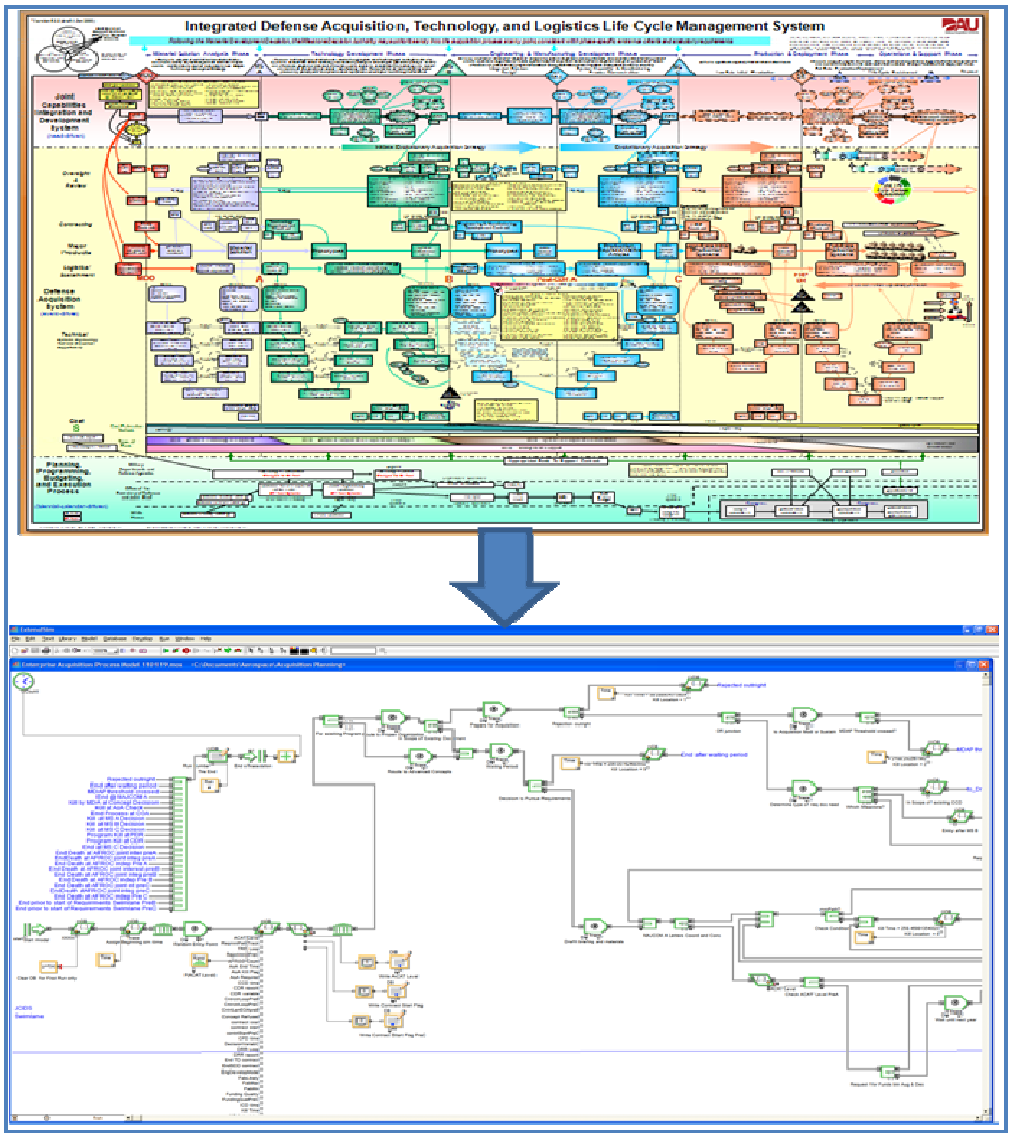

Figure 5. The CPDE Acquisition duration discrete event modeling tool

F. Cost and Schedule

Cost has always been a staple of the Concept Design Center (CDC) and a key element of DSF. From CDC beginnings it became apparent that cost was a prime factor, on par with design variables such as mass and power. In fact, cost is a parameter that gets passed to the most senior levels of the decision process. However, in the CDC the cost output is treated as an engineering design parameter and not a budgetary input.

For this reason, several cost estimating enhancements were created for the CPDE. Foremost was to increase the validity of the estimate by adding a cost anchoring methodology to the parametric models currently in CDC use. The CPDE costing employs specific historic analogies and relevant current bids to anchor the CDC parametric estimates. A second cost estimating upgrade in CPDE is the addition of the cost time-phasing program that uses basic FAR funding requirements to spread the estimate over the relevant fiscal years. This latter function requires an accompanying schedule that can be applied to the projection. Schedule estimating is accomplished in two steps similar to the cost methodology. First is a parametric estimate using the Air Force Cost Analysis Agency (AFCAA) and NRO parametric schedule estimating relationships whose inputs come directly from the CDC design parameter

data base. The second analysis uses The Aerospace design library to make adjustments based on milestones from similar programs.

G. Risk

The risk tool/seat has become a standard feature of the CDC. This tool is connected to the database in the same manner as the other existing CDC tools with its own unique set of parameter. They are risk descriptions in the form of text and quantitative measure used in the generation of the 5x5 risk matrix. The left-hand side of Figure 6 shows the same set of experts as seen in the CDC/CPDE space segment team circle of Figure 2. In addition to their domain tools they each have risk tool that allows them to create parameters to feed the 5 by 5 matrix using the common CDC data base as the method of exchange.

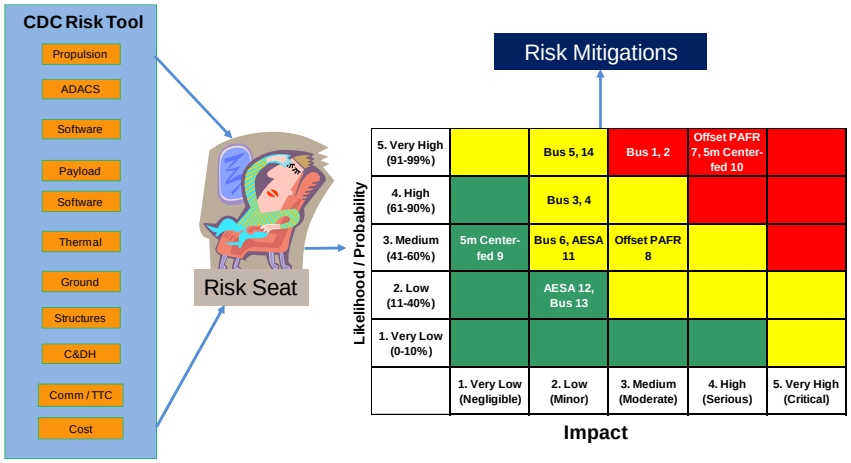

Figure 6. Risk analysis is generated by domain experts and transferred to decision support tool

Each expert identifies risks in his/her domain and calls upon other experts (seats) that might be impacted by the identified risk item. The selected experts can reply and/or modify the risk and send it back to the originator. The person staffing the risk seat is responsible for combining, eliminating adding and finally promoting risks into the matrix. In the CPDE, a senior review team adjudicates the risks and defines programmatic and technical mitigation remedies where appropriate. The process is extremely efficient because of the concurrent processing of risk identifications and the automatic documentation of the issues.

IV Sample Study Results

H. Small Synthetic Aperture Radar (SAR) Products

One practical instantiation of the DSF processes has been employed in several recent studies; including two evaluations of Synthetic Aperture Radars (SARs) designed for a light weight, low cost, common bus, space vehicle. Presented in this section are exemplary versions of the products generated by the Decision Support Framework tool set to show the breath of analysis.

The CDC session developed alternative SAR payload designs to support a top level concept of operations shown in the Operational View 1 (OV-1) diagram, Figure 7.

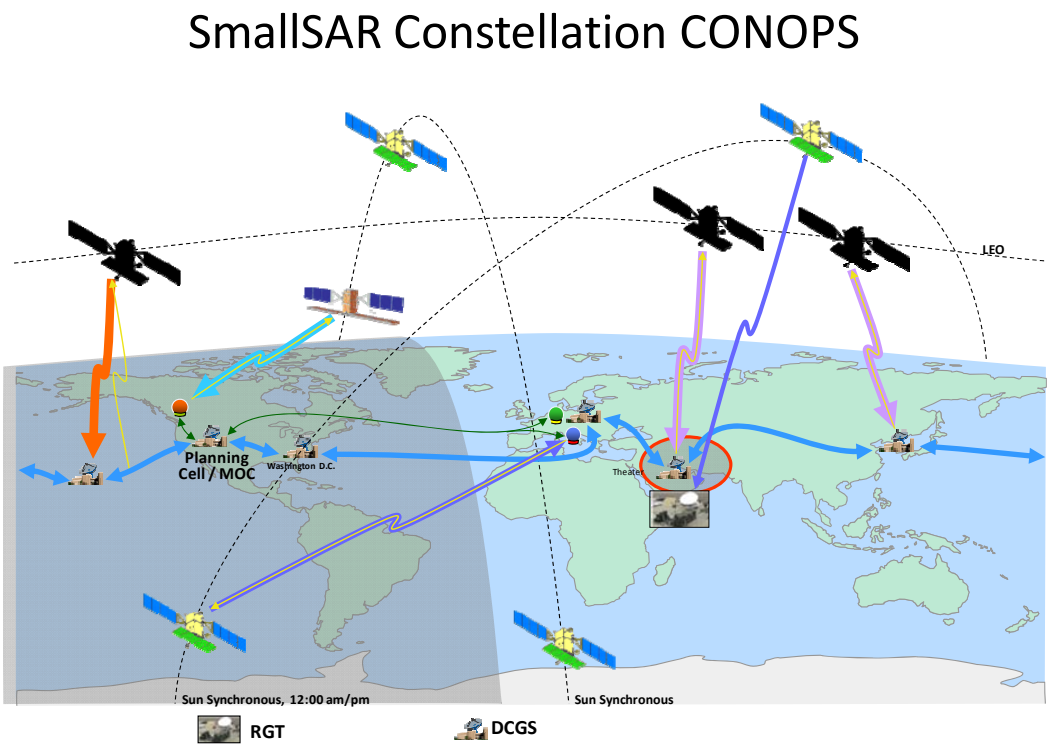

Figure 7. The Operational View -1 (OV-1) diagram is an important CDC customer diagram.

The CDC design parameters are passed to CET/CPDE for further analysis, focusing on customer requirements and acquisition strategies, refer to Figure 8. In this example, eight initial SAR payload and spacecraft designs were evaluated. The designs fall into three categories: parabolic antennas with an offset feed structures, center fed parabolic antennas, and electronic scan antennas. The red, yellow, green ratings in Figure 8 refer to the ability of each design to fit on a Minotaur I launch vehicle and meet the limitations of a common bus design.

		Design Modifications		Launch Vehicle Compatibility			
				EELV Size		PsP Size	
Case	Description	EELV Size	PsP Size	Medium I	Medium I/I	Medium I	Medium I/I
1	3m offset-fed reflector	ADACS?, Power	C&DH, Power	Will not fit	1 or 2 will fit	1 will fit with solar array modifications	1 or 2 will fit
2	4m offset-fed reflector	ADACS?, Power	C&DH, Power	Will not fit	1 or 2 will fit	1 will fit with solar array modifications	1 or 2 will fit
3	3m center-fed reflector	ADACS, Power	Power	Will not fit	1 will fit, 2 will not	1 will fit with solar array modifications	1 will fit, 2 will not
4	4.5m center-fed reflector	ADACS, Power	Power	Will not fit	1 will fit, 2 will not	1 will fit with solar array modifications	1 will fit, 2 will not
5a	2.4m x 1.5m AESA	Did not assess	Payload Mass, Power, Structure, Thermal	Did not assess	Did not assess	Will not fit	2 will fit
5b	2.4m x 1.5m AESA	Did not assess	Payload Mass, Power	Did not assess	Did not assess	Will not fit	2 will fit
6a	3.5m x 1.5m AESA	Did not assess	Payload Mass, Power, Structure, Thermal	Did not assess	Did not assess	Will not fit	2 will fit
6b	3.5m x 1.5m AESA	Did not assess	Payload Mass, Power, Structure, Thermal	Did not assess	Did not assess	Will not fit	2 will fit

Figure 8. CPDE products aid decisions, SAR Example: *Key Design Issues*

There are many aspects to SAR performance and its accompanying usefulness to the warfighter that can be evaluated. For example, Figure 9 shows the extent of area on the Earth where spot images of different resolution can be taken by various designs, depicted on one orbit's ground track. While the CDC has always computed orbits and ground tracks, this analysis factors-in radar performance to generate ground coverage area from the SAR's power and dwell time. The resultant "butterfly" area coupled with an additional analysis for downlink latency and intelligence imagery ratings has provided decision makers with an end to end comparison of the SAR's capability for the radar's image quality, persistence and timeliness of delivery.

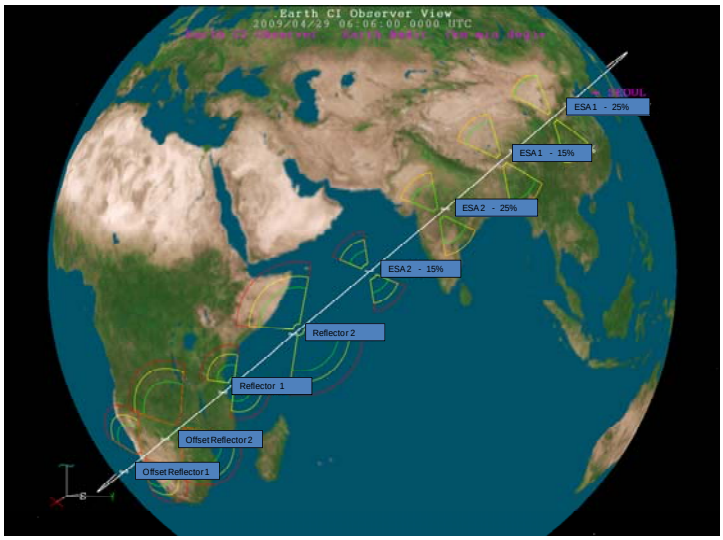

Figure 9. More than an astrodynamics plot the CPDE generates military utility analysis.

The next set of figures review the key summary products created by CPDE to provide decision making information. Using cost and schedule estimates enhanced by data from analogous programs CPDE creates accurate and encompassing deliverables used in the comparison matrices of Figures 10 through 12.

Category			
Government Programmatic Risks	**Cases 1, 2**	**Case 3, 4**	**Case 5, 6**
Funding Risk	Sufficient funding?	Sufficient funding?	Sufficient funding?
Funding support for new program start	Strong congressional support	Strong congressional support	Strong congressional support
Likelihood of stable funding	Sufficient funding in outyears?	Sufficient funding in outyears?	Sufficient funding in outyears?
Programmatic Complexity			
Program Management plan (Government)			
Government personnel plan at ATP	SETA/FFRDC team in place	SETA/FFRDC team in place	SETA/FFRDC team in place
Government acquisition strategy (approval	MDA delegation?	MDA delegation?	MDA delegation?
Program Acquisition strategy likely to succeed	Launch date availability issue. 2 yr feed tech maturation prior to ATP (TRL 4 to TRL 6)	Launch date availability issue. New IA architecture required	Launch date availability issue. AESA 1 yr long lead parts, 2 yr P/L AI&T, 1 yr SV I&T
inter-agency dependencies	New feed, AF PAFR development, MAJCOM TPED, AFSPACE MMSOC	MAJCOM TPED, AFSPACE MMSOC	MAJCOM TPED, AFSPACE MMSOC
Contractual Complexity			
Industry Source	PAFR payload	Contractor payload	AESA payload
Industrial Teams			
Enterprise Compatibility	Integrated Ground	Integrated Ground	Integrated Ground
Synergy	Integrated Ground	Integrated Ground	Integrated Ground

Figure 10. CPDE/CDC Products, SAR Example: *Programmatic Risks*

Schedule Risk	**CASE 1/2**	**CASE 3/4**	**CASE 5/6**
Design and Approach	Assumes payload EDM; no stated plans for bus EDM	No stated plans for bus EDMs	No stated plans for bus EDMs
Software Scope & Complexity	new payload S/W	Tailored S/W for new bus, adapted TPED S/W	Tailored S/W for new bus, adapted DCGS TPED S/W
Interfaces	Assume existing ground system; PACOM receive ground station	Assume existing ground system; PACOM receive ground station	Assume existing ground system; PACOM receive ground station
Infrastructure	new payload	production line and STE exist for similar bus and payload	production line and STE exist for similar bus and payload
Risk Mitigation Plans	Sufficient LV margin for Bus growth; 2 years risk reduction for feed	IA Arch risks; Sufficient LV margin for Bus growth	Sufficient LV margin for Bus growth
Management Factors	Assume mission assurance is not a factor; cost plus contract	Assume mission assurance is not a factor; cost plus contract	Assume mission assurance is not a factor; cost plus contract
Overall Schedule Risk			

Figure 11. CPDE products aid decisions SAR Example: *Schedule risks*

Although not shown on these summary matrices there is a great deal of effort put into associated definition matrices that define the criteria that is assigned to each color and with each item on the left hand column of the summary assessment. For example in Figure 11 the item labeled "Risk Mitigation Plans" has associated definitions such as "not described", "limited or vague", "incomplete" or "appropriately scoped" which are used for the color ratings.

Asssessment Categories	Case 1,2	Case 3/4	Case 5/6
Technical Feasibility	1 SV on Minotaur I	1 SV on Minotaur I	2 SV on Minotaur IV
Technical Risk	Space qualification	Info assurance of contractor	Power hungry
Performance	Few images per theater pass, <50 per day	Tens of images per theater pass, ~100-200 per day	Tens of images per theater pass, ~100-200 per day
Mission Potential	Mapping	Broad area SA & target recognition	Broad area SA & target recognition
Spacecraft Cost	>$60 M	~$60 M for clone	>$60 M
Cost Risk	Space qualification	US IA, SW & ground	US production
Schedule	>5 yrs	~4 yrs	< 5 yrs
Schedule Risk	New design	SW & ground	SW & ground
Programmatic Risk	Show stopper: 5yr to launch	Clone buy is unlikely: IA cert. of spacecraft & ground	Assured manufacturing
Goals Compatibility	Schedule & cost	Simple payload, agile bus	Mature costly payload

Figure 12. CPDE products aid decisions, SAR Example: *Top Level Summary Table*

V Conclusion

The Aerospace Corporation has a long history of providing technical, detailed and design and performance analyses of space, launch and ground systems. Cost, as the industry has repeatedly shown, is a primary decision consideration, but one that has less credibility than the technical design options. To correct this mismatch, recent work on The Aerospace Corporation's Decision Support Framework has made one of its key goals to focus on the implementation of an improved stepped-up cost estimating methodology to be consistent with the level of rigorous analyses demonstrated by the technical design and performance modeling community. To do this, we have expanded the traditional Cost Estimating Relationship (CER) based methodology with analogies based on the historical program information. We have captured underlying risks and projected schedules and have made them part of the cost process. And finally the DSF has added an acquisition modeling and analysis process to capture the programmatic perspectives needed by decision makers.

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