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ABSTRACT

The value-centric perspective of operationally responsive space (ORS) places emphasis on meeting the needs of stakeholders in a timely and effective manner. While ongoing technology developments for spacecraft standardization and rapid launch as well as efforts to develop enabling concepts of operations, tactics, and procedures support the advancement of an ORS paradigm, little work has been completed to evaluate responsive architectures using value-based design methods. To address this gap, Multi-Attribute Tradespace Exploration (MATE), a conceptual design methodology that applies decision theory to model and simulation-based design, is applied to the assessment of ORS and "big space" approaches for a notional intelligence, surveillance, and reconnaissance mission. Decoupling the design from the need through tradespace exploration, MATE is both a solution-generating as well as a decision-making framework. The focus in this paper is on the front-end of the MATE process—eliciting preferences from system stakeholders, including decision makers that have significant influence over the allocation of resources in a development effort. These preferences are captured in a multi-attribute utility function for guiding subsequent tradespace exploration. After enumerating both traditional and responsive attributes for a notional intelligence, surveillance, and reconnaissance mission, the implications of the expanded set of attributes for the MATE modeling architecture are discussed. A model for incorporating schedule as an independent variable within tradespace studies is proposed, as is future work on the identification of mission areas and operational contexts suitable to the ORS paradigm. Overall, the key contribution of the paper is setting up the application of a value-centric methodology for the objective assessment of operationally responsive architectures.

KEYWORDS: Multi-Attribute Tradespace Exploration, Operationally Responsive Space, schedule modeling

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The views expressed in this article are those of the author and do not reflect the official policy or position of the Unites States Air Force, Department of Defense, or the U.S. Government.

INTRODUCTION

What is ORS?

Operationally Responsive Space (ORS) has been defined broadly by the Department of Defense as "assured space power focused on timely satisfaction of Joint Force Commanders' needs... while also maintaining the ability to address other users' needs for improving the responsiveness of space capabilities to meet national security requirements."[1] The purpose of ORS is to reduce the time constants associated with space system acquisition, design, and operation to allow the national space architecture to keep pace with changing missions, environments, and technologies. The fundamental idea is to trade off the reliability and performance achieved by satellites under the "Big Space" paradigm—the currently accepted way of conceptualizing, specifying, developing, and operating space systems—for the speed, responsiveness, and customization which may be achieved by architectures that incorporate elements such as small, modular spacecraft and low-cost, commercial launch vehicles.[2] In addition to obtaining capability on-orbit quickly, ORS attributes include tactical control and assured access. Assured access refers to the potential ability of small, tactical spacecraft to be used to partially reconstitute Air Force space mission areas (*i.e.*, Intelligence, Surveillance, and Reconnaissance; Position, Navigation, and Timing; Communications; Environmental Sensing; Missile Warning; and Space Control) should adversaries negate existing space capabilities.[3] Implicit assumptions in the ORS and "Big Space" paradigms may be traced to their respective historical contexts and original beneficiaries. Table 1 provides a first-order approximation of the distinguishing characteristics of each approach.

Table 1: Distinguishing ORS from "Big Space"

Characteristic	"Big Space"	ORS
Historical Context	Cold War	acquisitions crisis; fragilities inherent in integral, long-life designs
Original Beneficiary	White House	theater combatant commander
Programmatic Drivers	performance	cost, schedule
Innovation Dynamic	capability-pull	technology-push
Payloads	customized, satisfy multiple missions	Off-the-shelf; single-mission focus
Design Life	10+ years	1+ year(s)
Risk Tolerance	risk averse	risk tolerant

Existing Analysis of Value Proposition

Despite the purported benefits of ORS, progress on operationally responsive programs has been slow. In addition to a well-documented set of implementation hurdles,[2,4] ORS progress is stymied by an uncertain value proposition to the U.S. military. Existing analyses in the literature conflict, with advocates finding that ORS "delivers the most utility to the warfighter per dollar spent,"[5] while a former deputy director for the Tactical Exploitation of National Capabilities at Air Force Space Command declares that "tactical satellites cannot serve the effect their proponents claim to want to achieve."[6] Mr. Gil Klinger, Director of Space Policy on the National Security Council from 2002 to 2005, states that operationally responsive architectures deserve, yet have not received, our "analytic due diligence."[*] This view is reinforced by an inability to find rigorous analyses of the value proposition for ORS across the Air Force space mission areas.[†] Furthermore, because one of the core values of ORS is an enhanced ability of the U.S. space architecture to sustain value delivery in dynamic contexts—and given the limited ability of existing conceptual design methodologies to accommodate changing system configurations and operational environments—it is understandable that current evaluations of ORS are unsatisfactory.

Having introduced ORS and discussed the limitations of existing assessments of ORS in terms of stakeholder value, the paper next introduces a promising methodology to address this gap.

MULTI-ATTRIBUTE TRADESPACE EXPLORATION

In order to properly assess what makes a "good" ORS architecture versus "Big Space" legacy architecture, it is necessary to decouple the expectations from the

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[*] Telephone conversation, 22 August 2007.

[†] The only study found, "The Case for Operationally Responsive Space: Cost and Utility,"[5] is severely limited in scope (*i.e.*, only examines one of six Air Force space mission areas), in design alternatives (*i.e.*, only three architectures considered), and in credibility (*i.e.*, assigns zero utility to peacetime intelligence collection—negating the value of strategic satellites except during war and skewing the results for a tactical solution). In addition, the availability of a reusable launch vehicle and low-cost commercial launch vehicles are assumed.

solutions. This section will describe a method that is used during conceptual design that separates the value-space from the design-space in order to understand the differential ability of system architectures to deliver value under changing expectations, here expressed as “paradigms.”

MATE Overview

Multi-Attribute Tradespace Exploration (MATE) is a conceptual design methodology that applies decision theory to model and simulation-based design (Figure 1). Decoupling the design from the need through tradespace exploration, MATE is both a solution-generating as well as a decision-making framework.[7,8]

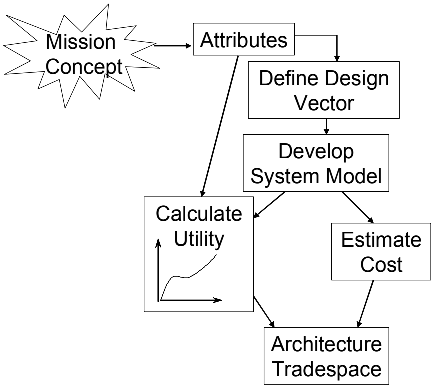
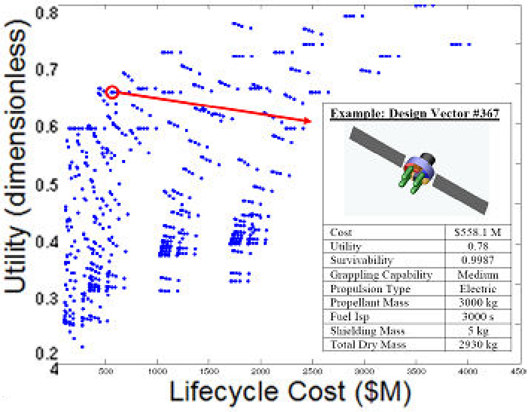


Figure 1. Multi-Attribute Tradespace Exploration

At a high level, implementing the MATE approach to system design involves three activities. First, the preferences of a decision maker (*i.e.*, architecture evaluation criteria) are defined and specified with attributes (*i.e.*, decision maker-perceived metrics that measure how well decision maker-defined objectives are met). These attributes are aggregated using multi-attribute utility theory[9] to arrive at a single utility function (*i.e.*, a dimensionless metric of user satisfaction ranging from 0, minimally acceptable, to 1, highest of expectations). Second, the attributes are inspected, and various design variables *(i.e.*, designer-controlled quantitative parameters that reflect aspects of a concept, which taken together as a set uniquely define a system architecture) are proposed. Each possible combination of design variables constitutes a unique design vector, and the set of all possible design vectors constitutes the design-space. Third, a system model is developed to assess the cost and utility of the candidate designs. Figure 2 provides a sample tradespace output, showing how MATE differentiates designs in terms of incurred cost and delivered utility to the decision maker. In a static MATE study, a limited number of Pareto-efficient designs may then be selected for more rigorous analysis.



Cost	$558.1 M
Utility	0.78
Survivability	0.9987
Grappling Capability	Medium
Propulsion Type	Electric
Propellant Mass	3000 kg
Fuel Isp	3000 s
Shielding Mass	5 kg
Total Dry Mass	2930 kg

Figure 2. Sample Tradespace Plot from MATE

MATE Data Collection Requirements

In order to perform a MATE study, it is necessary to have access to decision makers in order to elicit their value proposition. Specifically, several interviews are required to elicit a given decision maker’s decision metrics (attributes), including the definition, units, and range from least to most acceptable for each attribute, as well as an interview to elicit the single attribute utility functions for each attribute. This utility function expresses the perceived value under uncertainty of different levels of a given attribute. If multi-attribute utility will be used to aggregate the single attribute utilities into a single total utility score, then an additional multi-attribute utility interview will be needed. The nature of this multi-attribute utility interview places cognitive loading constraints on a decision maker, resulting in a practical limit in the number of attributes considered by a particular decision maker to about five.[*10] A follow-up interview is necessary to verify and validate the utility data’s predictive accuracy and consistent adherence to the axioms of utility theory. Often the first interview lasts approximately 1 hour, with the utility interview lasting 2-3 hours, and the follow-up interview lasting about 1 hour.

The assumption going into these interviews is that a decision maker can articulate decision criteria that can be used to distinguish the “goodness” of various design alternatives. It is important to note that attributes and

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[*] The limitation on the number of attributes in a given set is not theoretically limited, but rather practically limited. The multi-attribute utility interview requires consideration of all attributes simultaneously, which is limited by human cognition.[10]

their utility functions should be defined per decision maker, as no guarantee exists that one person's attribute will be value-perceived by another person.

ATTRIBUTES OF USAF SPACE MISSION AREA

Assessing ORS and "Big Space" paradigms in terms of stakeholder value using the MATE process requires thinking first about the fundamental service provided by space systems. For example, the United States Air Force (USAF) has extensive on-orbit capabilities which are categorized into mission areas. Whether provided through the ORS or "Big Space" paradigm, each mission area possesses several stakeholder-defined attributes that are constant across particular solution concepts.

To illustrate the steps of the MATE methodology, it is desirable to select one of these mission areas. As a critical mission area for supporting tactical operations, Intelligence, Surveillance and Reconnaissance (ISR) was chosen for further investigation to highlight the possible implications of the ORS paradigm for improving the legacy architecture. Within this broad mission area, the ISR mission selected for a case example is electro-optical imaging (EO). After discussing the methodology employed to understand and specify a notional EO ISR mission, the elicited attributes are enumerated.

Methodology

Attributes are generated by decision makers, in this case an Air Force acquisition office who volunteered to act as the proxy decision maker and stakeholder. A series of three interviews were conducted. During the first interview, the MATE process was explained to our decision maker. The decision maker desires a design that meets all of his needs. The attributes are the decision criteria that he will use to compare designs to determine their relative "goodness". It is important that the decision maker is able to articulate attributes that will describe his decision process. In this case, he was shown example attributes from previous MATE studies, and asked to describe the criteria he would use to select the "best" design, given a tradespace of possibilities.

During the second interview, the decision maker was asked to define an acceptable range for each of the attributes. Attribute scores extending beyond the specified range in the direction increasing satisfaction provide no extra benefit in terms of perceived value delivery. (Conversely, attribute scores extending beyond the specified range in the direction decreasing satisfaction fail to meet requirements and are excluded from tradespace outputs such as in Figure 2.) It is important to note that all attribute values falling within the specified range are deemed acceptable by the decision maker.

Utility curves were elicited during the third interview. While the range of the attribute is acceptable, some values are more useful to the stakeholder than others. The utility curve describes the varying levels of desirability of the attribute over the bounded range. The elicited attributes and their definitions now follow.

EO ISR Attributes

<u>Signal Coverage</u> – This attribute describes the field of regard of the imaging system. Field of regard (FOR) is a combination of the field of view (FOV) and the pointing capabilities of the spacecraft, and is illustrated in Figure 3. The user is interested in the spacecraft's ability to view an area, the more square kilometers the better. This attribute can be addressed using several items of interest to the designer, specifically it can map almost directly to the complexity of the spacecraft's attitude control and determination system (ADCS). A relatively simple satellite with only nadir pointing capability will generally have a small FOR, that in the degenerate case will be equal to the FOV. A more complex satellite could contain a more powerful and accurate ADCS with the ability to slew the optics away from nadir, thus generating a larger FOR.

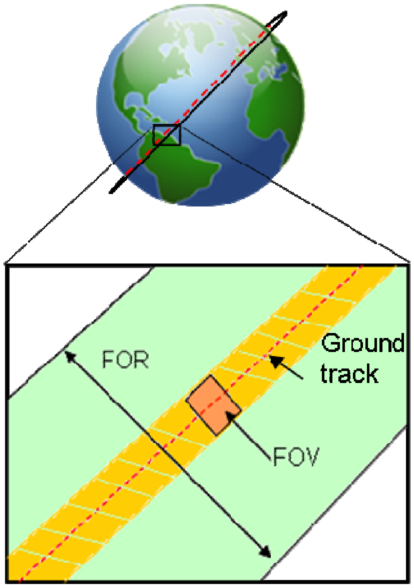

Figure 3. Relation between FOV and FOR.

<u>Global Coverage</u> – This attribute refers to the percentage of the globe that can be observed by the satellite or satellite constellation (Figure 4). This is measured over several orbits, until the satellite returns

to the same over-Earth point. In general, this means that if the ground track repeats in a few orbits, the global coverage percentage will be less than if the ground track takes many orbits to repeat. Global coverage is highly dependent on the orbital characteristics and number of satellites. A higher percentage of global coverage is better.

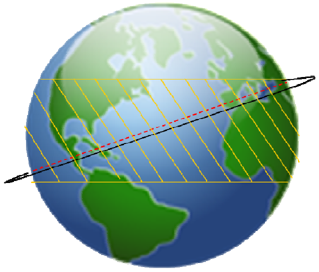

Figure 4. Sketch of Global Coverage Attribute.

Resolution – The metric for the resolution of an optical system is Ground Sampling Distance (GSD). GSD measures the ground area that maps to one pixel in the collection array. A small GSD is better, because you can tell the difference between smaller objects.

Revisit Rate – The revisit rate is the time between opportunities to observe the same location. An orbit that repeats very quickly will provide a shorter revisit rate. However, a satellite with an orbit that is very close to repeating and with a capability to slew off nadir will be able to observe an area off of the ground track, and so might also have a short revisit time. A smaller revisit rate is better since it provides more timely information to the decision maker.

Optics Sensitivity – The EO payload works best at certain wavelengths, and the choice of wavelength contributes to other payload considerations. For example, in the infrared (IR) wavelengths, a payload needs to be cooled, while cooling is less necessary in the visible range. The wavelength also contributes to when the payload can be used to image targets. A payload may be limited to operating in the visible range of light, and only can be useful during the day. A payload that can be operated during the day and night would be more useful. Therefore, the optics sensitivity attribute represents the time of day the payload can be used.

Availability – The availability describes the percentage of mission life that the satellite is operating. Downtime could include items like regularly scheduled maintenance, software updates, and safe mode times during solar storms. This attribute does not include any effects from weather on Earth or the space environment. A higher percentage of availability is better.

Two additional attributes are related to timeliness and control structure. These will be discussed in the following section.

Responsive Attributes

ORS represents a paradigm shift because it treats aspects of satellite design and operation that are treated as constraints in "Big Space" (*e.g.*, schedule, control infrastructure) as parameters subject to tradeoffs against more traditional performance attributes.

Timeliness – The difference between legacy systems and ORS is not necessarily the mission area performed on-orbit. Rather, the key difference lies in the emphasis placed on accelerating production and deployment schedules in the ORS paradigm. The time from identification of the user need to mission capability takes many years under the legacy paradigm. While schedule is a consideration for program managers in the "Big Space" paradigm, the ORS paradigm includes schedule in the tradespace—allowing for some sacrifice in performance in order to gain time. It is this willingness to trade time as an attribute that most clearly distinguishes between the two paradigms.

Control Structure – Another aspect of the paradigm shift is the desire to have on-orbit resources available at the tactical level. In many legacy systems, control of the satellite is many layers removed from the warfighter (*i.e.*, strategic national technical means). ORS aims to remove those layers by providing command authority over space assets to forces within the theater of operations. It is postulated that the effect of this ORS objective would not manifest in the spacecraft itself, but rather in the ground architecture. At this point in the case study, the ground systems are outside of the scope, but will be added later. The ground architecture is often a large investment, either to build a new system or to adapt legacy systems to ORS spacecraft.

Each of the ISR EO and responsive attributes are summarized in Table 2. It is hypothesized that the responsive space attributes enumerated in this paper for the EO ISR mission are applicable across other Air Force space mission areas.

Table 2: Electro-Optical Attributes

Attribute	Units	Acceptable Range
Signal Coverage	km^2	1,000-10,000
Global Coverage	%	66-100
Resolution	m	0.1-1
Revisit Rate	days	0.2-2
Sensitivity	Sensor type	Day-Night
Availability	%	95-99
Timeliness	Years	1-10
Control Structure	Structure type	Strategic-Tactical

Utility Elicitation for ISR Mission Area

The utility curves were elicited using the certainty equivalent probability method. The decision maker is presented with a choice between an attribute level for certain (a probability of 1), and a lottery of best or worst case attribute levels with a probability between *p* of getting the best outcome, and *1-p* of the worst outcome. This particular type of elicitation is not as rigorous as a lottery-lottery option, and may suffer from some bias.[11] However, for this case study, given limited time with the decision maker, it was felt to be easier for the decision maker to quickly become proficient with certainty equivalence probabilities.

An example of a utility curve is shown in Figure 5.

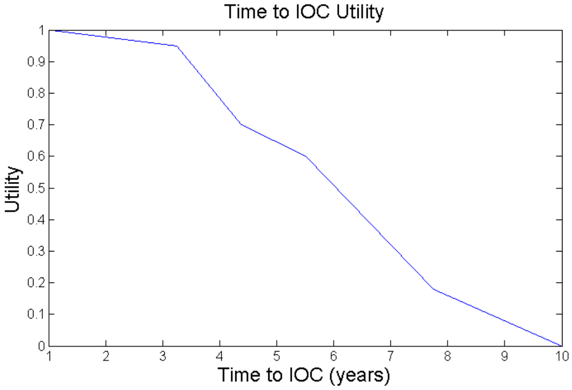

Figure 5. Time to IOC Utility Curve

The curve is monotonically decreasing. Given that utility is assessed at discrete attribute levels over the acceptability range, a linear interpolation is drawn between points. As observed in Figure 5, utility decreases slowly as Time to IOC (Timeliness) increases beyond year 1 before sharply declining following year 3. A single-attribute utility curve for Field of Regard (Signal Coverage) that monotonically increases is shown in Figure 6.

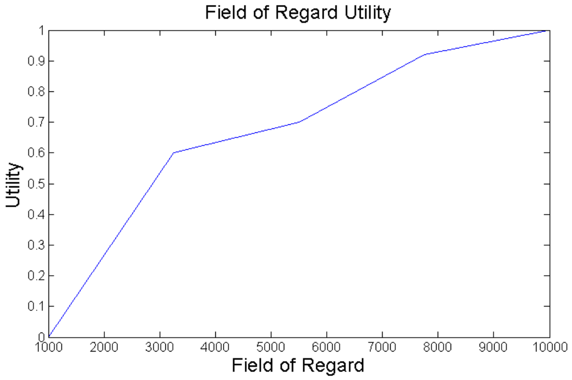

Figure 6. Field of Regard Utility Curve

MODELING ORS WITH MATE

Having introduced Multi-Attribute Tradespace Exploration as a promising value-centric systems analysis technique and outlined stakeholder utility elicitation activities, this section discusses the implications of modeling ORS within the MATE framework. In particular, given the unique attributes introduced by the ORS paradigm (*e.g.*, timeliness), how might MATE be applied to allow a value-centric analysis of ORS? After outlining the ORS modeling architecture, a model for incorporating schedule as an independent variable is presented.

ORS Modeling Architecture

The second step of the MATE process includes generating design variables. Ideally, design variables are aspects of the design that affect the attributes. Attributes are decision maker generated, and are the things that the decision maker will use to differentiate the "goodness" of system alternatives. Design variables are aspects of the system that the designer or architect can control. For instance, a decision maker might care about the final mass of a system. The designer can chose among different materials to build the system, and the choice of material is the design variable. The decision maker did not specify the material as an attribute, and so should not care about that design except as it affects the final mass.

Modeling a system is done with design variables as independent variables, with the attributes as dependent variables. A good, believable model, which assesses the attribute levels of a particular set of enumerated design variables, needs to have enough design variables to drive the first-order relationships between attributes and system designs. However, computing restrictions often limit the number of design variables that can be practically modeled because the number of potential designs grows geometrically as the number of variables increases.

One way to select appropriate design variables is to use a derivative Quality Function Deployment (QFD) method. To build a QFD, brainstorm a list of possible design variables. List attributes on one axis, and the design variables on the other. Figure 7 shows an initial QFD for the EO ISR mission, with attributes as rows and design variables as columns.

	Orbit Alt	Orbit Inclination	# S/C	Slew Ability	Power/Duty Cycle	Optic Size	Optic Sensitivity	Software reliability	Tech level	Reuse of Design	Size/Mass	Integration Complexity	Launch	Testing
Global Coverage	9	9	9	1	3	1								
Signal Coverage	9			9	1	9								
Resolution	9			3		9	9		3					
Revisit rate	9	9	9	3	1									
Sensitivity	1						9							
Availability	1	3	9		3			9						3
Timeliness	1	1	9	3	3	9	9	3	3	9	9	9	9	9
Cost	1	3	9	3	3	9	9	3	3	9	9	9	9	3

Figure 7. Initial Quality Function Deployment

Relationships between attributes and design variables are captured with a {0, 1, 3, 9} scheme. The higher the number, the stronger the design variable will influence the attribute. In some cases, a design variable will map directly to an attribute. Columns and rows are summed (not depicted in Figure 7). A simplistic metric to choose which design variables to include could be to take the five or so highest scoring, and fix other design variables as constants. A slightly more sophisticated method is to calculate the mean value of the summed columns and rows, and then keep all design variables with sums above one standard deviation below the mean. The design variables chosen for the ISR mission, including a factor for schedule (to be discussed in following section) are summarized in Table 3.

Table 3: Electro Optical Design Variables

Design Variable	Units	Range
Orbit Altitude	km	200-500
Orbit Inclination	degrees	20-90
# of Spacecraft	integer	1-10
Focal Length	m	0.5-2
Design Reuse	yes/no	0-1
Optic Sensitivity	day and/or night	0-2
Desired Schedule	years	1-10

Incorporating Schedule Models into Parametric Tradespace Studies

In order to assess the timeliness of various system designs, it is necessary to add a schedule model to the MATE study. Capturing the impact of schedule on design and production of large and complex engineering projects has been the subject of process development research. Several models exist for assessing the possible impact to the overall project of schedule and risk.[12] A simplified model is described below and is based on previous work that incorporates many of the first-order effects of scheduling. However, this model is still under development and its limitations are well understood. For instance, Browning (2007) asserts that most schedule overruns occur because of rework and iterations[13].

The schedule model begins with a list of activities that are required to proceed from a user need to an operational satellite. These broad activities encompass many shorter tasks. Activities and tasks in the schedule model are shown in Table 4.

Table 4: Schedule Activities

Activity	Tasks Included
Architect	Identifying Needs Choosing Concepts Picking Design
Build	Build/Purchase Bus Develop Payload
Assembly, Integration, Testing (AIT)	Component Tests Environmental Tests Integrate Payload and Bus
Launch	Range Scheduling Stacking
Mission Prep	Transfer to Mission orbit Commissioning

Each activity has several tasks assigned to it. For example, based on the architectural choice made by the designer, a bus could be purchased from a commercial company or built from scratch by the procuring agency. Each choice has associated with it a nominal timeline. Buying a satellite bus has a shorter nominal timeline than building one. All of the tasks have an assigned nominal timeline. The time to accomplish all tasks within an activity is added together, which forms the baseline timeline for that activity. The risk associated with such a scenario is assumed to be within acceptable bounds. In this case, risk is modeled as the probability that the overall performance of the satellite will be degraded. Performance degradation is captured in the final design by reducing the design's attribute levels.

Several scenarios are considered beyond the baseline, including compressed, extended and parallel schedules. The first and most used in this model is the compressed schedule. This scenario contains a deadline, after which no utility can be derived from the satellite. In this case, trading time for risk is very attractive. To express schedule compression in the model, a schedule factor (SF) is used. In this case the factor is a simple ratio of the desired schedule, S to the baseline schedule, S_B:

$$SF = \frac{S}{S_B} \tag{1}$$

The SF for a compressed schedule will be less than one. Each SF has a corresponding risk associated with it. The risk introduced from schedule changes is modeled as the probability that the overall mission performance will be degraded.

One way to mitigate the schedule risk, while still reducing the time spent on the program, is to increase the amount of work being done concurrently. Conceptually, this would be like increasing the workforce to alter the effective schedule factor, SF':

$$SF' = SF * WF \tag{2}$$

where WF is a workforce multiplier. This assumption has many faults,[14] however, for capturing first-order effects, it is sufficient. To express an increase in workforce, multiply the SF by the fractional increase. For example, if the workforce, WF, is doubled, the SF is multiplied by two. This is only meant to represent a conceptual increase, not act as a design variable.

Many government programs have involved the development of new technology. A new type of payload could increase the performance of a satellite in a given mission. However, developing new technology is generally detrimental to schedule goals. In a program oriented toward responsiveness, delays stemming from research and development could result in a program arriving at mission capability too late to produce any utility. To capture this effect, each choice of technology is assigned a Technology Readiness Level (TRL), either the actual TRL for existing systems or a projected TRL for conceptual designs. The TRL will have a risk associated with it. In the case of ORS, new processes may also be utilized. Like new technologies, these processes will have kinks and setbacks, contributing to the risk of a delayed schedule. To capture that effect, each process is assigned a "Process Readiness Level" (PRL) which is analogous to TRL.

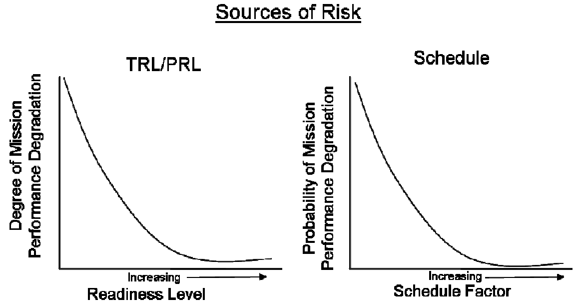

Figure 8. Notional Sketch of Probabilistic Risk Curves

The risk curve changes for each activity (Figure 8). Thinking generally, if the conceptual design task within the architect activity is compressed by a factor of two, the probability of impact to the overall system is higher than if a component test task is cut from the AIT activity. Exact values for these risk curves are not yet determined.

Once each activity is assigned a TRL/PRL and SF, the activities' risk for a scenario must be aggregated. This is done in two parts. The first part uses the SF to calculate the probability of performance degradation in the system risk (R_{SF}) from schedule changes. The second part uses TRL/PRL to calculate the probability of impact of the degradation, or risk from readiness level (R_{RL}). As an example, let SF=0.9, and RL= 9. The corresponding R_{SF} is determined from the risk curve and is found to be 0.4. A random number is generated, which in this example is found to be 0.35. Since the random number is less than R_{SF}, the schedule has caused an impact on the design. To determine the extent of the impact, next the R_{RL} calculation is performed. For RL=9, the R_{RL} is determined to be 0.2. Using the random number method again, 0.6 is generated. Since the R_{RL} is less than the random number, the degree of impact is determined to be negligible. The schedule was compressed such that an impact was probable; however, the high readiness level mitigated the impact on the design such that it was reduced to almost nothing. This notional example shows how modeling schedule can capture process and schedule risks taken in different architectures, and the impact of architecture choice on future performance. This model is not meant to take the place of rigorous risk analysis, but rather provide a first-order idea of schedule risks to use in tradespace analysis.

Given that there is a set of activities that is constant across all scenarios, the differences between scenarios are a function of the choice of TRL/PRL and SF. This creates a new trade within the schedule model. In order to keep risk constant with respect to the appropriate level assigned per activity, a trade between TRL/PRL and SF can occur. To reduce schedule, which increases R_{SF}, choose a higher TRL or PRL, which decreases R_{RL}. If the offset between the increase and decrease is equitable, the overall risk to the program may be constant.

FUTURE WORK

Future work will seek to identify mission areas where a responsive architecture is more valuable than legacy "Big Space" architectures. This work will apply the attribute elicitation process documented in the previous sections to a larger set of space mission areas, including volumetric space situational awareness (SSA) and UHF communications. Following elicitation of traditional and responsive attributes across mission areas, the impact of adding the responsive attributes to the overall design space will be analyzed. Models will be used to assess the attribute performance of different legacy and ORS-inspired system architectures. The end goal of the research is to identify mission areas and operational contexts where either traditional space or ORS architectures are the most valuable to decision makers. Sensitivity analysis will also be performed on the rate of changing stakeholder expectations and environmental conditions to assess the implications of ORS on architectural flexibility and survivability (through limited reconstitution).

CONCLUSION

Being explicit about the stakeholder value proposition enables a more objective assessment of how different space architectures are able to deliver value. Having indentified a need for a value-centric approach towards the assessment of the "goodness" of the ORS paradigm across space mission areas, a tradespace methodology was presented that enables designers to evaluate candidate system architectures across concept solutions. After illustrating the process for eliciting a stakeholder value proposition with a notional ISR mission, the unique challenges posed by applying MATE to ORS were discussed and a preliminary model for incorporating schedule as an independent variable in tradespace studies was introduced. In addition to enabling cost-utility trades within fixed contexts, the MATE methodology provides a framework for conducting future sensitivity analyses on changing stakeholder needs and operational environments.

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