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Real Options and Flexibility Approach to Systems Engineering Enterprise Wide Satellite Communications

Topics
Networks & Networking
Cognitive Social Issues
Organizational Issues

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Abstract

Satellite communications have become a significant form of communications for government agencies. While traditional systems engineering (TSE) has served the satellite developers and terminal developers, this has often been focused on determining the requirements for that constellation, and then separately determining the requirements for each terminal. The incorporation of Real Options (RO) and Flexibility concepts, combined with Enterprise Systems Engineering (ESE) paradigms, provides the opportunity to add significant value to the using community while not impacting the budget to any great extent. This paper will evaluate the concept of satellite communications from the standpoint of a group of satellite systems and terminals being procured by a single agency that would be responsible for the total capability for a 30 year timeperiod. This paper will remove the concept of each capability being bought by individual programs, and will introduce the concept of measuring initial utility and utility over rolling time periods to ensure progress is being made. This paper will also introduce the concepts of inserting Real Options from a bottom up approach for each subsystem (satellite and terminal), and from a top down approach across the total enterprise of constellations and terminals.

Introduction

The United States has made excellent use of satellite communications for many decades. As user requirements have changed, so have the types of satellites that are launched and the subsequent terminals that must use those satellites. As satellite communications is becoming ubiquitous, the potential for the merger of capabilities between satellite constellations and between ground terminals exists, and will likely save users significant investment funds. On the other hand, a focus on too much flexibility in a single satellite or terminal may ultimately ensure that the system does nothing well. This paper will look at ways to add Real Options and flexibility at the satellite and terminal level, as well as across the constellation. The paper will also review possible investment techniques for choosing the Real Options in which to invest, and how a common risk management technique can be adjusted to help identify the best opportunities for inserting Real Options. No detailed capabilities will be mentioned in the effort to ensure this paper remains unclassified and can be approved for public release. The concepts provided can be applied to a variety of systems in both the public and private sectors.

Real Options

The concept of Real Options is a natural extension of the use of options for financial systems. An option is a right that an investor can purchase to provide the opportunity to purchase a significant amount of some commodity at a future date. For instance, an investor may purchase options on 100 barrels of oil at $2/option with a strike price of

$65/barrel within a given time period of say 3 months. The investor would have paid $200.00 for the right, but not the obligation, to purchase those 100 barrels of oil at a later date. Of course the investor would only exercise the option if the price of oil rose above $65/barrel, since otherwise it would be less expensive to purchase the oil on the spot market. As time progressed people also bought options on parcels of real estate. These options were generally a price paid to have a right of refusal on purchasing the real estate at a given cost, within a stated time period. The concept of Real Options is relatively new and relates to designing options into a system. For instance, a common example used by Professor Richard de Neufville of MIT is that of building a parking garage in such a manner that additional floors can be added at a later date if the demand demonstrates the financial viability of such an investment. This is in contrast to building the parking garage to meet only the current demand. The difference in costs for these two designs represents the cost of the option. Another design choice is to build the garage to accommodate the demand that is projected 10 years out. This choice could lead the owners to invest a significant amount of money on a system capacity that might not be used for many years, if at all. The use of Real Options provides the owners the chance to save money in the initial system development and to expand the capacity as requirements, in this case system demand, becomes clearer. A key difference with a Real Option as opposed to the financial instruments is that the Real Option does not have an expiration date, and thus can be exercised at any time.

The Real Options thought processes often focused on the hardware aspects of the systems. In this way RO was closely related to TSE in that the options were related to a single system. Recent thoughts have extended the uses of RO to include systems, processes, and the people who use any/all of them. There may also be some overlap between how an option impacts the people, processes and systems. For instance, a satellite may be designed with additional fuel capacity as a way to purchase an option on additional orbital maneuvers. This option may ripple through the way users align the constellation over many years according to increased demand in a given geographic area.

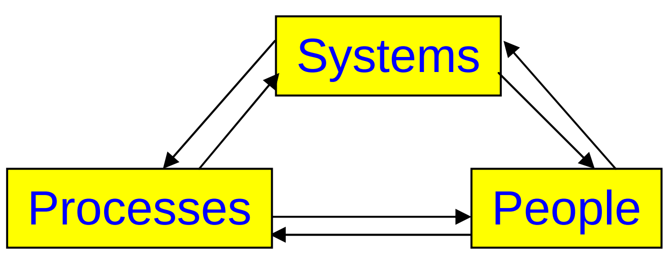

Figure 1. Real Options Impact Areas

Real Options and System Design

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The concept of inserting Real Options into a system first requires the ability to decompose the system into components. This decomposition allows the designers identify areas for possible standardization, and also areas for possible overdesign of components to enable future system evolution. A possible method to perform this decomposition is the Design Structure Matrix (DSM). The DSM is

A Design Structure Matrix (DSM) is a matrix that depicts the relationships among the components in a system (DSM Web Site 2006). Systems engineers use DSMs to illustrate relationships among subsystems. The relationships tracked by a DSM are directional. Thus the relationship of component A to component B is distinct from the relationship of component B to component A.

This study employs DSMs to articulate how changes made to components affect other components in a system. The relationships in the DSMs indicate whether a given component will require modification if another specified component is upgraded. These relationships are stated as dependencies. Figure 3 shows the three possible types of dependency relationships.

Three Configurations that Characterize a System

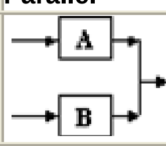
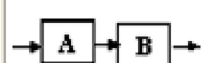
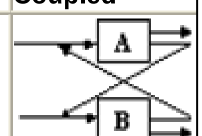
Relationship	**Parallel**			**Sequential**			**Coupled**		
Graph Representation									
DSM Representation		A	B		A	B		A	B
	A			A			A		X
	B			B	X		B	X	

Figure 2. DSM Component Relationships (DSM Web Site 2006)

In the first relationship depicted in the figure, changes to the system components do not interact with one another. Thus component B is independent of component A (and vice versa) with regard to modifications. Upgrades to either component can be made independently. In the sequential (also known as dependent) relationship, changes to one component require modifications to another component in order to maintain a working system. The figure depicts that component B is dependent upon component A. Thus, if component A is upgraded, then component B will require modifications to keep the system operational. Finally, in the coupled relationship, components A and B are interdependent and therefore coupled.

Figure 2 depicts a DSM for a generalized connectivity between a satellite terminal to satellite to satellite terminal. While some users of DSMs insert a "1" or an "X" in the boxes to indicate a relationship between to subsystems, this author has chosen to use an "H" to indicate a high degree of coupling, a "M" to indicate a medium degree of coupling, and a "L" to indicate a low degree of coupling. Each of this linkages, or couples, indicates an increased level of complexity since each relationship will impact the initial design and any efforts to upgrade one of the subsystems as that will also impact the other subsystem as well. Tight couples between subsystems can lead to customized design rules between each of the subsystems, and thus make the total system very tightly coupled and very difficult to design, maintain and upgrade.

		1	2	3	4	5	6	7	8	9
Baseband -- User 1	1		L	H						H
Input Port -- User 1	2			H						
Terminal -- User 1	3	H	H		M	H	L			
Uplink Channel -- User 1	4			H		H	M			
Satellite Communications Payload	5			M	L		L			
Downlink Channel -- User 2	6			M	M	H				
Terminal -- User 2	7			H	L	H	M		H	H
Output Port -- User 2	8							H		
Baseband -- User 2	9	H		M				H	L	

Figure 3. Generalized Satellite Terminal – Satellite – Terminal DSM

Figure 3 shows a less detailed DSM for a system of a satellite terminal to a satellite to another terminal. This low level of detail shows where some items are linked and others clearly are not coupled. Figure 4 provides a medium detailed DSM. The highly detailed DSM consists of an 83 X 83 matrix and becomes too difficult to read on a single page. These tools enable designers to identify the need for a close linkage between the satellite and each terminal. For instance, the modulation and coding mechanisms for each terminal and the satellite must be interoperable to ensure connectivity. Any changes in one system must match changes in the systems. In a lesser coupled manner, the interleavers between each terminal must be interoperable, but changes here do not impact the satellite. The least coupled subsystems are the antennas. The antennas are coupled in a manner to deal with the type of polarization and to support various link margins and data rates. The terminals changing their antenna size won't directly impact the other terminal or the satellite's antennas. The DSMs help to identify not only the areas for coupling but also the possible areas for overdesign of a subsystem. Such overdesign in the satellite or either terminal would relate to software, processing power and memory components that can support changes to the modulation and coding subsystems. Many satellite systems last at least 10 years and sometimes longer, therefore overdesigning some subsystems on the satellite can provide Real Options to possibly exercise if improved modulation and coding subsystems are developed after the satellite has been launched. While the satellite terminals can be upgraded much easier than the satellite, often the terminals are not designed to include these types of Real Options to facilitate easy upgrades. A not uncommon practice is to insist that the initial satellite terminal design allows for using not more than 50% of the available memory. Unfortunately there is no study, at least that this author can find, that provides technical reasoning behind this 50% factor as opposed to 100% or even 1000%. This author would contend that in this era of inexpensive memory and processing power, the satellite and the terminals should all include all of the memory and processing power the system can handle.

	Baseband -- User 1	Input Port -- User 1	Terminal -- User 1	Encoder -- Terminal 1	Interleaver -- Terminal 1	Modulator -- Terminal 1	Uplink Channel -- User 1	Antenna -- Terminal 1	Satellite Receive Antenna	Satellite Demodulator	Satellite Communications Payloa	Satellite Modulator	Satellite Transmit Antenna	Antenna -- User 2	Downlink Channel -- User 2	Demodulator -- Terminal 2	De-Interleaver -- Terminal 2	Decoder -- Terminal 2	Terminal -- User 2	Output Port -- User 2	Baseband -- User 2
Baseband -- User 1		L	H																		H
Input Port -- User 1			H																		
Terminal -- User 1	H	H					M				H				L						
Encoder -- Terminal 1										M								H			
Interleaver -- Terminal 1																	H				
Modulator -- Terminal 1				M						H						M					
Uplink Channel -- User 1			H	H	L						H				M						
Antenna -- Terminal 1									M				L	M							
Satellite Receive Antenna								M													
Satellite Demodulator				L		M															
Satellite Communications Payload			M				L								L						
Satellite Modulator																H					
Satellite Transmit Antenna									L			L									
Antenna -- Terminal 2								L	L				H								
Downlink Channel -- User 2			M				M				H						L	M			
Demodulator -- Terminal 2				L								H									
De-Interleaver -- Terminal 2					H																
Decoder -- Terminal 2				H								L									
Terminal -- User 2			H				L				H				M					H	H
Output Port -- User 2																			H		
Baseband -- User 2	H		M																H	L	

Figure 4. Medium Detail Terminal to Satellite to Terminal Connectivity

Identifying Real Options in Systems and Constellations

The process of identifying Real Options in systems is not always easy. Earlier in this paper the author discussed using the DSM to identify areas for overdesign. There are additional steps to provide a more robust systems engineering solution to identifying the Real Options. The theory and practice of Risk Management has often used the concept of identifying all of the major risks, and then rating each risk by probability and impact. The combination of probability and impact are necessary to rate the highest risk items. On the other hand, some risks may have a high impact but a very low probability, or a very low impact but a high probability, and those risks normally do not meet the criteria of causing significant activities to mitigate those risks. Real Options identification can follow a similar thought process by substituting the concept of opportunity for risk. The key step is to identify those areas where technology change has a high probability and a high impact to increase system capabilities. Figure 4 depicts a new manner to look at opportunities. Whereas the risk management paradigm makes the blocks in the upper right hand corner as red to depict a very high probability and impact of risks with those ratings, this opportunity management paradigm makes those blocks green since they will have the highest probability of happening and the highest impact if the technologies that facilitate those Real Options do materialize. Identifying the most likely technology improvements will include using forecasts from companies such as Gartner, working with government laboratories, performing a survey of the Internal Research and Development (IRaD) activities of private companies that develop the terminals and satellites, and initiating technology development efforts in given areas with the government laboratories. Two inevitable factors include that the forecasts for technology development won't be perfectly accurate, and that some of the impact forecasts may either be a bit inaccurate and/or that user needs have changed. The most important factor is that the designers use these techniques to identify the areas most likely to change (hot spots) and the areas needed to facilitate these changes (cold spots), and then action is taken to design in the Real Options to support future spiral development. Jason Bartolomei, a PhD student at MIT ESD, is developed the concept of hot and cold spots.

The concept of hot spots, cold spots, and Real Options can be applied to an individual satellite, constellations of satellites, and a mix of constellations, as well as including commercial satellite capabilities. Real Options within a constellation can include subsystems that help that specific constellation to react to changing user needs. Commonly a satellite is launched with extra fuel to facilitate orbital maneuvers.

Within a single constellation or a group of constellations, the single biggest Real Option is the ability to launch new satellites with increased capability into the needed orbital locations. Having a reliable and inexpensive launch capability means that satellites can be designed to support a lower life expectancy of the satellites. This provides a balance of designing Real Options into the satellite itself and by enabling a constellation upgrade as user requirements become better known or as technology development reaches a higher level of readiness. While software upgrades can enable upgrades to facilitate the

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incorporation of improved modulation, coding, and encryption schemes, there are limits to increased data rates without making improvements to the satellites' antenna systems.

The total SATCOM capability can also be improved by viewing the composite of the constellations as the total capability provided to the user community. In this way the provider can look at all possible solutions in an area such as slow throughput narrowband communications systems to meet the overall user community's needs. In a similar manner, any satellite system that provides high throughput capability can support the mix of users requiring a high throughput. In this way the providers of SATCOM throughput can view the mix of satellite constellation capabilities, even those in different frequency bands, and the mix of user terminal capabilities to provide a composite capability.

Commercial SATCOM offers an additional capability to support user needs. While the military has previously thought of commercial SATCOM as augmenting military systems, the current reality is that commercial SATCOM supports 80% of the military's needs and military systems support only the remaining 20%. It appears that military systems augment commercial capability by supporting the most mobile users. To exercise the Real Option of Commercial SATCOM will require the user community to either purchase terminals that support a multitude of frequency bands, or procure multiple types of terminals. The first step is likely to procure terminals that support military and commercial frequencies in the same frequency band and similar frequency bands. Looking back at the traditional systems engineering analysis of a satellite terminal (see figures 2 & 3) reveals that inserting too many capabilities within a single terminal may cause interdependencies that inhibit terminal performance. Such factors could include causing problems with processor and memory usage, power consumption, and heat dissipation.

Teaming with Commercial SATCOM providers may offer additional options not previously envisioned. For instance, commercial satellites that have not maximized the use every size, weight and power factor may offer the chance to use these satellites to augment a military capability and to perform experiments with new technologies. INTELSAT Corporation briefed just such a concept at the DOD Commercial SATCOM Users Work Shop in December 2006.

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		Positive Impact of inserting a new technology and Exercising a Real				
		Negligible	Minor	Moderate	Serious	Critical
Probability of Techno	Very Likely (VL) 81-100%	Low	Medium	High	High	High
	Somewhat Likely (SL)	Low	Medium	Medium	High	High
	About Even (AE) 41-60%	Low	Low	Medium	Medium	High
	Somewhat Unlikely (SU)	Low	Low	Medium	Medium	Medium
	Very Unlikely (VU) 0-20%	Low	Low	Low	Low	Medium
		Opportunity Rating:		Low (L)	Medium	High (H)

Figure 5. Real Option Opportunity Chart

All of the above mentioned Real Options can be rated according to the chart presented in Figure 5. This chart offers the chance to evaluate Real Options within a given area, such as a single satellite or constellation, between a type of satellite and the using terminals, and across the mix of constellation types. As previously stated the predictability of the options with the highest probability-impact score won't be perfect, which leads to including an investment methodology that helps to minimize that risk.

Investing in Real Options

Often Real Options investment techniques have involved determining items such as net present value and discounted cash flow. While these methods have been accepted by some users, these methods rely on accurately predicting the discount rate to apply. This author contends that such a prediction, especially over a long time period, will prove to be inaccurate no matter how precise the use of computers can make the predictions appear. An alternative method to investing in Real Options might be to apply the investment principles originally developed by Benjamin Graham and David Dodd in the 1930s, and documented in the books "The Intelligent Investor" and "Security Analysis". Graham and Dodd founded the area of Value Investing, which focuses on purchasing a security significantly below its intrinsic value. They also believed in purchasing a basket of securities and not investing a large percentage of available funds into a single security. Many of their students have utilized Value Investing to become some of the most successful investors in the world over the past 50 years. Their most famous student was Warren Buffett, currently the second wealthiest person in the world, who gained all of his wealth through investing in securities or purchasing large portions of or entire companies. The DoD satellite community can utilize the concept depicted in Figure 5 to identify the Real Options with the highest probability and impact score. At this point each Real Option would be priced for inclusion into the system (satellite and terminals) and for an exercise price on the option. All options in the green shaded areas would then be ranked according to their price. The acquisition community would need to purchase at least 5 Real Options to help mitigate the risk that their predictions will be incorrect. As such the satellite system acquisition community would invest in a basket of options, of which each option can be exercised if and when the user community's requirements show the need for such a capability.

Summary

This paper has discussed possible methods to identify Real Options opportunities within individual satellites and terminals, constellations of the same satellites, cross constellations, and including the Commercial SATCOM providers. To identify the possible options is only a first step in the process. The paper also presents a method to evaluate and compare options according to their impact on user capability and their probability of being exercised. This method enables the acquisition community to identify a basket of probable options in which to invest. The final step is to compare the price of purchasing the options and any incremental cost of exercising the options. Determining costs will enable the acquisition community to determine the best value/cost options in which to invest. This investment paradigm does not follow traditional net present value or discounted cash flow calculations, and that is its strength. This paradigm does follow the very successful Value Investing paradigm that has served many users over the past 50 years.

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