COST RISK ANALYSIS OF SATELLITE BANDWIDTH SERVICES

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ABSTRACT

The purpose of this paper is to demonstrate application of basic risk-analysis techniques to a real-world cost estimating problem. Each year the U.S. Marine Corps must budget millions of dollars for satellite bandwidth services. Communication via satellite is frequently required during operations in theater, disaster relief, and any situation in which a secure communication infrastructure is not already present. The USMC is developing an Expeditionary Command and Control Suite (ECCS) that allows small teams of soldiers to establish secure satellite voice and data links with headquarters. This study allows decision makers to compare bandwidth costs for three different ECCS alternatives. We surveyed airtime rates for INMARSAT M4, BGAN, and Ku-band services. We also developed four representative operational scenarios that describe how the system will be employed operationally. Finally, we interviewed USMC communication experts to determine the frequency and duration of each scenario, as well as the portion of time spent on each type of satellite band. We used ACE 7.0 to develop a flexible framework for modeling bandwidth costs and their associated cost risk. The results show that one of the ECCS alternatives is likely to require significantly more O&M funding because it relies on older satellite technology. In addition, the analysis provides a defendable estimate of annual bandwidth costs.

I. INTRODUCTION

Satellite bandwidth takes the lion's share of O&MMC cost, and in fact accounts for the majority of ECCS life cycle cost. We therefore spent much of the effort researching bandwidth price structures, developing operational scenarios, allocating bandwidth usage, and determining fleet-level optempos through interviews with SATCOM experts within the USMC community.

The ECCS Project Office will fund the first year of O&MMC costs for each MEF. After the first year, each MEF will submit a POM for its own O&M dollars. This analysis provides a defendable estimate of annual satellite bandwidth costs. The ECCS Project Office and the USMC operating forces can use the resulting risk-adjusted estimate for budget development and POM submissions.

II. Background

ECCS enables Marine commanders to establish data and voice communications with headquarters via satellite from remote and austere locations. The small footprint, high bandwidth system will be deployed to small Marine units across a range of scenarios such as disaster relief and advance party operations. ECCS supports connectivity to Secret Internet Protocol Router Network (SIPRNet), Unclassified but Sensitive Internet Protocol Router Network (NIPRNet), Defense Switched Network (DSN), Defense Red Switched Network (DRSN), and video teleconferencing (VTC).

In the spring of 2006, Marine Corps Systems Command (MCSC) in Quantico, Va. commissioned an Analysis of Alternatives (AoA) to evaluate material solutions for ECCS for cost and military effectiveness. The AoA study team, with representatives from Tecolote and MCSC, narrowed the field to three alternatives:

1. Integrate a Commercial-Off-The-Shelf (COTS) solution proposed by Dataline, Inc. called Data Communications Device Multi-Network (DCD-MN).
2. Procure a COTS solution called SwiftLink manufactured by TeleCommunication Systems for the U.S. Coast Guard.
3. Adopt the Army's Secure Enroute Communications Package – Improved (SECOMP-I), managed by PM WIN-T at Ft. Monmouth, NJ.

Each of the alternatives uses different satellite communication pathways, such as INMARSAT, BGAN, and Ku Band. Each pathway has a different price structure for air time, which can cause O&M costs to vary widely among the alternatives.

III. Market Research

We conducted extensive market research on bandwidth costs for multiple communication pathways. We used rates from published GSA schedules to estimate airtime costs for INMARSAT M4 (GAN) (Table 1) and BGAN (Tables 2 and 3). GAN is available at 64 kbps, while BGAN can reach speeds up to 492 kbps for the background IP service. In this study we assumed commands will use streaming BGAN at 256 kbps[1] to accommodate Video Teleconferencing (VTC).

Table 1: INMARSAT M4 Airtime Rates

M4 (GAN) - 64 kbps	$/Min
Intelsat	6.34
SATCOM	5.75
MJ Sales, Inc.	6.96
Mean	**6.35**

Table 2: BGAN Background IP Airtime Rates

BGAN / Background IP	$/Min
Telenor	6.89
SATWEST	5.93
Outfitter Satellite, Inc.	6.95
GMPCS	6.50
Mean	**6.57**

Table 3: BGAN Streaming Airtime Rates

BGAN / 256 kbps streaming	$/Min
Telenor	18.39
SATWEST	18.05
Outfitter Satellite, Inc.	19.90
GMPCS	18.07
Mean	**18.60**

To estimate Ku-band rates we obtained a commercial price list from Arrowhead Global Solutions, Inc., which provides SATCOM services through a DISA contract vehicle known as Defense Information System Network (DISN) Satellite Transmission Service, Global (DSTS-G). We chose the 9-MHz transponder lease based on the ECCS requirement for a minimum

[1] Streaming BGAN is also available at 32, 64, and 128 kbps. The minimum bit rate required to support VTC is 128 kbps.

bandwidth of 512 kbps.[2] We also researched costs for "on demand" Ku-band service through Segovia and TeleCommunication Systems, Inc. DISA and on-demand Ku-band rates appear in Tables 4 and 5, respectively. DISA Ku-band rates differ according to geolocation; therefore, we calculated median values across all global locations for Table 4. The data in Table 5 were obtained through vendor quotes.

Table 4: DISA Ku-band rates

9 MHz Ku-band	Median $
Yearly	543,426
Monthly	56,088
Weekly	18,424
Daily	3,256
Hourly	1,085

Table 5: Sampling of On-Demand Ku-band rates[3]

Cost for 24/7 service *512 kbps/512kbps*	**Cost (FY06 $)**
1 day	$460.07 / day
2 weeks	$5,367.50
1-3 months	$5,367.50 / month

IV. Operational Scenarios

Tecolote and Dataline, Inc. developed four standard operational scenarios to describe how ECCS deployable stations will be used in the field. The scenarios are described in Table 6. The next step in our analysis was to determine the annual frequency of each scenario type. We interviewed a Marine Corps communications expert[4] in III MEF to obtain estimates of annual frequency. Assuming I MEF and II MEF will operate approximately the same type and number of missions as III MEF, we multiplied the III MEF frequencies by a factor of three to obtain annual mission frequencies for the entire Marine Corps. The results for III MEF are shown in Table 7.

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[2] Transponder bandwidth is available through Arrowhead at 1, 9, 18, and 36 MHz. At minimum, a 512 kbps connection would require approximately 5 MHz of bandwidth to achieve an acceptable bit error rate.

[3] Rates in Table 5 were obtained through SegoviaIP Global IP Services. Rates obtained through TeleCommunication Systems, Inc. were comparable.

[4] III Marine Expeditionary Force, G-6 Division, System Planning & Engineering (SPE).

Table 6: Operational Scenarios

MISSION TYPE	DURATION	DESCRIPTION
Advance Party Operations (APO)	Low: 1 day Med: 3 days High: 4 days	This support could be anything from a site survey for an exercise in a remote area to the initial survey and assessment of operational/logistics requirements for a much larger scale operation. The survey or advance party team could be 2-20 personnel providing operational, intelligence, logistics, and communications assessments. The team could operate independent of any existing infrastructure (buildings, power, etc.), or operate out of a hotel.
Support for Forward Deployed Operations (FDO)	Low: 3 day Med: 7 days High: 14 days	This communications requirement would support an assessment team or operations detached from a deployed command. Examples might include a humanitarian relief assessment, Non-combatant Evacuation Operations (NEO), or detachment of personnel to support an on-going operation. Requirements for split operations from deployed Component Command, Marine Expeditionary Unit (MEU), Marine Expeditionary Brigade (MEB) and/or Marine Expeditionary Force (MEF) operations could use the ECCS capabilities to provide operations support to remote areas for early entry or limited duration operations. The ECCS capability is ideally suited for planning support of Marine Operators for deployed exercises and/or advance force operations.
Emergency Relief / Aid Missions (ERM)	Low: 14 days Med: 21 days High: 30 days	This communications requirement would support an assessment team with operations detached from a parent command (MEF) for up to 30 days. Examples would include humanitarian relief operations such as Hurricane Katrina/Rita or Tsunami relief efforts.
First Force Communications (FFC)	Low: 3 day Med: 7 days High: 14 days	This communications requirement would support an early assessment team with follow on operations for a JTF/Component operation of longer standing duration. Any one of a number of scenarios might dictate this support which would be characterized by perhaps ISP, INMARSAT and/or BGAN support initially and followed by Ku-Band support, if/as required, for longer duration. This scenario would build from the preceding scenarios wherein ECCS provides both early entry (until other communications capabilities are provided) and possibly support to operations within the theater. Component, MEU, MEB and/or MEF commands could use the ECCS capabilities to provide operations support to remote areas for early entry as well as detached operations.

Table 7: Annual Frequency of Operational Scenarios, III MEF

		point estimates		
		low	**mid**	**high**
scenarios	**advance party ops**	10	12	15
	supt for fwd deployed ops	18	20	23
	emergency relief / aid missions	5	7	10
	first force communications	15	17	20

V. Bandwidth Allocation

ECCS supports data communications via multiple pathways, i.e., Ku-band, M4, BGAN, public Internet, etc. To complete the analysis it was necessary to estimate usage of each communication pathway. Based on earth coverage of satellite systems and operational order of preference, Tecolote and MARCORSYSCOM developed a notional scheme for bandwidth allocation, as shown in Table 8.

The SECOMP-I system largely relies on INMARSAT M4. We assumed that in most SECOMP-I operations, two M4 channels would be bonded together to achieve 128 kbps, the minimum bandwidth required to support video teleconferencing. DCD-MN prototypes currently are using M4 terminals in testing. When production systems are fielded beginning in FY09, however, they are likely to be fielded with BGAN terminals instead of M4 terminals. We therefore assigned no time to M4 for DCD-MN and the SwiftLink solution, which is currently fielded to the U.S. Coast Guard with BGAN terminals. Ku-band is considered the primary satellite pathway for DCD-MN and SwiftLink, with BGAN representing the backup or secondary connection.

Table 8: Bandwidth Allocation

		ECCS Alternative		
		DCD-MN	**SwiftLink**	**SECOMP-I**
Communication Path	**M4 (2 x 64kbps)**	–	–	90%
	BGAN Streaming (256 kbps)	20%	20%	–
	BGAN IP (up to 492 kbps)	20%	20%	–
	DSTS-G (9MHz)	10%	10%	–
	On-Demand Ku (512 kbps)	40%	40%	–
	Local ISP (T1)	10%	10%	10%
	Total	100%	100%	100%

VI. RISK DISTRIBUTIONS

Table 9 shows the triangular and normal probability distributions that were specified in our cost-risk analysis. The Low and High bounds for INMARSAT M4, BGAN, and Ku-band airtime service came out of the market research we conducted for this study (refer to Section III). In most cases we surveyed three or four SATCOM service providers and obtained prices from their GSA schedules. The mean was calculated and entered into the Equation / Throughput column in Table 9. ACE automatically interprets numbers in this column as the modes (most likely values) of their respective triangular distributions. This immediately presents mathematical challenges; however, for simplicity we have assumed the most likely value approximates the expected value, i.e., the mean.[5] The columns labeled "Low %" and "High%" represent the lowest and highest vendor quotes obtained during our market research. We have interpreted the values in these columns as lying at the 15% and 85% confidence levels, respectively, which are the default settings in ACE 7.0.

The values for DISA Ku-band in the Equation / Throughput column are mean costs. Low and High values (at 15% and 85% confidence levels, respectively) were calculated from raw data using statistical functions in Excel. For on-demand Ku-band service there was only one vendor[6] whose price list was available for analysis. Prices were quoted by geographic area (CONUS, Atlantic Ocean Region, Pacific Ocean Region, Indian Ocean Region, Africa, Asia, and South America). Risk distributions for on-demand Ku-band were determined using a default measure of low dispersion, i.e., a coefficient of variation (CV) of 0.15.[7]

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[5] In most cases, the mean and mode are not equal unless the distribution is normal. We could have calculated a coefficient of variation (standard deviation divided by the mean) for each data set and assumed a normal distribution. In fact, we carried out this calculation and found that the two methods produce results at the mean that differ between 0.36% and 2.44% at the aggregate level. Similar results were obtained at the distribution tails (i.e., the 10% and 90% confidence levels). Therefore, our approximation appears reasonable for this particular study.

[6] Arrowhead Global Solutions, Inc. Commercial price list. http://www.arrowhead.com/pricing.

[7] The Air Force Cost Analysis Agency Cost Risk Handbook (expected publish date summer 2007) suggests default subjective distribution bounds based on the observation that CVs of regressed CERs tend to fall in the 0.15 to 0.35 range.

For scenario duration and frequency we simply specified triangular distributions using the high, medium and low values in Tables 6 and 7. Once again, ACE interprets the "medium" values in these tables as the modes of their respective distributions. Note that probability distributions were not assigned to the inputs for bandwidth allocation (see Table 8). Doing so would generate random-draw scenarios in which total communication path usage would not equal 1. Varying bandwidth allocation lends itself more easily to a what-if analysis in which discrete cases rather than a distribution of random draws are analyzed.

Table 9: Probability Distributions

WBS/CES Description	Equation / Throughput (Mode)	Distribution Form	Low %	High %
****Cost Per Unit Time**				
INMARSAT (M4) - 64kbps (Cost Per Min)	6.53	Triangular	88.1%	106.6%
BGAN - 32 kbps Streaming (Cost Per Min)	2.54	Triangular	88.5%	122%
BGAN - 64 kbps Streaming (Cost Per Min)	6.16	Triangular	95.8%	104%
BGAN - 128kbps Streaming (Cost Per Min)	10.71	Triangular	97.99%	104.6%
BGAN - 256 kbps Streaming (Cost Per Min)	18.60	Triangular	97.04%	107.00%
BGAN - Background IP (Cost Per Min)	6.57	Triangular	90.3%	106%
Local ISP (Cost Per Day)	20.00			
DISA Ku Band - (Cost Per Year)	543426.00	Triangular	49.9165%	166.524%
DISA Ku Band - (Cost Per Month)	56088.00	Triangular	47.868%	166.61%
DISA Ku Band - (Cost Per Week)	18424.00	Triangular	55.148%	120.48%
DISA Ku Band - (Cost Per Day)	3256.00	Triangular	60.73%	129.9%
DISA Ku Band - (Cost Per Hour)	1085.00	Triangular	85.65%	114.3%
On-Demand Ku (Cost Per Month)	5367.50	Normal	75%	125%
On-Demand Ku (Cost Per Week - 8 hr. Day)	1852.80	Normal	75%	125%
On-Demand Ku (Cost Per Week - 4 hr. Day)	926.40	Normal	75%	125%
****Mission Duration (Days)**				
Advance Party Operations (APO)	3	Triangular	1	4
Support for Forward Deployed Operations (FDO)	7	Triangular	3	14
Emergency Relief/Aid Missions (ER)	21	Triangular	14	30
First Force Communications (FFC)	7	Triangular	3	14
****Mission Frequency (Annual)**				
Annual Frequency of Bandwidth Scenarios - per MEF				
Advance Party Operations (APO)	12	Triangular	10	15
Support for Forward Deployed Operations (FDO)	20	Triangular	18	23
Emergency Relief Missions (ERM)	7	Triangular	5	10
First Force Communications (FFC)	17	Triangular	15	20

VII. Calculation

Cost per mission type can be described by the equation

$$\sum_{j=1}^{6} p_j \times c_j \times t_i \text{ (Eq. 1)},$$

where p_j is percent time spent on a particular communication pathway j such that $\sum p_j = 1$; c_j is cost per unit time for each j; t_i is mission duration for the given mission type i, and j is one of six communications pathways: M4 (GAN), BGAN IP, BGAN Streaming, ISP, DISA Ku-band, or on-Demand Ku-band. To calculate mean cost per mission type, Eq. 1 was evaluated 10,000 times by running a Latin Hypercube simulation with the inputs described in Tables 6-9. The results are shown in Table 10. Note the results for SwiftLink and DCD-MN are equivalent because both use the same bandwidth-allocation scheme (see Table 8).

Table 10: Mean Cost per Mission

2006 $K	Mean Duration	SwiftLink	SECOMP-I	DCD-MN
Advance Party Operation	2.6 days	$20.96	$43.77	$20.96
Forward Deployed Operation	8.7 days	$68.21	$144.50	$68.21
Emergency Relief Mission	21.9 days	$169.04	$362.00	$169.04
First Force Communications	8.7 days	$68.21	$144.51	$68.21

Annual bandwidth cost for the entire USMC is simply the sum of cost × quantity for each mission type:

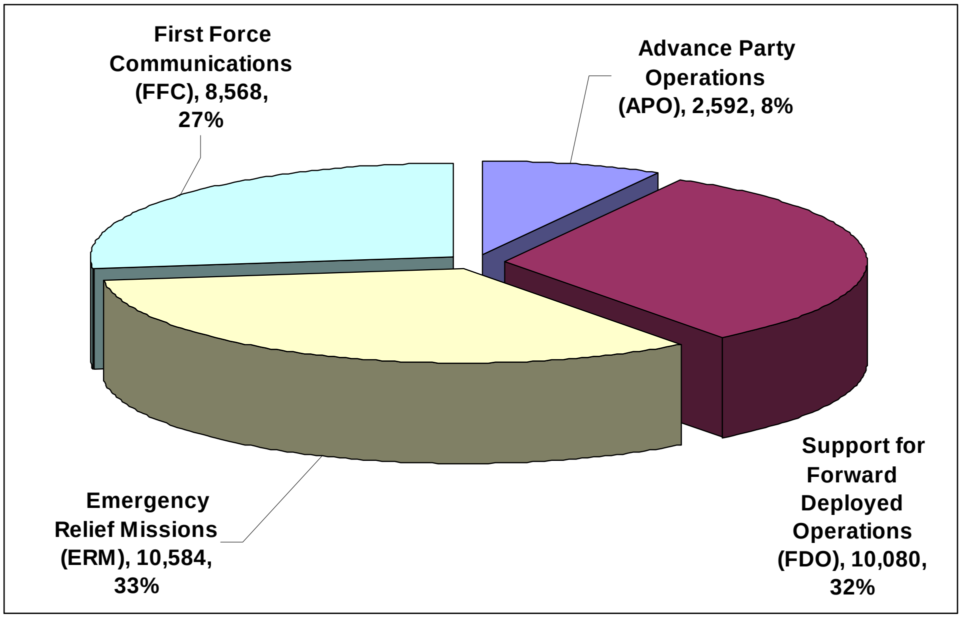
$$\sum_{i=1}^{4} \left(\sum_{j=1}^{6} p_j c_j t_i \right) \times f_i \text{ (Eq. 2)},$$

where i is one of four mission types (see Table 7) and f_i is the annual frequency for each mission type. Table 11 shows the mean cost per year for the total Marine Corps obtained by evaluating Eq. 2 10,000 times with the Latin Hypercube sampling method. Figure 1 breaks down total annual mission hours for the Marine Corps, which is equal to $\sum_{i=1}^{4} f_i t_i$.

Table 11: Mean Cost per Year (Total USMC)

2006 $K	SwiftLink	SECOMP-I	DCD-MN
Mean Cost (One Year)	$12,348	$26,219	$12,348

Figure 1: Annual Marine Corps mission hours for ECCS



Annual operating hours per deployable system are equal to $\frac{1}{q}\sum_{i=1}^{4} f_i t_i$, where q is the quantity of deployable stations. This expression evaluates to 31,824 / 20 = 1,591 hours, or about 18.2% of the time in a given year. This quantity is used in the calculation of Energy Consumption in the O&S phase of the estimate for each alternative. Furthermore, this calculation serves as a check on our optempo calculations, i.e., each deployable station is predicted to operate 1,591 hours per year, which is reasonable.

VIII. Correlation

The final step before running the risk simulation was to specify correlation. Before specifying correlation, existing correlation was measured across all of the inputs in Table 12 using the RI$K correlation report in ACE 7.0. The measured correlation was less than 0.025 across all inputs at 10,000 iterations, demonstrating there is little functional or unintended correlation inherent in the risk model. This step ensures we are not over-specifying correlation, thereby overestimating cost risk.

Table 12 shows how correlation was specified on the inputs. Note that correlation is not required at the WBS elements because there is no estimating risk, i.e., the inputs are simply multiplication factors and are not used in CERs. We separated the inputs into logical groups before applying correlation, reasoning that bandwidth costs would be highly correlated within bandwidth types. For example, if we observe an increase in the daily cost of Ku bandwidth, we should observe a concomitant increase in the monthly cost of Ku bandwidth. Similarly, if the Marine Corps experiences an increase in the number of advance party operations in a given year, they should observe a simultaneous increase in the frequency of other mission types. The same logic can be applied to mission duration.

All inputs were given a correlation strength of 0.9 within their own groups.[8] Note that for the mission-duration (Group 4) and mission-frequency inputs (Group 5), no correlation was assigned to "Emergency Relief/Aid Missions." These missions are primarily responses to natural disasters that are not logically correlated with missions with military objectives.

Table 12: Correlation Groups and Correlation Strength

Correlation Group	Cor. Strength
Group 1. *BGAN Cost*	
BGAN - 32 kbps Streaming (Cost Per Min)	0.9
BGAN - 64 kbps Streaming (Cost Per Min)	0.9
BGAN - 128kbps Streaming (Cost Per Min)	0.9
BGAN - 256 kbps Streaming (Cost Per Min)	0.9
BGAN - Background IP (Cost Per Min)	0.9
Group 2. *DISA Ku Cost*	
Ku Band - Mean (Cost Per Year)	0.9
Ku Band - Mean (Cost Per Monthly)	0.9
Ku Band - Mean (Cost Per Weekly)	0.9
Ku Band - Mean (Cost Per Daily)	0.9
Ku Band - Mean (Cost Per Hourly)	0.9
Group 3. *On Demand Ku Cost*	
512kbps / 512kbps (Cost Per Month - 24/7)	0.9
1024kbps / 512kbps (Cost Per Week - 8 hr. Day)	0.9
512kbps / 512kbps (Cost Per Week - 4 hr. Day)	0.9
512 kbps / 512 kbps (Cost Per Day - 24 hr. Day)	0.9
Group 4. *Mission Duration*	
Advance Party Operations (APO)	0.9
Support for Forward Deployed Operations (FDO)	0.9
Emergency Relief/Aid Missions (ERM)	
First Force Communications (FFC)	0.9
Group 5. *Mission Frequency*	
Advance Party Operations (APO)	0.9
Support for Forward Deployed Operations (FDO)	0.9
Emergency Relief Missions (ERM)	
First Force Communications (FFC)	0.9

Figure 2 illustrates the impact of applying the correlation in Table 12 to the risk inputs in Tables 6, 7 and 9. The applied correlation has the greatest impact at the tails of the distribution.

[8] The AFCAA Cost Risk Handbook recommends a correlation factor of 0.90 to model strong positive correlation.

Figure 3 shows the percent delta of the correlated risk S-curve relative to the uncorrelated risk S-curve. The x-axis represents the risk S-curve without correlation. The signed delta of the correlated S-curve is plotted in 5% increments. At the 80% confidence level, the level at which the Marine Corps funds its programs, correlation adds 7.5% to the uncorrelated total. Although the figures only show the DCD-MN alternative, very similar results were obtained for SwiftLink and SECOMP-I. Therefore, specifying correlation added a moderate amount of cost risk to the estimate that otherwise would have remained unaccounted for.

Figure 2: Impact of Correlation on Risk-Adjusted Estimate

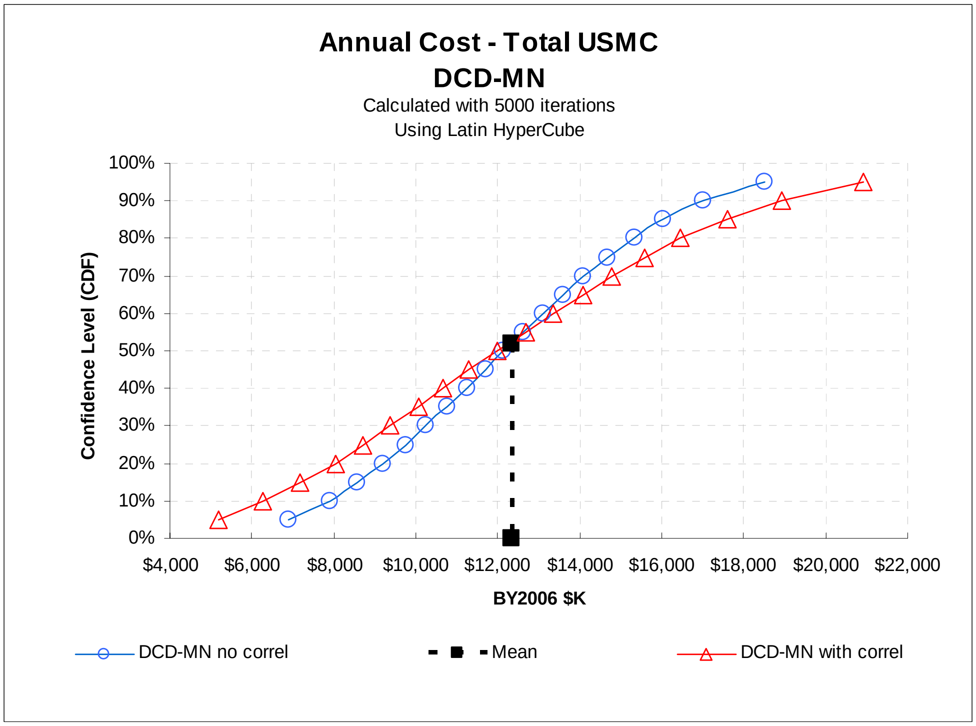
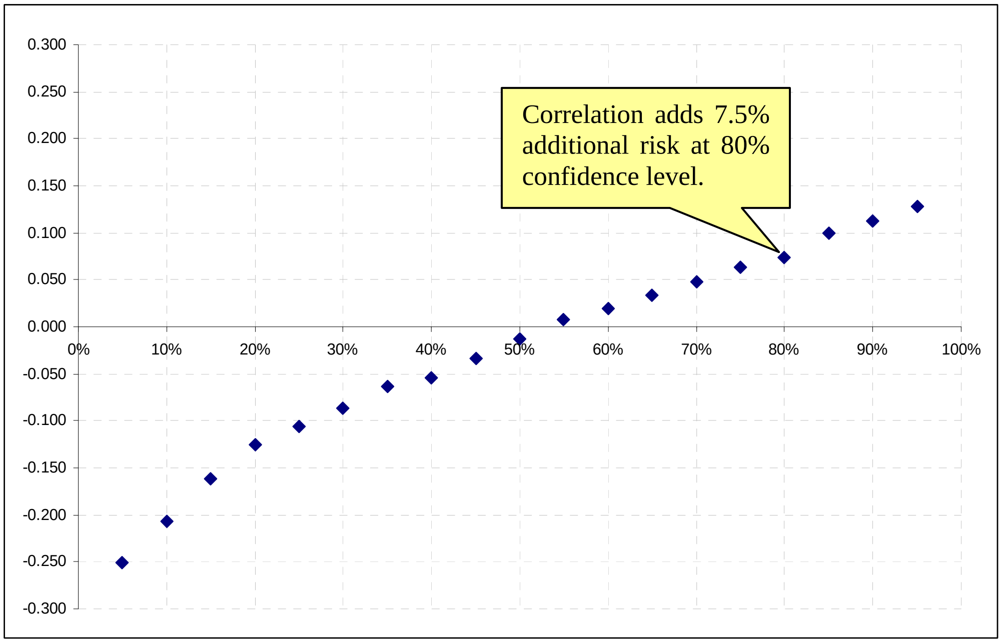


Figure 3: Correlated Risk, Percent Delta Relative to Non-Correlated Risk



VII. Results and Discussion

From the probability distributions specified in Tables 6, 7 and 9 and the correlation shown in Table 12, three cumulative density functions (CDFs) for annual bandwidth cost, one for each alternative, were generated using a Latin hypercube simulation with 10,000 iterations. We choose to show annual rather than total life cycle cost because total cost is dependent on the operational life of ECCS.[9] Furthermore, individual Marine Expeditionary Forces (MEFs) request O&M dollars for their operations on an annual basis. Annual costs are more relevant than life cycle costs with respect to O&M budget considerations.

The results appear in Figure 4. Note the CDFs for the SwiftLink and DCD-MN cases are coincident because both use the same bandwidth-allocation scheme (see Table 8). Figure 5 presents the results at specified confidence intervals: 10%, 50% (median), and 90%. Each cluster of bars in the figure represents an 80% prediction interval, i.e., we expect 80% of future observations to be greater than or equal to the lowest value and less than or equal to the greatest value. Individual MEFs should use Figures 4 and 5 to estimate annual bandwidth costs.

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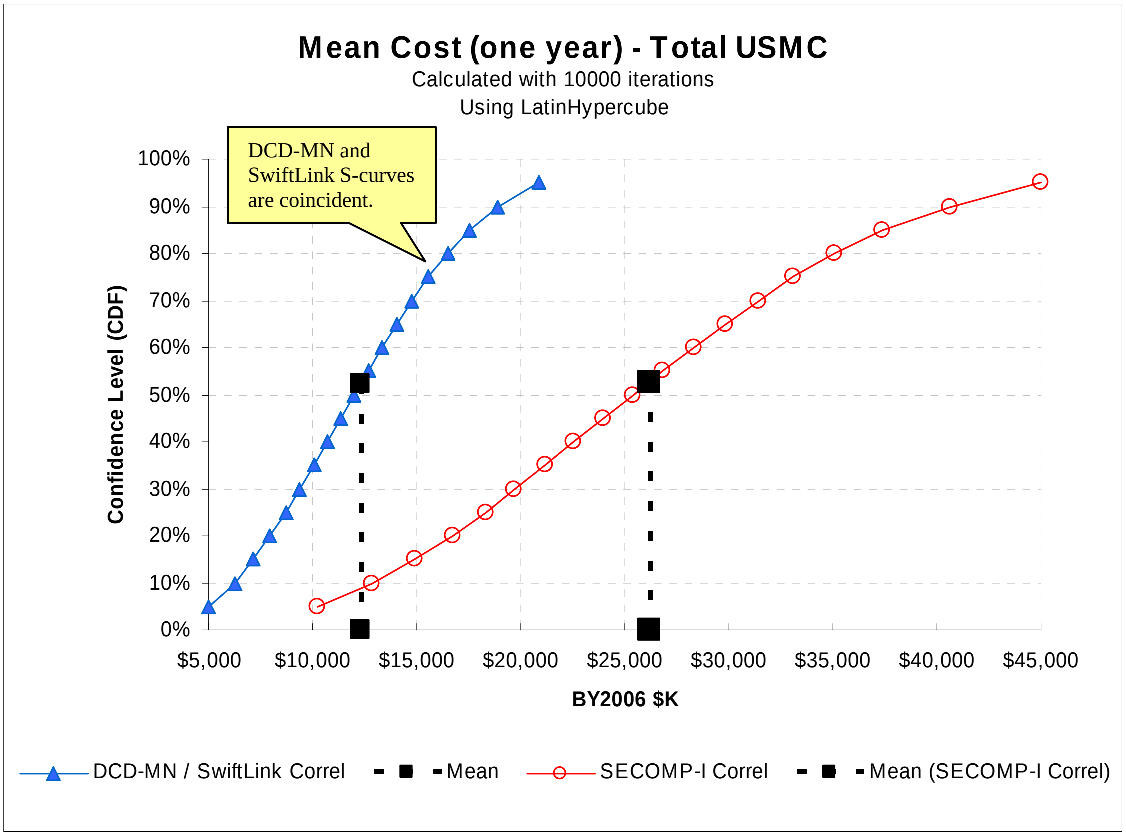
[9] O&S calculations in the ECCS cost model currently are based on an operational life of 10 years.

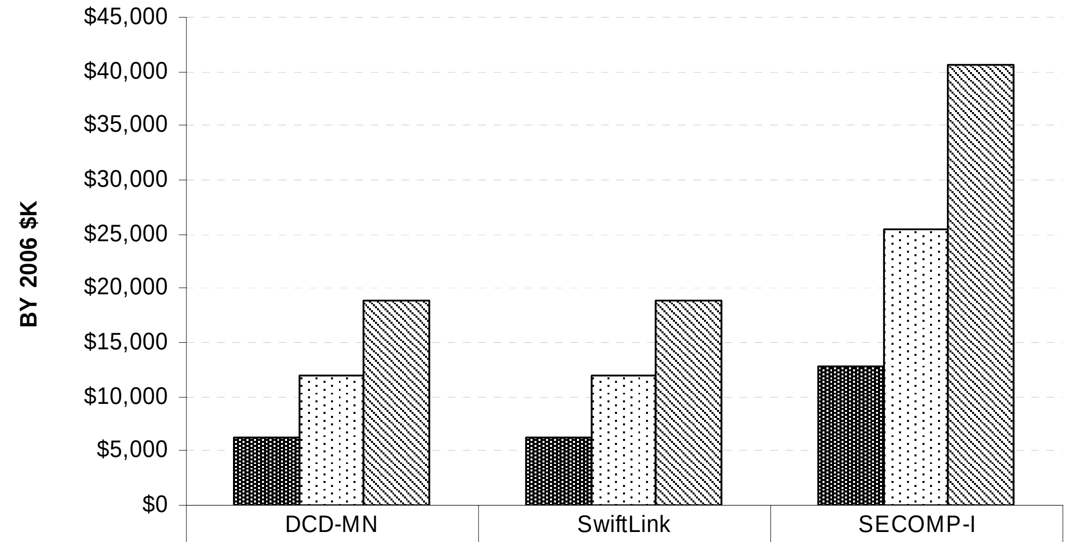
As expected, the CDF for SECOMP-I bandwidth cost exhibits a much larger mean than the CDFs for the other two alternatives. SECOMP-I hardware is limited to communication over INMARSAT M4 or public Internet, and is unable to access lower-cost on-demand Ku band, which makes up 40% of the air time for DCD-MN and SwiftLink (see Table 8). Despite access to lower-cost communication pathways, however, predicted annual O&M costs for DCD-MN and SwiftLink range from roughly $5 M to $20 M per year, producing a coefficient of variation (CV) of 39.3%.[10] This reflects our attempt to accurately model reasonable ranges of values for mission frequency, mission duration, and rates for each bandwidth service.

Figure 4: CDFs for Bandwidth Cost, Total USMC (One Year)



[10] The CV for the SECOMP-I CDF was very similar at 40.6%.

Figure 5: Bandwidth Cost, Total USMC (One Year)



	DCD-MN	SwiftLink	SECOMP-I
10th %ile	$6,234	$6,234	$12,876
50th %ile	$12,021	$12,021	$25,397
90th %ile	$18,879	$18,879	$40,643

VIII. SUMMARY AND CONCLUSIONS

Annual bandwidth costs for the SECOMP-I alternative will approximately double that of the SwiftLink and DCD-MN alternatives, given identical durations and frequencies for each mission type. SECOMP-I relies on older satellite technology (i.e., INMARSAT M4) that is limited to download speeds of 64 kbps per terminal. Achieving greater bandwidth with M4 requires bonding multiple terminals together. With M4 bandwidth costing more than $6.00 per minute on GSA schedules (see Table 1), this option becomes prohibitively expensive. Although the remaining alternatives are less costly, the SwiftLink and DCD-MN CDFs for annual bandwidth cost still encompass a wide range of values. Decision makers should closely examine the assumptions in this study, i.e., mission duration (Table 7), mission frequency (Table 6), and bandwidth allocation (Table 8), before choosing an O&M funding level.

XI. BIOGRAPHIES

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