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WEDNESDAY SESSIONS
VOLUME I

Measuring the Return on Investment and Real Option Value of Weather Sensor Bundles for Air Force Unmanned Aerial Vehicles

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Panel 2. Applications of Real Options Analysis in Defense Acquisition

Wednesday, May 4, 2016	
11:15 a.m. – 12:45 p.m.	**Chair: James E. Thomsen,** Former Principal Civilian Deputy, Assistant Secretary of the Navy for Research, Development, & Acquisition ***Acquiring Technical Data With Renewable Real Options*** Michael McGrath, ANSER Christopher Prather, Senior Associate Analyst, ANSER ***Incorporation of Outcome-Based Contract Requirements in a Real Options Approach for Maintenance Planning*** Xin Lei, Research Assistant, University of Maryland Navid Goudarzi, Postdoctoral Researcher, University of Maryland Amir Reza Kashani Pour, Research Assistant, University of Maryland Peter Sandborn, Professor, University of Maryland ***Measuring the Return on Investment and Real Option Value of Weather Sensor Bundles for Air Force Unmanned Aerial Vehicles*** Thomas Housel, Professor, NPS Johnathan Mun, Research Professor, NPS David Ford, Research Associate Professor, NPS Sandra Hom, Research Associate, NPS Dave Harris, NPS Matt Cornachio, NPS

Measuring the Return on Investment and Real Option Value of Weather Sensor Bundles for Air Force Unmanned Aerial Vehicles

Thomas J. Housel—specializes in valuing intellectual capital, knowledge management, telecommunications, information technology, value-based business process reengineering, and knowledge value measurement in profit and non-profit organizations. He is currently a tenured full professor for the Information Sciences (Systems) Department. He has conducted over 80 knowledge value added (KVA) projects within the non-profit, Department of Defense (DoD) sector for the Army, Navy, and Marines. He also completed over 100 KVA projects in the private sector. The results of these projects provided substantial performance improvement strategies and tactics for core processes throughout DoD organizations and private sector companies. He has managed a $3 million+ portfolio of field studies, educational initiatives, and industry relationships. His current research focuses on the use of KVA and "real options" models in identifying, valuing, maintaining, and exercising options in military decision-making. [tjhousel@nps.edu]

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David Ford—received his BS and MS degrees from Tulane University and his PhD degree from MIT. He is an associate professor in the Construction Engineering and Management Program, Zachry Department of Civil Engineering, Texas A&M University, and the Urban/Beavers Development Professor. He also serves as a research associate professor of acquisition with the Graduate School of Business and Public Policy at the U.S. Naval Postgraduate School in Monterey, CA. Prior to joining Texas A&M, he was on the faculty of the Department of Information Science, University of Bergen, Norway. For over 14 years, he designed and managed the development of constructed facilities in industry and government. His current research investigates the dynamics of development supply chains, risk management with real options, and sustainability. [davidford@tamu.edu]

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Measuring the Return on Investment and Real Options Valuation of a Weather Sensor Bundle in Mission Execution Processes

Weather-related losses of remotely piloted aircraft (RPA) have exceeded $100 million over the past 20 years (Preisser & Stutzreim, 2015). The growing ubiquity of RPAs in routine combat operations is driving fundamental changes to the nature of support for these unmanned aircraft. Support requirements such as bandwidth availability, data transmission capabilities, digital interoperability, and weather forecasting are being pushed to unprecedented limits to ensure they enhance RPA performance without imposing superfluous constraints. A persistent trend plaguing RPA operators has been poor environmental situational awareness degrading overall operational effectiveness.

The impact of suboptimal weather forecasting, especially regarding adverse weather conditions, on RPAs is significant, and it is driving an increasing need for fundamental changes to a system that has matured over several decades of proven operational success with manned aircraft. Without humans in the cockpit, the nature and frequency of weather forecasting processes and supporting technologies must evolve to enable optimized RPA operational performance by providing weather products that achieve high levels of resolution, accuracy, and timeliness.

This research supports Air Force A2I leadership by providing a comprehensive business case analysis that estimates the overall value of investing in, acquiring, and implementing WeatherNow technology. It provides a risk-based assessment for technology portfolio optimization. The WeatherNow technology in this research refers to an advanced weather forecasting software suite and an onboard weather sensor. The software suite collects, decodes, and processes space-based, airborne, and surface observations used in conjunction with numerical weather prediction models. Using advanced algorithms, data fusion techniques, and rapid update capability, it provides comprehensive environmental intelligence products, improved asset protection, and decreased operational risk. The onboard weather sensor provides real-time weather information about icing, humidity, and cloud top heights directly to RPA aircraft operators. The sensor also provides continuous weather data in otherwise data-deprived areas. The software suite and sensor were built to be integrated to provide timely, relevant, and mission-specific environmental intelligence, early threat detection for icing or instrument meteorological conditions (IMC), and overall enhanced ISR collection capability.

The study estimates the value of WeatherNow technology in terms of return on investment (ROI) and uses integrated risk management (IRM) to provide a way to value implementation options; both are indispensable tools that support informed decision-making for technology investment. The analysis and conclusions from this study will support development of effective policy and strategic investment decisions in the effort to transform the existing weather forecasting processes to meet modern demand for near real-time weather information to RPA operators.

To represent a typical mission execution process, this study focused on an RQ-4B Global Hawk squadron based at Beale Air Force Base (AFB). The mission execution process model (MEPM) describes how an RQ-4B squadron plans and executes a typical intelligence, surveillance, and reconnaissance (ISR) mission. The MEPM consists of five subprocesses that are further broken down into tasks. Each subprocess takes an input and changes it in some way to produce an output, which becomes the input for the next subprocess. This process flow continues until the final output is produced, the RPA mission itself. The MEPM in this study was verified by a number of SMEs to be an accurate representation while remaining generic enough to be extensible to a wide range of platforms and scenarios throughout the Air Force and the DoD at large. To ensure extensibility while conserving accuracy in the model, this study is driven by key assumptions that are explained in further detail in the study.

The quantitative framework for this research is known as ROI-IRM (return on investment with integrated risk management). This methodology measures the value added by the WeatherNow technology and by intangibles such as the people executing the process. Since traditional ROI calculation is inadequate for assessing the value of intangible assets such as embedded knowledge, this study uses the knowledge value added (KVA) methodology to estimate ROI. The benefit of using KVA is that a traditional metric such as ROI can be estimated without revenue, by using a surrogate by describing process outputs in common units of output (CUO). Another benefit of KVA is its ability to allocate value across the subprocesses and even down to the task level, a much improved granularity compared to traditional investment finance ROI estimates. To measure the intangible benefits, KVA uses a metric called return on knowledge (ROK). To determine ROI and ROK, KVA compares the As-Is MPEM, the current process, to the To-Be MPEM, the process with the WeatherNow technology included. ROI and ROK estimates are precisely comparable with regard to value for cost return estimates.

Integrated risk management (IRM) uses the KVA results to further develop the business case by forecasting the future value of technology options. IRM uses a methodology known as real options valuation (ROV) to provide leaders with a robust decision support tool to enable informed technology portfolio investment and implementation decisions based on future value estimates. ROI-IRM is an essential tool for supporting decisions on high level strategy and policy concerning new technology and its effective implementation and integration. KVA and IRM used together form a powerful and defensible analytical tool set for decision-making for technology investments.

KVA Analysis and Results

KVA produces two key metrics, ROI and ROK, both expressed as ratios. KVA takes the traditional ROI calculation used in finance and adapts it to non-revenue generating organizations such as the DoD. As in investment finance, a higher ROI indicates a better return for the money invested. For DoD applications, a surrogate value for revenue must be used to monetize the outputs for purposes of an ROI estimate that typically comes from a market comparable analysis. This research used a very conservative, putative value of $1 per unit of output. ROK is calculated as number of outputs (in common units) divided by the cost to produce the outputs. A higher ROK indicates a better use of knowledge assets, and therefore a better investment.

Overall, the results of the KVA analysis show that the use of WeatherNow technology in the RPA mission execution process will generate significantly higher returns and far better use of the WeatherNow technology over the current As-Is process. By comparing the As-Is MPEM to the To-Be MPEM, KVA not only reveals that the WeatherNow technology will add value, but exposes which tasks benefit the most and which benefit the least. Figure 1 displays the differences in returns between both models. With the WeatherNow technology included in the process, ROI increased by 69% and ROK is more than 2.8 times larger than the As-Is ROK. These gains are attributable to the large improvement within the Flight Brief/Outbrief/Weather Update subprocess, specifically the Weather Update task. The WeatherNow technology greatly improves the frequency at which RPA operators receive weather updates, from every four hours in the As-Is process, to every 15 minutes in the To-Be process. This increase means an ROK almost 300 times larger and an ROI over 1000 times larger than the As-Is model. These enormous improvements are due to the process recognizing the added value of the new technology many more times compared to the As-Is without WeatherNow.

	----- As-Is -----		----- To-Be -----		Change in Return on Knowledge as Ratios	Change in Return on Investment as Ratios
Mission Execution Process Description (RQ-4B) Items in red are WX-related	Return on Knowledge	Return on Investment	Return on Knowledge	Return on Investment		
TOTAL	38%	-62%	107%	7%	2.8	1.1
DAY PRIOR TO FLIGHT						
Data Extraction (mission study)	35%	-65%	35%	-65%	1.0	1.0
Confirm which mission you are flying (i.e. which COCOM, route, etc)	101%	1%	101%	1%	1.0	1.0
Confirm currency to fly in that theater and other currency items required for flight	169%	69%	169%	69%	1.0	1.0
Confirm aircraft assignment and status with maintenance	31%	-69%	31%	-69%	1.0	1.0
Review SPINS and classified regulations that pertain to your mission	23%	-77%	23%	-77%	1.0	1.0
Review en route procedures built by COCOM Flight Commander	31%	-69%	31%	-69%	1.0	1.0
File flight plan (DD-175 or 1801)	310%	210%	310%	210%	1.0	1.0
Disseminate products	62%	-38%	62%	-38%	1.0	1.0
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	31%	-69%	31%	-69%	1.0	1.0
DAY OF FLIGHT						
Identify Showstoppers (determine and decide)	78%	-22%	251%	151%	3.2	8.0
Does the weather forecast support flight safety and tactical execution of the mission?	61%	-39%	434%	334%	7.1	9.6
Are appropriate aircraft available for the mission?	21%	-79%	21%	-79%	1.0	1.0
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	103%	3%	103%	3%	1.0	1.0
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	123%	23%	434%	334%	3.5	14.7
Do we have satisfactory LOS comm/data link conditions?	62%	-38%	62%	-38%	1.0	1.0
Have the appropriate supporting agencies been assigned?	62%	-38%	62%	-38%	1.0	1.0
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	10%	-90%	10%	-90%	1.0	1.0
All mission materials and products complete for mission commander review	10%	-90%	10%	-90%	1.0	1.0
Formal Intelligence update (receive intelligence analysis of the following considerations)	124%	24%	124%	24%	1.0	1.0
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	124%	24%	124%	24%	1.0	1.0
Flight Brief/Outbrief/Weather Update Brief	79%	-21%	22659%	22559%	287.6	1064.7
All mission participants understand the plan and their role in support	41%	-59%	41%	-59%	1.0	1.0
Outbrief with Operations Duty Officer (receive latest updates)	45%	-55%	45%	-55%	1.0	1.0
Weather update (icing, convection, lightning, IMC, threat mitigation, etc)	82%	-18%	41616%	41516%	506.7	2324.9
Safety brief/ORM considerations prior to execution	62%	-38%	62%	-38%	1.0	1.0

Figure 1. Impacts of WeatherNow Technology Use on Mission Execution (Differences in Returns as Ratios)

IRM Analysis and Results

The IRM portion of this research incorporates raw data and KVA results from a concurrent study concerned specifically with the weather forecasting process. Both studies use the ROI-IRM methodologies and serve as complementary works. Three deployment options were evaluated using IRM Analysis of Alternatives. The first option, Strategy A, is a phased implementation in which the WeatherNow technology is implemented incrementally over time. The second option, Strategy B, is a higher risk option in terms of capital investment and involves immediate implementation and quick returns. The third option, Strategy C, is to proceed with the existing plan of implementing the new technology on 50 Global Hawk aircraft and no more. Figure 2 displays the results from the ROV analysis. Based on IRM economic valuation forecasting, the highest value option is to deploy the WeatherNow technology immediately.

AS-IS Strategy

Asset Value	$ 270,707
Implementation Cost	$ 1,342,045
Maturity	0
Risk-Free Rate (Annualized %)	0.00%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	9.85%
ROI %	-79.83%
Net Present Value	$ (1,071,338)
Option Value	$ -
Total Strategic Value	**$ (1,071,338)**

TO-BE Strategy: Immediate Implementation

Asset Value	$3,986,537,414
Implementation Cost	$ 5,198,024
Maturity	3
Risk-Free Rate (Annualized %)	0.92%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$3,981,480,893**
Incremental Value-Added	**$3,982,552,231**

TO-BE Strategy: Sequential Implementation

Asset Value	$ 1,993,268,707
Implementation Cost: Phase I	$ 519,802
Implementation Cost: Phase II	$ 1,039,605
Implementation Cost: Phase III	$ 1,039,605
Maturity: Phase I	2
Maturity: Phase II	4
Maturity: Phase III	6
Risk-Free Rate (Annualized %)	1.56%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$ 1,990,841,590**
Incremental Value-Added	**$ 1,991,912,928**

Real Options Valuation

Strategy A Phased Implementation	$ 1,990,841,590
Strategy B Immediate Execution	$ 3,981,480,893
Strategy C As-Is Base Case	$ (1,071,338)

Figure 2. ROV Results

Insights

Although enormous improvements in ROI and ROK were realized, there are still more unrealized benefits of using WeatherNow technology. These benefits include the improvement in the richness of information that RPA operators receive and the implications of this richness on the level of confidence that operators have in making critical go/no-go decisions during mission execution.

Recommendations

Based on the results of this analysis, the following recommendations are submitted. To reduce uncertainty and mitigate risks, leaders should consider total strategic value through sophisticated analytical techniques, such as those used in this study, to inform critical decision-making. Once selected, investments should be tracked and monitored over time and then adjusted as necessary based on observed performance. This study was designed around a mature analytical framework and is extensible to a wide range of services, technologies, and platforms. Similar economic valuation analyses should be performed on other aviation platforms that may benefit from the WeatherNow technology, particularly lower flying RPA platforms that are more limited by adverse weather than the high-flying Global Hawk.

Conclusion

This quantitative analysis has proven that implementation of WeatherNow technology will improve the current mission execution process and has provided risk-based decision support tools to assist with critical decisions. This research did not examine the socio-technical implications of implementing such sophisticated technology in the mature weather forecasting system. Thus, there is opportunity for further research to conduct a detailed examination of potential acceptance issues with WeatherNow and how policy should evolve to support the optimal integration and sustained success of WeatherNow technology. This is an important area for continued research, investment, and innovation, toward modernizing the weather forecasting system to complement the unique needs of RPAs, improving their operational effectiveness, and reducing their susceptibility to adverse weather conditions.

Measuring the Return on Investment and Real Options Value of a Weather Sensor Bundle in Weather Forecasting Processes

Remotely Piloted Aircraft (RPA) usage has grown exponentially both in ubiquity and utility over the past decade and a half. From their initial use as a purely tactical-level asset in providing ground troops with aerial reconnaissance and surveillance, RPAs have become a strategic-level asset with the precision strike capability to take out high-level targets anywhere in the world. Currently, the greatest threat to RPAs is not surface-to-air missiles, but rather their susceptibility to severe weather conditions (Preisser & Stutzreim, 2015). When Unmanned Aerial Vehicles (UAVs) conduct missions in austere and remote environments where little or no infrastructure exists, timely and accurate weather forecasts have become difficult and in some cases almost impossible to produce. Losses in the hundreds of millions of dollars can be attributed to UAV crashes caused by high winds, icing, lightning, and heavy turbulence (Preisser & Stutzreim, 2015). Unfortunately during the development and acquisition of many UAVs in use today, very little testing and analysis of environmental situational awareness was conducted in order to prepare for this threat. Furthermore, without a human present on the platform itself, it becomes even more difficult to determine current weather conditions throughout the mission, exacerbating the threat that severe weather creates. It is for these reasons that a need for increased weather situational awareness has arisen among the UAV community.

The current weather forecasting process for UAV missions reflects a high degree of uncertainty and is often based on hours-old and sometimes inaccurate information. WeatherNow technology will attempt to mitigate the risks presented by the current weather forecasting process by providing significantly improved environmental awareness to maximize mission effectiveness and platform survivability. The program consists of an on-board weather sensor referred to as an Atmospheric Sensing and Prediction System (ASAPS) as well as a software suite, called Nowcasting, that fuses together data from the sensor as well as from existing weather nodes (such as satellite imagery and ground-based radar) to create weather updates that are accurate, timely, and relevant to the RPA crew.

Unique to the WeatherNow technology is the method in which the sensor and software suite are able to interoperate and integrate with current RPA tactics, tools, and procedures (Preisser & Stutzreim, 2015). The WeatherNow program consists of three separate phases that together produce actionable, real time, and much improved environmental awareness. Part one, Mission Area Sensor Streaming (MASS) retrieves environmental data from several sources, both typical and atypical (such as overhead persistent infrared) for the area of interest. Part two, Dynamic Rapid Update Module (DRUM), fuses together the data from the MASS phase (as well as data retrieved from the ASAPS sensor) to create a 4-D view of the environmental situation in the targeted area. As the name suggests, updates are conducted at a high rate, but the system is able to maintain a low level of latency while still producing a high-resolution view. The third portion of the Nowcasting program is Fused, Integrated Representation of the Environment (FIRE). The goal of FIRE is to provide the RPA crew with near-real-time products that give them enhanced environmental awareness of the area of interest. The WeatherNow program has the potential to significantly enhance the weather intelligence gathered in support of unmanned platform missions, but more broadly, it could radically improve the weather forecasting process as it exists in the Air Force today.

In order to estimate the value added by purchasing and implementing the WeatherNow technology, it is necessary to conduct a thorough analysis of the costs and benefits of using both the ASAPS sensor and Nowcasting software suite. This research uses the Knowledge Value Added (KVA) methodology to quantify the benefits of introducing the Nowcasting program into the Air Force weather forecasting process, specifically for the RQ-4B Global Hawk UAV community. This study quantifies value in terms of a Return on Investment (ROI), as well as provides implementation options through the use of Integrated Risk Management (IRM) and Real Options Valuation (ROV) portfolio optimization strategy.

This research documents a process model of the current "as-is" weather forecasting procedures based on input from Subject Matter Experts (SMEs) in the 9th Reconnaissance Wing aboard Beale Air Force Base (AFB). The process model describes how a weather forecast is created for use by an RQ-4B Global Hawk squadron while remaining generic enough to be applied to any Air Force squadron in which weather forecasts are produced. The process is broken down into six main subprocesses, which are further disaggregated to capture the complex nature of weather forecasting. Each subprocess takes a given input and produces an output, which becomes the input to the subsequent subprocess. The final output of the process is an actionable weather forecast brief to be used by the Global Hawk aircrew.

KVA methodology estimates the productivity embedded in an organization by measuring the value of knowledge contained in its people, technology, and processes (Housel & Bell, 2001). In this study, KVA quantifies the value of each subprocess of weather forecasting in terms of a common unit of output. In a non-profit organization like the DoD, estimating the ROI of a technology investment in dollars is not possible in the traditional sense. KVA produces a measure known as Return on Knowledge (ROK) based on the knowledge that is embedded within the organization's people, technology, and processes. This study uses KVA to assess the value added to the weather forecasting process by implementing WeatherNow technology.

The IRM and ROV portions of this study determine the different pathways for the implementation of WeatherNow into the weather forecasting process. Due to the inherent volatility within the DoD acquisition of technology, Air Force leadership needs to have the flexibility to make changes to their adoption strategy. IRM and ROV provides those decision-makers with a tool that helps optimize the value of strategic decisions.

Knowledge Value Added Results

As in traditional financial investment return calculations, ROK is determined by dividing total output by total input. In this study the same ratio is applied to calculate the return on knowledge for each subprocess of weather forecasting and weather forecasting as a whole for both the as-is model and the to-be model (process with WeatherNow technology included). The numerator is calculated by multiplying the total learning time (time required to learn how to do that specific task) by the number of times that task is executed ("fired") per year, and the value of one hour's worth of learning time. In this case a value of $1.00 was used as a very conservative estimate (this is done in both the as-is and to-be models). The denominator is calculated by multiplying the labor cost by the number of people performing the task, the number of times the task is fired in one year, and the time required to perform the task. ROK values allow management to determine which subprocesses within their organization add more value to the process as a whole. Ultimately a higher ROK value for the to-be subprocesses (as well as the overall ROK value) would indicate that investing in WeatherNow technology adds value.

The results of the KVA analysis overwhelmingly support the adoption of WeatherNow technology into the Air Force weather forecasting process. The mission-watching subprocess received the greatest increase in return on knowledge from the as-is to the to-be scenario, as seen in Figure 3. The reason for this is because of the increase in the number of times the tasks within that sub-process are fired in one year. The Nowcasting software suite increases the number of weather updates by almost 20 times per Global Hawk flight mission. The knowledge embedded within the WeatherNow technology is another factor that contributes to the increase in ROK. The Nowcasting software and ASAPS sensor take thousands of hours of learning time and are able to fire at much higher rates than humans are capable. It is this central principle that explains the enormous increases in ROK and ROI. The return on knowledge in the to-be scenario is over 3,000 times greater than the as-is return on knowledge.

RQ-4 Weather Forecasting Process: Comparison of As-Is and To-Be ScenarioResults	As-Is Return on Knowledge	As-Is Return on Investment	To-Be Return on Knowledge	To-Be Return on Investment	Change in Return on Knowledgeas Ratio	Change in Return on Investment as Ratio
TOTAL	20%	-80%	76693%	76593%	3,802.1	612.1
Conduct Annual Cross Talk Between Forecasters and RPA Operators	276%	176%	276%	176%	1.0	1.0
Data Collection	322%	222%	3213%	3113%	10.0	14.0
sensitivities to determine mission-critical weather information	1084%	984%	148349%	148249%	136.9	150.7
Assemble the weather brief, tailoring the collected data to suit the specific mission set	274%	174%	274%	174%	1.0	1.0
Conduct mssion-watching	16%	-84%	366054%	365954%	23,386.8	3,087.5
Conduct debrief	45%	-55%	45%	-55%	1.0	1.0

Figure 3. Changes in Return on Knowledge and Return on Investment Due to WeatherNow Sensor (Differences in Returns as Ratios)

Integrated Risk Management and Real Options Valuation Analysis and Results

The IRM and ROV portions of this study evaluated three different strategies for adopting the WeatherNow Technology. Strategy A implements both the Nowcasting software and the ASAPS sensors over time in a phased approach. This is done with the intent to limit potential risks of failure early in adoption, as technology and software acquisition programs are prone to do. Phase I will outfit 10 Global Hawks with the ASAPS sensor within two years, Phase II will outfit another 20 Global Hawks in the next two years, and Phase III will outfit another 20 aircraft within the last two years. Strategy B is an approach that incurs very high capital investments early in order to reap the returns as quickly as possible. It calls for the implementation of the ASAPS sensor on 100 Global Hawks within three years. Strategy C adopts the technology to only 50 Global Hawks to be outfitted with the sensors, with no specific time constraint. The strategic option strategies are seen in Figure 4. As a result of the ROV calculations, the most optimal solution is Strategy B, immediate execution. It produces a total strategic value of just under $4 billion, as compared to a negative strategic value of $1.07 million for the as-is strategy. These results are seen in Figure 5.

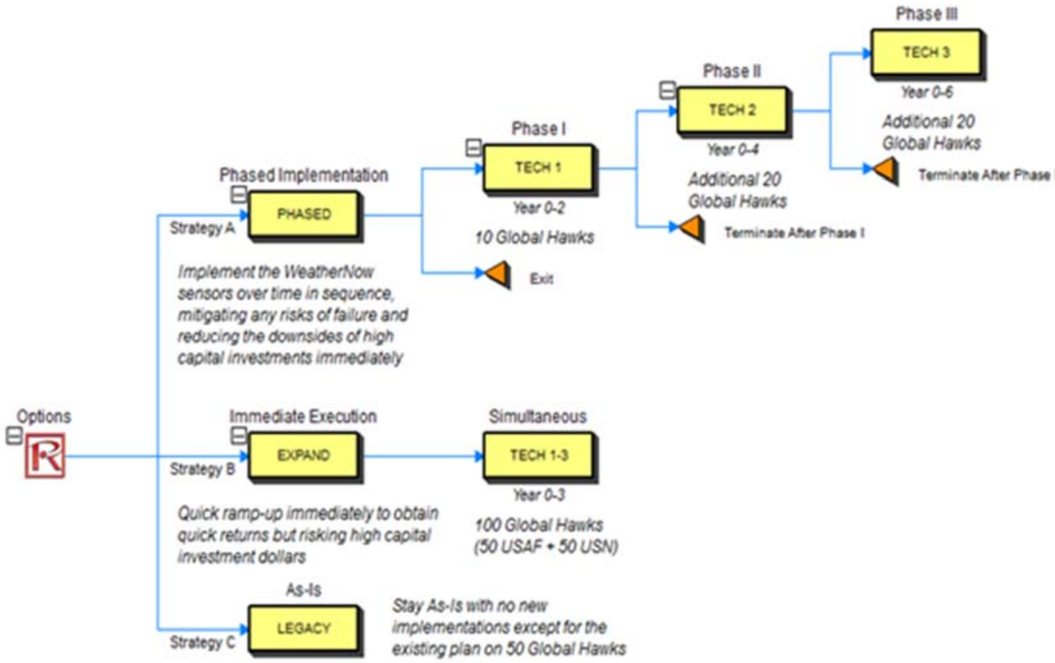

Figure 4. Adoption Strategies for WeatherNow

AS-IS Strategy	
Asset Value	$ 270,707
Implementation Cost	$ 1,342,045
Maturity	0
Risk-Free Rate (Annualized %)	0.00%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	9.85%
ROI %	-79.83%
Net Present Value	$ (1,071,338)
Option Value	$ -
Total Strategic Value	**$ (1,071,338)**

TO-BE Strategy: Immediate Implementation	
Asset Value	$3,986,537,414
Implementation Cost	$ 5,198,024
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Risk-Free Rate (Annualized %)	0.92%
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Real Options Valuation	
Strategy A Phased Implementation	$ 1,990,841,590
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Strategy C As-Is Base Case	$ (1,071,338)

Figure 5. Real Options Valuation Results

Insights, Recommendations, and Conclusions

The KVA analysis conducted in this research indicates a favorable return should the DoD decide to invest in WeatherNow technology. Return on knowledge and cost savings aside, WeatherNow has potential benefits in several other areas as well. This study has only looked at implementation on the Global Hawk platform. Today there are over 10 different RPA platforms in use by the DoD, all of which are susceptible to adverse weather conditions. This study is generic enough to be extensible to not just Air Force weather forecasting in support of Air Force only RPA platforms. Army, Navy, and Marine Corps forces are potential benefactors of WeatherNow technology as well. Furthermore, the accurate weather forecasts produced by the Nowcasting software suite are not necessarily for use by RPA aircrews only. Manned aircraft have the potential to benefit from the increased environmental awareness afforded by WeatherNow. Additionally, ground units, specifically those that fire long-range rockets like the High Mobility Artillery Rocket System (HIMARS) and Guided Multiple Launch Rocket System (GMLRS) rely on timely and accurate weather forecasts. Improved weather intelligence would help those units improve the accuracy and lethality of their strike missions. As with most technological innovations that may disrupt current practices, however, appropriate care and time must be taken to train personnel in the operations and implications of WeatherNow technology. The relevant publications and doctrine would also have to reflect the use of WeatherNow as well. It is the recommendation of this study, however, that Air Force leadership adopts this technology and implements it rapidly.

Conclusion

This quantitative analysis supports the conclusion that implementation of the WeatherNow technology that was examined for this study will improve the current mission execution process and real time weather forecasting process. The results also have provided a risk-based decision support framework and supporting tool set to assist with future investment in technology decisions by treating such decisions as a portfolio of options with varying future quantitative values and risks.

The focus of this research precluded examining the socio-technical implications of implementing such sophisticated weather forecasting technology in the current weather forecasting system. Thus, there is opportunity for further research to conduct a detailed examination of potential acceptance issues with WeatherNow and how policy should evolve to support the optimal integration and sustained success of WeatherNow technology. This is an important area for continued research, investment, and innovation, all in the course of modernizing the weather forecasting system to complement the unique needs of RPA pilots. By improving their operational effectiveness and reducing their susceptibility to adverse weather conditions, the number of successful missions will increase over time.

Recommendations

The results clearly indicate that the immediate option to deploy the WeatherNow technology RAP fleet-wide are warranted. Delays in acquiring and implementing this technology will likely result in reduced value added and lower than possible mission success. The effect of this technology on mission success should be tracked over time so that options, risks, and ROIs can be adjusted to reflect real usage of the technology.

The performance analytical framework used in this study is extensible to a wide range of services, technologies, and platforms beyond its use in evaluating the potential value added of the WeatherNow technology. Similar economic valuation analyses should be performed on other aviation platforms that may benefit from the WeatherNow technology, particularly lower flying RPA platforms that are more limited by adverse weather than the high-flying Global Hawk.

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Weather NOWCasting: ROI and Integrated Risk Management Analysis

Dr. Thomas Housel, Dr. David Ford, Dr. Johnathan Mun, Sandra Hom, Richard Bergin, Dr. Erik Jansen NPS and Captains' David M. Harris and Mathew Cornachio USMC (Masters Theses Students)

Project Purpose

- The problem: UAV missions are frequently scrapped due to inadequate, detailed, micro weather in time sensitive weather voids in mission areas
- The purpose of this activity is to provide A2I Air Force leaders in their mission to:
  a) Measure the return on investment (ROI) and future value (IRM) for weather sensors and forecasting algorithms that provide instantaneous weather information for pilots and UAV operators in combat zones.
  b) Complement ongoing economic evaluation of field experimentation activities for the rapid testing and fielding of new sensor technologies.
- The NPS team worked with the A2I team to help them structure the business case for acquiring the requisite technologies using the ROI-IRM* framework and analysis results and utilize the analysis to manage the program trade-offs over time.

** Return on Investment using the Integrated Risk Management process*

Presentation Outline

- Secondary research conducted to review current options for weather sensors and forecasting
  - There are ***no acceptable market comparable(s) for monetization of the value of the sensor bundle***
  - Research has established that sensors are valuable ***but has not monetized that value***
- ROI-KVA Analysis: Method and Results
- Integrated Risk Management: Monte Carlo Risk Simulation with Real Options Valuation and Analysis of Alternatives
- Recommendations

ROI Methodology: Knowledge Value Added (KVA)

- ROI = [$Revenue – $Cost]/[$Cost]
  - There is no revenue in a non-profit requiring a revenue surrogate for ROI
  - Market comparable(s) is a common approach for estimating revenue surrogate
  - We used a very conservative market comparable = $1 (Mission Execution Process) and $.10 (Weather Only Forecasting Process) for per unit of output monetized value

- KVA: Measures all outputs in common units of value – Knowledge
  - Market comps are used to establish a putative revenue per unit of knowledge
  - Knowledge is measured in common units of learning time (with a common reference point learner): i.e., 10K hours of actual learning time = Ph.D. in meteorology and 1440 hours represents actual training of an E5 for 9 months in interpreting weather forecasts
  - We used normalized learning time estimates for the mission execution process (and converted them to actual learning time) and actual learning time for the WeatherNow forecasting and use of that weather information process.
- KVA ROI = 10K units of actual knowledge * $.10 * number of uses of the knowledge in a given sample period (i.e., 1 year)/cost to use the resources (i.e., sensor bundle and human resources—O3, E5)

ROI on Mission Execution Results: As-Is and To-Be Comparison

	----- As-Is -----		----- To-Be -----			
	Return on Knowledge	Return on Investment	Return on Knowledge	Return on Investment	Change in Return on Knowledge	Change in Return on Investment
TOTAL	**38%**	**-62%**	**107%**	**7%**	**69%**	**69%**
DAY PRIOR TO FLIGHT						
Data Extraction (mission study)	35%	-65%	35%	-65%	0%	0%
Confirm which mission you are flying (i.e. which COCOM, route, etc)	101%	1%	101%	1%	0%	0%
Confirm currency to fly in that theater and other currency items required for flight	169%	69%	169%	69%	0%	0%
Confirm aircraft assignment and status with maintenance	31%	-69%	31%	-69%	0%	0%
Review SPINS and classified regulations that pertain to your mission	23%	-77%	23%	-77%	0%	0%
Review en route procedures built by COCOM Flight Commander	31%	-69%	31%	-69%	0%	0%
File flight plan (DD-175 or 1801)	310%	210%	310%	210%	0%	0%
Disseminate products	62%	-38%	62%	-38%	0%	0%
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	31%	-69%	31%	-69%	0%	0%
DAY OF FLIGHT						
Identify Showstoppers (determine and decide)	78%	-22%	251%	151%	172%	172%
Does the weather forecast support flight safety and tactical execution of the mission?	61%	-39%	434%	334%	372%	372%
Are appropriate aircraft available for the mission?	21%	-79%	21%	-79%	0%	0%
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	103%	3%	103%	3%	0%	0%
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	123%	23%	434%	334%	311%	311%
Do we have satisfactory LOS comm/data link conditions?	62%	-38%	62%	-38%	0%	0%
Have the appropriate supporting agencies been assigned?	62%	-38%	62%	-38%	0%	0%
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	10%	-90%	10%	-90%	0%	0%
All mission materials and products complete for mission commander review	10%	-90%	10%	-90%	0%	0%
Formal Intelligence update (receive intelligence analysis of the following considerations)	124%	24%	124%	24%	0%	0%
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	124%	24%	124%	24%	0%	0%
Flight Brief/Outbrief/Weather Update Brief	79%	-21%	22659%	22559%	22580%	22580%
All mission participants understand the plan and their role in support	41%	-59%	41%	-59%	0%	0%
Outbrief with Operations Duty Officer (receive latest updates)	45%	-55%	45%	-55%	0%	0%
Weather update (icing, convection, lightning, IMC, threat mitigation, etc)	82%	-18%	41616%	41516%	41534%	41534%
Safety brief/ORM considerations prior to execution	62%	-38%	62%	-38%	0%	0%

Weather-Now Forecasting Results: As-Is Scenario

RQ-4 Weather Forecasting Process: As-Is Scenario Results	Return on Knowledge	Return on Investment
TOTAL	**20%**	**-80%**
Conduct Annual Cross Talk Between Forecasters and RPA Operators	**276%**	**176%**
Conduct systematic review of forecasts from previous period (annually, monthly, etc)	274%	174%
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	274%	174%
Based on operational factors, determine the information needed in forecast briefs	274%	174%
Data Collection	**322%**	**222%**
Consult the appropriate sources of data (satelliete imagery, sensors, PiReps, etc)	282%	182%
Based on feedback in Process 1, what are appropriate parameters of weather data	282%	182%
Assimilate data into relevancy for mission (i.e. wind data, icing data, turbulence, etc)	282%	182%
Are the proper sensors, other collection agents available?	282%	182%
Cross-reference the assimilated weather data with aircraft sensitivities to determine mission-critical weather information	**1084%**	**984%**
Based on severity of weather data, make the determination of what weather aspects will impact the mission	1084%	984%
mission set	**274%**	**174%**
Ensure all mission-essential weather information is included in the brief	271%	171%
thunderstorm data, etc	271%	171%
Conduct mssion-watching	**16%**	**-84%**
Using an array of collections assets, monitor the weather throughout the flight mission	14%	-86%
Conduct rebrief at least every four hours throughout the mission or more frequently if unexpected/severe weather appear	14%	-86%
Stay in constant contact with pilots via MRC chat	14%	-86%
Conduct debrief	**45%**	**-55%**

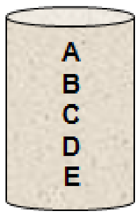
Weather-Now Forecasting Results: To-Be Scenario

RQ-4 Weather Forecasting Process: To-Be Scenario Results	Return on Knowledge	Return on Investment
TOTAL	**76693%**	**76593%**
Conduct Annual Cross Talk Between Forecasters and RPA Operators	**276%**	**176%**
Conduct systematic review of forecasts from previous period (annually)	274%	174%
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	274%	174%
Based on operational factors, determine the information needed in forecast briefs	274%	174%
Data Collection	**3213%**	**3113%**
Multi-data source deconfliction and data quality control	1545%	1445%
4D Data assimilation/fusion	7727%	7627%
High-resolution 4D forecast	3091%	2991%
High-resolution 4D weather threat assessment	1545%	1445%
Operator-focused weather threat analysis	1545%	1445%
Cross-reference the assimilated weather data with aircraft sensitivities to determine mission-critical weather information	**148349%**	**148249%**
Nowcasting (fire-decision support tool)	148349%	148249%
Assemble the weather brief, tailoring the collected data to suit the specific mission set	**274%**	**174%**
Ensure all mission-essential weather information is included in the brief	271%	171%
Scintillation, sky cover, stratospheric turbulence, wind/temperature charts, thunderstorm data, etc	271%	171%
Conduct mssion-watching	**366054%**	**365954%**
ASAPS real-time sensing (humidity sensor only)	716656%	716556%
Nowcasting (mass, drum, fire)	15453%	15353%
Conduct debrief	**45%**	**-55%**

Integrated Risk Management Process

1 List of projects and strategies to evaluate

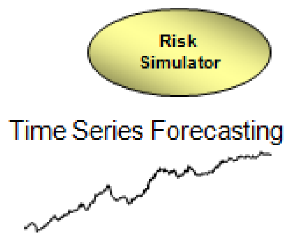
RISK IDENTIFICATION



Start with a list of projects or strategies to be evaluated… these projects have already been through qualitative screening

2 Base case projections for each project

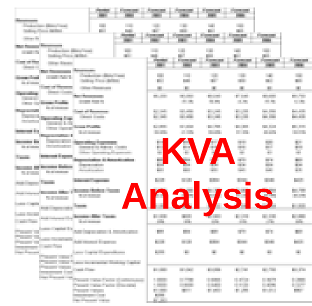
RISK PREDICTION



…with the assistance of time-series forecasting, future outcomes can be predicted…

3 Develop static financial models

RISK MODELING

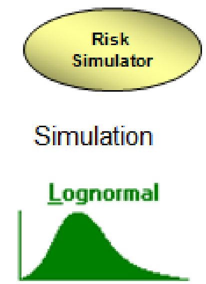


Traditional analysis stops here!

…the user generates a traditional series of static base case financial (discounted cash flow) models for each project…

4 Dynamic Monte Carlo simulation

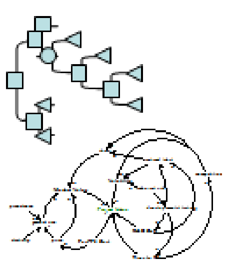
RISK ANALYSIS



…Monte Carlo simulation is added to the analysis and the financial model outputs become inputs into the real options analysis…

5 Framing Real Options

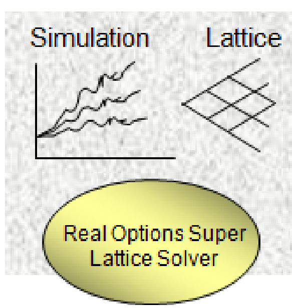
RISK MITIGATION



…the relevant projects are chosen for real options analysis and the project or portfolio real options are framed…

6 Options analytics, simulation, optimization

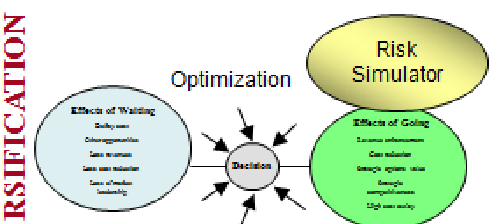
RISK HEDGING



…real options analytics are calculated through binomial lattices and closed-form partial-differential models with simulation…

7 Portfolio optimization and asset allocation

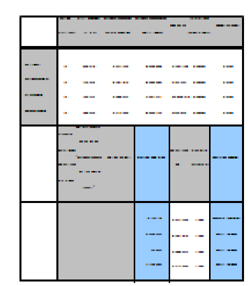
RISK DIVERSIFICATION



…stochastic optimization is the next optional step if multiple projects exist that require efficient asset allocation given some budgetary constraints… useful for strategic portfolio management…

8 Reports presentation and update analysis

RISK MANAGEMENT



…create reports, make decisions, and do it all again iteratively over time…

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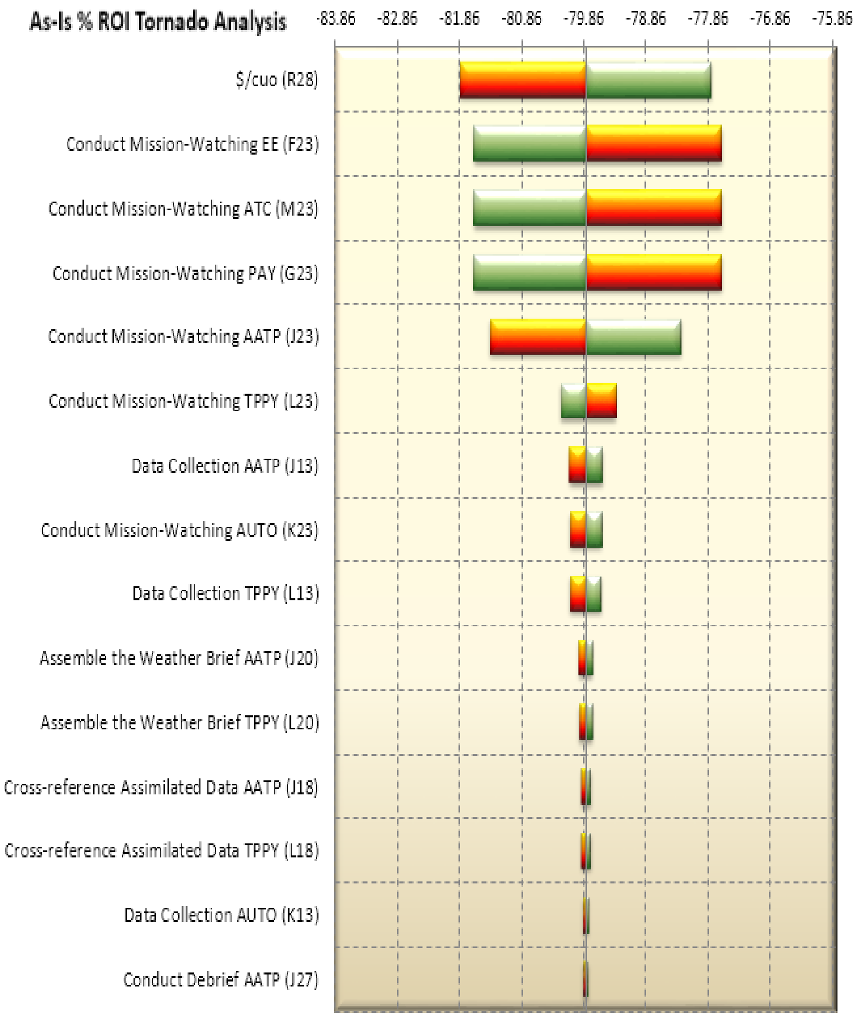
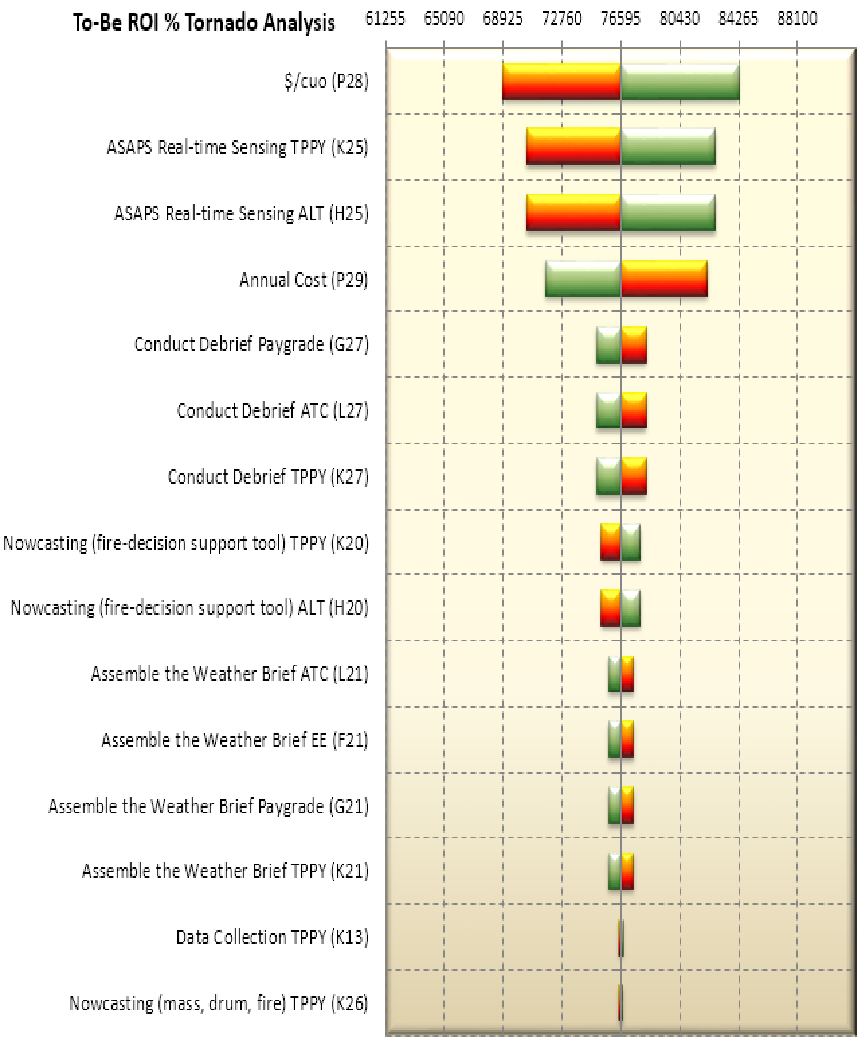
ROI on Weather-Now Forecasting Sensitivity Analysis



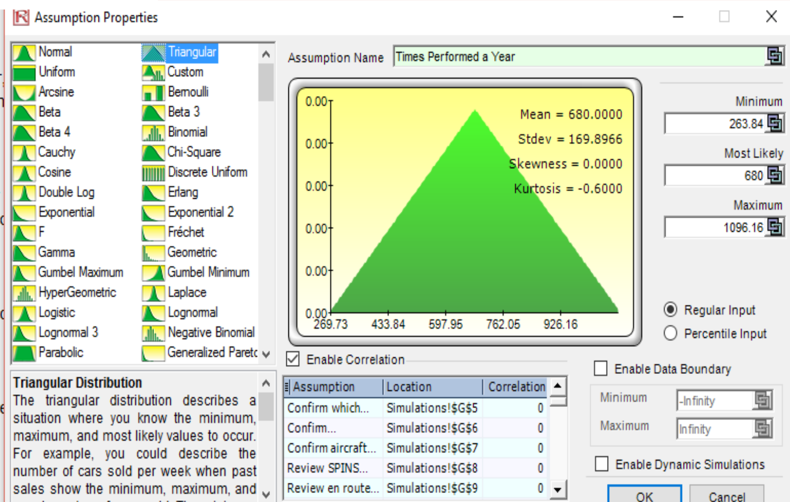


IRM Monte Carlo Risk Simulations: Mission Execution

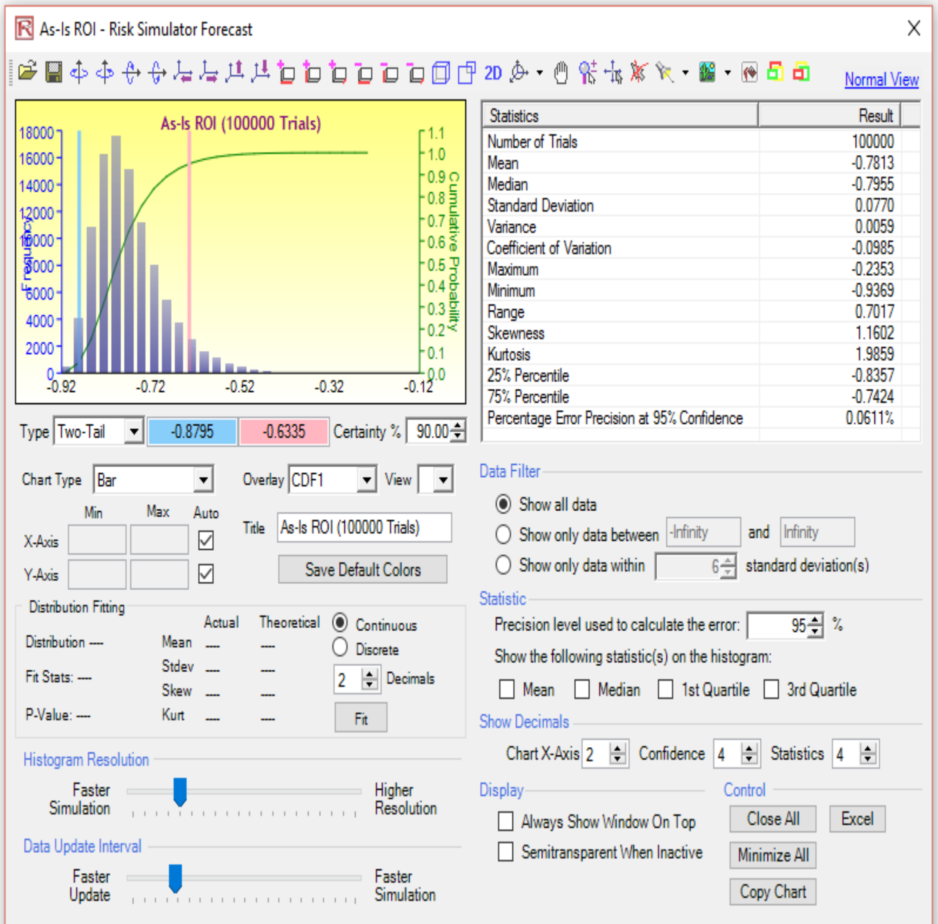
U.S. Air Force Cost Analysis Handbook (AFCAA)

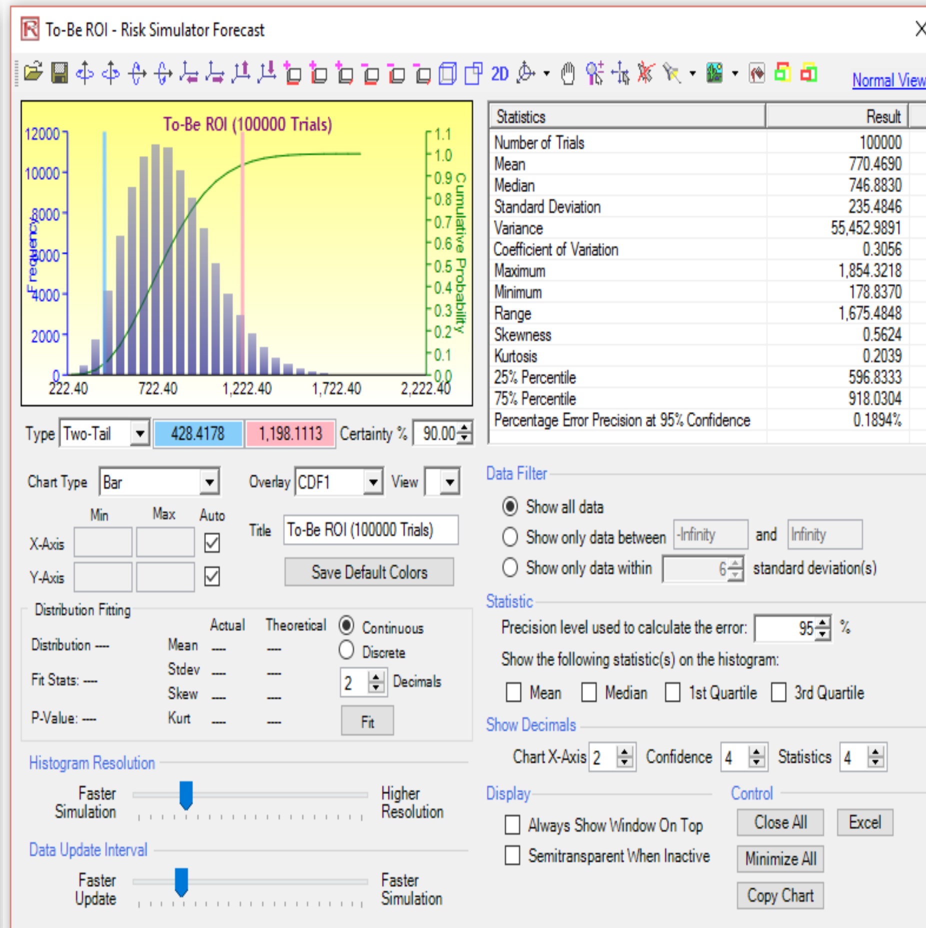
Distribution	PEI	Probability	15%	Mode	85%	Fitted Distributions Min	Fitted Distributions Likely	Fitted Distributions Max
Triangular Low Left	Mode	1.0 (75%)	0.695	0.878	1.041	0.482	0.878	1.247
Triangular Low	Mode	1.0 (50%)	0.834	1	1.166	0.633	1.000	1.367
Triangular Low Right	Mode	1.0 (25%)	0.959	1.122	1.305	0.753	1.122	1.518
Triangular Medium Left	Mode	1.0 (75%)	0.492	0.796	1.069	0.137	0.796	1.412
Triangular Medium	Mode	1.0 (50%)	0.723	1	1.277	0.388	1.000	1.612
Triangular Medium Right	Mode	1.0 (25%)	0.931	1.204	1.508	0.588	1.204	1.863
Triangular High Left	Mode	1.0 (75%)	0.347	0.754	1.103	0.000	0.754	1.550
Triangular High	Mode	1.0 (50%)	0.612	1	1.388	0.142	1.000	1.858
Triangular High Right	Mode	1.0 (25%)	0.903	1.236	1.711	0.442	1.236	2.225
Triangular EHigh Left	Mode	1.0 (75%)	0.3	0.745	1.15	0.000	0.745	1.657
Triangular EHigh	Mode	1.0 (50%)	0.509	1.004	1.5	0.000	1.004	2.100
Triangular EHigh Right	Mode	1.0 (25%)	0.876	1.367	1.914	0.258	1.367	2.553

	As-Is Condition Min	Likely	Max	Simulation	To-Be Condition Min	Likely	Max	Simulation
	263.84	680.00	1096.16	680.00	263.84	680.00	1096.16	680.00
	1.164	3.00	4.836	3.00	1.164	3.00	4.836	3.00
	1.940	5.00	8.060	5.00	1.940	5.00	8.060	5.00
	0.388	1.00	1.612	1.00	0.388	1.00	1.612	1.00
	5.820	15.00	24.180	15.00	5.820	15.00	24.180	15.00
	3.880	10.00	16.120	10.00	3.880	10.00	16.120	10.00
	1.940	5.00	8.060	5.00	1.940	5.00	8.060	5.00
	0.388	1.00	1.612	1.00	0.388	1.00	1.612	1.00
	3.880	10.00	16.120	10.00	3.880	10.00	16.120	10.00
RLT Does the weather forecast support flight safety and tactical execution							137.020	85.00
RLT Are appropriate aircraft available for the mission?							1.612	1.00
RLT No prohibitive interference (GPS degraded/denied, SAM threat, red air							8.060	5.00
RLT Can we mitigate expected threats en route and in the target area to an							137.020	85.00
RLT Do we have satisfactory LOS comm/data link conditions?							4.836	3.00
RLT Have the appropriate supporting agencies been assigned?							1.612	1.00
RLT All mission materials and products complete for mission commander							8.060	5.00
RLT METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situati							4.836	3.00
RLT All mission participants understand the plan and their role in support							3.224	2.00
RLT Outbrief with Operations Duty Officer (receive latest updates)							3.224	2.00
RLT Weather update (icing, convection, lightning, IMC, threat mitigation, etc							137.020	85.00
RLT Safety brief/ORM considerations prior to execution							4.836	3.00
ATCP Confirm which mission you are flying (i.e. which COCOM, route, etc)							0.081	0.05
ATCP Confirm currency to fly in that theater and other currency items require							0.081	0.05
ATCP Confirm aircraft assignment and status with maintenance							0.081	0.05
ATCP Review SPINS and classified regulations that pertain to your mission							1.612	1.00
ATCP Review en route procedures built by COCOM Flight Commander							1.612	1.00
ATCP File flight plan (DD-175 or 1801)							0.081	0.05
ATCP Disseminate products	0.019	0.05	0.081	0.05	0.019	0.05	0.081	0.05
ATCP Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	0.194	0.50	0.806	0.50	0.194	0.50	0.806	0.50

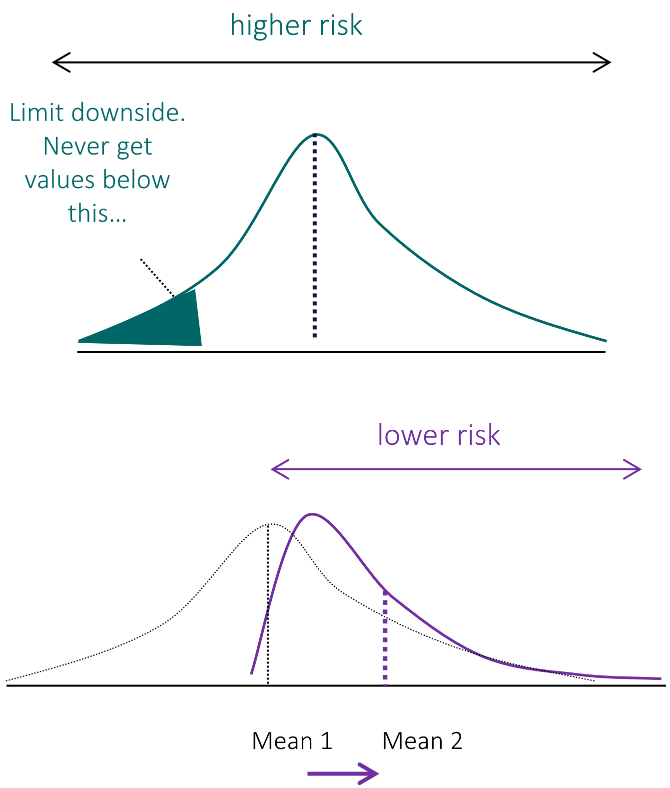


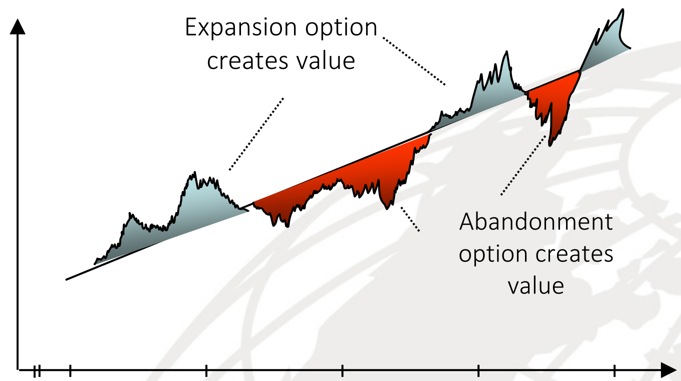
IRM Monte Carlo Risk Simulations on Weather Forecasting





Truncating the Downside Risk and Taking Advantage of the Upside Opportunity

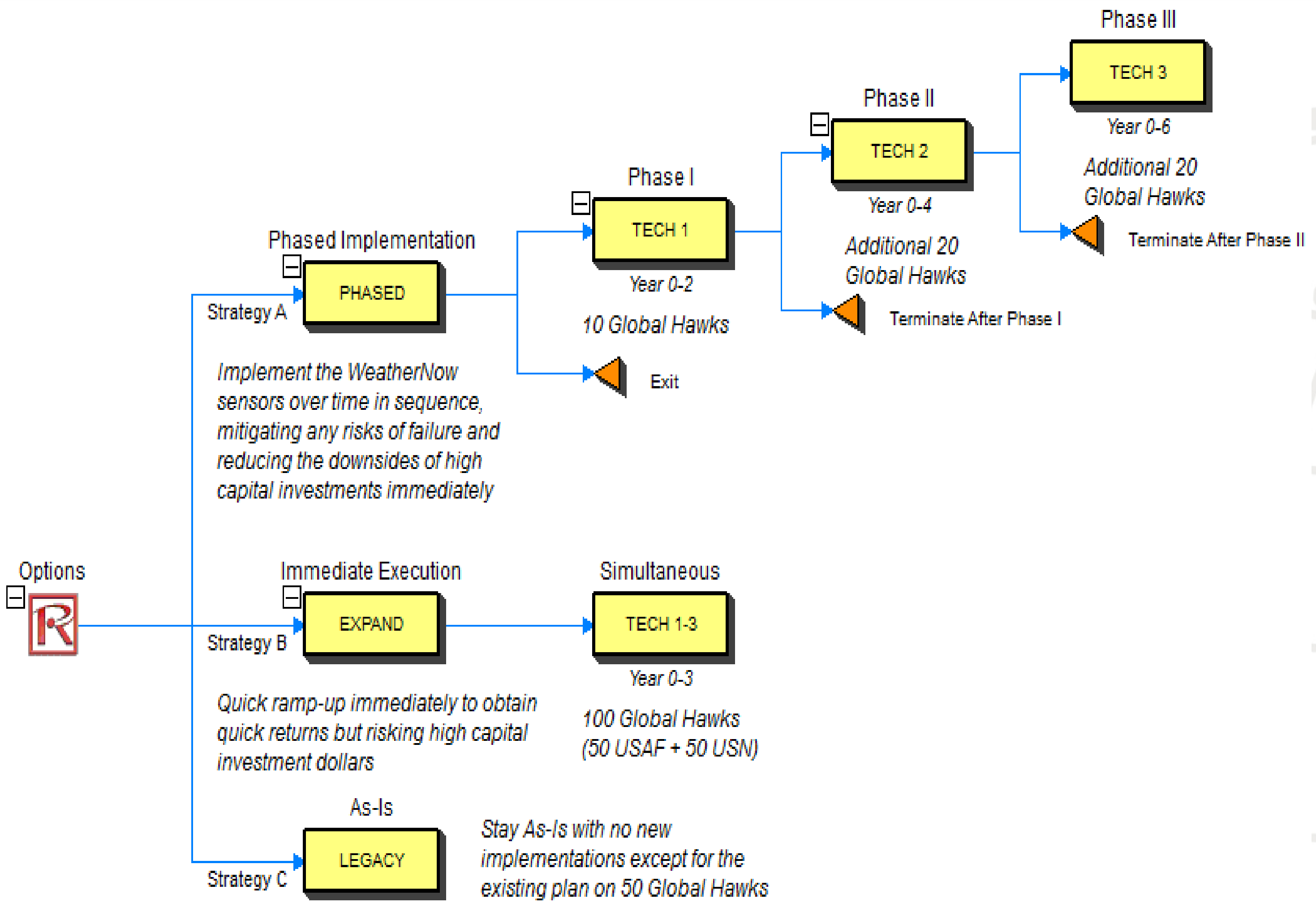




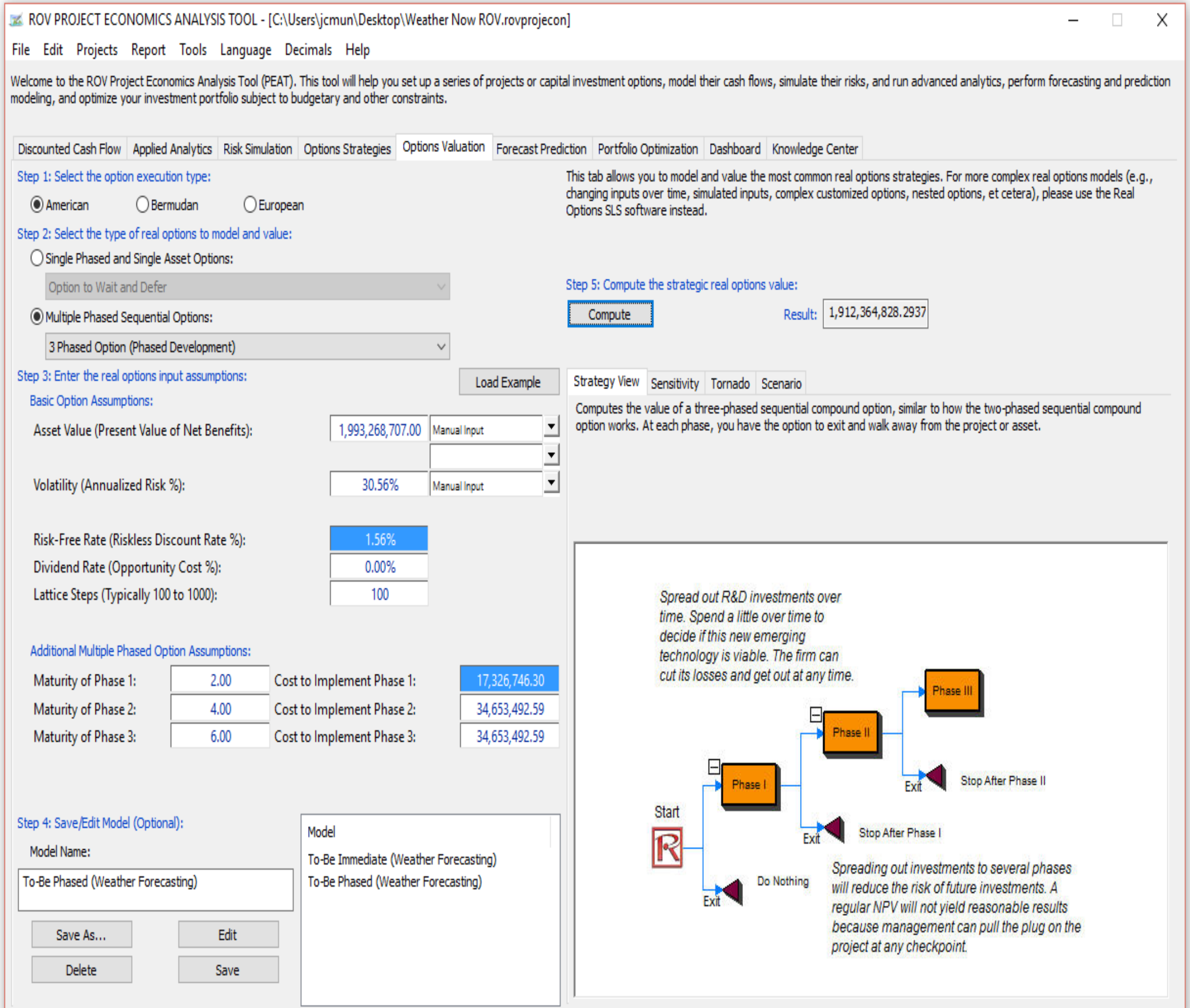
If we have the ability to reduce the downside uncertainties (risk) by walking away and abandoning when things look bad, and ability to execute and continue with a path only when things are looking up (in real life, we make midcourse corrections along the way when uncertainties become resolved over the passage of time, actions, and events), we can truncate the downside and shift expectations to the right.

Real options will reduce risk (chop off the left tail downside, thereby reducing the distributional width and variability) and shift the distribution to the right, and increase the expected value (mean returns).

IRM Analysis of Alternatives: Deployment Options



Real Options Valuation: Modeling Methodology



Deployment Options Valuation: Weather-Now Forecasting

AS-IS Strategy

Asset Value	$ 270,707
Implementation Cost	$ 1,342,045
Maturity	0
Risk-Free Rate (Annualized %)	0.00%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	9.85%
ROI %	-79.83%
Net Present Value	$ (1,071,338)
Option Value	$ -
Total Strategic Value	**$ (1,071,338)**

TO-BE Strategy: Sequential Implementation

Asset Value	$ 1,993,268,707
Implementation Cost: Phase I	$ 519,802
Implementation Cost: Phase II	$ 1,039,605
Implementation Cost: Phase III	$ 1,039,605
Maturity: Phase I	2
Maturity: Phase II	4
Maturity: Phase III	6
Risk-Free Rate (Annualized %)	1.56%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$ 1,990,841,590**
Incremental Value-Added	**$ 1,991,912,928**

TO-BE Strategy: Immediate Implementation

Asset Value	$3,986,537,414
Implementation Cost	$ 5,198,024
Maturity	3
Risk-Free Rate (Annualized %)	0.92%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$3,981,480,893**
Incremental Value-Added	**$3,982,552,231**

Real Options Valuation

Strategy A Phased Implementation	$ 1,990,841,590
Strategy B Immediate Execution	$ 3,981,480,893
Strategy C As-Is Base Case	$ (1,071,338)

Recommendations

- ROI results clearly indicated that the use of the WeatherNow sensor bundle provides very large relative returns to the current approach
- Economic valuation forecasting results indicated that, if the sensor bundle performs as promised, the option to deploy should be immediate to gain the highest option value
- Once an option path is selected, economic results should be tracked over time to make adjustments as value analysis would suggest
- Do the same economic value analysis for all Air Force, Navy, and Army flying platforms with regard possible use of the weather sensor bundle

Back-up Slides

NAVAL POSTGRADUATE SCHOOL

Air Force Memo on New Weather Model

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON DC

MAR 30 2015

MEMORANDUM FOR SEE DISTRIBUTION

FROM: AF/A3W

SUBJECT: Update on the Air Force's Numerical Weather Model

1. On 19 Nov 14, I provided a general way-ahead for AF Numerical Weather Models (NWM) (see attached). The Air Force will adopt the United Kingdom Met Office's Unified Model (MetUM) as our authoritative global NWM. The Air Force implementation will hereafter be known as **Global Air-Land Weather Exploitation Model (GALWEM)**. This model will also become the base model for our higher-resolution, rapidly relocatable regional windows.

2. In accordance with the timeline below, the Air Force will replace products and data based on the National Center for Atmospheric Research's Weather Research and Forecasting (WRF) and National Centers for Environmental Prediction's Global Forecast System (GFS) models with similar products based on GALWEM. Additionally, all Operational Weather Squadrons (OWS) will adopt the GALWEM in place of GFS and WRF and modify their internal processes and locally-generated software to utilize GALWEM in support of Air Force and Army operations.

a. 1st Quarter, CY16. Decommission global coverage WRF and all WRF 45km and 15km regional windows and transition to GALWEM output. This will impact users reliant on WRF-based AFW-WEBS products and external applications dependent on WRF gridded data.

b. 2nd Quarter, CY16. Replace GFS with GALWEM. This will impact users reliant on GFS-based AFW-WEBS products and external applications dependent on GFS gridded data.

c. 1st Quarter, CY17. Replace WRF 5km and 1.67km high-res windows, coincident with the stand-up of similar domains based on GALWEM.

3. Please forward this memo within your commands to offices currently developing or planning capabilities to leverage WRF or GFS from the 557th WW. They should take immediate action to redirect resources and efforts to develop capabilities to utilize GALWEM.

4. The Lead Command POC for this transition is Mr. Michael Horner, DSN 271-9645.

RALPH O. STOFFLER, GS-15, DAF
Acting Director of Weather

Air Force Memo on New Weather Model

(For Official Use Only)

A3W GRAM

DIRECTOR OF WEATHER
DCS, OPERATIONS

NUMBER: 15-03 **19 November 2014**

Weather Warriors,

We are pleased to announce the next evolution of atmospheric modeling within the Air Force weather community and provide a general overview of "the way ahead" for AF Numerical Weather Models (NWM).

Current

The Air Force Weather Agency (AFWA) is a recognized leader in NWM and a premier provider of operational products and services derived from its models. Without exception, the professionals charged with this critical mission have proven vital to the Joint Warfighter's ability to mitigate weather impacts on operations and positively shape weapons systems employment and mission profiles.

In today's environment, it is imperative we focus our investments in NWM to provide the best possible decision-quality information to the USAF and Army operators. We have discovered over the past two-and-a-half decades of combat operations, that our global mission set demands the best possible global solution.

Future

We plan to adopt the Met Office Unified Model (MetUM) as the USAF authoritative global NWM for the following reasons:

- Improve Overseas Contingency Operations: The US and its coalition partners must be prepared to respond to contingencies anywhere in the world. To support this challenge, we will focus our efforts on a proven overseas global NWM. In CENTCOM the US is the designated lead nation for NATO-led operations. We can enhance our interoperability and success ensuring "One Operation, One Forecast" by using the same model as some of our coalition and international partners.

- Improve Forecast Quality: The MetUM utilizes superior data assimilation and atmospheric modeling. Many sub-grid scale processes represented, including convection, boundary layer turbulence, radiation, clouds, microphysics and orographic drag result in the MetUM consistently outscoring most other global forecast models across a range of performance characteristics.

- Improve Enterprise Capability: Running the MetUM data assimilation system at AFWA allows us to utilize in-theater observations taken by deployed AF weather personnel. The MetUM will be the base model for our rapidly relocatable regional windows for OCONUS and CONUS operations.

- Improve Interoperability: Many warfighting systems depend on machine-to-machine data exchanges; therefore, we will ensure they can ingest weather data from the MetUM. Further, this postures us to be a contributing partner to the National Earth System Prediction Capability and expands the U.S. global ensemble modeling capability. For CONUS operations, we will continue to leverage the capability provided by our NOAA partners.

To implement this we will plan and program to ensure seamless support to the warfighter. It will take all of us to make this a success; I know I can count on your support. Thanks for all you do.

RALPH O. STOFFLER, GS-15, DAF
Acting Director of Weather

"Own The Weather"

- U.S. Army is developing technologies to address DVE safety issues and operational limitations Aviation and Missile Research, Development and Engineering Center at Redstone Arsenal.
- The team's mantra is "Own the Weather," and seeks to expand commander's capability of deploying rotorcraft aviation assets when weather is below condition minimums.
- The AMRDEC Degraded Visual Environment Mitigation Program, an integrated three-pronged approach to a DVE system solution, is designed to increase air-crew safety and survivability.
- The DVE-M program fuses images of multiple sensor technologies such as radar, infrared, and laser detection and ranging, also known as LADAR. Each of these sensor technologies provide unique advantages for operating in various types of DVE conditions.

Mission Execution: Assumptions

Assumptions		
	a)	Based on an RQ-4B squadron conducting a routine ISR mission type (24 hour duration per sortie)
	b)	Does not include mission planning considerations from Northrup Grumman planning system
	c)	Avg O-3 hourly wage: 32.60 (base pay)
	d)	Avg E-5 hourly wage: 16.10 (base Pay)
	e)	Learning time is based on a second lieutenant (undergraduate degree and officer training completed)
	f)	MCE & LRE tasks are consolidated into one process model and are not differentiated between
	g)	Columns O and P are the same time values in different formats
	h)	750 sorties per year is a rough, (unclassified) estimate given by subject matter expert, the actual number is classifed and therefore beyond the scope and classification of this study.
	i)	2303 is the number of weather updates given to RQ-4B crews during sorties over the period of one year (Beale
	j)	85 (cell K34) reflects the increased complexity of the ASAPS/NOWcasting output (products). See weather forecasting model for details.
	k)	36848 (cell N34) was derived by multiplying the number of weather updates per year (2303) by the new frequency of weather updates provided by NOW casting/ASAPS (16, or every 15 minutes for a 24 hour period)
	l)	Fixed costs are assumed to be constant and therefore not included in the analysis
	m)	45% labor burden and overhead added to base pay rates.
	n)	$40,000/year sensor maintenance costs.

Mission Execution Raw Data (As-Is)

Mission Execution Process Description (RQ-4B) Items in red are WX-related	Title of Head Process Executer	Number of Employees	Average Pay Grades of Employees	Average ops labor cost ($/per-hour)	Avg hours paid per day (hours/day)	Rank Order of Difficulty	Relative Learning Time	Relative Learning Time including Automation	Actual Avg Training Period	Percent of Process Automated	Times Performed In a Year	Average Time to Complete Process (hours)	Average Time to Complete (hr:min)	Automation Tools
Total		2.26		$29.30	24			106.65			680	4.25		
DAY PRIOR TO FLIGHT														
Data Extraction (mission study)	PIC (MCE and/or LRE)	1.63	O-3	$32.60	24	4	50	51.22	70		680	2.75	2:45	
Confirm which mission you are flying (i.e. which COCOM, route, etc)	PIC (MCE and LRE)	2	O-3	$32.60	24	3	3	3.3		10%	680	0.05	0:03	PPTX, Excel, PEX
Confirm currency to fly in that theater and other currency items required for flight	PIC (MCE and LRE)	2	O-3	$32.60	24	4	5	5.5		10%	680	0.05	0:03	PEX
Confirm aircraft assignment and status with maintenance	PIC (MCE and LRE)	2	O-3	$32.60	24	2	1	1.01		1%	680	0.05	0:03	PPTX, Excel
Review SPINS and classified regulations that pertain to your mission	PIC (MCE and LRE)	2	O-3	$32.60	24	8	15	15.15		1%	680	1	1:00	Word
Review en route procedures built by COCOM Flight Commander	PIC (MCE)	1	O-3	$32.60	24	6	10	10.1		1%	680	1	1:00	Word
File flight plan (DD-175 or 1801)	PIC (MCE or LRE)	1	O-3	$32.60	24	5	5	5.05		1%	680	0.05	0:03	PDF, Outlook
Disseminate products	PIC (LRE)	1	O-3	$32.60	24	1	1	1.01		1%	680	0.05	0:03	Excel, Word, PPTX, Outlook
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	PIC (MCE and LRE)	2	O-3	$32.60	24	7	10	10.1		1%	680	0.5	0:30	PPTX
DAY OF FLIGHT														
Identify Showstoppers (determine and decide)	PIC (MCE and LRE) &/or MC	2.67	O-3	32.60	24	5	30	34.1	20		680	0.5	0:30	
Does the weather forecast support flight safety and tactical execution of the mission? This is a one-time go/no-go decision made prior to launch.	PIC (MCE and LRE) & MC	3	O-3	32.60	24	5	10	12		20%	680	0.2	0:12	PPTX, AFWEBS
Are appropriate aircraft available for the mission?	PIC (MCE and LRE) & MC	3	O-3	32.60	24	1	1	1.01		1%	680	0.05	0:03	PPTX, Excel
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	PIC (MCE and LRE) & MC	3	O-3	32.60	24	4	5	5.05		1%	680	0.05	0:03	PPTX
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	PIC (MCE and LRE) & MC	3	O-3	32.60	24	6	10	12		20%	680	0.1	0:06	PPTX, AFWEBS
Do we have satisfactory LOS comm/data link conditions?	PIC (MCE and LRE) & MC	3	O-3	32.60	24	3	3	3.03		1%	680	0.05	0:03	PPTX
Have the appropriate supporting agencies been assigned?	MC	1	O-3	32.60	24	2	1	1.01		1%	680	0.05	0:03	PPTX
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	PIC (MCE and LRE) & MC	3	O-3	32.60	24	2	5	5.05	8		680	0.5	0:30	
All mission materials and products complete for mission commander review	PIC (MCE and LRE) & MC	3	O-3	32.60	24		5	5.05		1%	680	0.5	0:30	PPTX, Excel, Word
Formal Intelligence update (receive intelligence analysis of the following considerations)	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	1	3	3.03	2		680	0.05	0:03	
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24		3	3.03		1%	680	0.05	0:03	PPTX
Flight Brief/Outbrief/Weather Update Brief	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	3	12	13.25	10		1085.75	0.45	0:27	
All mission participants understand the plan and their role in support	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	2	2	2.02		1%	680	0.1	0:06	Word
Outbrief with Operations Duty Officer (receive latest updates)	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	1	2	2.2		10%	680	0.1	0:06	PEX, Excel
Weather update (icing, convection, lightning, IMC, threat mitigation, etc) *This is a recurring decision point throughout the sortie and occurs each	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	4	5	6		20%	2303	0.15	0:09	PPTX, AFWEBS
Safety brief/ORM considerations prior to execution	PIC (MCE) & SO	2	one O-3 +one E-5	24.35	24	3	3	3.03		1%	680	0.1	0:06	Word

NAVAL POSTGRADUATE SCHOOL

Mission Execution: As-Is Expenses, Revenues, ROI, ROK

Mission Execution Process Description (RQ-4B) Items in red are WX-related	Total Knowledge (learning hours fired)	Ops Expenses ($/yr)	Denominator (cost)($/yr)	Numerator (revenue) ($/yr)	Return on Knowledge	Return on Investment
Total	72,522	191,229	191,229	72,522	38%	-62.08%
DAY PRIOR TO FLIGHT						
Data Extraction (mission study)	34,830	99,063	99,063	34,830	35%	-65%
Confirm which mission you are flying (i.e. which COCOM, route, etc)	2,244	2,217	2,217	2,244	101%	1%
Confirm currency to fly in that theater and other currency items required for flight	3,740	2,217	2,217	3,740	169%	69%
Confirm aircraft assignment and status with maintenance	687	2,217	2,217	687	31%	-69%
Review SPINS and classified regulations that pertain to your mission	10,302	44,336	44,336	10,302	23%	-77%
Review en route procedures built by COCOM Flight Commander	6,868	22,168	22,168	6,868	31%	-69%
File flight plan (DD-175 or 1801)	3,434	1,108	1,108	3,434	310%	210%
Disseminate products	687	1,108	1,108	687	62%	-38%
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	6,868	22,168	22,168	6,868	31%	-69%
DAY OF FLIGHT						
Identify Showstoppers (determine and decide)	23,188	29,557	29,557	23,188	78%	-22%
Does the weather forecast support flight safety and tactical execution of the mission? This is a one-time go/no-go decision made prior to launch.	8,160	13,301	13,301	8,160	61%	-39%
Are appropriate aircraft available for the mission?	687	3,325	3,325	687	21%	-79%
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	3,434	3,325	3,325	3,434	103%	3%
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	8,160	6,650	6,650	8,160	123%	23%
Do we have satisfactory LOS comm/data link conditions?	2,060	3,325	3,325	2,060	62%	-38%
Have the appropriate supporting agencies been assigned?	687	1,108	1,108	687	62%	-38%
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	3,434	33,252	33,252	3,434	10%	-90%
All mission materials and products complete for mission commander review	3,434	33,252	33,252	3,434	10%	-90%
Formal Intelligence update (receive intelligence analysis of the following considerations)	2,060	1,656	1,656	2,060	124%	24%
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	2,060	1,656	1,656	2,060	124%	24%
Flight Brief/Outbrief/Weather Update Brief	18,748	23,794	23,794	18,748	79%	-21%
All mission participants understand the plan and their role in support	1,374	3,312	3,312	1,374	41%	-59%
Outbrief with Operations Duty Officer (receive latest updates)	1,496	3,312	3,312	1,496	45%	-55%
Weather update (icing, convection, lightning, IMC, threat mitigation, etc) *This is a recurring decision point throughout the sortie and occurs each	13,818	16,823	16,823	13,818	82%	-18%
Safety brief/ORM considerations prior to execution	2,060	3,312	3,312	2,060	62%	-38%

NAVAL POSTGRADUATE SCHOOL

Mission Execution Raw Data (To-Be)

Mission Execution Process Description (RQ-4B) Items in red are WX-related	Title of Head Process Executer	Number of Employees	Average Pay Grades of Employees	Average ops labor cost ($/hour)	Avg hours paid per day (hours/day)	Rank Order of Difficulty	Relative Learning Time	Relative Learning Time including Automation	Actual Avg Training Period	Percent of Process Automated	Times Performed In a Year	Average Time to Complete Process (hours)	Average Time to Complete (hr:min)	Automation Tools
Total		2.025		$29.30	24			331.63			680	4.25		
DAY PRIOR TO FLIGHT														
Data Extraction (mission study)	PIC (MCE and/or LRE)	1.625	0-3	$32.60	24	4	50	51.22	70		680	2.75	2:45	
Confirm which mission you are flying (i.e. which COCOM, route, etc)	PIC (MCE and LRE)	2	0-3	$32.60	24	3	3	3.3		10%	680	0.05	0:03	PPTX, Excel, PEX
Confirm currency to fly in that theater and other currency items required for flight	PIC (MCE and LRE)	2	0-3	$32.60	24	4	5	5.5		10%	680	0.05	0:03	PEX
Confirm aircraft assignment and status with maintenance	PIC (MCE and LRE)	2	0-3	$32.60	24	2	1	1.01		1%	680	0.05	0:03	PPTX, Excel
Review SPINS and classified regulations that pertain to your mission	PIC (MCE and LRE)	2	0-3	$32.60	24	8	15	15.15		1%	680	1	1:00	Word
Review en route procedures built by COCOM Flight Commander	PIC (MCE)	1	0-3	$32.60	24	6	10	10.1		1%	680	1	1:00	Word
File flight plan (DD-175 or 1801)	PIC (MCE or LRE)	1	0-3	$32.60	24	5	5	5.05		1%	680	0.05	0:03	PDF, Outlook
Disseminate products	PIC (LRE)	1	0-3	$32.60	24	1	1	1.01		1%	680	0.05	0:03	Excel, Word, PPTX, Outlook
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	PIC (MCE and LRE)	2	0-3	$32.60	24	7	10	10.1		1%	680	0.5	0:30	PPTX
DAY OF FLIGHT														
Identify Showstoppers (determine and decide)	PIC (MCE and LRE) &/or MC	2	0-3	32.60	24	5	180	180.1	20		680	0.5	0:30	
Does the weather forecast support flight safety and tactical execution of the mission? This is a one-time go/no-go decision made	PIC (MCE and LRE) & MC			32.60	24	5	85	85		0%	680	0.2	0:12	PPTX, AFWEBS
Are appropriate aircraft available for the mission?	PIC (MCE and LRE) & MC	3	0-3	32.60	24	1	1	1.01		1%	680	0.05	0:03	PPTX, Excel
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	PIC (MCE and LRE) & MC	3	0-3	32.60	24	4	5	5.05		1%	680	0.05	0:03	PPTX
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	PIC (MCE and LRE) & MC	0		32.60	24	6	85	85		0%	680	0.1	0:06	PPTX, AFWEBS
Do we have satisfactory LOS comm/data link conditions?	PIC (MCE and LRE) & MC	3	0-3	32.60	24	3	3	3.03		1%	680	0.05	0:03	PPTX
Have the appropriate supporting agencies been assigned?	MC	1	0-3	32.60	24	2	1	1.01		1%	680	0.05	0:03	PPTX
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	PIC (MCE and LRE) & MC	3	0-3	32.60	24	2	5	5.05	8		680	0.5	0:30	
All mission materials and products complete for mission commander review	PIC (MCE and LRE) & MC	3	0-3	32.60	24		5	5.05		1%	680	0.5	0:30	PPTX, Excel, Word
Formal Intelligence update (receive intelligence analysis of the following considerations)	PIC (MCE) & SO	2	one 0-3 +one E-5	24.35	24	1	3	3.03	2		680	0.05	0:03	
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	PIC (MCE) & SO	2	one 0-3 +one E-5	24.35	24		3	3.03		1%	680	0.05	0:03	PPTX
Flight Brief/Outbrief/Weather Update Brief	PIC (MCE) & SO	1.5	one 0-3 +one E-5	24.35	24	3	92	92.23	10		680	0.45	0:27	
All mission participants understand the plan and their role in support	PIC (MCE) & SO	2	one 0-3 +one E-5	24.35	24	2	2	2		0%	680	0.1	0:06	Word
Outbrief with Operations Duty Officer (receive latest updates)	PIC (MCE) & SO	2	one 0-3 +one E-5	24.35	24	1	2	2.2		10%	680	0.1	0:06	PEX, Excel
Weather update (icing, convection, lightning, IMC, threat mitigation, etc) *This is a recurring decision point throughout the sortie and	PIC (MCE) & SO	0		24.35	24	4	85	85		0%	65280	0.15	0:09	PPTX, AFWEBS
Safety brief/ORM considerations prior to execution	PIC (MCE) & SO	2	one 0-3 +one E-5	24.35	24	3	3	3.03		1%	680	0.1	0:06	Word

Mission Execution: To-Be Expenses, Revenues, ROI, ROK

Mission Execution Process Description (RQ-4B) Items in red are WX-related	Total Knowledge (learning hours fired)	Ops Expenses ($/yr)	Sensor Maintenance Expenses ($/yr)	Sensor Development Expenses ($/yr)	Total Expenses ($/yr)	Denominator (cost)($/yr)	Numerator (revenue) ($/yr)	Return on Knowledge	Return on Investment
Total	225,508	171,471	20,000	20,000	211,471	211,471	225,508	107%	6.64%
DAY PRIOR TO FLIGHT									
Data Extraction (mission study)	34,830	99,063	0	0	99,063	99,063	34,830	35%	-65%
Confirm which mission you are flying (i.e. which COCOM, route, etc)	2,244	2,217	0	0	2,217	2,217	2,244	101%	1%
Confirm currency to fly in that theater and other currency items required for flight	3,740	2,217	0	0	2,217	2,217	3,740	169%	69%
Confirm aircraft assignment and status with maintenance	687	2,217	0	0	2,217	2,217	687	31%	-69%
Review SPINS and classified regulations that pertain to your mission	10,302	44,336	0	0	44,336	44,336	10,302	23%	-77%
Review en route procedures built by COCOM Flight Commander	6,868	22,168	0	0	22,168	22,168	6,868	31%	-69%
File flight plan (DD-175 or 1801)	3,434	1,108	0	0	1,108	1,108	3,434	310%	210%
Disseminate products	687	1,108	0	0	1,108	1,108	687	62%	-38%
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	6,868	22,168	0	0	22,168	22,168	6,868	31%	-69%
DAY OF FLIGHT									
Identify Showstoppers (determine and decide)	122,468	22,168	13,333	13,333	48,835	48,835	122,468	251%	151%
Does the weather forecast support flight safety and tactical execution of the mission? This is a one-time go/no-go decision made	57,800	0	6,667	6,667	13,333	13,333	57,800	434%	334%
Are appropriate aircraft available for the mission?	687	3,325	0	0	3,325	3,325	687	21%	-79%
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	3,434	3,325	0	0	3,325	3,325	3,434	103%	3%
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	57,800	0	6,667	6,667	13,333	13,333	57,800	434%	334%
Do we have satisfactory LOS comm/data link conditions?	2,060	3,325	0	0	3,325	3,325	2,060	62%	-38%
Have the appropriate supporting agencies been assigned?	687	1,108	0	0	1,108	1,108	687	62%	-38%
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	3,434	33,252	0	0	33,252	33,252	3,434	10%	-90%
All mission materials and products complete for mission commander review	3,434	33,252	0	0	33,252	33,252	3,434	10%	-90%
Formal Intelligence update (receive intelligence analysis of the following considerations)	2,060	1,656	0	0	1,656	1,656	2,060	124%	24%
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	2,060	1,656	0	0	1,656	1,656	2,060	124%	24%
Flight Brief/Outbrief/Weather Update Brief	5,553,716	11,177	6,667	6,667	24,510	24,510	5,553,716	22659%	22559%
All mission participants understand the plan and their role in support	1,360	3,312	0	0	3,312	3,312	1,360	41%	-59%
Outbrief with Operations Duty Officer (receive latest updates)	1,496	3,312	0	0	3,312	3,312	1,496	45%	-55%
Weather update (icing, convection, lightning, IMC, threat mitigation, etc) *This is a recurring decision point throughout the sortie and	5,548,800	0	6,667	6,667	13,333	13,333	5,548,800	41616%	41516%
Safety brief/ORM considerations prior to execution	2,060	3,312	0	0	3,312	3,312	2,060	62%	-38%

The average cost for the WeatherNow Sensor Bundle = $40K per year and is included in the ROI analysis

Weather Forecasting Only: As-Is Raw Data and ROI, ROK

RQ-4 Weather Forecasting Process	Title of Head Process Executer	Number of Employees	Corresponding Pay Grades ($/hr)	Rank Order of Difficulty	Relative Learning Time	Actual Average Training Period	Percentage Automation	Times Performed per year	Average Time to Complete (min)	Automation Tools	Total Knowledge (learning hours fired)
TOTAL											**2,707,073**
Conduct Cross Talk Between Forecasters and RPA Operators	E5	1	16.10	1	5	72	3%	1	10		74
Conduct systematic review of forecasts from previous period (annually, monthly, etc)	E5	1	16.10			24	1%	1	3.3		24
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	E5	1	16.10			24	1%	1	3.3		24
Based on operational factors, determine the information needed in forecast briefs	E5	1	16.10			24	1%	1	3.3		24
Data Collection	E5	1	16.10	5	30	432	20%	680	60	AFWEBS	352,512
Consult the appropriate sources of data (satelliete imagery, sensors, PiReps, etc)	E5	1	16.10			108	5%	680	15		77,112
Based on feedback in Process 1, what are appropriate parameters of weather data	E5	1	16.10			108	5%	680	15		77,112
Assimilate data into relevancy for mission (i.e. wind data, icing data, turbulence, etc)	E5	1	16.10			108	5%	680	15		77,112
Are the proper sensors, other collection agents available?	E5	1	16.10			108	5%	680	15		77,112
sensitivities to determine mission-critical weather information	E5	1	16.10	3	10	144	1%	680	5		98,899
Based on severity of weather data, make the determination of what weather aspects will impact the mission	E5	1	16.10			144	1%	680	5		98,899
Assemble the weather brief, tailoring the collected data to suit the specific mission set	E5	1	16.10	4	15	216	2%	680	30		149,818
Ensure all mission-essential weather information is included in the brief	E5	1	16.10			108	1%	680	15		74,174
Scintillation, sky cover, stratospheric turbulence, wind/temperature charts, thunderstorm data, etc	E5	1	16.10			108	1%	680	15		74,174
Conduct mssion-watching	E5	1	16.10	6	35	504	20%	3400	1440	AFWEBS	2,056,320
Using an array of collections assets, monitor the weather throughout the flight mission	E5	1	16.10			168	7%	3400	480		609,299
Conduct rebrief at least every four hours throughout the mission or more frequently if unexpected/severe weather appear	E5	1	16.10			168	7%	3400	480		609,299
Stay in constant contact with pilots via MRC chat	E5	1	16.10			168	7%	3400	480		609,299
Conduct debrief	E5	1	16.10	2	5	72	1%	680	60		49,450

NAVAL POSTGRADUATE SCHOOL

Weather Forecasting Only: As-Is Costs, Revenues, ROI, ROK

RQ-4 Weather Forecasting Process	Ops Expenses ($/yr)	Denominator (cost) ($/yr)	Numerator (revenue) ($/yr)	Return on Knowledge	Return on Investment
TOTAL	**1,342,045**	**$1,342,045**	**$270,707**	**20%**	**-80%**
Conduct Cross Talk Between Forecasters and RPA Operators	$2.68	**$2.68**	**$7**	**276%**	**176%**
Conduct systematic review of forecasts from previous period (annually, monthly, etc)	$0.89	**$0.89**	**$2**	**274%**	**174%**
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	$0.89	**$0.89**	**$2**	**274%**	**174%**
Based on operational factors, determine the information needed in forecast briefs	$0.89	**$0.89**	**$2**	**274%**	**174%**
Data Collection	$10,948.00	**$10,948.00**	**$35,251**	**322%**	**222%**
Consult the appropriate sources of data (satelliete imagery, sensors, PiReps, etc)	$2,737.00	**$2,737.00**	**$7,711**	**282%**	**182%**
Based on feedback in Process 1, what are appropriate parameters of weather data	$2,737.00	**$2,737.00**	**$7,711**	**282%**	**182%**
Assimilate data into relevancy for mission (i.e. wind data, icing data, turbulence, etc)	$2,737.00	**$2,737.00**	**$7,711**	**282%**	**182%**
Are the proper sensors, other collection agents available?	$2,737.00	**$2,737.00**	**$7,711**	**282%**	**182%**
Cross-reference the assimilated weather data with aircraft sensitivities to determine mission-critical weather information	$912.33	**$912.33**	**$9,890**	**1084%**	**984%**
Based on severity of weather data, make the determination of what weather aspects will impact the mission	$912.33	**$912.33**	**$9,890**	**1084%**	**984%**
Assemble the weather brief, tailoring the collected data to suit the specific mission set	$5,474.00	**$5,474.00**	**$14,982**	**274%**	**174%**
Ensure all mission-essential weather information is included in the brief	$2,737.00	**$2,737.00**	**$7,417**	**271%**	**171%**
Scintillation, sky cover, stratospheric turbulence, wind/temperature charts, thunderstorm data, etc	$2,737.00	**$2,737.00**	**$7,417**	**271%**	**171%**
Conduct mssion-watching	$1,313,760.00	**$1,313,760.00**	**$205,632**	**16%**	**-84%**
Using an array of collections assets, monitor the weather throughout the flight mission	$437,920.00	**$437,920.00**	**$60,930**	**14%**	**-86%**
Conduct rebrief at least every four hours throughout the mission or more frequently if unexpected/severe weather appear	$437,920.00	**$437,920.00**	**$60,930**	**14%**	**-86%**
Stay in constant contact with pilots via MRC chat	$437,920.00	**$437,920.00**	**$60,930**	**14%**	**-86%**
Conduct debrief	$10,948.00	**$10,948.00**	**$4,945**	**45%**	**-55%**

NAVAL POSTGRADUATE SCHOOL

Weather Forecasting Only: To-Be Raw Data and ROI, ROK

RQ-4 Weather Forecasting Process	Title of Head Process Executer	Number of Employees	Corresponding Pay Grades ($/hr)	Actual Learning Time (hours)	Learning Time adjusted for Automation	Percentage Automation	Times Performed per year	Average Time to Complete (min)	Total Knowledge (learning hours fired)
TOTAL									398,653,741
Conduct Annual Cross Talk Between Forecasters and RPA Operators	E5	1	16.1	72	74.16	3%	1	10	74
Conduct systematic review of forecasts from previous period (annually)	E5	1	16.1	24	24.24	1%	1	3.3	24
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	E5	1	16.1	24	24.24	1%	1	3.3	24
Based on operational factors, determine the information needed in forecast briefs	E5	1	16.1	24	24.24	1%	1	3.3	24
Data Collection	E5	1		10000	10500	5%	680		7,140,000
Multi-data source deconfliction and data quality control	Nowcasting			1000	1010	1%	680	$ 1.307	686,800
4D Data assimilation/fusion	Nowcasting			5000	5050	1%	680	$ 1.307	3,434,000
High-resolution 4D forecast	Nowcasting			2000	2020	1%	680	$ 1.307	1,373,600
High-resolution 4D weather threat assessment	Nowcasting			1000	1010	1%	680	$ 1.307	686,800
Operator-focused weather threat analysis				1000	1010	1%	680	$ 1.307	686,800
Cross-reference the assimilated weather data with aircraft sensitivities to determine mission-critical weather information	E5			1000	1010	1%			65,932,800
Nowcasting (fire-decision support tool)				1000	1010	1%	65280	$ 0.068	65,932,800
Assemble the weather brief, tailoring the collected data to suit the specific mission set	E5	1	16.1	216	220.32	2%	680	30	149,818
Ensure all mission-essential weather information is included in the brief	E5	1	16.1	108	109.08	1%	680	15	74,174
Scintillation, sky cover, stratospheric turbulence, wind/temperature charts, thunderstorm data, etc	E5	1	16.1	108	109.08	1%	680	15	74,174
Conduct mssion-watching				10010	10110.1	1%			325,381,600
ASAPS real-time sensing (humidity sensor only)				10	10.1	1%	31,536,000	Executes every 1 second for 1 year	318,513,600
Nowcasting (mass, drum, fire)				10000	10100	1%	680	$ 0.068	6,868,000
Conduct debrief	E5	1	16.1	72	72.72	1%	680	60	49,450

NAVAL POSTGRADUATE SCHOOL

Weather Forecasting Only: To-Be Costs, Revenues, ROI, ROK

RQ-4 Weather Forecasting Process	Ops Expenses ($/yr)	Denominator (cost) ($/yr)	Numerator (revenue) ($/yr)	Return on Knowledge	Return on Investment
TOTAL	51,980	51,980	39,865,374	76693%	76593%
Conduct Annual Cross Talk Between Forecasters and RPA Operators	$2.68	$2.68	$7	276%	176%
Conduct systematic review of forecasts from previous period (annually)	$0.89	$0.89	$2	274%	174%
Review previous forecasts to tailor future forecasts specific to RQ-4 flights	$0.89	$0.89	$2	274%	174%
Based on operational factors, determine the information needed in forecast briefs	$0.89	$0.89	$2	274%	174%
Data Collection	$22,222.22	$22,222.22	$714,000	3213%	3113%
Multi-data source deconfliction and data quality control	$4,444.44	$4,444.44	$68,680	1545%	1445%
4D Data assimilation/fusion	$4,444.44	$4,444.44	$343,400	7727%	7627%
High-resolution 4D forecast	$4,444.44	$4,444.44	$137,360	3091%	2991%
High-resolution 4D weather threat assessment	$4,444.44	$4,444.44	$68,680	1545%	1445%
Operator-focused weather threat analysis	$4,444.44	$4,444.44	$68,680	1545%	1445%
Cross-reference the assimilated weather data with aircraft sensitivities to determine mission-critical weather information	$4,444.44	$4,444.44	$6,593,280	148349%	148249%
Nowcasting (fire-decision support tool)	$4,444.44	$4,444.44	$6,593,280	148349%	148249%
Assemble the weather brief, tailoring the collected data to suit the specific mission set	$5,474.00	$5,474.00	$14,982	274%	174%
Ensure all mission-essential weather information is included in the brief	$2,737.00	$2,737.00	$7,417	271%	171%
Scintillation, sky cover, stratospheric turbulence, wind/temperature charts, thunderstorm data, etc	$2,737.00	$2,737.00	$7,417	271%	171%
Conduct msion-watching	$8,888.89	$8,888.89	$32,538,160	366054%	365954%
ASAPS real-time sensing (humidity sensor only)	$4,444.44	$4,444.44	$31,851,360	716656%	716556%
Nowcasting (mass, drum, fire)	$4,444.44	$4,444.44	$686,800	15453%	15353%
Conduct debrief	$10,948.00	$10,948.00	$4,945	45%	-55%

Real Option Valuation Example Methods

- Closed-Form Approximation using the Bjerksund-Stansland Model with Partial Differential Equations
- Monte Carlo Simulation of Closed-Form Models
- Binomial Lattice Approach

$$C = \alpha S^{\psi} - \alpha\phi(S,T,\beta,I,I) + \phi(S,T,1,I,I) - \phi(S,T,1,X,I) - X(S,T,0,I,I) + X\phi(S,T,0,X,I)$$

$$\phi(S,T,\gamma,H,I) = e^{\lambda} S^{\gamma}\left[N(d) - \left(\frac{I}{S}\right)^{\kappa} N\left(d - \frac{s\ln(I/S)}{\sigma\sqrt{T}}\right)\right]$$

$$\alpha = (I-X)I^{-\beta} \text{ and } \beta = \left(\frac{1}{2} - \frac{b}{\sigma^2}\right) + \sqrt{\left(\frac{b}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r}{\sigma^2}}$$

$$Put = C(X,S,T,r-b,-b,\sigma)$$

- Closed-Form Approximation using the Barone-Adesi-Whaley Model with Partial Differential Equations

$$C(S,X,T) = Sup(C + \psi(S/S')^{q}, S - X)^{+}$$

$$\psi = (1 - e^{(b-r)T}\Phi\left[\frac{\ln(S/X) + (b+\sigma^2/2)T}{\sigma\sqrt{T}}\right](S'))(S'/q)$$

$$q = \frac{N + 1 + \sqrt{(N^2 + N + 8r/(1-e^{-rT})\sigma^2 + 1}}{2}$$

Solving S' with the Newton - Raphson algorithm

Air Force Weather Service Evolution

- First 60 years of the Air Force Weather Service was period of growth, the tools used for weather operations were electromechanical, analog sensing and display systems; teletype bulletins and manually plotted maps, analyzed with acetates and grease pencils; and commanders received weather mission forecasts from staff weather personnel that were largely based on the four-times a day synoptic cycle of the meteorological community (AFWA, 2012, pg. xvii).

- Air Force Weather Service transformed over the next several decades due to technological innovation and organizational change:
  - Third-generation microprocessor based integrated processing, analysis, and display capabilities that tie into the Department of Defense's (DoD) Global Communications Grid are now used.
  - Commanders can receive highly tailored weather updates relevant to their mission and area of responsibility as soon as the data becomes available.
  - Weather personnel now characterize and interpret environment to determine the effects weather events will have on unit operations; previously time and effort spent on the collection and analysis of basic weather data.

Value Of Sensors

- Economic value of sensors has been applied to a number of industries.
  - ***Agriculture.*** Economic value of weather sensor data has been measured in terms agriculture yields and/or frost damage mitigation efforts. Beckwith, Teibel, Bowen (2004) measured the value of a sensor network versus individual data logging devices in better capturing local environmental variability. Mathews (2013) describes the value of sensor data and related GIS tools in optimizing agricultural site selection and precision agriculture yields.

  - ***Technology.*** Use of networked IP addressable sensors has been increasing and provides new opportunities to enhance situational awareness and augment real-time decision-making across a wide range of environments and processes. "Forward looking companies are adopting real-time monitoring and management to build smarter supply chains, manage remote resources, and in general, improve their return on investment"(O'Reilly and Battelle 2009). Fleisch (2010) provides a deconstruction of customer and business value based on enhanced and/or automated feedback mechanisms that better optimize interdependent business processes, such as those found in many supply-chains. Krishnamurthy et al. (2005) designed and measured the performance of hardware sensor network architectures in a shipboard engine room to enhance situational awareness and better enable predictive maintenance and related part delivery.

Background

- The United States Air Force weather function began on July 1, 1937 when the War Department transferred the responsibility for providing Army Air Corps weather services from the Signal Corps to a small group known then as the Army Air Corps Weather Service (AFWA, 2012).
- In 1937 the fledging weather service consisted of about 280 enlisted and 22 officers manning 40 weather stations and has evolved provide forecasting support for Air Force and Army operations around the globe with several thousand airmen.
- Air Force weather organizations enable DoD decision-makers to anticipate and exploit the weather for air, ground, space, cyberspace, and intelligence operations.
- Air Force weather personnel provide mission-tailored terrestrial and space environment observations, forecasts, and services to the U.S. Air Force (USAF), U.S. Army (USA), and variety of U.S. Government departments and agencies.
- Air Force weather personnel support Air Force, Army, Joint, and DoD conventional and special operations at various garrison and deployed locations worldwide.

Importance of Sensors

- Sensor technology is playing an increasingly critical role in military applications.
- January/February issue of Army Technology Magazine highlighted how sensors are being integrated into military gear and vehicles which will empower, unburden and protect solders.
- According to Jyuji D. Hewitt, U.S. Army Research, Development and Engineering Command (RDECOM) Executive Deputy to the Commanding General, in the future “sensors will be everywhere. Army researchers are working on flexible plastic sensors that could be attached to individuals, gear or vehicles. With this technology, Soldiers will gather information on the chemical-biological environment, troop movements and signal intelligence.”
- Army of 2025 and beyond calls for advanced sensors that can locate and identify threats, enable protection systems to counter those threats and make it less likely an enemy will detect our vehicles.

Army Sensors

- Army researchers are working on a variety of sensor projects, including:
  - Flexible plastic sensors that could be attached to individuals, gear or vehicles. This technology allows soldiers to gather information on the chemical-biological environment, troop movements and signal intelligence.
  - Weapon systems in which future sensors pinpoint accuracy and scalable effects lethality in GPS-denied environments.
- Army researchers are also developing solutions to help aircraft crews navigate in degraded visual environments (DVE) where weather or other obstacles are extremely hazardous.
  - DVE are the primary contributing factor to a vast majority of Army aviation mishaps over the last decade: 80-percent of rotorcraft losses in operations in Iraq and Afghanistan were due to “combat non-hostile or non-combat factors” including DVE (Crawford, 2015).
  - DVE includes blowing sand, darkness, snow, rain, dust, fog, smoke, clouds; all conditions that hamper aviation operations and produce scenarios where aircraft control may be lost.