Business Case Assessment of Unmanned Systems Level of Autonomy

by

Edward W. Liu

B.A. Computer Science, Boston College, 2006
B.A. Mathematics, Boston College, 2006

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Electrical Engineering and Computer Science

In conjunction with the Leaders for Global Operations Program at the Massachusetts Institute of Technology

June 2012

© 2012 Edward W. Liu. All rights reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part in any medium now known or hereafter created.

Signature of Author

Department of Electrical Engineering and Computer Science, MIT Sloan School of Management

May 4, 2012

Certified by ___________________________  
Jonathan How, Thesis Supervisor  
Professor, Aeronautics and Astronautics

Certified by ___________________________  
Roy Welsch, Thesis Supervisor  
Professor of Statistics and Management Science, Director CCREMS, MIT Sloan School of Management

Accepted by ___________________________  
Leslie A. Kolodziejski, Professor  
Graduate Officer, Electrical Engineering and Computer Science

Accepted by ___________________________  
Maura Herson, Director, MBA Program  
MIT Sloan School of Management
This page intentionally left blank.
Business Case Assessment of Unmanned Systems Level of Autonomy

by

Edward W. Liu

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science on May 4, 2012 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Electrical Engineering and Computer Science

Abstract

The federal government has continually increased its spending on unmanned aerial vehicles (UAVs) during the past decade. Efforts to drive down UAV costs have primarily focused on the physical characteristics of the UAV, such as weight, size, and shape. Due to the saturation of the UAV business in the federal sector, the civilian sector is not as penetrated. Hence, companies see this phenomenon as an opportunity to establish itself as the standard bearer in this sector.

This thesis will address how Boeing can establish guidelines for business strategies in UAV offerings to potential clients. The key innovation that will be introduced is a modeling tool that will focus on simulation/trending and sensitivity analysis to help provide some insight into what these guidelines will be. The modeling tool will quantify many of the benefits and costs of the components and features of the production and utilization of UAVs.

Other notable recommendations include defining a new data recording process to obtain sets of sample data to validate the results of the modeling tool and streamlining the complexity of additional features and enhancements that will be incorporated in future versions of the modeling tool.

Project Supervisor: John Vian
Title: Technical Fellow, Boeing Research & Technology

Thesis Supervisor: Jonathan How
Title: Professor, Aeronautics and Astronautics

Thesis Supervisor: Roy Welsch
Title: Professor of Statistics and Management Science, Director CCREMS, MIT Sloan School of Management
This page intentionally left blank.
Acknowledgments

First, I would like to thank my thesis advisors, Jonathan How and Roy Welsch, for their input and direction throughout the duration of the project.

I would also like to thank the Boeing Company for giving me the opportunity to learn more about product development and the flexibility to drive the internship in the direction that I deemed most essential to my career advancement. I would like to personally thank John Vian, my supervisor; Tom Hagen, my project champion; and Josh Binder, my Boeing buddy, for their support and guidance throughout my time while I was in Seattle.

Next, I would like to thank all of the LGO staff and students who have offered me such a great opportunity to learn from such wise and knowledgeable people. Five particular LGO classmates (John Chou, Greg Sham, Jason Chen, Jose Cavazos, and Esther Lee) proved to be such a great support network during my time away from Boston during the internship.

I would also like to thank the entire Sloan class of 2012 for welcoming me with open arms throughout the duration of my MIT experience. Two particular Sloanies, Michael Chen and Patty Chung, have been especially vital in my embracing of and commitment to the Sloan class. Two other particular Sloanies, Tommy Choi and Joy Lee, have been enormous inspirations for me to be faithful and give back to the entire Sloan community, even after I have graduated from MIT.

I also thank my family (Mom, Dad, and Winson) and friends (especially my longtime middle school mates Sodany Sor and Jason Frye) for their encouragement and support of my efforts at MIT.

Lastly, I thank the community at Highrock Church for its blessings in my initial interest in pursuing graduate study. Pastor Ryan Yi has been there every step of the way to help guide me through both the easy and rough times in school. I especially want to thank fellow church members Seung Wook Kim and Tina Tian for invigorating me with the pursuit of further study in engineering and business, respectively. And last but not least, I thank God for watching over me throughout the LGO journey.

Thank you all.
This page intentionally left blank.
# Table of Contents

Abstract ......................................................................................................................................................... 3

Acknowledgments ......................................................................................................................................... 5

Table of Contents ......................................................................................................................................... 7

List of Figures ............................................................................................................................................. 10

Glossary of Abbreviations ........................................................................................................................... 12

1 Introduction ........................................................................................................................................... 13

1.1 Problem Statement ........................................................................................................................... 13

1.2 Hypothesis ......................................................................................................................................... 15

1.3 Research Methodology .................................................................................................................... 16

1.4 Approach ......................................................................................................................................... 17

1.5 Thesis Outline ................................................................................................................................. 19

2 Background and Context ....................................................................................................................... 20

2.1 Overview of History of UAV Usage and Development ................................................................. 20

2.2 Current Trends for UAVs ............................................................................................................. 22

3 Current State of UAV Technology and Autonomy ........................................................................... 24

3.1 Current Technological Barriers ........................................................................................................ 24

3.2 Benefits and Drawbacks of Autonomy ......................................................................................... 26

3.3 Current Focus Areas ...................................................................................................................... 28
3.4 Current Marketing Strategies ................................................................. 30
3.5 Art of the Possible .................................................................................. 30

4 Future State ............................................................................................ 32
4.1 Expansion into Commercial/Civilian Offerings ....................................... 32

5 Approach .................................................................................................. 33
5.1 Model Background ................................................................................ 33
5.2 Model Description ................................................................................ 35
5.3 Performance Factors ............................................................................ 44
5.3.1 Technical .......................................................................................... 44
5.3.2 Business .......................................................................................... 45
5.4 Model Structure ................................................................................... 46
5.4.1 Breakdown into Benefits and Costs .................................................... 46
5.4.2 Cost Range Estimates ...................................................................... 48
5.4.3 Framework Logic Rules ................................................................. 48
5.4.4 Consolidation .................................................................................. 49
5.5 Case Study .......................................................................................... 50
5.5.1 Topic/Focus Area .......................................................................... 51
5.5.2 Generation Process ........................................................................ 51
List of Figures

Figure 1. Launching of ScanEagle UAV produced by Boeing .................................................. 14
Figure 2. UAV produced by Boeing .......................................................................................... 15
Figure 3. Landing page for new modeling tool ......................................................................... 16
Figure 4. Boeing's Intelligence Systems Group .......................................................................... 17
Figure 5. Firefighters on the job .............................................................................................. 19
Figure 6. ScanEagle in flight ................................................................................................... 29
Figure 7. Screenshot of new modeling tool developed in Microsoft Excel ............................... 30
Figure 8. Example of current complexity of modeling tool ....................................................... 31
Figure 9. Design of framework for modeling tool .................................................................... 36
Figure 10. Example of parameter input page for modeling tool ............................................... 37
Figure 11. Example of annual trend factor page for modeling tool ......................................... 38
Figure 12. Example histogram from modeling tool .................................................................. 40
Figure 13. Example line chart from modeling tool ................................................................... 41
Figure 14. Example box plot from modeling tool .................................................................... 42
Figure 15. Example tornado chart from modeling tool ............................................................ 43
Figure 16. The six applications supported in modeling tool .................................................... 44
Figure 17. Primary UAV Components .................................................................................... 45
Figure 18. Relationship of innovation premium factors to total revenue .................................. 47
Figure 19. Four business models for UAV offerings ................................................................. 47
Figure 20. Incorporation of factors into modeling tool framework logic ................................... 49
Figure 21. Screenshot of modeling tool after simulation/trending function has completed ....... 50
Figure 22. Screenshot of modeling tool after sensitivity analysis function has completed ....... 50
Figure 23. Histogram for example with vehicle operation services .......................................... 58
Figure 24. Box plot for example with vehicle operation services ............................................. 59
Figure 25. Tornado chart for example with vehicle operation services. ..................................................60
Figure 26. Histogram for example with detection/surveillance services. ..................................................61
Figure 27. Box plot for example with detection/surveillance services. ..................................................62
Figure 28. Tornado chart for example with detection/surveillance services...........................................63
Figure 29. Histogram for example with sale of images. .................................................................64
Figure 30. Box plot for example with sale of images. .................................................................65
Figure 31. Tornado chart for example with sale of images.................................................................66
Glossary of Abbreviations

ACES: Atlus Cumulus Electrification Study

ACTD: Advanced Concept Technology Demonstration

BAMS: Broad Area Maritime Surveillance

CER: Cost Estimating Relationship

DARPA: Defense Advanced Research Projects Agency

DoD: Department of Defense

DRER: Disaster Relief and Emergency Response

FiRE: First Response Experiment

FTC: Fault-Tolerant Control

HALE: High-Altitude Long-Endurance

ISR: Intelligence, Surveillance, and Reconnaissance

ROI: Return on Investment

UAS: Unmanned Aerial System

UAV: Unmanned Aerial Vehicle

VBA: Visual Basic for Applications
1 Introduction

The Boeing Company has designed and manufactured unmanned airborne vehicles (UAVs) and unmanned airborne systems (UASs) for many years. Boeing has been primarily focused on satisfying the needs of its federal customers, especially from the United States. The features of these UAVs and UASs have been heavily catered to the government’s specifications. Yet, the market for government UAV contracts is already saturated with more substantial involvement from competitors such as General Atomics and Northrup Grumman, which provide more prolific UAVs such as the Predator and Global Hawk, respectively. With lesser breathing room to grow in the federal sector, companies are interested in growing the UAS business in the civilian sector, focusing on such targeted applications for their UAVs.

This thesis will focus on how business strategies can be established through guidelines on the parameters and configurations of UASs, with a specific emphasis on the level of autonomy in the components of a UAV. The key innovation from this thesis will be a modeling tool that is based on simulation, trending, and sensitivity analysis to potentially establish guidelines for UAV autonomy, a study that has not been previously done. The rest of this chapter will thus provide a summary of the logistics of the project surrounding this key innovation, including a problem statement (incorporating a project motivation as well), approach, and outline for the remainder of the thesis.

1.1 Problem Statement

Because of the saturation in the federal UAV market, companies are attempting to find new and innovative ways to increase revenue on their own UAV and UAS offerings. Although companies could increase their penetration in the federal sector, this sector does not offer much space for future growth. The lack of major players in the civilian UAV market, driven largely by lack of access to airspace, is seen as an opportunity to grow a company’s own UAV and UAS businesses when that expected pent-up demand is realized. The major question thus revolves around how to differentiate from competitors in such a way that a company can become the leader in this market.
Although national airspace restrictions do limit the ability of UAVs in their flight over specific geographical areas (recent developments have since lightened these restrictions), the importance of UAVs in civilian applications has been highlighted in many forums. For instance, Boeing has deemed UAVs useful for situations such as firefighting, storm tracking, and border security, as well as many other missions. UAVs have been used in a limited fashion, so there is still much room for expansion. Because of the lack of exposure into the civilian market, there have been no guidelines or standards established as to how to increase or stabilize the bottom line from this market. Hence, this is an opportunity to delve into this market and establish market share.

In the federal sector, previous improvements in the design of UAVs and UASs have mostly focused on physical attributes, such as aircraft size, aircraft weight, payload size, and aircraft type. With these attributes in mind, Boeing has a system characteristic, the level of autonomy in a UAS. By focusing on the software features of its UAV components, a company can use this as the differentiator between itself and its competitors. Also, there is a lack of prior research and case studies performed dealing with the level of autonomy as the evaluation factor for influences on the bottom line of UAS offerings, so companies can use this lack of established standards as the stepping-stone to become the leader in the
market. The big question then revolves around what a company can do to establish itself in this market when no such standard exists.

![A160T Hummingbird UAV produced by Boeing.](image)

**Figure 2.** A160T Hummingbird UAV produced by Boeing.

### 1.2 Hypothesis

To provide the guidelines for establishing business strategies in its UAV and UAS offerings to the civilian sector, a new modeling tool that focuses on simulation, trending, and sensitivity analysis is proposed. This modeling tool can be used to gauge the potential revenues, costs, and returns on investment (ROIs) for any given civilian application of a UAV. The tool can generate a given number of runs, simulating a single possible scenario that could occur if a customer request/order is fulfilled. The tool can also be used to model the future development of a UAV/UAS project’s financial considerations, helping to determine whether the project will be worth the initial investment based on the future payouts.

The key innovation of this tool is the focus on the level of autonomy in the UAS. Both revenues and costs are greatly impacted by changes in the level of autonomy, either by a single component or through the whole UAV itself. The breakdown of the tool’s technical and business cost factors is also influenced by the classification of the autonomy factors into the model. More details about autonomy and the modeling tool parameters will be provided later in this thesis.
This modeling tool will be able to generate the necessary business strategies to deal appropriately with clients from the civilian sector. The tool can be used to better understand the potential benefits and risks of undertaking a given UAS project, especially with estimated ROI figures in hand. Because no other standard has been established for selling UAV/UAS offerings for civilian applications, Boeing can use this tool to generate those standards.

1.3 Research Methodology

To prepare for this thesis and the project, multiple sources of information have been referenced. Primary individual stakeholders (supervisors, engineers, business operations, etc.) provided the most feedback and suggestions for the modeling tool, particularly in regards to the parameters, features, and enhancements that would be incorporated into the tool. Research into prior UAV/UAS manufacturing trends is referenced to better understand how UAV and UAS technology have progressed throughout the years. Many journal articles will be relied upon to provide insights into both the federal and civilian UAV markets. Lastly, there will be a reference to one substantial case study performed by NASA on the potential revenue growth opportunities of providing UAVs for specific NASA applications.

There is not much research in terms of the progression of UAVs from companies, as much of this data is proprietary. Boeing was unable to release information from its federal market offerings to assist
with the development of the modeling tool dealing with the civilian sector. Hence, research and past experiences are based on civilian applications and publicly available information.

Although there have been a few studies examining the prospect of establishing guidelines for the development of UAVs, there are none dealing with the level of autonomy as the primary contributing factor to the bottom line. Because of the lack of evidence of prior research in this area, this appears to be the first modeling tool to address the subject.

1.4 Approach

To develop the modeling tool in this project's timeframe, the implementation process followed five phases. First, the individual stakeholders were contacted to provide their suggestions for what would be the most vital parameters in designing a UAV. Supervisors and engineers helped to provide significant insight into the technical cost factors and to validate the generation of the twelve most essential UAV components where autonomy is deemed most appropriate. Business operations individuals helped to define the business cost factors and were the most crucial resource for periodic evaluation of the project's progress and the development of the modeling tool.

Figure 4. Boeing's Intelligence Systems Group.
Second, the technical and business cost factors were determined and finalized with the supervisors. The breakdown of components for each cost factor was determined later, but the overall structure of the cost factors was agreed upon first. The technical cost factors primarily focus on the impact of autonomy on the valuation of a UAS project, while the business cost factors deal with the physical attributes of a UAV and other logistics regarding the civilian UAV application.

Third, the framework logic was devised to determine the relationships among the cost factors. This phase is also the point where the components of each cost factor were created. The framework logic provides the foundation for the modeling tool to run on and provides a better understanding of how UAV business strategies can be established in the tool. The revenue and cost projections from the tool are based on the calculations and formulas that are specified in the framework logic.

Fourth, the development of the modeling tool then took place. The tool was developed in Microsoft Excel using Visual Basic for Applications (VBA), making heavy use of macros and automated functionality. The modeling tool utilizes the framework logic in a practical setting and is developed such that simulation, trending, and sensitivity analysis act as the primary operations for the final ROI figures. Because the tool is developed in Excel, any business operations individual is able to make use of the tool.

Last, a case study based on one given civilian application was created to demonstrate the capabilities of the modeling tool and the tool's usefulness in determining some guidelines to follow in that application. This aforementioned case study is based on a firefighting scenario, being a very common instance where the use of UAVs would provide substantial benefits. This case study makes use of the tool to provide final revenue, cost, and ROI figures.
1.5 Thesis Outline

The rest of this thesis will focus on the development of the modeling tool to help establish guidelines for business strategies of UAV/UAS offerings. Chapter 2 focuses on the history of UAV and autonomy development, with some discussion into the benefits and drawbacks of autonomy in a UAV. Chapter 3 focuses on the current state of the UAV market, while Chapter 4 focuses on the future state of said market. Chapter 5 deals further with the approach for the project, particularly on the modeling tool and the case study. Chapter 6 describes the validation of the modeling tool and the case study. Finally, Chapter 7 describes the next steps, recommendations, and future considerations for this project.
2 Background and Context

This chapter will briefly describe the history of UAV and autonomy development. Both UAVs and autonomy have progressed significantly during the past decade, and these have been proven successful with the generally positive results from military applications. Although more autonomy has resulted in lesser death risks and higher chances of penetration into critical regions, there are still several concerns about the use of autonomy in UAVs. Yet, with more autonomy, the potential for lower costs in UAV pricing is possible.

2.1 Overview of History of UAV Usage and Development

UAVs have been around for many decades, but did not get much traction or attention until the past decade. The attacks of September 11, 2001 truly kicked off the advent of UAVs into more military applications, where UAVs could venture more stealthily into enemy territory without risking as many human lives as before. Although UAVs are now a staple of military deployments, this was not always the case. This section will discuss the use and development of UAVs from several different entities, ranging from the military to civilian-sector firms.

A primary (and arguably the most prolific) consumer of UAVs has been the United States Army. The Army’s UAS program came to fruition in 1991 when the Pioneer UAV successfully flew in over 300 combat missions during Operation Desert Shield/Storm. Yet, growth of this program was severely limited, as the need for UAVs was not as substantial. In October of 2001, less than a month after the attacks of 9/11/01, the Army began incorporating more UAVs in its combat operations, with the deployment of 54 operational Hunter and Shadow unmanned aircraft. UAV usage has increased substantially since then, as the Army has over 4,000 UAS today and has deployed over 328 UAS in theater, which have flown over one million hours in support of combat operations. [1] With such usage, UAVs have become much more associated to the military than to any other entity.
NASA has also been an active participant in the usage of UAVs, deploying them for various science missions. Yet, cost breakdowns and utilization are not well understood from NASA’s perspective. The Coffee Harvest Optimization mission in 2002 made use of the solar-powered Pathfinder UAV, but there was too much developmental equipment used to provide useful cost information. The Vineyard project in 2003 used a small APV-3 UAV, but the project represented the low end of UAV science missions in terms of cost and performance. The Longitude 122 West provided cost and schedule data for the First Response Experiment (FiRE) and Atlus Cumulus Electrification Study (ACES) proposals. Although FiRE was the first UAV science mission to use the Atlus II HALE UAV, the mission was too short to provide useful cost information. The Atlus II constituted 48% of the total mission cost to NASA, but was deployed in only one of the four weeks of FiRE program, flying in 13 sorties and accumulating 38 flight hours. [2]

NASA’s usage of UAVs has a stark contrast to what the U.S. Department of Defense (DoD) has done throughout the past few decades. Through the 1980s, annual DoD spending for UAVs was less than $200 million, primarily allocated for research and development. Annual UAV spending increased in the 1990s, but only once exceeded $500 million in 1996. By 1995, UAV procurement comprised about 31% of the DoD’s UAV budget, up from just 2% ten years ago. NASA spent approximately $100 million on UAVs from 1994 to 2003, primarily to develop a new generation of low-cost vehicles, in stark contrast to the DoD’s $4.9 billion spending on UAVs during the same time. Because of the heavy dependence on UAVs by the DoD, the Department of Homeland Security has even shown interest in using UAVs for maritime and border surveillance. [2] Hence, as spending continues to increase for UAVs, so does the customer base for these aircraft.

One of the two most prominent UAVs has been the Global Hawk (the other being the Predator), currently championed through development from Northrup Grumman. The first Global Hawk was launched by the U.S. Defense Advanced Research Projects Agency (DARPA) in 1995 as a high-altitude, long-endurance (HALE) UAV advanced concept technology demonstration (ACTD) vehicle. This was
then rolled out at the Teledyne Ryan Aeronautical site in San Diego, CA in February 1997. In November 1998, the AV-2 became the first Global Hawk model to fly with a sensor payload. In April 2001, the Global Hawk became the first UAV to cross the Pacific Ocean on a deployment to Australia. Due to the advances made by the Global Hawk, the U.S. DoD approved a plan in February 2002 to develop the Global Hawk’s capabilities in phases and directed the Air Force to support Navy proposals to use the UAV as a test-bed for its Broad Area Maritime Surveillance (BAMS) program. Continuing onto the next generation of the Global Hawk, the AV-3 model amassed a 95% mission effectiveness rate and flew in 40 consecutive missions with no reported system problems during an approach to Baghdad in 2003. The AV-3 built up more than 4,000 hours of combat time upon the completion of its flight, logging more time than any single high-altitude UAV. Achievements such as these continue to make the Global Hawk a prominent UAV in the federal sector.

### 2.2 Current Trends for UAVs

The past decade has shown tremendous growth in UAV production and autonomy advancement. Many UAV manufacturers have focused on making significant strides in the progress of more efficient and complex autonomy systems to allow for greater versatility and usage from UAVs. This section will describe several of the current trends in UAV and autonomy development that have been prevalent in the last few years.

UAV manufacturers have achieved many innovations in UAV development. Proxity Digital Networks, Inc. has developed a 2 lb. micro-mini UAV called the CyberBug, which is priced at $5,500. General Atomic’s Predator and Northrup Grumman’s Global Hawk cost just around $5,000 and $26,500, respectively, to operate, while they each actually cost $4.5 million and $35 million, respectively, to purchase. Most UAVs usually fly no more than ten hours per flight, so the cost savings are substantial.

In June 2009, Boeing launched a new unmanned airborne systems division to group the company’s UAS projects together to better compete for military contracts. The company estimates that the UAV market could be worth $160 billion over the next ten years, which explains its plans to become a more major
player in this market. The U.S. has also increased its commitment to UAV deployment, as the military tallied 800,000 UAV flight hours (which excludes flights of small UAVs) in Afghanistan and Iraq in 2009, eclipsing the 35,000-hour mark in 2003. The DoD also had planned to spend more than $22 billion to develop, buy, and operate UAS during the past six years. However, these big UAVs that the military has invested in will continue to be hugely expensive, as more complex weapon systems are incorporated into the payloads of the UAVs. [4]

The trend for UAV development has gained much traction in the U.S. and overseas. The Israeli Defense Forces’ fleet of UAVs tripled in size from 2007 to 2009, and Israel ranks second to the U.S. in the development and possession of UAVs. [4] At least thirty-two countries are developing a total of more than 250 UAV models, and forty-one countries already operate eighty models. American spending on UAVs has gone from $300-$400 million in 2008 to over $1 billion in 2010. This trend has caused the Pentagon to estimate that one-third of American combat planes will be robotic by 2020. This also prompted DARPA to sign an $89 million contract with Boeing to build the SolarEagle, which ultimately will be capable of remaining at heights over 60,000 feet for over five years. Overseas, researchers in Cyprus have also developed an unmanned aircraft able to withstand severe weather conditions by changing shape. [5]

The U.S. Navy has become a primary user of UAVs in many of its applications. The Navy has requested for high-flying robotic aircraft capable of flying as far as 2,000 miles to an aerial patrol station, where it can provide maritime surveillance for almost 24 hours. The BAMS program mentioned above represents the first large-scale development of UAVs to monitor strategic shipping lanes, ports, and other regions protected by U.S. warships. The Navy has also developed a modified version of General Atomics’ Predator called the Mariner, prompting Northrup Grumman to offer a modified version of the Global Hawk (BAMS) to the Navy as well. The Navy also plans to organize a fleet of unmanned reconnaissance aircraft (BAMS) to be situated at five bases in sufficient numbers to provide surveillance of key oceans around the world, with the entire system expected to be fully functional by 2013. [6]
3 Current State of UAV Technology and Autonomy

Because the UAV market continues to be saturated with a variety of manufacturers, companies need to find some unique differentiator to allow the company to gain a larger share of the customer base. Boeing will continue to develop product discriminators for the civilian sector to gain more leverage into the overall UAV market. This chapter will elaborate further on the current situation of UAV technology and autonomy, with a particular focus on the adaptation to civilian applications.

3.1 Current Technological Barriers

UAV technology has particularly catered to military applications for the past few decades, with some emphasis for civilian applications. The future successful integration of UAV missions into this shared space depends not only on the development of standards for civilian applications, but also on the development of technology to assess the level of robust autonomy in a UAS. This development of assessment technology has been limited, because of the difficulty in the development of methods to quantify various levels of performance and safety in a UAS. UASs have a higher degree of autonomy in decision-making today because of the onboard agent replacing onboard or remote pilots. Successful integration of UASs into civilian airspace depends on improved UAS design and capabilities, regulations for certification, and technologies for operational performance assessment. Currently, only a small percentage of regulations for piloted aircraft apply to UASs. [7]

To help narrow the scope of the assessment, robust autonomy of a UAS can be defined as the characteristic that allows uninhabited systems to either continue operation in the presence of faults or safely shut down. To achieve reliability, a UAS has to incorporate mechanisms that augment reliability of its guidance, communication, and control systems. Fault-tolerant control (FTC) can add to the reliability of the system, as this will then depend on the likelihood of component failures and on the handling of faulty states that would prevent system failure. Determining these utility functions to quantify robust autonomy and the use of efficient scenario generation for variance reduction of significant data points and
of reliable models capturing dynamic responses of faulty aircraft have been challenging, because these models and scenarios are not simple to develop, and this type of simulation must cover a large spectrum of flying conditions. [7]

Developing more autonomous UAVs with considerations for low costs and small sizes has been a challenge as well. Connectivity, computational power, and lack of resource integration have previously been the three most major limiting factors in developing capabilities for small, low-cost autonomous UAVs. Small UAVs have a restricted amount of processing power, because they cannot have the same amount of power or same processor types (partly due to cost) as in larger UAVs. In the production of smaller UAVs, the largest portion of unit cost for a UAV lies not in the airframe, but in support (software) systems. Rarely does a smaller UAV contain a basic computing environment that would support significant amounts of onboard processing. Yet, the number of different airframes and types of computer hardware for UAVs has significantly grown, allowing for greater flexibility to develop smaller, more cost-effective UAVs. [8]

The further development of civil unmanned technology in the U.S. currently lags behind that for military unmanned technology also in part because of unresolved regulatory and technological issues. As mentioned before, the military market currently dominates the unmanned systems sector due to significantly fewer operational constraints. Strict airspace restrictions, underdeveloped technology, and the lack of funding and support have been the primary barriers to the growth of the civil UAV market in the U.S. NASA has essentially been the primary customer of UAVs for civilian applications, particularly in dealing with disaster relief and emergency response (DRER) situations. UAV systems have the potential to improve the effectiveness of DRER efforts by enhancing first-responder capabilities and providing advanced predictive capabilities and early warning. Yet, DRER UASs may require a more substantial investment in database and communications technology, whereas more conventional UASs might only require simple radio/satellite links. [9] This notion of increased cost has been a great deterrent
in the greater adoption of UAVs in civilian applications and the continued development of autonomy for civilian missions.

High mishap rates are frequently cited as a deterrent to more widespread adoption of UAVs. Although investments in unmanned aircraft reliability have been made to drive equipment failures to near zero over the last five decades, the experience level of UAV operators and maintainers still significantly contributes to UAV mishaps. Many of the most experienced operators/maintainers either separate themselves from service or rotate to other assignments at the height of their proficiency with certain UASs. Adding to the complexity is that no single mission management system will fit all UAVs, but common systems could still be used for controlling certain classes and types of UAVs. Also, current operational UASs have not explicitly included stealth or active countermeasure technology, thus limiting the true versatility of these UASs. [10]

The impediments to civilian UAV adoption can also be demonstrated by the prior lack of commitment to UAVs and UAV technology from the military sector. The practice of starting a military program and then, when production is about to commence, canceling it in favor of a slightly more promising system, has plagued the UAV market for years. The reasons for this lack of strong commitment to UAV progress are that the new UASs cost more than anticipated, that they suffer from high accident rates because of subsystem unreliability and operator error, and that they lack combat survivability features of manned aircraft. Although significant advances to autonomy have been made, interoperability is still a discussion point, as mission management may include all or part of the functions of route planning, air vehicle management and control, communications, sensor tracking, and data dissemination and exploitation. [10] This complexity is just one component of the considerations for the advancing of UAVs in the civilian market.

3.2 Benefits and Drawbacks of Autonomy
In spite of the above limitations and with the continuous advances that have been made towards autonomy technology, the customers of UAV purchases have been able to take advantage of many of the benefits that these advances offer. However, although the benefits have greatly helped in the successes of UAV missions, there are still some underlying drawbacks with the use of UAVs. This section will delve into the two primary benefits and two primary drawbacks of UAV usage.

First will be the discussion on the two primary benefits of UAVs. The first benefit is the ability of UAVs to traverse into much more perilous environments without risking human life. Before the advent of UAVs, much intelligence gathering was performed through the deployment of military personnel into enemy territory. Depending on the skill of the military agent and the security capabilities of the enemy, the success of such a reconnaissance mission was never a confident guarantee, as the agent’s life was at risk in enemy territory. Thus, with more autonomy on UAVs, there is little to no need of a human operator to be on board the aircraft. Even remote human operation or the aircraft’s own autonomous capabilities allow the UAV to make those critical decisions to handle the mission logistics as appropriately as possible or change the aircraft’s behavior depending on the varying circumstances and events of the mission. Thus, these autonomous features allow for UAVs to traverse into more fatal mission situations.

The second benefit of autonomy in UAVs is the afforded cost savings on the aircraft. The more sophisticated and advanced the autonomy technology, the more that a UAV can handle varying conditions on its own. With such precise decision-making for most situations, there is lesser need for a large number of operators to monitor the actions of the UAV. Because the number of operators thus decreases, there is less consideration for operator salaries in the costs of a UAV. More advanced and robust technology also leads to lesser maintenance and support, driving down the cost of UAV production.

Although these benefits can benefit both the manufacturer and customer, the two primary drawbacks of UAV autonomy also need to be highlighted. The first drawback is the perceived safety of
civilian life when UAVs are deployed in a more highly populated region. Although UAV autonomy software is highly advanced and has proven to be highly reliable, there are still some fears of UAVs going out of control and endangering civilians or property on the ground. This concern is not as emphasized in regions that are lowly populated, but is evident in the case of highly-congested areas. If a UAV goes out of control and no operator is managing the UAV, civilians either on the ground or in the air are put at risk by the instability of the UAV. Thus, the danger that an uncontrollable UAV could put civilians in is a consideration into why the government has taken such a long time to begin releasing the national airspace restrictions as of the time of the writing of this thesis.

The second drawback of UAV autonomy is the decreased amount of flying experience that is given to amateur aircraft operators. Because more advanced technology affords less direct involvement from aircraft operators, these operators are thus spending less time performing “hands-on” operations of the air vehicle needed to gain valuable flying experience. Thus, the time to get certified or licensed as an aircraft operator increases substantially, leading to higher turnover rates in the conversion of aircraft operators to fulltime status. There is already a perceived shortage in aircraft operators, so the increasing number of purchased UAVs does not help the situation.

3.3 Current Focus Areas

The ScanEagle is Boeing’s most notable UAV and offers state-of-the-art technology designed in a way to allow for the greatest versatility to handle many mission types. Because the UAV market has been heavily focused on the federal sector, the ScanEagle’s largest client base is with the government. Yet, the government continues to invest heavily in other UAVs.
Hence, companies are devising strategies to penetrate into the civilian sector (more details about this strategy in the next section). Previous attempts by UAV manufacturers to raise revenues or cut costs have focused on physical characteristics of the UAV or its payload, such as size, shape, and weight. This thesis focuses on a different aspect of the UAV, the level of autonomy in the software of UAV components. From what is commonly realized in the software industry, the complexity of software can warrant a great premium on the price of a software package or offering and can act as a substantial differentiator to the quality of the software when compared to that from other providers. Companies can drive more innovation and uniqueness into its UAVs through technology, and thus the level of autonomy in its UAVs could be the primary focus area for the company to gain some premiums or cut some costs.

Currently, as alluded to earlier, companies have not attempted to establish guidelines or standards in UAV business strategies through the level of autonomy in UAVs. Because there is little to no prior research on the topic, a new modeling tool is developed, especially incorporating the sensitivity-analysis functionality of the former tool. This new modeling tool is intended to be useful in establishing guidelines for UAV business strategies with potential civilian-sector clients.
3.4 Current Marketing Strategies

Companies are attempting to address the lack of UAVs in the civilian sector by drafting plans and proposals to prepare for the time when the government will loosen the national airspace restrictions (which the government has started to do in the past several months). The new modeling tool described in this thesis will be used to help Boeing better understand how UAV components are contributing to the bottom line of UAV production, in order to deal with the rising costs of UAVs in general. Civilian-sector clients are perceived by some to be more cost-conscious than their federal-sector counterparts, so UAV manufacturers, including Boeing, will need to be more sensitive to cost differences and changes. Thus, this tool can better handle this dilemma.

3.5 Art of the Possible

In the ideal state, all UAV characteristics, components, functionality, and functions will be able to be mapped into and quantified through the modeling tool. Currently, data on UAV benefits and costs is not readily available. Even if the tool is completed to its final versions, there still needs to be sample data to be inputted into the tool parameters. Thus, both the complexity and amount of possible data fields add to the intended capabilities of future versions of the tool.
Because the modeling tool is initially designed in Excel with VBA, the portability of the tool is greatly enhanced. Any of the primary stakeholders of the tool (supervisors, engineers, and business operations) should be able to use and modify the tool to accommodate for the desired specifications of the tool's behavior. Also, the tool is developed for faster and more efficient processing with the use of VBA to automatically run the primary functions. These VBA macros allow for fewer user interactions with the tool interface.

Because no other previous case study can be referenced from as a foundation for this modeling tool, the current version of this tool can act as a proof-of-concept tool for Boeing. With later versions, added functionality will contribute greatly to the final output values of return on investment. The current version only incorporates more than 100 parameters, so the results of the tool are slightly skewed due to the possible number of parameters that the tool should eventually handle. Hence, the future acceptance of the tool as a guidelines setter for UAV business standards depends greatly on the tool's ability to deal appropriately with an extremely complex framework logic model.

Figure 88. Example of current complexity of modeling tool.
4 Future State

The goal for companies is to make positive return on investment on their offerings of UAVs and UASs for all customers, either federal or civilian. The civilian sector has been open to the idea of utilizing UAVs in its operations for years, but no UAV manufacturer has a stranglehold on this market at the moment.

4.1 Expansion into Commercial/Civilian Offerings

Because of the current national airspace restrictions limiting where UAVs can travel in public airspaces, the expansion of UAVs into the civilian sector is still hindered. Although many civilian-sector clients are open to having UAVs become a regular component of their operations, they do not have complete freedom over where to fly the UAVs, because the government has sanctioned severe penalties for the intentional endangerment of civilians. For example, UAV operators still cannot direct their UAVs into a metropolis, where the lives and safety of a substantial number of people would be compromised.

The expansion into the civilian sector will need to happen gradually, as the movement truly depends on the will of the government. The federal government is the entity with the most power over the fate of the civilian UAV market and has started to loosen the national airspace restrictions, so progress can be made in providing UAVs to commercial firms. Any attempts for a manufacturer to penetrate the market at this point in time will be most critical in becoming the leading player in the market.

Now that the government has released the restrictions to some degree, companies would be well served to satisfy as many civilian-sector requests as possible. The modeling tool will have made significant advances to accommodate a large set of possible scenarios in the incoming civilian-sector requests. The tool will be able to effectively gauge the viability of a project based on the resultant ROI. Boeing can thus use this information to relay more profitable options to its clients and increase its bottom line on its UAS offerings as much as possible.
5 Approach

To establish guidelines for business strategies in dealing with UAV offerings, a modeling tool has been developed to provide better understanding into the benefits and costs of the individual components in a UAV. The tool primarily focuses on the impact of autonomy on the return on investment for a UAV project, but also contains many references to the physical and financial aspects to UAV production and operations. This chapter will delve deeper into the logistics and development of the modeling tool and discuss an example of the modeling tool in use for a sample client UAV application.

5.1 Model Background

Currently, traditional software and hardware cost models do not provide the capability to estimate the total cost of ownership for UASs, because the systems used to create and calibrate these models were not UAVs themselves. There are several models that have been proposed to help analyze the costs of UAVs. First, expert opinion involves querying experts in a specific domain and taking their subjective opinion as input. Second, the bottom-up, activity-based model begins with the lowest-level cost component and rolls it up to the highest level for its estimate, thus breaking down the aircraft costs into its main components. Third, the top-down, design-to-cost model aims for aggregate estimates for the cost of the system based upon overall features of the system and assigns each subcomponent a percentage of that cost, once total cost is estimated. [11]

Fourth, case studies describe projects similar to the targeted project for which estimators and planners will be attempting to develop estimates and apply a rule of analogy that assumes previous performance is an indicator of future performance. Fifth, heuristics and rules of thumb are based on experience to arrive at quick answers to engineers’ questions. Sixth, parametric cost estimation models (or cost estimating relationships, CERs) generate cost estimates based on mathematical relationships between independent and dependent variables. However, there is not enough data that is currently available to develop CERs for UAV cost analysis, assuming that parametric models are really most
appropriate for UAV cost analysis. [11] In any case, even with the amount of possible models, there is still much debate about what the appropriate metrics should be to determine valuations for UAVs.

There is a report produced by Jeff Cherwonik of Technomics utilizing the concept of CERs for a cost evaluation model of UAVs. The methodology of this model highlights the significance of several key drivers, such as operational ceiling, endurance, sensor resolution, base of operations, prototype quantity, production quantity, production rate, payload weight, and aircraft weight. The CERs focus on positioning and location of UAV usage and do not produce monetary amounts, as the new modeling tool would be required to do. [12] Also, this report does not provide a complete breakdown of the impact that each UAV component would have on the total revenues and costs for UAV offerings.

In the previously-noted NASA science missions, UAV costs are commonly reported in dollars per flight-hour plus mission peculiar costs. The cost per flight-hour is a marginal cost, reflecting the change in cost with flight time. Mission peculiar costs are non-recurring costs incurred throughout a mission. For four NASA missions funded between 2001 and 2004, the total proposed UAV flight service cost was $19,433 per flight-hour, with insurance comprising about 24% of this cost. The use of a UAV constituted 48% of the total mission cost to NASA. UAV insurance has been a major factor in the relatively high cost of a UAV science mission, partly due to UAV manufacturers not obtaining competitive insurance bids and to widespread misperceptions about UAV reliability. [13] As can be seen, there is no deep dive into the true costs of a UAV from the NASA perspective (just primarily the overall picture).

Because there is a lack of available case studies illustrating the generation of revenues and costs of a UAV project through its components, the framework for the modeling tool is based primarily on another tool that was developed in Boeing prior to the initiation of the project related to this thesis. The NASA case study previously mentioned deals with UAV costs on an aggregate level and does not expose any details on a component-wise basis. Likewise, any federal study surrounding UAVs does not describe in great detail about the specific costs of UAV parts and production, so even the determination of the
parameters for the modeling tool has to be decided upon internally through the primary stakeholders of the project.

As the modeling tool leverages methods in other Boeing-internal tools, this cost/benefit tool calculates return on investment as its final output and creates tornado and line charts focused on ROI to convey the data in a clear visual display. There are hundreds of input parameters into this internal tool, increasing the complexity of the final output calculations. In contrast, the complexity of the modeling tool discussed in this thesis is decreased due to the short timeframe of this project so far. The current version of this modeling tool still incorporates over 100 input factors (the methodology to determine these factors is discussed in a later section), but more will be considered for future versions. Similar to the other internal tool, this modeling tool is developed for use in Excel with VBA.

5.2 Model Description

The modeling tool has two primary functions: simulation/trending and sensitivity analysis. Currently, the simulation/trending operation has been more fully developed and incorporates a greater number of the input parameters than does the sensitivity analysis function. The simulation/trending operation produces future projections of return on investment for a UAV project, based on a combination of expected values and annual trending factors. For each year of a UAV project, each parameter’s value is calculated randomly based on a sequence of steps. This aforementioned sequence will describe how a parameter’s value will be calculated throughout the project’s lifetime.
First, the user of the modeling tool needs to enter in each parameter's expected/average value, minimum and maximum changes to this expected/average value (thus referencing the minimum and maximum possible values for the parameter), and probabilities that the minimum and maximum changes will take effect on this parameter's initial (i.e. expected/average) value. The minimum and maximum changes are only applicable to the first year of a UAV project, as changes for all subsequent years of the project's lifetime are based on an additional trending factor for each parameter. The user must also enter in an expected/average annual change (increment or decrement) to the parameter’s first-year value and the probability that this value will change for each subsequent year. To reduce the initial complexity of the model, only one probability is desired to apply for all subsequent years, as opposed to a single probability for each subsequent year.
Second, the first-year value is calculated for each parameter. To perform this operation, two random number generators are utilized to determine if the minimum and maximum change factors will be applied to the expected value for a parameter. Randomness is a prevalent feature of this modeling tool, as it allows for the model to generate different scenarios in the calculation of possible ROIs for some given UAV application/project. This randomness thus allows for better understanding of what autonomy guidelines could be established for a UAV offering. The aforementioned random number generators are configured to produce any decimal number from 0 to 1, inclusive. For each of the two change factors, if the generator produces a number that is less than or equal to the probability of occurrence specified for the change factor, then the amount of the change factor is applied to the expected value. For the minimum change factor, its value is subtracted from the expected value. The additive operation applies for the maximum change factor, if the random number generator produces the appropriate decimal. If a generator produces a number that is greater than the change factor’s probability, then the change factor is not applied to the expected value. Note that with this behavior, the expected base value can be adjusted to have a value anywhere between its parameter’s minimum and maximum values.
Third, the framework logic for the modeling tool is applied to the newly produced base values. This logic calculates the annual revenue and cost for a UAV project and uses these final numbers to calculate the ROI for a given year of the project. The cost calculations and formulas incorporated into this model will be discussed in a subsequent section.

Fourth, if the project only has a lifetime of one year, then the modeling tool moves on to the charting operation. Otherwise, the annual trending factors are utilized to help generate future projection values for each parameter. For any subsequent year of a project, the modeling tool takes the value from the previous year and uses a random number generator to determine whether the value for the annual trending factor will be applied against this previous year’s value. Similar to the generators for calculating the first-year’s base values, if this annual trending generator produces a number less than or equal to the probability of occurrence for the annual trending factor, then the trend value (positive or negative) is applied to the previous year’s value. Otherwise, the previous year’s value becomes the current year’s value. Once all of the input parameters have their current-year values updated, the modeling tool will then calculate the revenue, cost, and return on investment for that given year. To determine the ROI for each subsequent year, a discount factor (to reduce the complexity of the tool, this discount factor is the same for the duration of the project) is applied to the revenue and cost for that year before the ROI is calculated. Thus, when the final ROI for the project is calculated, all ROI figures have already been discounted back to the present year.

<table>
<thead>
<tr>
<th>Trend Value</th>
<th>Probability of Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price per Image</td>
<td>$1.0 20%</td>
</tr>
<tr>
<td>Images per Mission</td>
<td>2 25%</td>
</tr>
<tr>
<td>Missions</td>
<td>4 15%</td>
</tr>
</tbody>
</table>

Figure 11. Example of annual trend factor page for modeling tool.

Fifth, assuming that the project lifetime is more than one year and that all calculations have been made, the modeling tool will then calculate a consolidated ROI for the duration of the project. To do this, the model sums up all of the calculated ROIs during the project’s lifetime and determines the average of
this sum. The tool does not give more weight to any specific year’s ROI, so weights are not considered in the final output. This final consolidated ROI acts as a true threshold for the project’s viability.

Sixth, assuming that more than one simulation run is desired, the process specified in the previous five steps is repeated for the specified total number of runs desired. For example, if the user inputs in fifty for the number of runs, then the process is repeated forty-nine more times. Because the modeling tool relies greatly on randomization and trending, generating a range of viable ROIs gives a better picture of what is possible for the returns on a UAV project.

Seventh and lastly, three charts are created to visually capture the final annual and consolidated ROIs. The histogram shows the distribution of potential ROIs calculated from all of the runs of the simulation. The box plot shows the quartile distribution of the potential ROIs to help illustrate the reasonable range of ROIs for a given UAV project. The line chart shows the projected discounted ROIs during a project lifetime for a given run. The chart for other runs can also be displayed through an interactive drop-down menu. Overall, the three charts provide a clear picture of what is possible in terms of revenue, cost, and return of investment for a given project.
Figure 12. Example histogram from modeling tool.
Figure 13. Example line chart from modeling tool.
The other primary function of the modeling tool is sensitivity analysis. Similarly to the simulation/trending function, the sensitivity analysis function will also focus on the expected/average values and minimum and maximum changes to these parameters. For each parameter, the tool will fix the values of the other parameters to their expected/average values and calculate the ROI at the parameter’s minimum and maximum values, to help illustrate the effect of this parameter on the final ROI. Unlike the simulation/trending function, the sensitivity analysis function only calculates ROI for the first year of a project’s lifetime. Because the tool currently relies on randomization to calculate future projections, there is too much variability to calculate reasonable ROIs past year one. The model makes use of over 100 different parameters, and there are no expected base values for any of these parameters for subsequent years of a UAV application’s lifetime. Because of the lack of certainty in the base values after year one,
there are an exponential number of possibilities for these values. Thus, this phenomenon would add a layer of complexity to the tornado chart generation that is outside the scope of this thesis.

Once a range of ROIs has been calculated for each parameter, the tool will then create a tornado chart to graph the top twenty-five factors that provide the greatest range of ROIs. These factors are sorted from greatest to least in terms of range on the chart. This chart helps to determine which factors should be focused on more intently during UAV production and to provide guidance for the appropriate level of autonomy that should be incorporated into a component for a UAV.

![ROI Differences Tornado Chart](image)

**Figure 15. Example tornado chart from modeling tool.**

Besides providing two essential functions, the modeling tool has been created to handle six different types of UAV applications (border security, firefighting, storm tracking, agriculture, search & rescue, and law enforcement ISR [intelligence, surveillance, and reconnaissance]) very flexibly.
Application-specific tasks have not been included in this version to alleviate the complexity of the tool. The tool can also export revenue and cost figures calculated for all the runs to two new spreadsheets.

![Application Choice](image)

**Figure 16. The six applications supported in modeling tool.**

### 5.3 Performance Factors

The framework of the modeling tool handles two types of parameters: technical and business. The business factors deal with the physical characteristics of a UAV and mission-specific details of a UAV application. The technical factors are focused more on the engineering considerations of a UAV application, with a stronger emphasis on autonomy. These factors were decided upon through many discussions with supervisors, engineers, and business operations. Because prior research does not go into much depth about the individual costs of UAV production, many of these factors are considered vital through internal discussions.

#### 5.3.1 Technical

The technical factors of the modeling tool revolve around the twelve primary autonomous components of a UAV: launch sequence, landing sequence, recovery, contingency management, redundancy, health monitoring, tracking, pre-positioning, collision avoidance, decision-making capability, control room automation, and fault-tolerant control. These twelve were determined to be the most crucial in the autonomous operations of a UAV and finalized by a variety of stakeholders of the project: business
operations, engineers, supervisors, and me. Each of these components has a similar cost structure, incorporating costs such as software, maintenance, operation, and autonomy. Risks to these components and the complexity/autonomy of the software in each component are also considered in the final valuation of each component. There are also a few technical factors not directly related to UAV components, but to the entire UAV in general. More details of the technical factors are provided in the technical specification for the modeling tool (which is noted in the References section at the end of this thesis; the technical specification and certain specific details about the model framework cannot be released at this time due to proprietary concerns).

![Primary UAV Components](image)

**Figure 17. Primary UAV Components.**

### 5.3.2 Business

The modeling tool’s business factors are comprised of physical characteristics of a UAV aircraft and application. These factors affect either revenue or cost, but not both simultaneously. In the modeling tool, there are four revenue streams: sale of images, detection/surveillance services, vehicle operation services, and sale of UAV aircraft. There is an associated innovation premium for UAV offerings based on autonomy features, such as autonomy level, software performance, and UAV operator expertise. Non-
technical factors such as operator and non-operator salaries, mission-specific costs, and additional aircraft
costs are also considered business factors. More details of the business factors are also provided in the
technical specification for the modeling tool.

5.4 Model Structure

The framework for the modeling tool is divided into multiple layers. At the bottom are the
parameters into the model framework. These parameters have already been broken down into technical
and business factors, but must also be separated into benefits and costs. The framework logic defines the
relationships among those parameters on a benefit-cost basis. The interface of the modeling tool then
links everything together.

5.4.1 Breakdown into Benefits and Costs

The framework for the modeling tool breaks down all of the technical and business factors into
revenue and cost factors. There are two types of revenue factors: innovation premium and sales.
Likewise, there are two types of cost factors (with similar names to the types of factors in the framework):
technical and business. Not all technical framework factors are technical cost factors, and likewise for the
business parameters. The innovation premium and sales factors are also a mix between technical and
business framework factors. (Please note that descriptions of all of the framework factors are contained
in the technical specification for the modeling tool).

In regards to the revenue factors, the innovation premium factors are comprised of three different
parameters: autonomy level, software performance, and operator expertise. These innovation premium
factors are the technological leverage that Boeing has to produce a higher-quality offering for its UAV-
market clients. They represent the advantages that Boeing-produced software may have over that from
other UAV manufacturers. Because these factors are considered a premium to utilize Boeing's UAV
offerings, they thus increase sales.
Innovation Premiums
- Autonomy Level
- Software Performance
- Operator Expertise

Figure 18. Relationship of innovation premium factors to total revenue.

The other component of the revenue factors are sales. Sales are comprised of four different parameters: sale of images, detection/surveillance services, vehicle operation services, and sale of aircraft. Each of these factors can be used in tandem for a combination of UAV offerings for a client. Most likely, a client request will focus on one particular business model from the four listed above. Each sales factor incorporates the price for some type of tangible product/service that is being offered (i.e. images from the sale of images business model), the frequency of the type of tangible offering, and the number of times that the offering might need to be used on an annual basis. The sales factors make up the base values for the revenue calculations.

Figure 19. Four business models for UAV offerings.
In regards to the cost factors, the technical factors are entirely comprised of the twelve components. The primary components of these factors were discussed above. As such, these component factors have the exact same cost structure and are considered premium adjustments for the base costs in UAV production. These factors represent the complexity and innovation behind the software of Boeing’s UAVs, so there is a premium to support such progress in technology (as discussed earlier).

The other component of the cost factors are business factors. The business factors that are non-technical were discussed above as well. Other business cost factors include the mission application, fuel, and airspace restriction premium costs. These factors represent the base values for the cost calculations. More details about all the revenue and cost configurations can be found in the technical specification.

5.4.2 Cost Range Estimates

The modeling tool incorporates expected/average base values and minimum and maximum change values that only take effect when the random number generator acts favorably for the increase/decrease (as discussed earlier). As such, there is the need for cost range and base value estimates for each parameter in the modeling tool framework. Due to the lack of available data to obtain cost estimates, estimates are generated based on expectations by supervisors and business operations individuals. Although there is no actual data used in these estimates, the numbers used (which are currently only applicable for the case study UAV application) are within reasonable bounds to be considered for the time being. Future planning will be considered to provide more substantial sets of relevant and reasonable data.

5.4.3 Framework Logic Rules

The entire framework logic of the modeling tool is defined in the technical specification of the modeling tool and will be briefly discussed in this section. This logic creates all of the links between the components of all revenue and cost factors together. There are some factors that share similar parameters, which are linked together and simultaneously change, such as number of missions for operators, non-
operators, fuel cost, a specific business model sales factor, etc. There are also a few factors that act as aggregates for the UAV as a whole, with totals greater than or equal to the sum of the values for the individual pieces themselves (such as software bugs, support engineers, and lines of code). The technical specification provides more details into the framework logic and the relationships defined among the factors (many of these details cannot be disclosed yet due to proprietary reasons).

5.4.4 Consolidation

The modeling tool interface wraps all of the functionality of the tool together into a single visual presentation. Although considerations were discussed to design the tool in MATLAB, Excel was chosen
as the platform for the code base and data store of the tool. Because business operations individuals
would be most exposed to the tool, Excel is the most appropriate choice to allow for greater familiarity
and ease of use. A future version written in MATLAB is still being considered.

The interface separates the two primary functions (simulation/trending and sensitivity analysis) of
the tool and also allows for resetting calculations and for exporting revenue and cost data to new
spreadsheets. The interface also allows for the choice of UAV application that the tool tries to simulate.
The current version does not treat each UAV application differently, but will do so in a future version.
Also, access to the charts for each function is accessible after the initial calculations have been produced.

![ROI Simulation Test Results](image1)

Figure 21. Screenshot of modeling tool after simulation/trending function has completed.

![ROI Sensitivity Analysis Results](image2)

Figure 22. Screenshot of modeling tool after sensitivity analysis function has completed.

5.5 Case Study
After development of the modeling tool was finished, a case study around a particular UAV application was generated to reflect the visual and calculated outputs of the tool. This case study acts as the prime example of how the modeling tool can be used to assist in establishing guidelines for business strategies dealing with UAV offerings. The case study also validates the ability of the modeling tool to generate possible strategy scenarios for a given UAV application.

5.5.1 Topic/Focus Area

Out of the six UAV applications in the modeling tool, firefighting was the chosen UAV application for the focus of the case study. Firefighting is a very desirable example application from the perspective of clients, as this application can appeal to many potential customers looking into UAVs to deal with fires. The supervisors assigned to this project are also very supportive of using firefighting as the example choice, due to this application being very generic and making use of many parameters that are shared with other UAV applications.

Firefighting also illustrates a very appropriate setting for the use of UAVs. In many fire scenes, the lives of firefighters are greatly compromised, due to the size, severity, and complexity of the situation. There have been many instances where firefighters are unable to sustain the heat and danger of a fire, thus causing unintentional loss of life or severe injuries. Thus, because UAVs can primarily be remote-controlled and are not required to house people, UAVs are a suitable solution to allow firefighters to stay away from more perilous fires, as UAVs can be sent in to handle such fires. UAVs can thus decrease the number of firefighters who are inadvertently put into danger zones, thus showing their true worth in such civilian pressure situations. This narrative thus provides the motivation for the case study.

5.5.2 Generation Process

To generate the contents of the case study, the modeling tool provides the relevant data and parameters that form the primary basis of evaluation of the business models considered in the case study. The charts that are produced by the modeling tool are included into the case study’s set of figures, while
tables showing the set of expected/average base values and minimum and maximum change values are also inserted at the end of the case study. The case study is summarized in this and the next section.

To determine the various parameter values, the brute force approach is applied to help produce final numbers and charts that would seem reasonable to business operations. The annual trend factors have probabilities set to lower values (lower than those configured during the implementation and testing phases of the modeling tool) to allow for lesser variation and randomness in future projections of revenues and costs during a project’s lifetime. The base values of each parameter were tweaked gradually to check the soundness of the calculated data. Once the cost values were finalized, much more tweaking went into the revenue factors, as the established values for the cost factors seemed to be reasonable to a great degree. The tables at the end of the case study document show the finalized values for the revenue factors.

5.5.3 Primary Details

The initial version of the case study contained a substantial section dedicated to a narrative, highlighting the circumstances leading to the situation where UAVs would be needed in a firefighting case. A story was utilized to describe the major players and events of the situation in order to provide the background before the relevant data would be inserted into the document.

The current version has the narrative removed and focuses solely on the data for the original situation. Nonetheless, the case study still describes the need to choose among three different business models: sale of images, detection/surveillance services, and vehicle operation services. The charts and final numbers from the modeling tool help to justify the choice for a business model, which will be described in greater detail in the next chapter.
6 Validation

This chapter will go into depth about the results of the modeling tool and case study. Because there is a lack of prior research into this area of study, much of the verification of the data and analysis is based on the judgment of the stakeholders of the project. Estimates are primarily used in the data, and these stakeholders are aware of the lack of credible findings in the field to justify the analysis against some established standard. Since no such standard currently exists, there is more leeway in terms of defining what the true benefits and costs are in UAV production.

6.1 Model Results

As this thesis has previously mentioned, the modeling tool produces ROI as the final output. The individual annual ROIs are just as vital as the final consolidated ROI through a UAV project’s lifetime. The three charts (histogram, line chart, and box plot) illustrate the possibilities that Boeing could envision for a business strategy with a potential client. There is no similar tool currently in the field to compare with this modeling tool, as the NASA-specific tool used in the study mentioned previously does not delve deeply into the individual components that comprise a UAV.

This tool depends greatly on randomization, so there is greater room for skewed results in the data. The randomization probability for each parameter is the same throughout the duration of a project, which is not the case in a real-world situation. Thus, the variability that is introduced by the tool can lead to less than reasonable results. For the majority of the runs, the tool produces revenue, cost, and return on investment figures that are within the limits that are hard-coded into the tool (these limits reflect that return on investment is between -100% and 100% for any given year). When there are cases where the ROI exceeds either the lower or upper bound, that result is rejected without being recorded into the final results. Thus, there may be an excessive number of rejections before there are enough defined successes (the number of successes is the number of runs that the user specifies in the miscellaneous parameters section of the modeling tool) once the tool stops the simulation.
Although the tweaking process required substantial time to handle, the case study does contain appropriately-looking charts (including the tornado chart) to portray the comparison among the three business models. In this situation, appropriately-looking means having the majority of generated ROIs within the range of -50% and 50%, which is even more restrictive than the model’s set limitations of ROIs ranging from -100% to 100%. The case study results (which will be discussed in more detail below) illustrate the potential of the modeling tool to provide appropriate analyses.

6.1.1 Model Data Analysis and Reliability

As mentioned before, there is no prior research available to compare the functionality of the modeling tool to a previous tool built before the inception of this project. The NASA tool described earlier does not specialize on individual components but on the UAV as a whole. Thus, the NASA tool cannot be used as a measuring stick for the modeling tool of this project.

The modeling tool is based on a previously developed internal tool that specializes on sensitivity analysis and tornado charts. However, this internal tool is based on a different form of assessment of UAVs and is unrelated to the topic area (level of autonomy and functional component breakdowns) for the modeling tool of this project. The internal tool is only used as a reference point and an example case for this modeling tool. Only the concept of the tornado chart is incorporated into the modeling tool.

The defense of the data, results, and analysis of the modeling tool comes from the individual stakeholders (supervisors, engineers, and business operations) of the project. These individuals helped to verify the reasonableness of the data and of the charts. They are aware of there being no previous data, internal or external, to base the generated numbers against, but do have a general sense of what the appropriate figures might look like. With this in mind, this modeling tool is being viewed more as a proof-of-concept than an officially released product, as relevant data is not readily available to truly defend the functionality of the modeling tool.
As a reference point, other similar Boeing-internal tools began as a proof-of-concept tool and required over one year of substantial development to realize their true potential and use in the company. Appropriate data for this tool was also provided at a later date, after the proof-of-concept stage. Thus, the modeling tool for this project is undergoing a similar development process, and appropriate numbers will be provided during the later stages of this tool’s development.

6.2 Model Limitations

The user guide that is associated to the modeling tool lists the bugs and enhancements that need to be addressed at a future date. This section summarizes open issues in the current version of the modeling tool. Details are contained in an internal Boeing user guide document.

Currently, the sensitivity analysis function is limited to only one year’s worth of projections, the first year. The tornado chart that is produced through this function only shows the potential ROIs for each parameter during the first year of expected values. All subsequent years of a project are ignored by the tool and not considered in any subsequent sensitivity analysis phases. The main issue with incorporating the remaining years of a project’s lifetime is the variability in projected values due to the randomness of the annual trend factors taking effect on the previous year’s values. Because of the injection of random behavior in the modeling tool, there is a great lack of stability in projected values to truly understand how a tornado chart could be used to map out this variability even with base values. The current tornado chart is two-dimensional, while a tornado chart to fully incorporate the randomness and complexity of the model could be at least three-dimensional or even higher. This phenomenon is outside the scope of this project.

The modeling tool also does not incorporate the concept of a utilization rate for UAVs. Currently, the tool will treat any customer who participates in the business model of the sale of aircraft as a regular annual purchaser of aircraft. In a real-world scenario, hardly any customer would buy UAVs every single year of a project’s lifetime and would create a new purchase order after a certain amount of
usage of a UAV. Thus, the modeling tool is limited in dealing with the utilization rate of UAVs. The tool already automatically injects much more revenue for the business model of the sale of aircraft, which skews what the perceived results should be. Thus, when designing the case study, this business model is intentionally excluded, because even reasonable results could not be obtained for this model.

Another limitation of the model is the degree of fulfillment of the original intent of the model, establishing the level of autonomy in UAV components. In many of the tornado charts results, component and overall autonomy levels do appear, but are very low on the charts. Some physical and logistical factors, such as business model pricing and employee salaries, have substantially greater effects on ROI than do these autonomy levels, either on a component or overall basis in the selected case study. The original intent of the tool was to allow the inclusion of the impact of autonomy on UAV pricing.

The final notable limitation of the model is the lower and upper bounds for a permissible ROI to be accepted as a result of the simulation/trending function. Currently, the modeling tool only allows for ROIs between -100% and 100%. However, for many projects, the range of permissible ROIs will vary greatly from one customer to another, and from one application to another. There is no existing method to configure this range, so any user of the modeling tool will see all runs that produce an ROI within the default range. This also highlights another problem, where there is no data validation for calculated projected values. Due to the randomization capability of the tool, some calculated values exceeded their permissible minimums and maximums, thus allowing for additional skewed results. Thus, there is a lack of the combination of configurable ROI ranges and data validation to deal with runs producing results that exceed appropriate thresholds.

6.3 Case Study Data and Results Analysis

Overall, the case study illustrates that the business model of vehicle operation services is the most attractive out of the three proposed models. Vehicle operation services are those where a company would directly manage the operations, maintenance, and support of UAVs, while the customer provides the
direction of how the UAVs are utilized for a given application. The models of detection/surveillance services (a subset of vehicle operation services) and of sale of images also offer generally positive returns on the initial investment, but do not have as desirable positive investment opportunities as vehicle operation services. The other two business models also have greater variability with the distribution of potential ROIs than that for vehicle operation services. To make this decision, greater weight is emphasized on the box plot and tornado chart. The box plot shows favorable possibilities for all three options, so this chart helps to justify the consideration to accept any of the three. The tornado chart analysis shows the evident choice, as the vehicle operation services business model portrays service price as a lesser variant in the potential ROI range, as opposed to the service price for either detection/surveillance services or the sale of images. With this justification, the chosen business model is vehicle operation services. All of the relevant charts for the case study are included at the end of this section.

A story narrative was included in the initial versions of the case study. However, the narrative is excluded from the current version, so the case study only contains the relevant data and chosen business model defense. Because there is no previous case study or other research materials based on firefighting and UAVs, the validity of the results cannot be compared for verification with an external source. The following pages will display the figures and charts from the case study document. Direct comparisons can be made among the following figures: 23, 26, and 29; 24, 27, and 30; and 25, 28, and 31.

Besides having its service-related price being lower on the tornado chart, the business model of vehicle operation services also illustrates the most stable behavior in the distribution on the histogram. The three box plots show similar expected returns, so no business model has a large advantage over any other in this regard. Yet, the greater stability of vehicle operation services from the tornado chart and histogram gives this business model the advantage to be chosen.
Figure 23. Histogram for example with vehicle operation services.
ROI Box Plot Distribution for Test Runs

Figure 24. Box plot for example with vehicle operation services.
Figure 25. Tornado chart for example with vehicle operation services.
Figure 26. Histogram for example with detection/surveillance services.
Figure 27. Box plot for example with detection/surveillance services.
Figure 28. Tornado chart for example with detection/surveillance services.
Figure 29. Histogram for example with sale of images.
Figure 30. Box plot for example with sale of images.
Figure 31. Tornado chart for example with sale of images.
7 Conclusion

As described throughout this thesis, the modeling tool is the key innovation to help establish guidelines for business strategies in dealing with UAV offerings to clients. The simulation/trending and sensitivity analysis functionality allows for better understanding the financial costs of UAV production and the amount of software complexity that should be programmed into the UAV components. Although there are still many considerations that need to be discussed around the degree of impact that autonomy should have in these guidelines or on the modeling tool itself, the current version of the modeling tool acts as a precursor to process improvement steps to the UAV manufacturing process and cost recording procedures. The modeling tool will require further enhancements to truly provide real value, from both the business and technical standpoints, to Boeing’s UAV business endeavors.

7.1 Model Growth and Future Goals

The current version of the modeling tool still requires many enhancements before it can be a true indicator of the expected ROI for a UAV project. The user guide to the modeling tool (which may be released at a later date) provides a list of the bugs and enhancements that still need to be addressed with the tool, with the more urgent features discussed earlier in the thesis. For many of the primary stakeholders of this project, the modeling tool is still viewed as being a proof of concept, so another version or upgrade is completely viable. The tool will still need to incorporate even more input parameters, thus adding to the complexity of the tool and the underlying framework. The current framework logic is also primitive in nature, so future enhancements will most likely make use of more sophisticated mathematical structures and models.

Thus, complexity is one of the two primary considerations for future versions of this modeling tool. Although the tool already makes use of more than 100 parameters, there are still many more variables to consider for UAV production that can contribute significantly to the bottom line of the UAV business. Due to the potential increased complexity, the sensitivity analysis functionality will need to be
further refined, as the tornado chart can only handle calculations for the first year of a UAV project with just over 100 parameters. The increased complexity will force additional layers of computation to be incorporated into the model, thus also necessitating additional time and resources to computing the final output values. The modeling tool currently requires a variable amount of time, depending on the operating system and processing power of the computer that the tool runs on. The tool runs significantly faster on more recent processors (such as the Core i3, i5, and i7), as opposed to older processors (such as the Pentium).

The second primary consideration for the modeling tool is the configuration settings for each type of possible UAV application. Currently, the tool treats each application with a generic format, so that no single application has any differentiators from one another. Future versions of the tool will need to handle more than just six applications, so customization will be more vital for the tool. Also, pre-configurations of the data values for the tool's parameters will need to be incorporated into the framework logic. With each application, there will need to be some appropriate standard with default parameter values. This precedent is to satisfy the purpose of the tool in establishing guidelines for UAV business strategies. Also, once these processes have been implemented into the tool, the tool can be easily modified to deal with military UAV applications as well.

7.2 Recommendations

With development needed for future versions of the modeling tool, a few procedures must be undertaken to allow for better integration of concepts into the tool. First, new data recording procedures must be adopted to give a basis for generating number estimates and ranges. Because no such data is available in the federal and civilian domains, and such numbers are not easily provided by internal sources, new procedures should be adopted by the stakeholders and the company to store the relevant information and data. With currently no data to base the original estimates on, validation does not allow for as great a defense of the results as would be desired. Financial cost information for UAV components, production procedures, and UAV logistics should all be readily available whenever the tool needs to be
used. Thus, Boeing as a company needs to implement new standardized recording procedures for UAV data to allow the company to better understand how money is allocated amongst the UAV parts.

Second, the primary stakeholders need to have more direct interaction with the development of the tool itself. Much of the development of the modeling tool has been done remotely, outside of the local work areas of the stakeholders. Thus, for future developers and stakeholders of this project, there would be great benefits with closer proximity among the invested parties. There also needs to be closer communication between the technical- and business-focused stakeholders, as both types of stakeholders are not located closely together to each other.

Third, the modeling tool is currently developed using VBA in Excel. A future version of the tool should make use of more sophisticated technology, such as MATLAB or some software programming suite. Excel does have much of the functionality that is needed, but does not have many of the processing efficiencies that are afforded with using more advanced technology. Also, the design of the user interface would be more intuitive with the use of some software programming suite. The use of Excel was based on similar Boeing-internal tools and the background of the business operations users of the tool. Thus, the tool would become even more powerful with a change in the implementation layer.

7.3 Next Steps

Progress in the modeling tool can be further accomplished with more dedicated developers on the project. The tool has been developed only through the efforts of a single developer, with oversight from two supervisors. The next step is to engage additional developers into enhancing the tool even further. The tool has already incorporated some acknowledgement of software trends, but this could be expanded more thoroughly with more engineers who know the low-level details of UAV production. Also, these new developers will assist in further defining the effect of autonomy on the pricing of UAV offerings.

In greatest need, a new data recording process should be designed to be implemented well before the first release version of the tool is available. Currently, the estimates in the modeling tool have no true
justification against any external data. Companies should maintain some financial history of UAV component benefits and costs. Although the process might not be available in the near future, this process should be considered and defined in a shorter timeframe. Having these records stored in the company’s servers will provide Boeing with more leverage in trying to establish guidelines, as the company will have done something that many of the other UAV manufacturers are not even considering at the moment.

The focus on the modeling tool has been on civilian applications, but the growth opportunities for these are more limited due to national airspace restrictions. Much of the revenue opportunities are still in military applications, due to continual increased spending on UAVs and UASs from the government. Thus, a tool could be developed to accommodate defense applications. In addition to government customers demonstrating increased awareness of UAS cost elements, UAS suppliers are becoming increasingly proactive in driving down cost for what promises to be an even more competitive civilian market segment. Thus, this same approach can be taken for the federal sector as well. By better understanding how costs are being allocated in its UAV business, with a particular focus on level of autonomy in UAV components, companies can use this information to better price its UAVs amidst its greater competition. The dual goals of raising the bottom line and increasing market share will be better accommodated with a greater understanding of how the revenues and costs are being generated.
References


Figure References


