12-10-2009

Extending the Strategy Based Risk Model Using the Delphi Method: An Application to the Validation Process for Research and Developmental (R&D) Satellites

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Recommended Citation

Langenbrunner, Amanda J. and Trautwein, Mary R., "Extending the Strategy Based Risk Model Using the Delphi Method: An Application to the Validation Process for Research and Developmental (R&D) Satellites" (2009). *Theses and Dissertations*. 1938.
https://scholar.afit.edu/etd/1938

EXTENDING THE STRATEGY BASED RISK MODEL USING THE DELPHI METHOD: AN APPLICATION TO THE VALIDATION PROCESS FOR RESEARCH AND DEVELOPMENTAL (R&D) SATELLITES

THESIS

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

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December 2009

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Abstract

The validation between a research and developmental satellite and its ground system is critical to ensuring the success on-orbit. However, the exact process for completing validation is not documented, frequently underfunded, and accomplished ad hoc. This leads to debate regarding maintenance of budget and schedule, while ensuring on-orbit success.

This thesis examines readiness and on-orbit activities within the U.S. Air Force Space Development and Test Wing's Research Development Test and Evaluation Support Complex. Combining historical data with the consultation of subject matter experts, a validation process was defined. Risks associated with this process were then analyzed using the Strategy Based Risk Model, and were evaluated based on the probability of occurrence and severity of impact. The validation process and associated costs were validated using the Delphi Method. Next, we transformed the results into a simulation that generates distributions of possible costs and risk outcomes. Finally we applied the simulation to a program, and distributed it to program managers for feedback. The simulation will be distributed to program offices to support tailoring a validation plan relative to their budget. The simulation will give decision makers greater fidelity into the expected risks and costs associated with the selected validation process.

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I. Introduction

1.1 Background

Prior to launching a satellite, the satellite and ground system must undergo a series of validation tests to ensure they are capable of communicating with one another. The validation of the compatibility between a satellite and its ground system is comprised of three main events: a compatibility test between the satellite, the ground system, and the Command Control and Communication (C3) node (e.g. Air Force Satellite Control Network (AFSCN), Tracking and Data Relay Satellite System (TDRSS), or other), database (command and telemetry) validation, and data flow testing. Although thorough verification, validation, and testing processes have been laid out between large budget satellite programs and their ground systems, no such process has been defined for Research & Developmental (R&D) satellite missions. Therefore, organizations that specialize in flying unique R&D satellites are presented with specific challenges because there is no standardized approach for validating the ground systems. Since there is no standardization of the system validation process, every satellite program varies or modifies its own validation plan. Additionally, the limited budgets of most R&D satellite program offices contribute to the widely varying validation plans.

Furthermore, each stakeholder has a different methodology for conducting validation testing. An example of this difference is apparent between the Space Development and Test Wing (SDTW) and the Air Force Research Laboratory (AFRL). SDTW specializes in space technology demonstrations; this includes flying, launching and funding experimental satellites missions. A large quantity of these experimental satellite missions are developed and funded in part by AFRL, making them one of SDTW's largest customers. SDTW and AFRL frequently disagree in regard to their stance on Launch Based Compatibility Tests (LBCT). SDTW, along with their parent organization, Space and Missile Systems Center (SMC), under the control of Air Force Space Command (AFSPC) requires an LBCT. AFRL, under Air Force Materiel Command (AFMC), frequently deems an LBCT as unnecessary. This philosophical difference stems from AFRL working primarily in R&D, while most of AFSPC works with operational satellites. Agencies are more likely to take risks with R&D satellites than the operational satellites upon which our military and country depend. Although the philosophical differences are well understood, it causes conflict within the organizations because AFMC has satellite control authority (SCA), yet AFSPC operates the satellites.

Conflicts like the one presented above stem from a difference in stakeholder priorities. Each satellite mission has a different set of stakeholders. The stakeholders have different methods for validating compatibility between the satellite and the ground system. These differences arise from adversity to risk, a direct result of their different and limited budgets. Nobody wants to put a satellite into orbit that cannot communicate with the ground system, but the office paying the validation bill will question the necessity of the full validation process. There are numerous ways to reduce costs during the validation process, namely the reduction of validation events. However, each skipped event adds risk to the program. Discerning the potential program risks helps stakeholders determine the optimal steps in the validation process for the program based on their budget. Validation occurs late in the lifecycle of a program, thus most of the budget reserve has been consumed. As a result, this is the least opportune time for a program to encounter a problem.

1.2 Scope and Purpose

The purpose of this thesis was to develop a simulation that generates distributions of possible risk and cost impacts. This simulation will aide R&D satellite program offices in identifying the critical steps in the process of the validating the compatibility between a satellite and its ground system. This model will help determine the necessary validation steps, while also determining possible steps to eliminate to balance cost and risk. For this thesis, validation refers to those steps that ensure the correct system was built. Verification ensures the system was built correctly. Verification is not within the scope of this thesis. Validation determines the correctness and completeness of the end product, and ensures the system satisfies the needs of the stakeholders [Bahill & Henderson, 2004]. R&D satellites frequently remove and/or modify steps during the validation of the satellite and its ground system to meet budget. Stakeholders can use this simulation to support discussions on balancing the validation effort with cost and risk.

1.3 Research Questions

This thesis answered the following questions in order to develop a simulation that generates distributions of possible costs and risk outcomes:

- What are the steps that need to be carried out as part of the process for validating the compatibility between the satellite and its ground system?
- What are the costs to complete each step of the validation process?
- What are the risks associated with not completing each step of the validation process?
- What is the desired balance between cost and risk for a given validation strategy?

These outcomes were analyzed in relation to the impact events associated with the realization of risks.

1.4 Methodology

Our thesis methodology is based on Avner Engel and Miryam Barad's paper, *A Methodology for Modeling Verification Validation and Testing (VVT) Risks and Costs*. In this paper Engle and Barad examine the risks and costs associated with VVT for the Israeli aircraft industry [Engel & Barad, 2003]. We have adapted their methodology to fit our model for the validation of the compatibility between R&D satellite and their ground systems.

The methodology was divided into four distinct steps. During the first two steps we relied on a panel of experts to provide data. The first step was broken into two parts: (1) develop a model of all of the steps associated with validating the compatibility between an R&D satellite and its ground system, and (2) assign appropriate costs to each activity. In the second step we identified the program risks that are mitigated by executing the steps in the validation process and the costs associated with the impacts of those risks. The third step in our methodology used the data collected in the previous steps to create a simulation that generates distributions of possible costs and risk outcomes. This simulation aides the program office when building a validation plan and justifying the validation plan to leadership. The program office is able to review all possible risks concerning the ground system and satellite validation plan, along with the severity and probability of the risks. Next, they can review the validation steps that mitigate the risks and their costs. Finally, they review the generated distributions to build their validation plan and allow for risk realization based on their budget and the risks they wish to mitigate. The fourth and final step in our methodology was to demonstrate the usability of our simulation by applying it to an on-going R&D program. Additionally, we had two program managers apply the technique and simulation to their programs. This was done to validate that the technique and simulation were easily understood and could be applied by program managers that did not have insight into our thesis.

1.5 Assumptions and Limitations

Engel and Barad made a number of assumptions when conducting their research on the Israeli aircraft industry’s VVT efforts. As our thesis is based on the works of Engel and Barad, we made many of the same assumptions. First, we assumed that the Canonical Verification, Validation and Test Model (CVM) is a sequential process that assumes linear progression of steps. Second, we assumed that all of the validation steps take place within the same phase of the mission lifecycle – the readiness phase. Third, we assumed that the risk impact costs and probabilities of all risk sources are independent. Finally we assumed that each validation step is either performed or not performed, and that a step may not be partially completed [Engel & Barad, 2003].

Additionally, we made a number of other assumptions in our thesis that Engel and Barad did not. The first assumption was that the same basic risk areas apply to all satellites and ground systems. As all R&D satellites investigated during this thesis use the same mechanisms for communication, their risks areas will be the same. Next we assumed that the impact of each risk is represented with a dollar value. Sometimes the impact of a risk being realized is a schedule slip. However, for the purpose of this thesis we only tracked budgetary concerns; therefore, a schedule slip was correlated to the monetary cost associated with it. Finally it was determined that each risk is mitigated by at least one step in the validation process.

We also encountered limitations to our research. First, our data only examined validation (end to end testing) and not inspection or system level testing. Inspection and system level testing occur prior to validation testing in the systems engineering process and thus was not considered in this thesis. Next, all satellite systems we reviewed during the course of this thesis communicated via the AFSCN. However, satellites utilizing other communications mechanisms would follow similar validation steps to ensure compatibility between the satellite and its ground system. Additionally, because CVM is a sequential process that assumes linear progression of steps, CVM does not account for re-execution of steps due to failure. Another limitation in our thesis was due to the availability of information. Moreover, only four programs were used to derive the cost data for the validation steps. The technique developed in our thesis examined how the validation steps can reduce the probability of a risk being realized, the steps in the validation process do not mitigate the severity of the realization of risks. Finally, risks can be defined as threats and opportunities; however this thesis only examined threats.

II. Background

2.1 Validation in the System's Engineering Process

According to Dennis M. Buede, author of *The Engineering Design of Systems: Models and Methods*, Systems Engineering is defined as: "an interdisciplinary approach encompassing the entire set of scientific, technical, and managerial efforts needed to evolve, verify, deploy (or field), and support an integrated and life-cycle balanced set of system solutions that satisfy customer needs" [Buede, 2000]. The Systems Engineering Process is an important part of any development effort, but it is especially important for R&D satellite program offices because of their limited budgets. One of the most accepted models of the systems engineering process is the Vee Model. Figure 1 shows a typical system development lifecycle as a "Vee" with the emphasis of the model from a systems engineering perspective. The left, or decomposition, side of the Vee illustrates the phases at the beginning of a typical system lifecycle, and focuses on requirements definition and development of the system specification. The bottom of the Vee develops system specifications into a build-to design and the resulting products product. The right side of the Vee depicts the final steps in system development.

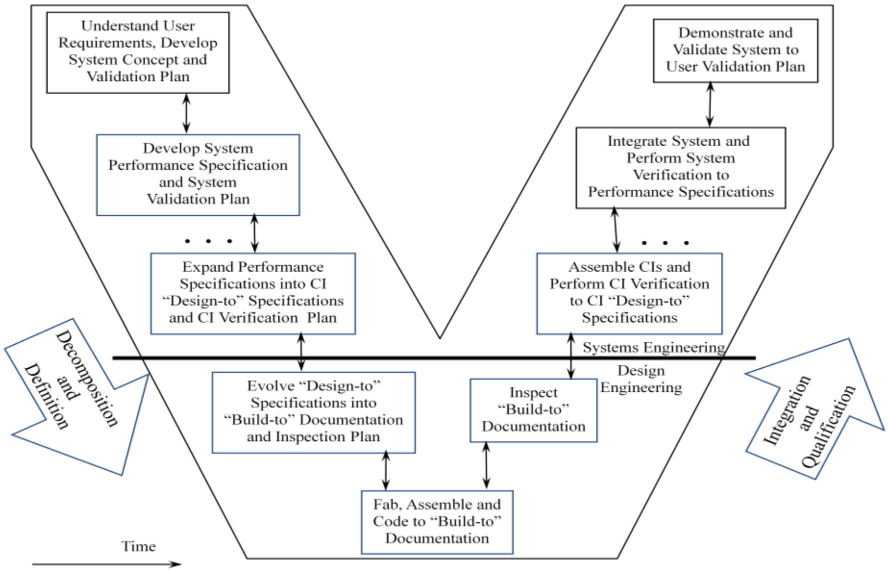


Figure 1: Systems Engineering Vee [Buede, 2000]

These steps focus on ensuring the system meets the requirements and user needs. This process is Verification Validation and Testing (VVT). Our thesis focused on a particular part of the final step in the Systems Engineering Vee: Demonstrate and Validate System to User. Specifically we defined our user as the Research and Developmental (R&D) Satellite Program Office. We demonstrated and validated that our System-of-Systems, the satellite and ground system, are compatible.

According to Buede, "validation of the design problem demonstrates as completely as possible that the design problem as defined by a large set of requirements is the same design problem as reflected in the operational concept and in the minds of the stakeholders." Validation illustrates to the stakeholders that the ground system design and integration meets the needs of the satellite and that the satellite can communicate with the ground system [Buede, 2000].

2.2 R&D Satellites

R&D satellite programs flown through the Space Development and Test Wing (SDTW) come from variety of different sources. They can be manifested by the Department of Defense (DoD) Space Test Program (STP) through the Satellite Experiment and Review Board (SERB). Programs that come to STP are able to request help with launch, integration and/or operations costs. The programs requesting STP services can be small payloads or small satellites such as cubesats, which are 10cm x10cm satellites. STP also supports large complex multi-satellite systems. R&D satellite programs across DoD use the SERB to help find flights to space due to their own funding shortages and DoD STPs ability to engineer partnerships for successful spaceflight.

When DoD STP services (funds) are requested for operations, the satellites are operated within SDTW. Similarly, when AF R&D organizations, such as the Air Force Research Laboratory (AFRL), look to outside agencies to fly their satellites, they also come to SDTW on a cost reimbursable basis.

R&D satellites come in a variety of shapes, sizes, and budgets. A cubesat is typically about $300K, and the most expensive R&D satellite mission to fly out of SDTW in recent years was over $400M.

As R&D satellite size can vary depending on mission, so can the complexity. Some satellites conduct simple operations of scientific payloads and have basic operational concepts. Others are much more complicated and thus, the operating system and ground system are much more complex. The complexity of the mission will affect how thorough some steps in the validation process are and how long they will take. As the cost of each validation step is related to the number of hours it takes to complete the step, there is a direct correlation between the complexity of a satellite program and the cost of the validation effort.

2.2.1 R&D Satellite Validation

There are many similarities between Operational Satellite VVT and Experimental Satellite VVT. Both operational and experimental satellites undergo rigorous testing to ensure the mission's success. They both complete basic testing, to include: environmental, thermal, and basic compatibility testing. However, the testing does not always have the same focus area. Operational satellites are part of a constellation whereas most experimental satellites are one-of-a-kind. Previous satellites in the constellation have already validated the compatibility between operational satellites and their ground system. Therefore the focus of the operational satellite testing is sustainability and ensuring that planned redundancy will work for the mission. Sustainability is comprised of reliability, maintainability and availability (RMA) of both the satellite and the ground system. This validation activity ensures the new satellite is the same as the previous satellites in the constellation. Testing for RMA of experimental satellites is not possible because this type of testing requires previous data for comparison. Operational satellites do not have Week in the Life (WITL) or Day in the

Life (DITL) tests. Additionally, the command and telemetry databases have already been validated. Operational satellites also have significantly fewer training events since the operators know how to fly the satellite. Most experimental satellites have at least six exercises and rehearsals, while operational satellites will only have two training events. These events focus on the launch and initialization sequences. Additional information on these steps is included in the methodology and analysis & results sections [Trautwein, 2009].

As briefly mentioned in Section 1.1, Air Force Space Command (AFSPC) requires a rigorous set of validation tests because the majority of their programs have multi-billion dollar budgets. In the R&D arena, there are a number of different stakeholders and the stakeholders involved all come prepared to fight for the validation plan their leadership favors. The first set of stakeholder is the ground system developer/operator, in this case SDTW. Next is the experiment owner, also known as the satellite program office. The satellite program office typically has satellite control authority and wants to see a successful mission. The satellite program office is typically most concerned with the validation budget. The final stakeholder is the satellite manufacturer, who needs a successful mission to generate future revenue, but has little input into the overall validation plan. The overall decision on the satellite/ground system validation plan is made between the ground system developer/operator and the satellite program office.

The cost of large systems VVT is approximately 40% of the total life cycle cost of the system [Engel & Barad, 2003]. However, R&D satellite program offices do not have large budgets and therefore cannot spend 40% of their budget on VVT. Engel and Barad’s paper on methodology for risk and cost monitoring for VVT proposes a novel approach for modeling VVT strategies as decision problems. This paper only addresses the VVT issue in regards to large aircraft programs [Engel & Barad, 2003]. In this thesis, we took their study and focused on the validation of the compatibility between R&D satellites and their ground systems. Within validation some steps are required and the costs are the same regardless the size of the program. Other steps can be modified to fit the size of the program and the level of risk the program is willing to accept [Engel & Barad, 2003].

2.3 Engel and Barad’s Methodology for Modeling VVT Risks and Costs

Throughout Engel and Barad’s research they found that most modeling methodologies have two significant weaknesses. These weaknesses are that most models are not organized, and consequently all risks are not necessarily identified. Additionally, they found that cost estimates do not consider all factors, i.e. variances in cost estimates and VVT costs associated with the life cycle of the system. In order to counter this, they developed a process that accounted for these weaknesses, yielding an advanced model. This process includes: defining a canonical model, modeling VVT strategy as a decision problem, and developing a strategy-based VVT process for risk, cost, and performance duration.

2.3.1 Defining a Canonical VVT Model

The canonical data model is the standard organizational view on a particular subject, mapping back to each application view on the same subject. The standard organizational view is built traditionally using simple yet useful structures [Hoberman, 2008]. The Canonical VVT Model (CVM) assumes each activity associated with the validation effort occurs sequentially. Figure 2 depicts the life cycles phases, activities, costs, and timeline elements of the CVM. This model should only be used to evaluate partial sets of activities in relation to the full set. This model was appropriate for our research because we researched a specific part of the systems engineering process as it applies to small satellite missions.

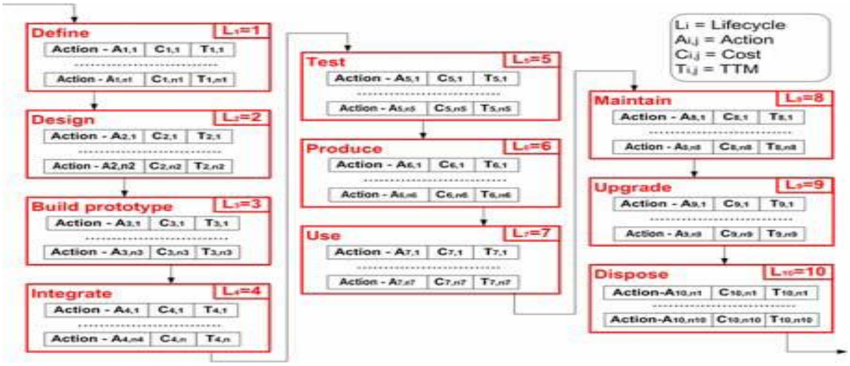


Figure 2: Canonical VVT Model [Engel & Barad, 2003]

2.3.2 VVT Strategy as a Decision Problem

Engel and Barad recognized that executing the all inclusive CVM is not practical due to budgetary constraints. Therefore to account for this reality, the VVT strategy must be considered a decision problem [Engel & Barad, 2003]. In order to do this, Engel and Barad introduced some basic concepts. The first was to define VVT Strategy. “A VVT strategy is a policy for a given system life cycle, under which a subset of steps are fully performed another subset of steps is partially performed and the remaining activities are not performed at all” [Engel & Barad, 2003]. The other concept Engel and Barad introduced was the decision variable. As stated above, every step in the VVT model can be fully performed, partially performed or not performed at all. The decision variable is the performance level of any step in the VVT process. The value of the decision variable is always 0, 1, or somewhere in between. A value of 0 indicates that the VVT step was not performed. Similarly a value of 1 indicates that the VVT step was fully performed. Any value between 0 and 1 indicates partial performance of a validation step. As stated in the assumptions in Chapter One, for the scope of this thesis we will assume that the decision variable is either 0 or 1.

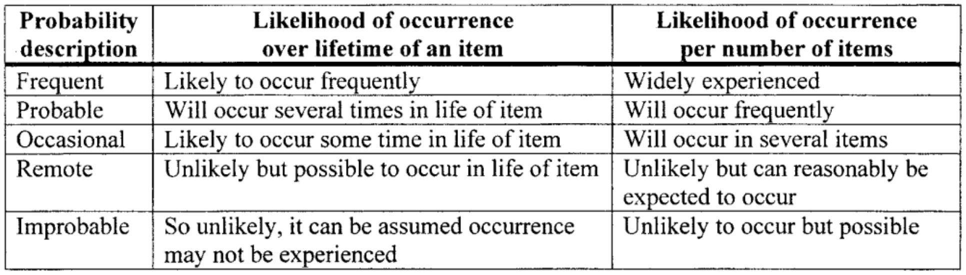
2.3.3 Developing a Strategy Based Risk Model

Throughout their research Engel and Barad used the Strategy Based Risk Model (SRM) to create their risk mock-up. Before we examine SRM, it is important to understand the definition of risk. “A risk is defined as: any uncertainty that, if it occurs, would have a positive or negative effect on achievement of one or more objectives.” Risk includes both threats and opportunities [Hillson & Simon, 2007]. “Risk management is defined as: the structured process of making appropriate decisions and implementing actions in response to known risk events and overall project risk” [Hillson

& Simon, 2007]. Risk is then considered a cost driver because managing risk creates cost and any risk that comes to fruition will either impact the schedule and/or the problem will need to be resolved thus having cost implications. Engel and Barad define SRM as a model for discerning risk, probability of impact and cost of impact for a given VVT strategy. The SRM concept comprises "risk identification attributes" and "risk variables." The risk attributes include, the risk source and risk destination. The risk source is a qualitative description of the risk. The risk destination is a step in the validation process that is designed to address the risk. The two risk variables are the probability that the risk will impact the mission, and the severity of that impact [Engel & Barad, 2003].

MIL-STD-882C breaks the probability of risk into five categories. Table 1 is extracted from this standard and provides guidelines in terms of the likelihood of the occurrence over the lifetime of an item and the likelihood of occurrence per number of items.

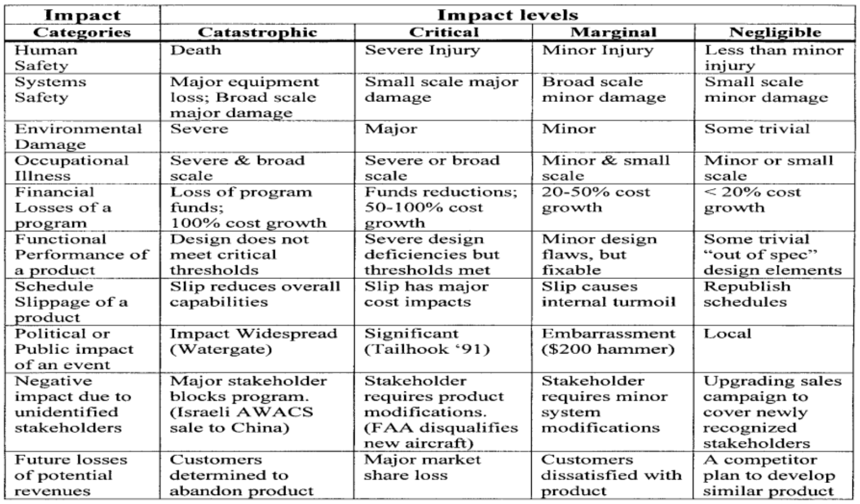
Table 1: Probability of Risk Occurrence [MIL-STD-882C]



Probability description	Likelihood of occurrence over lifetime of an item	Likelihood of occurrence per number of items
Frequent	Likely to occur frequently	Widely experienced
Probable	Will occur several times in life of item	Will occur frequently
Occasional	Likely to occur some time in life of item	Will occur in several items
Remote	Unlikely but possible to occur in life of item	Unlikely but can reasonably be expected to occur
Improbable	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur but possible

MIL-STD-882C also breaks the severity of risk into four categories. These categories are: catastrophic, critical, marginal and negligible. Engel & Barad extrapolate the information out of MIL-STD-882C and create Table 2, which uses the criteria for the safety categories and adds parallel criteria for the additional categories [Engel and Barad, 2003].

Table 2: Severity of Risk Effects [MIL-STD-882C]



Impact	Impact levels			
Categories	**Catastrophic**	**Critical**	**Marginal**	**Negligible**
Human Safety	Death	Severe Injury	Minor Injury	Less than minor injury
Systems Safety	Major equipment loss; Broad scale major damage	Small scale major damage	Broad scale minor damage	Small scale minor damage
Environmental Damage	Severe	Major	Minor	Some trivial
Occupational Illness	Severe & broad scale	Severe or broad scale	Minor & small scale	Minor or small scale
Financial Losses of a program	Loss of program funds; 100% cost growth	Funds reductions; 50-100% cost growth	20-50% cost growth	< 20% cost growth
Functional Performance of a product	Design does not meet critical thresholds	Severe design deficiencies but thresholds met	Minor design flaws, but fixable	Some trivial "out of spec" design elements
Schedule Slippage of a product	Slip reduces overall capabilities	Slip has major cost impacts	Slip causes internal turmoil	Republish schedules
Political or Public impact of an event	Impact Widespread (Watergate)	Significant (Tailhook '91)	Embarrassment ($200 hammer)	Local
Negative impact due to unidentified stakeholders	Major stakeholder blocks program. (Israeli AWACS sale to China)	Stakeholder requires product modifications. (FAA disqualifies new aircraft)	Stakeholder requires minor system modifications	Upgrading sales campaign to cover newly recognized stakeholders
Future losses of potential revenues	Customers determined to abandon product	Major market share loss	Customers dissatisfied with product	A competitor plan to develop similar product

Engel and Barad used the SRM "in order to carry out a qualitative and quantitative model of the risk associated with a given VVT strategy" [Engel & Barad, 2003].

2.4. Define Costs Associated with Impacts of Risks

In Engel and Barad's paper, they defined two types of quality costs. The term quality cost is used to define the costs associated with risk. The first quality cost is the cost associated with the prevention of faults, these are considered validation costs. The second type of quality costs are associated with internal and external failures, the risk impact costs [Engel & Barad, 2003]. The overall VVT cost is the cost of the validation effort and the risk impact costs. This is shown in Figure 3.

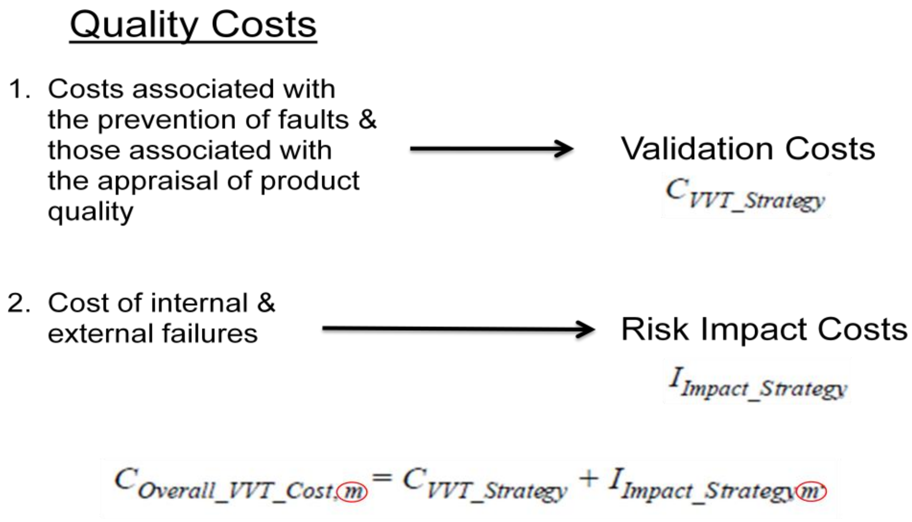


Figure 3: Quality Costs Equation [Engel & Barad, 2003]

Figure 4 illustrates that either all of the VVT can be modeled, none of it, or parts of it. Neglecting to complete the entire life cycle portion will create risk for the stakeholders [Engel & Barad, 2003].

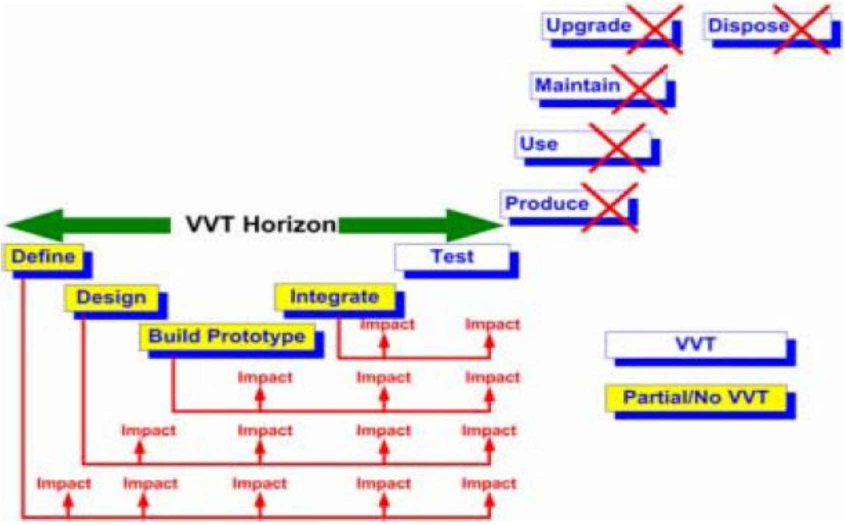


Figure 4: VVT Strategy [Engel & Barad, 2003].

When a particular validation activity is not performed, it increases one or more risks. Therefore, a given validation strategy gives rise to a collection of risks.

III. Methodology

3.1 Introduction

This chapter presents the methodology that we used to complete our thesis. In Engel and Barad's study they proposed a methodology for modeling validation costs and risks. They laid out their methodology in four simple steps as shown in the Figure 5 below [Engel & Barad, 2003].

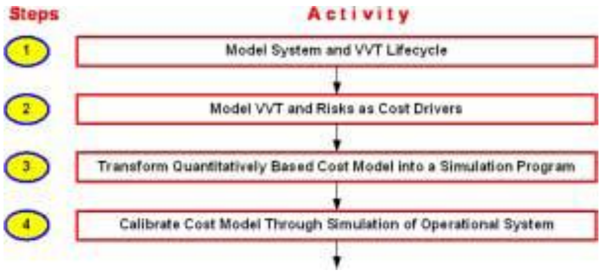


Figure 5: Methodology for quantitatively assessing system life cycle VVT & risk cost [Engel & Barad, 2003].

Our research is based on the research of Engel and Barad, so we also broke our methodology into four steps. The first step was broken into two parts: (1) Develop a model of all of the steps associated with validating the compatibility between a Research and Developmental (R&D) satellite and its ground system. (2) Assign appropriate costs to each activity. In the second step we identified the program risks that can be mitigated by executing the steps in the validation process. We also defined costs associated with the impacts of the risks. Throughout steps one and two, we used the Delphi Method of collecting and distilling knowledge from a group of Subject Matter Experts (SMEs) by means of a series of surveys. The third step in our methodology was to create a simulation that generates distributions of possible cost and risk outcomes to be analyzed in relation to the information found in steps one and two. This technique will help program offices make informed decisions about how to execute the validation process. The fourth and final step in our methodology was to demonstrate the accuracy and usability of our simulation.

3.2 Data Collection Using the Delphi Method

Lieutenant Commander Timothy J. Gilbribe performed his Air Force Institute of Technology (AFIT) thesis work using the Delphi Method. He stated that when using the Delphi Method, one can receive three types of feedback. The experts can speculate, give their opinions, or respond based on factual knowledge of the topic area [Gilbribe, 2002].

Speculation or opinion can be defined as beliefs of someone (in our case the expert) based on their experiences. It is important to note that these SME opinions were formulated primarily through career experiences, learned facts, and personal observations and beliefs. As a result, these opinions cannot be assumed to be proven facts, but rather a means of gathering a breadth of information to help guide us to the most correct conclusion. To help discern and discount the opinions that can best be referred to as inaccurate "outliers" we issued several iterations of the survey to the SMEs [Rayens and

Hahn, 2000]. In-depth reviews of the responses allowed us to pinpoint the majority opinion. This helped guide our final answer.

3.2.1 The Delphi Method

The Delphi Method is described within *Measuring and Optimizing Systems' Quality Costs and Project Duration* by Avner Engel and Shalom Shachar, as a systematic, interactive interviewing method which relies on a panel of independent experts [Engel & Shachar, 2005]. The theory of the Delphi Method is that a structured group of experts will come to a more accurate "correct" answer than an unstructured group. According to Linstone and Turoff, authors of *The Delphi Method: Techniques and Applications*, the Delphi Method should be considered a communication process. It is particularly useful when attempting to gather current or historical information not accurately known or available, evaluating possible budget allocations and creating the structure of a model [Linstone & Turoff, 2002]. As stated in chapter one of our thesis, there is no process for conducting validation of the compatibility of R&D satellites and their ground systems. Cost is almost always a key driver for the scope of these validation steps and we have created a model for this effort. In addition, Linstone and Turoff recommend asking a series of questions to evaluate whether the Delphi Method is a desirable choice for an information gathering process. These questions are: (1) Does the issue not require a precise analytical technique, but can be evaluated by subjective judgment? (2) Do the individuals need to contribute to the examination of a broad or complex problem have no history of adequate communication and may represent a diverse background with respect to experience and expertise? (3) Can the diversity and independence of the subject matter experts (SMEs) be preserved to assure validity of the results and avoid group think [Linstone & Turoff, 2002]? Because the validation of the compatibility of R&D satellites and their ground systems does not have a documented process and is done differently for every program, we feel that this issue can be evaluated by subjective judgment. We also feel that in order to ensure that all stakeholders were represented, our SMEs needed to have a variety of experiences and expertise. Finally to address the last question, the primary reason we choose to collect our data using the Delphi Method was to avoid group think. For these reasons we feel that the Delphi Method was the appropriate choice for conducting the research for our thesis.

3.2.2 Selection of Subject Matter Experts

The panel of experts used for our thesis comes from a variety of different backgrounds. According to Dean, Wood, Moore, and Bogart this helps to avoid the three sources of error introduced by experts. These experts weighed in on whether or not we built the correct model, and determined whether the model yields accurate cost data.

In order to create our panel of SMEs, we looked within our organization, the Space Development and Test Wing (SDTW), to establish a wide range of panel members with various areas of expertise. We assembled a panel of eight experts for this thesis. Our SMEs consisted of ourselves, a military member that works for the organization that provides test assets to the Space Community, a government civilian, two ground system contractors, an operations contractor, and an individual from our independent technical advisory contract.

The ground system contractor is responsible for the procurement and development of new ground systems and sustainment of both pre-existing and new ground systems. They are a key team member during many stages of the validation process and therefore have insight into both the process and the ramifications of ground system risk realizations.

The operations contractor personnel operate the satellites. They are members of each integrated product team throughout the entire mission life cycle. The operations personnel have expert knowledge about the ramifications of risk realization pertaining to both the satellite and the ground system.

The independent technical advisors are the team of individuals that our commanders turn to for technical consultation. They have a wide breadth of experience. They gave an objective perspective to our thesis. The specific independent technical advisor on our panel has expertise in both ground system development and satellite operations.

The military and government civilians were selected based on their experiences within the wing, and their unique perspective based on the programs they had worked and the years of experience they brought to the table. In the following paragraphs we discuss the unique expertise of each SME. In order to keep our SMEs identities confidential, excluding ourselves, we have given each SME a number.

We each acted as a SME for this thesis. SME #1, Mary Trautwein, is a 1st Lt in the United States Air Force. She has worked at SDTW for over three years. She has been an

On-Orbit Mission Lead, a Mission Ground System and Satellite Test Lead and a Mission Ground System Development Lead. All of these missions flew, or will fly, out of SDTW.

SME #2, Amanda Langenbrunner, is a Captain in the United States Air Force. She has worked at SDTW for over three years. She has been the Operations Flight Commander for the squadron within SDTW that operates R&D satellites. She is currently working for the Department of Defense (DoD) Space Test Program (STP) manifesting R&D satellite missions.

SME #3 is a Captain in the United States Air Force. He has worked at SDTW for one year. He is the Mobile Range Flight Commander. This is the organization that provides test assets to the Space Community. SME #3 was chosen as a part of our panel of experts, due to his position as the Mobile Range Flight Commander. He is responsible for customer service and all cost and contracting actions for the test assets provided by the Mobile Range Flight. He is currently the SDTW expert on availability, cost, and operations of these important test assets.

SME #4 is currently a government civilian with the Responsive Satellite Command and Control Division at SDTW. He has worked at SDTW for 9 years. He is the Chief Architect for the development of a new ground system that will fly satellites at SDTW and the 50th Space Wing in Colorado Springs.

SME #5 currently works for the Operations Contract at SDTW. He has worked at the Space Development and Test Wing for 8.5 years. He is currently the Operations Mission

Lead for a satellite mission flying at SDTW. He has more than 12 years of experience in the Space Industry.

SME #6 currently works for the Ground System Development Contract in the RSC. He has worked at SDTW for more than 10 years. He is currently the technical lead for the ground system development of a satellite mission that will fly at SDTW within the next 12 months. In the past he has worked as the Ground System Development Lead for a past ground system, and the overall hardware architect for the newest Ground System to be used at SDTW.

SME #7 currently works for the Ground System Development Contract at SDTW. His current position is Project Lead and Hardware Systems Engineer. He has held this position for the last 12 years. Prior to working at SDTW he was the Senior Hardware Engineer with Loral Space and Range Systems in Sunnyvale, CA. SME #7 has 37.5 years experience with the Air Force Satellite Control Network (AFSCN).

SME #8 is a senior technical advisor for the government at SDTW. He has worked at SDTW for 16 years. He has worked with satellites at SDTW for 16 years and ground systems at SDTW for 12 years. SME #8 has worked in the space industry for over 30 years.

Overall, our panel of experts has a long history of experience in all aspects of the R&D satellite business.

3.2.3 Development of the Delphi Survey

In order to develop our validation model and assign appropriate costs to each activity, we conducted research using the Delphi Method. We issued a series of surveys to a group of SMEs. All of the questions in these surveys had answers that required the SMEs to select an answer that was either a binary (i.e. Yes, No or Agree, Disagree) or scaled (i.e. Negligible, Minor, Moderate, Serious or Critical) answer. The SMEs also had the option of providing written explanations of their answers. The surveys were conducted this way to limit the SME answers in order to obtain a consensus. However, the surveys also allowed the SMEs to explain their opinions so that other SMEs could either accept or dispute them. In the first survey we also asked open ended questions. These questions and responses were considered when we created the second survey and were used in the final discussion.

In the first survey, we defined the Initial Validation Process using the Canonical Verification, Validation and Test (VVT) Model (CVM) shown in Appendix A. This process was developed based on our combined years of ground system and satellite compatibility validation testing. Throughout this time, we have been involved in the validation testing for six satellite missions. Each mission had a unique validation plan, and therefore unique CVMs. We ensured that all possible validation steps were included in the plan. We gave the CVM to the SMEs to analyze the process and provide comments to yield a correct model. Next, we asked our SMEs to define the cost of executing each step in the process. Additionally, the SMEs defined risks associated with failing to complete various validation efforts. They defined these risks based on the Strategy Based Risk Model (SRM). First they defined the risk attributes and then the two risk variables were derived. The two risk variables are the probability that the risk will impact the mission, and the severity of that impact. The results from Survey #1 were the basis for the creation of Survey #2.

During Survey #1, we did not get any cost data from several SMEs. Upon further inquiry with the SMEs we were informed that they did not have the time to collect this information and did not want to give us incorrect data. We instead collected the information ourselves and presented the cost data to them in Survey #2 for comment. To do this, we created point estimates by looking at each contract for each validation activity. For every program, we always have a ground system contract, an operations contract, a satellite development contractor and the organization that provides test assets to the Space Community. We looked at each of these contracts and collected cost data from four programs. These programs varied in budget, mission and launch date. We looked at programs that have launched or will launch between 2001 and 2010. Some of these programs had actual cost data and hours associated with steps in the validation process. Others only had contractor proposals because either the validation steps have yet to be conducted, or actual cost data was not recorded. In order to account for inflation between 2001 and 2009, we examine the number of hours either executed or proposed for the validation steps and applied a current hourly rate for each organization. The test asset organization provided a menu of pre-defined prices for use of each of their test assets; we used this to identify the costs for use of the test assets. To do this, we had to remove programmatic anomalies to get an estimate for the cost of each activity. Some of the anomalies that we call "outliers" are listed below:

- A program had a 7 year slip that included the program being cancelled and resumed. This program had three Factory Compatibility Tests (FCT), we only used the cost data on the final FCT.
- Due to the complexity of one program and the high level interest, the program completed command and telemetry validation on every single command that could be passed from the ground system to the satellite multiple times. We chose to look at the cost data from one round of command and telemetry validation as this is the preferred method of command and telemetry validation for programs.
- One program chose to do as little validation as possible due to schedule and budget. This program knew they were putting a satellite in orbit with a large amount of risk. We only looked at cost data from this program on validation steps they performed.

After eliminating the outliers and deriving point estimates for each validation activity, we added these point estimates to Survey #2 for comments and feedback from our SMEs.

In Survey #2, all of the questions asked in Survey #1 were included and the SMEs were asked to agree or disagree with the other SMEs. Additionally all comments from Survey #1were incorporated. The SMEs were also asked to agree or disagree with each of these comments. We added the point estimates calculated after Survey #1 into Survey

#2 and asked the SMEs whether these estimates appeared too high, too low, or correct. We also asked them to comment on why they felt this way. Finally, we left additional space on the survey for any additional comments. The feedback received from Survey #2 was used to create Survey #3.

In the formation of Survey #3, any question from Survey #2 that everyone agreed on, was considered truth, and it was left off Survey #3. We included all of the disparities from Survey #2, we asked the SMEs once again to agree or disagree with these comments. We then asked the SMEs specific questions about each of the areas of disparity to try and understand the rationale. All of the SMEs concurred on each of the risks and its attributes. As a result, Survey #3, focused on refining the risk variables and steps in the validation process that mitigated the risk.

Through these surveys, the group was given the opportunity to comment on the responses of other SMEs, while simultaneously allowing them to change their responses as a result of reviewing others answers and explanations. The iterations were complete when there was a final group agreement and when we believed the experts were no longer changing their opinion or commenting on the opinions of the other panel members. This is defined as saturation [Rayens and Hahn, 2000]. For the scope of this thesis saturation was reached when each SMEs response changed less than 5%. The 5% was determined by adding up the number of questions, and subset of questions in Survey #2. Survey #2 was used because it had all 18 risks identified in the survey, it included the cost data for the validation steps, and it did not include the open ended questions asked in

Survey #1. The total number of questions in Survey #2 is 148, 5% of this is 7.4. From this we conclude that saturation was reached when each SME changed their answer on less than 7 questions. This occurred on Survey #3.

When receiving data from experts we documented a wide range of responses. As the iterations completed, the original spectrum of responses was narrowed. The spectrum narrowed after the second survey and reached saturation following the third survey.

3.2.4 Administration of the Survey

The surveys were distributed through electronic mail, with each SME as a blind courtesy copy. This ensured that each SME received the same instruction and survey, while ensuring the integrity of the system. A systematic procedure allows the experts to have a sense of objectivity throughout the study [Dalkey, 1969]. The group of experts only interacted with one another through the feedback loop that was established. The SMEs responded in one of two methods. Either they completed the surveys in hard copy and delivered them back to us or they filled out a soft copy of the survey and emailed it back to us. To ensure we were not swayed by the beliefs of the other SMEs we completed our surveys immediately after we sent them out, and thus before we received any feedback from the other SMEs.

3.3 Methodology for Modeling VVT Risks and Costs

As Engel and Barad used a four step methodology to model their VVT risks and costs, we will also used four steps. The details for each step in our methodology are explained in the subsequent sections.

3.3.1 Define the Validation Process

The first step in analyzing the costs vs. risks associated with the validation of the compatibility of a satellite and its ground system is to define the process. In order to do this, we developed a CVM of all steps associated with this process. The CVM discussed in chapter two was used when developing the model. Each node of the diagram is a discrete validation step. We developed the first iteration of this process, shown in Appendix A, from satellite programs flown by the RSC. This process was developed based on our combined experience in ground system and satellite compatibility validation testing. Throughout this time, we have been involved in the validation testing for six different satellite missions. As each mission had a unique validation plan, they had unique CVMs. We took the base validation plan and ensured we incorporated all possible validation steps into the plan. The process was provided to our SMEs for evaluation. The SMEs provided feedback through the Delphi Method. A final CVM was created from this feedback.

3.3.2 Assign Appropriate Cost to Each Step

The value of a validation step has two parts; the first is defined as the cost of the validation step. The costs associated with each step in the validation process were based on hours of work required to complete the task. They were calculated using actual cost data and contractor estimates. The costs were included in the surveys provided to our SMEs and changes were made based on SME feedback.

In order to define the costs of the validation steps we used expert opinion. According to Dean, Wood, Moore and Bogart in *Cost Risk Analysis Based on Perception of the Engineering Process* many cost risk analyses are based upon an expert's knowledge of the cost of similar projects in the past [Dean, Wood, Moore & Bogart, 1986]. They applied this method by asking managers and engineers to estimate the cost of a project in their area of expertise based on historical data or similar projects. This is an excellent method for estimating costs, however according to Dean, Wood, Moore, and Bogart there are three sources of error that are introduced by using expert opinion. The first is that the historical cost data may be in error by some unknown amount. For example inflation needs to be considered. Also the application of the task may be different or modernized equipment could be available. The second source of error is that the expert may inaccurately evaluate the new project's similarities to an older project and provide inaccurate estimations based on this. The third source of error is that the factors used to adjust the costs of an old project may not correctly reflect the new project. In order to reduce the error caused by these three sources Dean, Wood, Moore, and Bogart used a range of cost estimations. This method allows for a higher level of confidence in the accuracy of the expert estimations [Dean, Wood, Moore & Bogart, 1986].

In order to help eliminate the sources of error introduced by Dean, Wood, Moore and Bogart, we went through several programs and came up with a point estimate for each validation activity. The derivation of these point estimates was based on the hours of work required to complete the task. They were calculated using actual cost data and contractor estimates. The process for finding these point estimates is explained in further detail in Section 3.2.3. These point estimates were given to the SMEs to determine if they believed the cost of each validation effort was too high, too low, or acceptable. They then gave us rationale for their beliefs.

The second cost associated with the value of a validation step is the impact cost of the risk being realized. During Step 2 of our methodology, we identified program risks that can be mitigated by executing steps in the validation process, and we defined costs associated with the impacts of the risks.

3.3.3 Identify Program Risks

Like Engel and Barad we used the Strategy based Risk Model (SRM) to define risks associated with the compatibility between a satellite and its ground system. We defined risk attributes (risk description and validation steps associated with this risk) and risk variables (probability and severity of the risk impacts). However unlike Engel and Barad, this thesis will not use the probabilities and impact levels identified in MIL-STD-882C. Instead we will use the risk chart that is used and accepted within SDTW. This chart is based on the MIL-STD-882C but is tailored for R&D satellite programs. The probabilities used and SDTW are: 0-10%, 11-40%, 41-60%, 61-90% and 91-100%. The Severity levels used at SDTW are: Critical, Serious, Moderate, Minor and Negligible. These severity levels are more qualitatively defined than in the MIL-STD-882C. This is for several reasons. Budgets can vary from mission to mission, money means different things to each mission. For example $1M is worth a lot more to a program office with a

$30M budget than it is to a program office with a $200M budget. The second reason is that severity of risk may not be tied to the cost of resolving the risk. The cost of resolving the risk may only be $20,000 and one week, but if it is not resolved realization of this risk could lead to a loss of mission and therefore would still be carried as critical.

The risk variables (the probability and severity) were defined for each risk. The probability was defined twice. First the probability was defined based on the risk prior to performing any mitigation steps. Then, the probability was defined after the execution of the steps in the validation process. This is an improvement over Engel and Barad's model. Engle and Barad assumed that if steps were taken to mitigate the risk, then the risk would not occur. We acknowledged that this is not realistic and this is why we calculate the probability of the risk being realized before and after the validation process is executed. The validation steps mitigate the risk and thus the probability of the risk being realized is less, but it is not zero [Engel & Barad, 2003]. Once the risks were determined and fully defined, there are multiple options for mitigating risks. These include: accept, avoid, reduce, share and transfer. Risk avoidance is a response to a threat that eliminates its probability of impact on the project. Risk transfer is a response to a threat that transfers the risk to a third party who is better able to manage the risk. Risk reduction is a response to a threat that reduces its probability and/or impact on the project, aiming to reduce the risk to an acceptable level. Finally risk acceptance is a response where either no proactive action is taken or where responses are designed that are contingent upon a change in circumstances [Hillson & Simon, 2007]. For the scope of this thesis we will only be focusing on reducing risks through the validation process, and accepting them due to budgetary constraints that prevent the program from executing every step in the validation process. If the risk can be reduced, the program office must evaluate the cost associated with the reduction efforts. These costs were defined as part of our thesis. This helps determine whether the program manager should mitigate the risk, or assume the risk and plan for realization. In order to do this, cost drivers were modeled. The validation process was designed to mitigate a set of known risks associated with the compatibility between an R&D satellite and its unique ground system. Through our panel of experts, 18 program risks were identified. For each of these risks, we ascertained a definition, probability of impact, and cost of impact. This allowed us to assign a value to each of the validation steps. In order to validate that this list of risks was in fact a complete and correct list we investigated past R&D satellite programs. We were able to locate risk registers for five satellite programs. Each program identified between 10 and 16 risks associated with the compatibility between the satellite and the ground system. Each one of the risks identified on the risk registers was a risk that we identified in our thesis. Although this number is less than the 18 we identified, our list of risks was complete. Some of the programs combined similar risks. Occasionally due to the unique nature of the R&D satellites and their ground systems, sometimes a risk was not present. The probability of realizing the risk is lower if the step in the validation process is executed. We asked our SMEs to identify the probability of the risk being realized before the validation effort, and after. This allowed us to define the importance of the associated validation steps.

3.3.4 Define Costs Associated with the Impacts of Risks

It is important to characterize the costs associated with the impacts of each of the risks identified. A cost value was assigned to the impact of each risk. The cost value was defined through the Delphi Method. The SMEs identified the cost impacts in Survey #1 and in subsequent surveys, other SMEs agreed or disagreed with the cost of the risk impact. When there was disagreement, we asked the SMEs specifically why they disagreed and then added their comments to the next iteration of the survey for agreement from the other SMEs. However, during the original process, we didn’t ask the SMEs to identify why they disagreed. As a result, we had to send follow-up emails to the SMEs that disagreed after Survey #2, so that we could include their comments in Survey #3. If the risk was a schedule slip or technical risk the cost value assigned correlated with the associated schedule slip, and/or the cost of resolving the technical issue.

3.3.5 Transform the Validation Model into a Simulation

Monte Carlo simulation uses random number generation to simulate the occurrence or nonoccurrence of a given probabilistic event according to given distributions [Engel & Barad, 2003]. In our simulation, the probabilistic event is the realization of a risk associated with the compatibility between a satellite and its ground system. From this many hypothetical scenarios of risk impacts may be generated. These scenarios were used create distributions of overall validation costs. Our simulation follows the process identified by Engel and Barad and detailed below. First we defined the validation effort using the CVM and calculated the deterministic costs of the performed validation steps. Then we simulated the risks impact costs stemming from the validation steps that were not performed. Finally we summed the overall deterministic validation costs and the risk impact costs [Engel & Barad, 2003].

The cost of a particular validation strategy is deterministic and does not change from run to run. The validation steps that will be performed were determined for a given strategy and defined up front. The overall cost of a given validation strategy was calculated using Equation 1 below. The decision variable is X. If a step in the validation process was fully performed X = 1, if a step in the validation process was not performed X = 0. This is determined by the validation strategy [Engel & Barad, 2003].

$$C_{Validation\ \_strategy} = \sum (C_n * X)$$

$$C_{Validation\ \_strategy} = Overall\ cost\ of\ validation\ strategy$$

(Equation 1)

$$C_n = Costs\ associated\ with\ executing\ validtion\ step$$

$$X = 0{,}1\ as\ determined\ by\ validation\ strategy$$

[Engel & Barad, 2003]

Risk impact costs are probabilistic and must be generated using a Monte Carlo simulation and random number generation. During each simulation run, a random number was generated for each risk to determine an occurrence or a nonoccurrence of risk impact cost, according to its respective given probability. The simulation run was a decision point for each risk to determine if the risk was realized. If the risk was realized, the associated impact costs were applied for that risk. If the risk was not realized then the associated impact costs were zero. For each simulation run, the impact costs for the validation strategy were calculated using the equation below [Engel & Barad, 2003].

$$I_{Impact\ \_strategy} = \sum(I_{Impact\ \_risk\,1}, I_{Impact\ \_risk\,2} \dots I_{Impact\ \_riskn})$$

$$I_{Impac\ t_{strategy}} = Impact\ Costs\ for\ a\ given\ simulation\ run \qquad \text{(Equation 2)}$$

[Engel & Barad, 2003]

For each Monte Carlo simulation run the overall validation costs incurred were:

$$C_{overall\ \_validation\ \ \_costs} = I_{Impact\ \_strategy} + C_{validation\ \ \_strategy} \qquad \text{(Equation 3)}$$

$$C_{overall\ \_vaidation\ \_costs} = Overall\ Validation\ Costs\ for\ a\ given\ simulation\ run$$

[Engel & Barad, 2003]

This simulation was run a number of times to perform a trial. When applied to the sample program in chapter four of this thesis, a trial consisted of 1,000 runs of the simulation. The results, Overall Validation Costs, for every simulation trial were depicted in a histogram. Figure 6 is an example histogram for one trial of a 1,000 simulation runs.

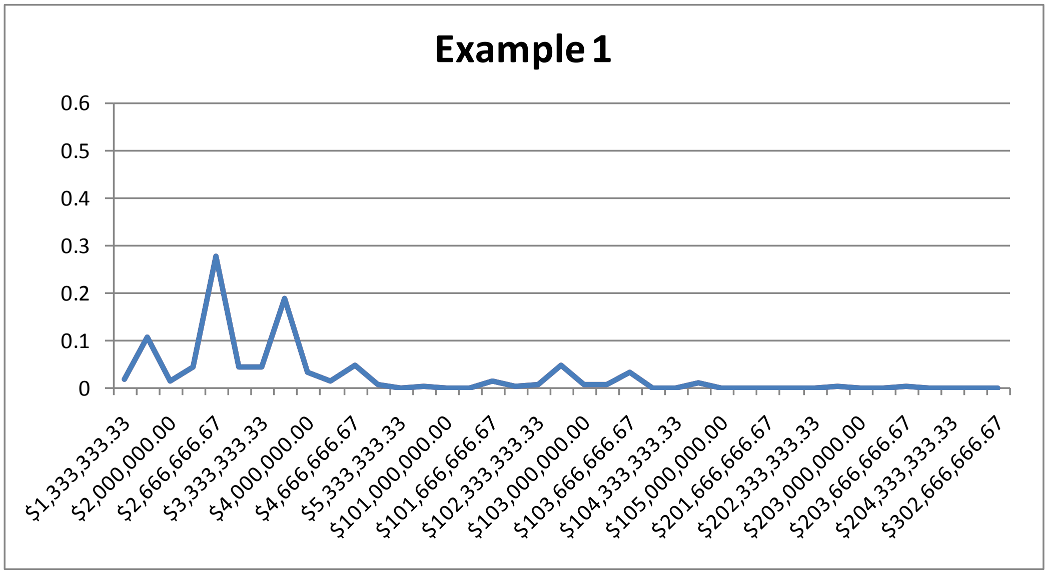


Figure 6: Example Histogram of Simulation Trial

In this figure the Y-axis depicts the percentage of runs that yielded an overall validation cost value corresponding to the ones shown on the X-axis. From this histogram it is useful to calculate the following information for comparison to simulation trials of other validation strategies: the range, the mean, the standard deviation, and the median. These data points allow program offices to directly compare multiple validation strategies and decipher which is the most effective based on their budget and adversity to risk.

3.3.6 Evaluate the Simulation

The simulation created in Step 3 of our methodology will be available to SDTW. It will provide them with the ability to evaluate potential validation plans, thereby focusing resources on the validation steps with the most value. R&D satellite program offices will be able to use this technique to have a quantitative method for determining validation efforts based on cost and risk.

The fourth and final step in our methodology evaluated the accuracy of our simulation. We accomplished this in two ways. We first applied our simulation to a sample program that is performing validation steps in preparation for operations in the RSC. We compared three different validation strategies to help evaluate the accuracy and usability of our simulation.

Finally, in order to demonstrate the accuracy of the simulation used to generate distributions of possible costs and risk outcomes, we provided the simulation to two program managers. We asked the program managers to run the simulation for their on-going programs and answer a series of questions. We asked them to also keep in mind past programs when answering the questions. The first set of question we asked dealt with the risks identified by the Delphi Method. We first asked the program managers if these risks encompassed all the risks on their current satellite program. Next we asked both program managers if they had ever worked an R&D satellite program that tracked a risk not identified in our thesis. The next set of questions we asked the program managers dealt with their thoughts on the simulation technique. Specifically, what were the results using the simulation on their program? Does using the simulation help save their programs cost or schedule? In addition, how could utilizing the simulation help their program?

IV. Analysis and Results

4.1 Introduction

Throughout this chapter we will be examining the results we obtained through the Delphi Method. We will be demonstrating how we used these results to create our simulation. We will apply these results to a sample Research and Developmental (R&D) satellite program and present program manager feedback to demonstrate the accuracy of our findings. Initially we started with a draft of the validation process, which we provided to our Subject Matter Experts (SMEs) using the Delphi Method. Through their feedback, we identified the Final Validation Process and costs associated with executing each step. Through the Delphi Method our SMEs also provided the risks associated with the compatibility of a satellite and its ground system and what specific steps in the validation process mitigated these risks. For each risk we asked our SMEs to define the probability of impact, severity of impact, and impact costs. From this information we were able to create a simulation that generates distributions of possible risk and cost outcomes. This information will be used to help R&D satellite program offices evaluate the fidelity of their proposed validation strategy. They can use our simulation to compare validation strategies and assess if their validation strategy is complete or if there are steps that can be skipped to preserve cost. This section of our thesis will present these findings, discuss our SME feedback, apply our simulation, and demonstrate the fidelity of this method.

4.2 The CVM for R&D Satellite Validation

We developed the initial Canonical Validation Model (CVM) based on our combined experience in ground system and satellite compatibility validation testing. This was provided to our SMEs for evaluation. The final CVM was created based on the SME feedback through the Delphi process. In the sections below we will present the initial and final CVMs.

4.2.1 The Initial CVM

Shown below, Figure 7 depicts our initial draft of the validation process. During the execution of the Delphi Method, we provided the draft CVM to our SMEs as a starting point for their comments. A detailed description of this process can be found in Appendix A. This process was developed based on our combined experience in ground system and satellite compatibility validation testing within the Research Development Test and Evaluation (RDT&E) Support Complex (RSC). Throughout this time, we have been involved in the validation testing for six satellite missions. As each mission had a unique validation plan, they had unique CVMs. We incorporated all possible validation steps into the Initial Validation Process.

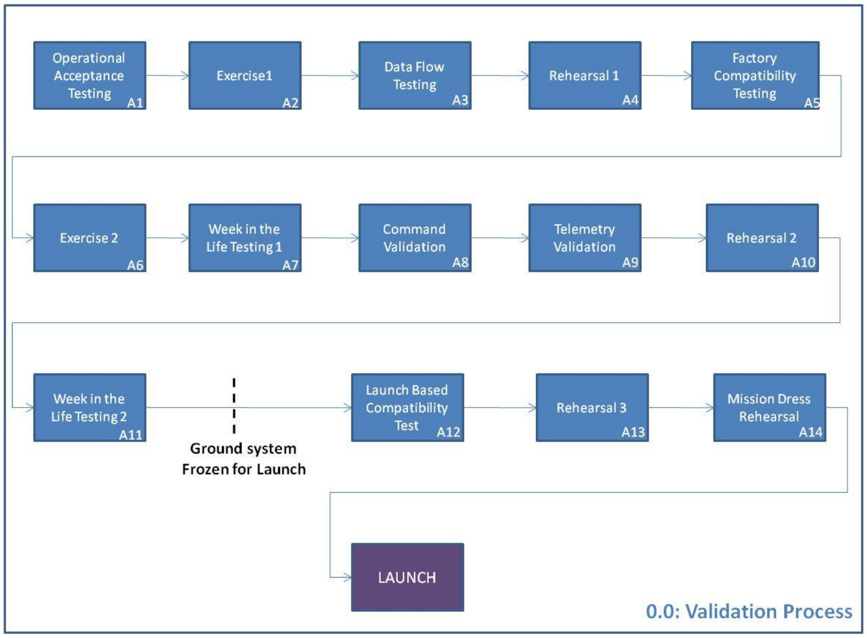


Figure 7: Initial Validation Process

4.2.2 Final CVM

Shown below, Figure 8 depicts the Final Validation Process. This process was developed based on feedback ascertained throughout the Delphi Method. Changes were made from the Initial Validation Process. We deleted Mission Dress Rehearsal because typically the ground system does not change after Launch Based Compatibility Test (LBCT) and is “frozen” prior to this event, therefore is not a part of the Validation Process. Also Exercises and Rehearsals were condensed. Rather than calling out each Exercise and Rehearsal individually, one block is shown for Exercises and one block for Rehearsals. This was done because Exercises and Rehearsals are primarily training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. Also Exercises and Rehearsals are often executed as needed throughout the Validation Process. Our SMEs concluded from this that they did not need to be individually called out in our process. The order of the validation process was debated throughout the surveys. Finally all SMEs concurred that the order of the validation process will vary from mission to mission, particularly the placement of Exercises and Rehearsals. All of the SMEs agreed the order of our Final Validation Process represented a typical R&D satellite program.

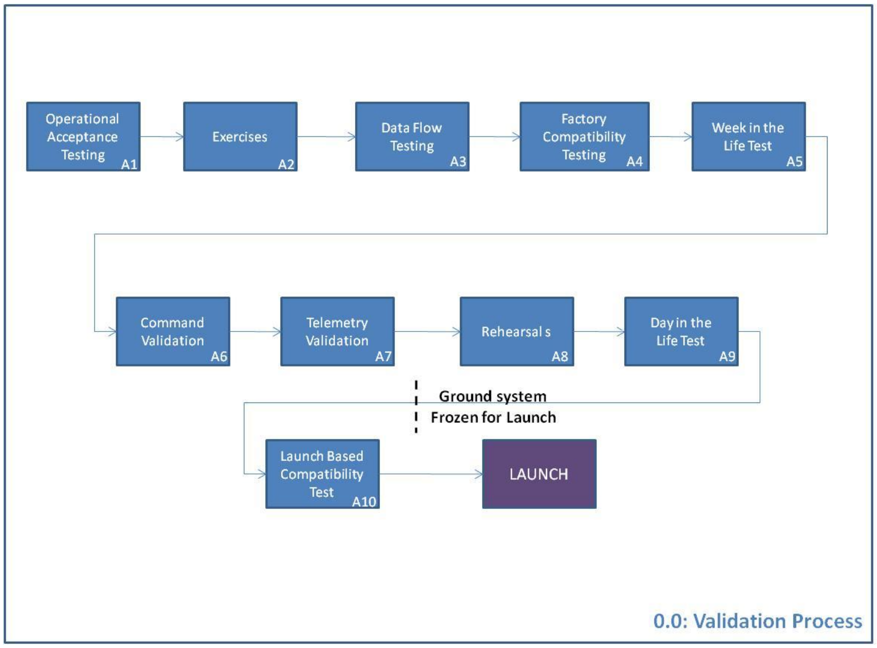


Figure 8: Final Validation Process

Exercises: Exercises are mainly used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. Also Exercises are often executed as needed throughout the validation process. Because of this, our SMEs concluded that they did not need to be individually called out in our process.

Week in the Life Tests: Week in the Life Tests (WITLs) are performed during the readiness phase of a mission. The WITL is used to ensure that the system can handle the loading of nominal operations. Our SMEs feedback was that typically only one WITL is performed for an R&D satellite mission, so we deleted the second WITL from our CVM.

Rehearsals: Like Exercises, Rehearsals are mainly used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. Also Rehearsals are often executed as needed throughout the validation process. Because of this, our SMEs concluded that they did not need to be individually called out in our process.

Day in the Life Tests: Day in the Life Test (DITL) is the only step in the validation process that was added based on SME feedback. The DITL exercises the system based on a normal day's activities (not a Launch and Early Orbit (LEO) activities.) The main goal is to identify any deficiencies with the ground system that would prevent normal operations. A secondary goal is to examine the routine operational usability of the system at a point where there is still some ability to make modifications if a more efficient, or better process can be established. Routine procedures should be run. Post pass processing of data should be completed. Everything should work as expected on-orbit or changes to the Concept of Operations (CONOPS) or the ground system need to be made. The focus is mainly on the ground system's ability to perform the procedures and CONOPS.

4.3 Costs Associated with Executing Each Validation Step

Operational Acceptance Testing: If Operational Acceptance Testing (OAT) is executed as a separate step it typically costs approximately $12,600. OAT is conducted by the operators with little to no outside support. This allows the most realistic assessment of operational objectives. Table 3 is a cost breakdown of OAT.

Table 3: OAT Cost Analysis

OAT		
Contract	**Hours**	**Dollars**
GS Development Contractor	0	$0.00
Operations Contractor	168	$12,600.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$12,600.00

Exercises: The number of exercises executed by an operations team is based on operator experience and uniqueness of the mission objectives. Table 4 shows the typical cost of one exercise, which is $25,300. The operators conduct them and the ground system development contractor has one person on standby to resolve ground system (GS) issues. A typical program will execute between one and three exercises.

Table 4: Exercise Cost Analysis

Exercise		
Contract	Hours	Dollars
GS Development Contractor	40	$4,000.00
Operations Contractor	284	$21,300.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$25,300.00

Data Flow Testing: Data Flow Tests (DFT) are usually executed by connecting the satellite and ground system through a mobile communication system and a T-1 line. No Radio Frequency (RF) functionality is tested during this step. The cost of a DFT is $123,150. The satellite and ground system contractors usually conduct the DFT. The operators observe this test, but do not actively participate. Table 5 is the cost breakout for DFT.

Table 5: DFT Cost Analysis

DFT		
Contract	Hours	Dollars
GS Development Contractor	702	$70,200.00
Operations Contractor	252	$18,900.00
Test Asset	0	$0.00
Satellite Development Contractor	454	$34,050.00
		$123,150.00

Factory Compatibility Test: Factory Compatibility Test (FCT) can be executed using one of two sets of equipment provided by the organization that provides test assets to the Space Community. The first choice is the Transportable Space Test and Evaluation Resource (TSTR) van. TSTR is an exact replica of an Air Force Satellite Control Network (AFSCN) Remote Tracking Station (ARTS). The second choice, used if TSTR is not available, is S-Band Transportable Ground System-T (STGS-T). It is used in conjunction with manual calculations to ensure the accuracy of the Inter-Range Operating Number (IRON) Database. The operators and satellite contractor execute the FCT with support from the ground system contractor. The cost profiles for an FCT executed with TSTR and an FCT execute with STGS-T are below in Table 6. The typical cost of an FCT is between $333,600 and $393,600.

Table 6: FCT Cost Analysis

FCT with TSTR			**FCT With STGS-T**		
Contract	**Hours**	**Dollars**	**Contract**	**Hours**	**Dollars**
GS Development Contractor	296	$29,600.00	GS Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00	Operations Contractor	412	$30,900.00
Test Asset Site Survey		$60,000.00	Test Asset Site Survey		$60,000.00
Test Asset		$220,000.00	Test Asset		$160,000.00
Satellite Development Contractor	708	$53,100.00	Satellite Development Contractor	708	$53,100.00
		$393,600.00			$333,600.00

Week in the Life Tests: A WITL includes participation from the satellite contractor, the ground system contractor and the operator. The typical cost of a WITL shown in Table 7 is $58,000.

Table 7: WITL Cost Analysis

WITL		
Contract	**Hours**	**Dollars**
GS Development Contractor	40	$4,000.00
Operations Contractor	360	$27,000.00
Test Asset	0	$0.00
Satellite Development Contractor	360	$27,000.00
		$58,000.00

Command Validation: The operators, with minimal support from the ground system contractor, execute Command Validation (CV). The satellite contractor typically produces the "truth data" for the event, or completes the analysis to ensure compatibility of all commands. The typical cost of CV shown in Table 8 is $19,900.

Table 8: CV Cost Analysis

CV		
Contract	**Hours**	**Dollars**
GS Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00
Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00
		$19,900.00

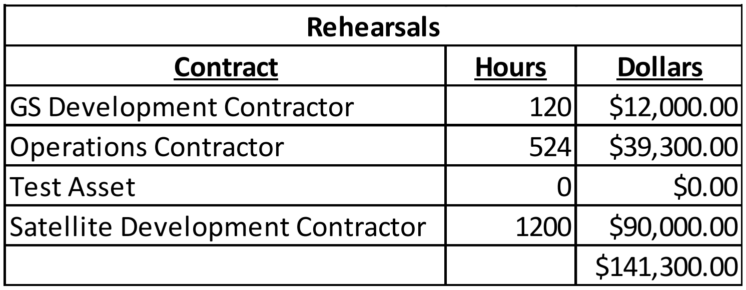
Telemetry Validation: Telemetry Validation (TV) is executed by the operators, sometimes in conjunction with CV and with minimal support from the ground system contractor. The satellite contractor typically produces the “truth data” for the event, or completes the analysis to ensure compatibility of all telemetry. The typical cost of TV shown in Table 9 is $19,900.

Table 9: TV Cost Analysis

TV		
Contract	**Hours**	**Dollars**
GS Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00
Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00
		$19,900.00

Rehearsals: The typical cost of one rehearsal, shown in Table 10 is $141,300. Rehearsals are executed with participation from the entire Mission Control Force (MCF). The MCF includes the operator, the members of the satellite contract that will be present during the LEO phase of the mission and the payload specialists. The ground system development contractor has one person on standby to resolve ground system issues. A typical program will execute three rehearsals.

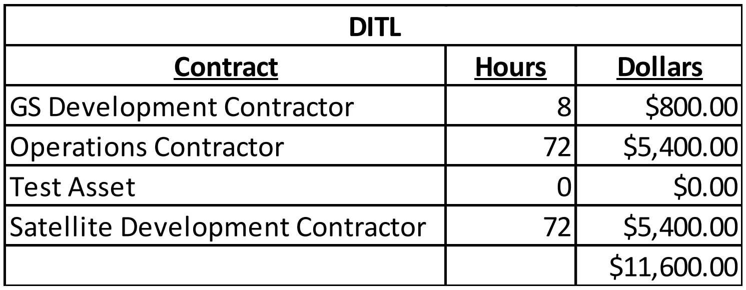
Table 10: Rehearsal Cost Analysis



Rehearsals		
Contract	**Hours**	**Dollars**
GS Development Contractor	120	$12,000.00
Operations Contractor	524	$39,300.00
Test Asset	0	$0.00
Satellite Development Contractor	1200	$90,000.00
		$141,300.00

Day in the Life Test: A DITL includes participation from the satellite contractor, the ground system contractor and the operator. The typical cost of a DITL is shown in Table 11. The typical cost is $11,600.

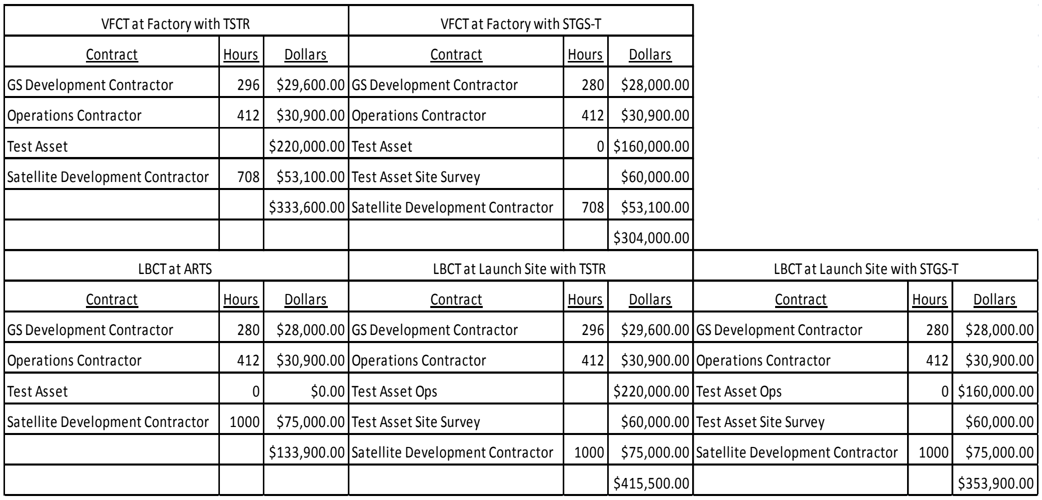
Table 11: DITL Cost Analysis



DITL		
Contract	**Hours**	**Dollars**
GS Development Contractor	8	$800.00
Operations Contractor	72	$5,400.00
Test Asset	0	$0.00
Satellite Development Contractor	72	$5,400.00
		$11,600.00

Launch Based Compatibility Test: An LBCT can be executed in several different ways depending on the launch site, launch configuration, budget, and schedule of the R&D program. The recommended way to execute an LBCT is to use ARTS and execute the LBCT once the satellite has been integrated with the launch vehicle. However, this is only feasible if the R&D satellite is launching from a location with ARTS, such as the Eastern or Western Range. Another advantage of this is that use of ARTS does not require the additional costs of a test asset. It is scheduled like a normal satellite support. If the satellite is not launching from the Eastern or Western Range, TSTR or STGS-T can be shipped to the launch site to perform the LBCT. This provides the same amount of risk mitigation as ARTS, but shipment of TSTR or STGS-T is expensive, especially if the launch site is secluded, like Kwajalein Atoll. Because of this, some program offices may elect to perform their final compatibility validation test at the factory before shipment of the satellite. They will perform limited RF testing with the satellite at the launch site to ensure nothing was damaged during the shipment. This is referred to as a Validation Factory Compatibility Test (VFCT). It is performed in the place of an LBCT in certain situations. Because of the variety of ways this test can be executed the range of costs is large. The least expensive LBCT alternative is the ARTS option at $133,900. The most expensive option is LBCT at Launch Site with TSTR at $415,500. The remaining alternatives fall in between. The costs of LBCT are shown in Table 12 below.

Table 12: LBCT Cost Analysis

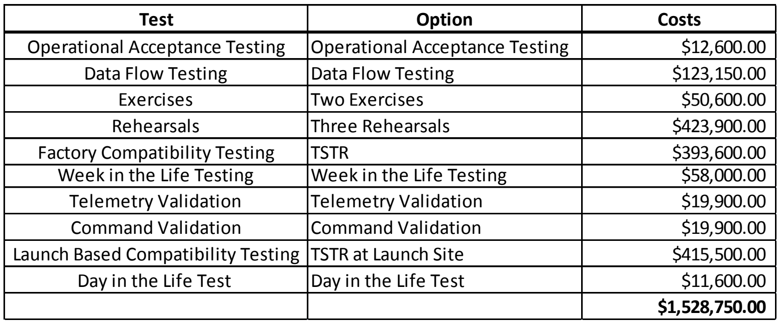


VFCT at Factory with TSTR			VFCT at Factory with STGS-T		
Contract	Hours	Dollars	Contract	Hours	Dollars
GS Development Contractor	296	$29,600.00	GS Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00	Operations Contractor	412	$30,900.00
Test Asset		$220,000.00	Test Asset	0	$160,000.00
Satellite Development Contractor	708	$53,100.00	Test Asset Site Survey		$60,000.00
		$333,600.00	Satellite Development Contractor	708	$53,100.00
					$304,000.00

LBCT at ARTS			LBCT at Launch Site with TSTR			LBCT at Launch Site with STGS-T		
Contract	Hours	Dollars	Contract	Hours	Dollars	Contract	Hours	Dollars
GS Development Contractor	280	$28,000.00	GS Development Contractor	296	$29,600.00	GS Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00	Operations Contractor	412	$30,900.00	Operations Contractor	412	$30,900.00
Test Asset	0	$0.00	Test Asset Ops		$220,000.00	Test Asset Ops	0	$160,000.00
Satellite Development Contractor	1000	$75,000.00	Test Asset Site Survey		$60,000.00	Test Asset Site Survey		$60,000.00
		$133,900.00	Satellite Development Contractor	1000	$75,000.00	Satellite Development Contractor	1000	$75,000.00
					$415,500.00			$353,900.00

All of the steps in our final CVM are possible steps that can be selected when defining a validation strategy. Table 13 is an example compatibility validation strategy illustrating possible total costs of the validation effort. In the next section we will evaluate the risks our SMEs defined that the CVM is designed to mitigate.

Table 13: Example Validation Steps and Associated Costs



Test	Option	Costs
Operational Acceptance Testing	Operational Acceptance Testing	$12,600.00
Data Flow Testing	Data Flow Testing	$123,150.00
Exercises	Two Exercises	$50,600.00
Rehearsals	Three Rehearsals	$423,900.00
Factory Compatibility Testing	TSTR	$393,600.00
Week in the Life Testing	Week in the Life Testing	$58,000.00
Telemetry Validation	Telemetry Validation	$19,900.00
Command Validation	Command Validation	$19,900.00
Launch Based Compatibility Testing	TSTR at Launch Site	$415,500.00
Day in the Life Test	Day in the Life Test	$11,600.00
		$1,528,750.00

4.4 Strategy Based Risk Model

During the Delphi Method, we asked our SMEs to list all of the risks associated with the compatibility between a satellite and its ground system. These risks make up the Strategy Based Risk Model (SRM) for ground system and satellite validation testing. In order to develop the SRM we asked them to define the risk attributes and variables. Our SMEs identified 18 risks. Table 14 below lists these 18 risks, a description of each risk and the steps in the validation process that mitigate the risk. Also included are the probabilities of each risk being realized before executing the validation process, the probability of each risk being realized after executing the validation process, the severity of the impact of realizing the risk, and the costs associated with that impact. We have also included these risks in the Space Development and Test Wing (SDTW) risk matrix discussed in Chapter 3. This matrix will allow program offices to easily assess whether this risk will be acceptable to SDTW leadership. Table 15 displays the risk profile before executing the validation process. The “B” following each risk number indicates that the risk probability shown is before the validation process was completed. Table 16 displays the risk profile after the validation process is completed assuming all risks are mitigated. The “A” following each risk number indicates the risk probability shown is after the validation steps are completed.

Table 14: Final Risk Table

Risk	Description	Probability before validation step:	Probability after validation step:	Impact Severity	Impact Costs	Steps
1	If SC and GS are not RF Compatible then GS cannot communicate with SC and mission is lost	41-60%	0-10%	Critical	$100,000,000.00	FCT and LBCT
2	If ARTS Iron Database is incorrect then GS cannot communicate with SC and mission is lost	41-60%	0-10%	Critical	$100,000,000.00	FCT, LBCT and CV
3	If cmds from ground system do not execute properly on SC then new command database will be required before commands can be used	41-60%	0-10%	Serious	$1,000,000.00	CV
4	If there are telemetry incompatibilities and errors between the SC and GS then telemetry may be reported incorrectly	41-60%	0-10%	Serious	$1,000,000.00	TV
5	If there are telemetry is displayed incorrectly on GS then telemetry may be reported incorrectly; could cause operator to incorrectly assess SOH of SC and take improper measures	41-60%	0-10%	Serious	$1,000,000.00	TV, FCT and DFT
6	If Ground system software does not construct and release spacecraft command correctly then software will have to be modified before commands can be sent to the SC	11-40%	0-10%	Critical	$100,000,000.00	CV, FCT and DFT
7	If Ground system is unable correctly post-pass process payload/mission data then customer will not get there data	41-60%	0-10%	Moderate	$200,000.00	WITL, FCT
8	If there are data latency impacts based GS processessing time then Customer will be delayed in receiving data	41-60%	11-40%	Serious	$1,000,000.00	OAT, Exercises, Rehearsals, DFT, FCT and LBCT
9	If vehicle manufacture tries something new with command, format then it could cause compatibility problems between ground system and spacecraft.	61-90%	11-40%	Serious	$150,000.00	DFT, FCT, LBCT, CV and TV
10	If there is insufficient documentation on the SC for the GS manufacturer then GS manufacture incorrectly code software and it will not be compatible with SC	61-90%	11-40%	Minor	$24,000.00	OAT, DFT, FCT and LBCT
11	If there is insufficient documentation on the GS for the SC manufacturer then SC manufacture will build capability that ground system can't handle, ground system	41-60%	0-10%	Minor	$24,000.00	OAT, DFT
12	If SC is not mature then GS development will have to change to continue to be compatible with the SC	11-40%	0-10%	Serious	$150,000.00	CV and TV
13	If ground system development is immature then ground system will have last minutes changes that will increase costs	11-40%	0-10%	Moderate	$65,000.00	OAT, FCT, LBCT and DFT
14	If the SC manufacturer does not provide telemetry truth data then telemetry may not be processed correctly resulting in SW fixes	41-60%	11-40%	Minor	$65,000.00	DFT, TV, FCT and LBCT
15	If the SC manufacturer does not provide vehicle command samples then commands may not be compatible with SC	41-60%	11-40%	Minor	$6,000.00	DFT and CV
16	If the system fails to support all operational requirements of the satellite then large changes will have to be made to GS to fix	11-40%	0-10%	Moderate	$500,000.00	OAT, Exercises, Rehearsals, WITL, DITL
17	If GS loses or corrupts SC data then Satellite commanding and telemetry will be erratic	41-60%	0-10%	Minor	$100,000.00	OAT, CV and TV
18	If Post Pas processing does not format products correctly then delivered products will be improperly formatted (i.e. tasking files)	0-10%	0-10%	Minor	$100,000.00	TV, WITL, exercises and rehearsal

Table 15: Final Risk Matrix Before Validation

	Negligible	Minor	Moderate	Serious	Critical
0-10%		18B			
11-40%			13B, 16B	12B	6B
41-60%		11B, 14B, 15B, 17B	7B	3B, 4B, 5B, 8B	1B, 2B
61-90%		10B		9B	
91-100%					

Table 16: Final Risk Matrix After Validation

	Negligible	Minor	Moderate	Serious	Critical
0-10%		11A, 17A, 18A	7A, 13A, 16A	3A, 4A, 5A, 12A	1A, 2A, 6A
11-40%		10A, 14A, 15A		8A, 9A	
41-60%					
61-90%					
91-100%					

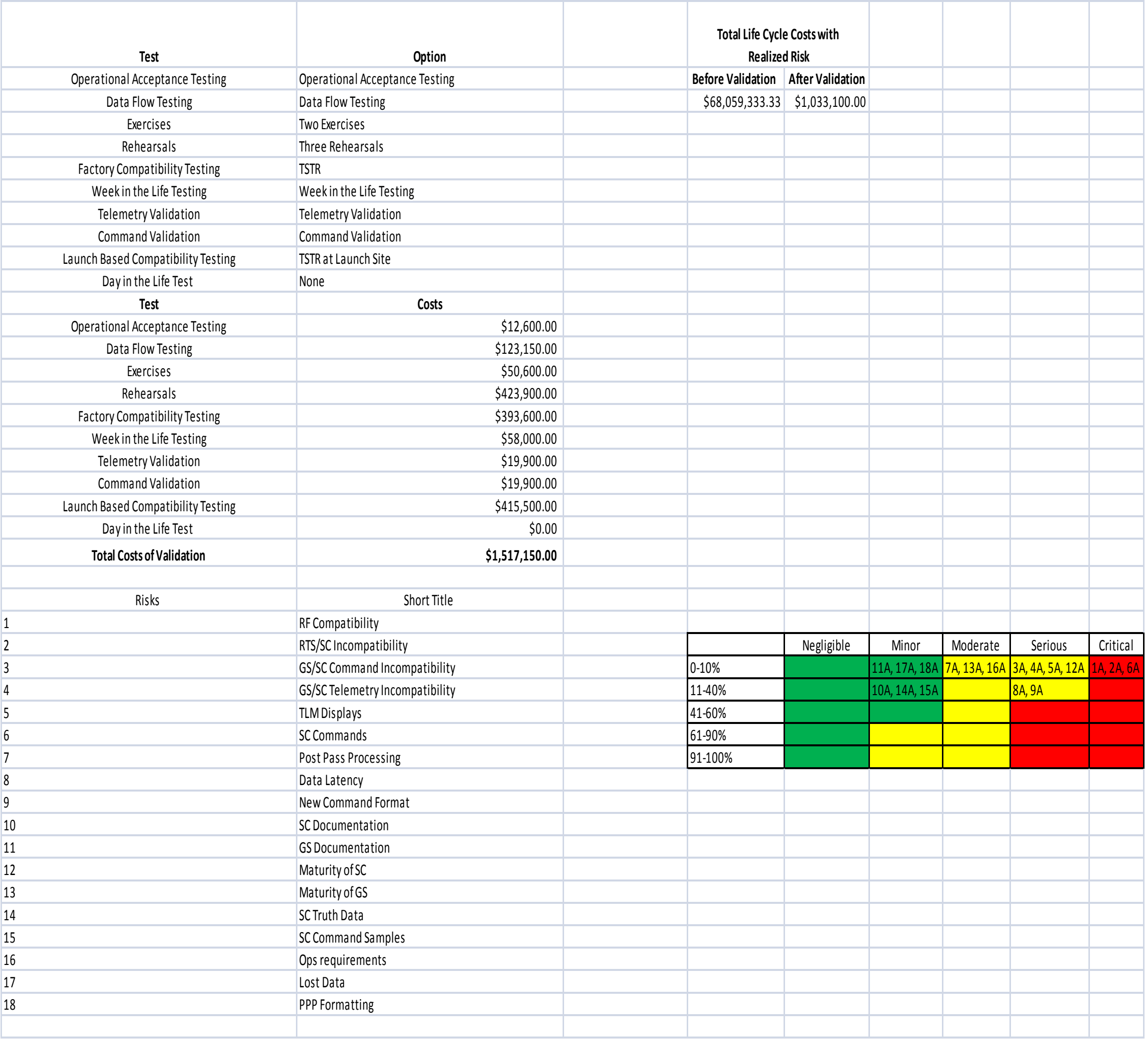
As we can see, from the Final Risk Table and the Risk Matrices above, Risk # 18, “If Post Pass processing does not format products correctly then delivered products will be improperly formatted (i.e. tasking files),” already resides in the lowest risks probability range: 0-10%, and therefore cannot be mitigated into a new probability range. Risk # 18 also has a Minor Severity.

4.5 How to Apply the Simulation

The purpose of our thesis was to create a simulation that can be used by program offices to help develop a validation strategy that provides the best balance of risk mitigation and costs. The simulation we created is easy for the program offices to use. We created our simulation by using the empirical decision aided method for selecting a process to validate an R&D satellite and its ground system, and the SRM for ascertaining risk, probability of impact, and severity of impact.

The program office can use the results of our simulation to select a preferred validation strategy and defend it to senior leadership. It can also be used to illustrate the fact that various steps in the validation process can be skipped with little impact to the mission. For a program office to use our simulation, they will follow a decision analysis plan. This section will demonstrate how this works.

First the program office will need to identify which steps in the validation process they would like to execute. The validation steps that the program office wishes to perform will be selected from drop down menus in the “Summary” sheet of our simulation, Figure 9 below. As stated in Section 4.3, some steps will be executed differently depending on the circumstances of the program. For example an FCT can be executed with TSTR if it is available, but if it is not available the program office may select to execute an FCT using STGS-T.



Test	Option
Operational Acceptance Testing	Operational Acceptance Testing
Data Flow Testing	Data Flow Testing
Exercises	Two Exercises
Rehearsals	Three Rehearsals
Factory Compatibility Testing	TSTR
Week in the Life Testing	Week in the Life Testing
Telemetry Validation	Telemetry Validation
Command Validation	Command Validation
Launch Based Compatibility Testing	TSTR at Launch Site
Day in the Life Test	None

Total Life Cycle Costs with Realized Risk	
Before Validation	**After Validation**
$68,059,333.33	$1,033,100.00

Test	Costs
Operational Acceptance Testing	$12,600.00
Data Flow Testing	$123,150.00
Exercises	$50,600.00
Rehearsals	$423,900.00
Factory Compatibility Testing	$393,600.00
Week in the Life Testing	$58,000.00
Telemetry Validation	$19,900.00
Command Validation	$19,900.00
Launch Based Compatibility Testing	$415,500.00
Day in the Life Test	$0.00
Total Costs of Validation	**$1,517,150.00**

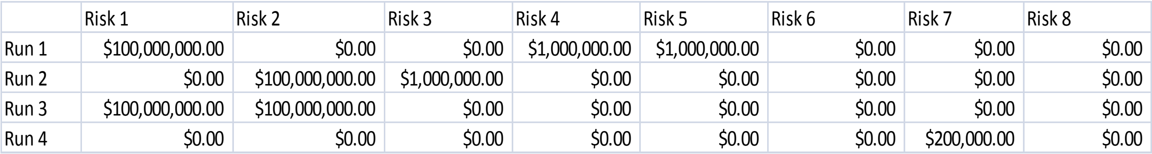
Risks	Short Title
1	RF Compatibility
2	RTS/SC Incompatibility
3	GS/SC Command Incompatibility
4	GS/SC Telemetry Incompatibility
5	TLM Displays
6	SC Commands
7	Post Pass Processing
8	Data Latency
9	New Command Format
10	SC Documentation
11	GS Documentation
12	Maturity of SC
13	Maturity of GS
14	SC Truth Data
15	SC Command Samples
16	Ops requirements
17	Lost Data
18	PPP Formatting

	Negligible	Minor	Moderate	Serious	Critical
0-10%	🟩	🟩 11A, 17A, 18A	🟨 7A, 13A, 16A	🟨 3A, 4A, 5A, 12A	🟥 1A, 2A, 6A
11-40%	🟩	🟩 10A, 14A, 15A	🟨	🟨 8A, 9A	🟥
41-60%	🟩	🟩	🟨	🟥	🟥
61-90%	🟩	🟨	🟨	🟥	🟥
91-100%	🟩	🟨	🟨	🟥	🟥

Figure 9: "Summary" Sheet of Simulation

As we can see in Figure 9 above, a step in the validation process is executed using a drop down menu under the “Option” column. From this selection, the associated costs are populated and the total costs for a validation strategy is calculated using the equation presented in the methodology. The SDTW risk matrix is also populated illustrating what risks have been mitigated by executing the selected validation strategy. From this, the program office will determine their risk level and decide if it is an acceptable level of risk for their program. Every program is different, but most tend to accept risks that are in the green and the yellow categories at the lowest possible probability of impact. The program office can reference Table 14 to note what other steps in the validation process can be executed to mitigate the indentified risks.

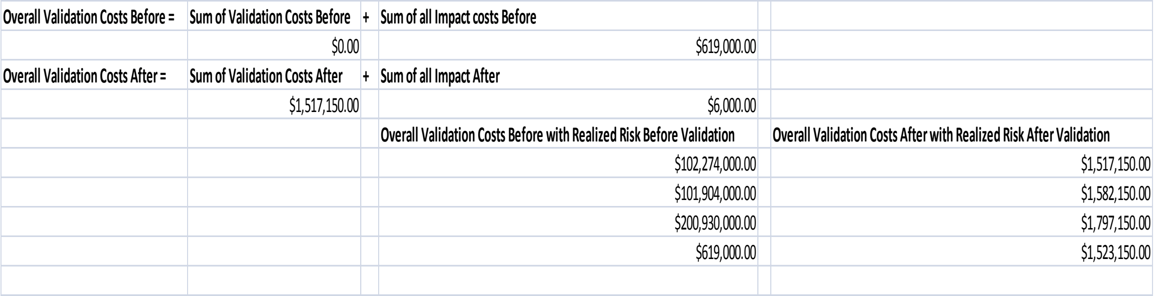
Once the validation steps have been identified and the simulation is set up, it can be run one time by pressing "Control+M" or several times using a macro. In order to gain statistical confidence, we ran the simulation 1,000 times in every trial. When the simulation is running, it decides whether a risk is an occurrence or nonoccurrence by selecting a random number for each risk. Figure 10 is a screen shot of the "After" sheet displaying whether each individual risk was an occurrence or a nonoccurrence. If there is an impact cost displayed in the cell, then the risk was an occurrence, if the cell displays $0.00 then the risk was a nonoccurrence. For risks that result in loss of mission, the impact costs are $100,000,000. This the representative cost of re-accomplishing the mission. This number can be changed within the simulation to represent the actual cost of the mission. Although only 8 risks are shown in Figure 10 below, all 18 risks are considered.



	Risk 1	Risk 2	Risk 3	Risk 4	Risk 5	Risk 6	Risk 7	Risk 8
Run 1	$100,000,000.00	$0.00	$0.00	$1,000,000.00	$1,000,000.00	$0.00	$0.00	$0.00
Run 2	$0.00	$100,000,000.00	$1,000,000.00	$0.00	$0.00	$0.00	$0.00	$0.00
Run 3	$100,000,000.00	$100,000,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Run 4	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$200,000.00	$0.00

Figure 10: “After” Sheet of Simulation

From this the Risk Impact Costs and Overall Validation Costs are calculated using the equations presented in our methodology. The Overall Validation Costs are displayed on the “Overall Validation Costs” sheet of our simulation, shown in Figure 11. The average Overall Validation Costs are displayed on the “Summary” sheet in Figure 9.



Overall Validation Costs Before =	Sum of Validation Costs Before	+	Sum of all Impact costs Before		
	$0.00		$619,000.00		
Overall Validation Costs After =	Sum of Validation Costs After	+	Sum of all Impact After		
	$1,517,150.00		$6,000.00		
			Overall Validation Costs Before with Realized Risk Before Validation		Overall Validation Costs After with Realized Risk After Validation
			$102,274,000.00		$1,517,150.00
			$101,904,000.00		$1,582,150.00
			$200,930,000.00		$1,797,150.00
			$619,000.00		$1,523,150.00

Figure 11: "Overall Validation Costs" Sheet of Simulation

This simulation can be executed as many times as the program office desires to compare different validation strategies. These strategies are compared in order select the desired strategy for an individual program based on cost and risk aversion. Once they have completed this exercise, the program office can go to their leadership and list out their program risks in a systematic method, how they wish to mitigate them, and what the total validation cost could be.

4.6 Apply Simulation to Sample Program

In order to demonstrate the usability and accuracy of our simulation we have applied it to a program that is currently performing validation steps in preparation for operations at SDTW. This sample program currently holds a launch date within the next 12 months and will be operated as the first satellite on SDTW's multi-mission ground system.

4.6.1 Define the Validation Strategies

This program has a limited budget for validation due to launch vehicle problems that caused significant launch slips and severe costs increases. In order to save money, the program office proposed a strategy for executing certain steps in the validation process and omitting others. The program office proposed to execute all validation steps with the exception of: OAT, WITL, TV, CV and DITL. This sample program is currently in the middle of the validation process and thus some steps have already been performed. The sample program has executed a DFT, FCT and the first of two planned exercises. The program office plans to execute Exercises and Rehearsals as well as a VFCT using TSTR at the factory two months prior to launch. Since this satellite is not launching from either the Eastern or Western Range, an LBCT with ARTS was not an option. The program office does not wish to send TSTR up to the launch site (Kodiak, AK) due to the costs associated with shipment. The satellite development contractor will conduct testing once the satellite has reached the launch site to ensure that it wasn't damaged during shipment.

The costs associated with the program offices proposed validation strategy are shown in Table 17 below. The risk matrix yielded by this proposed validation strategy is shown in Table 18. A risk in the final risk matrix that has a “B” following the risk number indicates that the risk was not mitigated and the risk probability shown is the same as the probability before the validation steps were completed. As we can see in this table, the risks that were not mitigated are: Risks 3, 4, 12 and 17.

Table 17: Summary Program Office Proposed Validation Strategy

Test	Option	Costs
Operational Acceptance Testing	None	$0.00
Data Flow Testing	Data Flow Testing	$123,150.00
Exercises	Two Exercises	$50,600.00
Rehearsals	Three Rehearsals	$423,900.00
Factory Compatibility Testing	TSTR	$393,600.00
Week in the Life Testing	None	$0.00
Telemetry Validation	None	$0.00
Command Validation	None	$0.00
Launch Based Compatibility Testing	TSTR at Factory	$333,600.00
Day in the Life Test	None	$0.00
Total Costs of Validation		**$1,324,850.00**

Table 18: Program Office Proposed Validation Strategy Risk Matrix

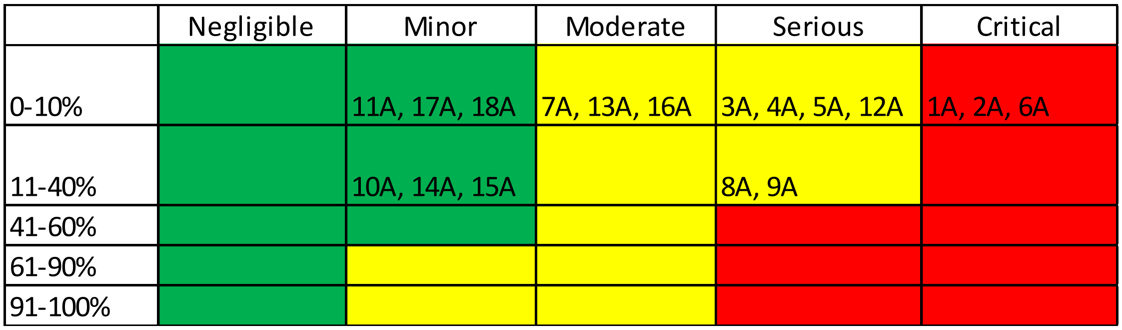
	Negligible	Minor	Moderate	Serious	Critical
0-10%	🟩	11A, 18A	7A, 13A, 16A	5A	1A, 2A, 6A
11-40%	🟩	10A, 14A, 15A	🟨	8A, 9A, 12B	🟥
41-60%	🟩	17B	🟨	3B, 4B	🟥
61-90%	🟩	🟨	🟨	🟥	🟥
91-100%	🟩	🟨	🟨	🟥	🟥

Because this sample program will be the first to fly on the multi-mission ground system, SMC assigned an Independent Readiness Review Team (IRRT) to the ground system. IRRTs are risk adverse and evaluate all programs on the same scale regardless of the budget. The IRRT has recommended a strategy for the validation process. The IRRT feels that all steps in the validation process were necessary with the exception of DITL. In addition, the IRRT feels that it was necessary to perform an LBCT at the launch site. The IRRT insists that separate CV and TV are conducted as well as an OAT and WITL. The costs associated with IRRTs proposed validation strategy are shown in Table 19 below. The risk matrix yielded by this proposed validation strategy is shown in Table 20. This risk matrix shows that the IRRT proposed validation strategy mitigates all identified risks.

Table 19: Summary IRRT Proposed Validation Strategy

Test	**Option**	**Costs**
Operational Acceptance Testing	Operational Acceptance Testing	$12,600.00
Data Flow Testing	Data Flow Testing	$123,150.00
Exercises	Two Exercises	$50,600.00
Rehearsals	Three Rehearsals	$423,900.00
Factory Compatibility Testing	TSTR	$393,600.00
Week in the Life Testing	Week in the Life Testing	$58,000.00
Telemetry Validation	Telemetry Validation	$19,900.00
Command Validation	Command Validation	$19,900.00
Launch Based Compatibility Testing	TSTR at Launch Site	$415,500.00
Day in the Life Test	None	$0.00
	Total Costs of Validation	**$1,517,150.00**

Table 20: IRRT Proposed Validation Strategy Risk Matrix



	Negligible	Minor	Moderate	Serious	Critical
0-10%	🟩	🟩 11A, 17A, 18A	🟨 7A, 13A, 16A	🟨 3A, 4A, 5A, 12A	🟥 1A, 2A, 6A
11-40%	🟩	🟩 10A, 14A, 15A	🟨	🟨 8A, 9A	🟥
41-60%	🟩	🟩	🟨	🟥	🟥
61-90%	🟩	🟨	🟨	🟥	🟥
91-100%	🟩	🟨	🟨	🟥	🟥

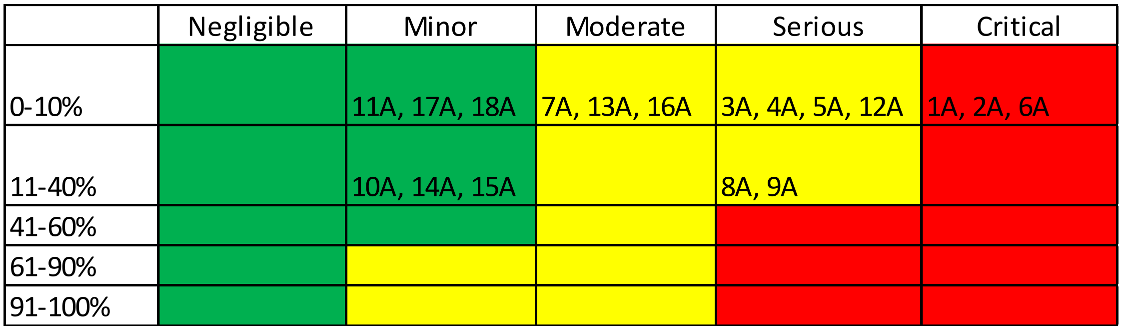
For the sample program we have also proposed an author recommended validation strategy. This strategy assumes that the steps in the validation process which have already been executed are considered "sunk costs."

The steps that have already been successfully completed are DFT, FCT and the first of two planned exercises. We recommend that in addition to the steps already completed, Exercises and Rehearsals be selected as part of the validation process because they have a primary objective of training and certification of the MCF. Since every R&D satellite mission is unique, each R&D mission requires training and certification of the MCF. Because of this, Exercises and Rehearsals will be performed and should be used as steps in the validation process as well as training activities. The final two steps in the validation process that we feel should be conducted are CV and TV. These should be conducted because there are two significant risks, Risk #3 and Risk #4, which can only be mitigated by CV and TV respectively. Risk #3 is: If commands from ground system do not execute properly on the satellite then a new command database will be required before commands can be used. A full CV will ensure that every command executes as designed onboard the satellite. Risk #4 is: If there are telemetry incompatibilities and errors between the satellite and ground system then telemetry may be reported incorrectly. TV, which includes the validation of real-time telemetry as well as post-pass processed files and limits, ensures that telemetry is being processed correctly by the ground system and thus communicated correctly to the operators. The costs of our proposed validation strategy considering "sunk costs" are shown in Table 21 below. The risk matrix yielded by this proposed validation strategy is shown in Table 22. This risk matrix shows that our proposed validation strategy mitigates all identified risks.

Table 21: Summary Author Proposed Validation Strategy

Test	**Option**	**Costs**
Operational Acceptance Testing	None	$0.00
Data Flow Testing	Data Flow Testing	$123,150.00
Exercises	Two Exercises	$50,600.00
Rehearsals	Three Rehearsals	$423,900.00
Factory Compatibility Testing	TSTR	$393,600.00
Week in the Life Testing	None	$0.00
Telemetry Validation	Telemetry Validation	$19,900.00
Command Validation	Command Validation	$19,900.00
Launch Based Compatibility Testing	None	$0.00
Day in the Life Test	None	$0.00
	Total Costs of Validation	**$1,031,050.00**

Table 22: Author Proposed Validation Strategy Risk Matrix



	Negligible	Minor	Moderate	Serious	Critical
0-10%	🟩	🟩 11A, 17A, 18A	🟨 7A, 13A, 16A	🟨 3A, 4A, 5A, 12A	🟥 1A, 2A, 6A
11-40%	🟩	🟩 10A, 14A, 15A	🟨	🟨 8A, 9A	🟥
41-60%	🟩	🟩	🟨	🟥	🟥
61-90%	🟩	🟨	🟨	🟥	🟥
91-100%	🟩	🟨	🟨	🟥	🟥

Each of these proposed validation strategies was modeled using our simulation. Three trials of 1,000 simulation runs each were completed. Three trials were preformed to ensure that the results were consistent and the simulation operated as designed. The three trials of 1,000 runs were also combined into one trial of 3,000 runs.

4.6.2 Simulation Results

After running simulation trials on all three validation strategies, we created histograms of each trial so that they could be compared. We also calculated the mean, standard deviation, range, and median. The histograms and calculations for all of the trials can be found in Appendix I. Figure 12 displays a comparison of all three validation strategies based on the 3,000 run trial.

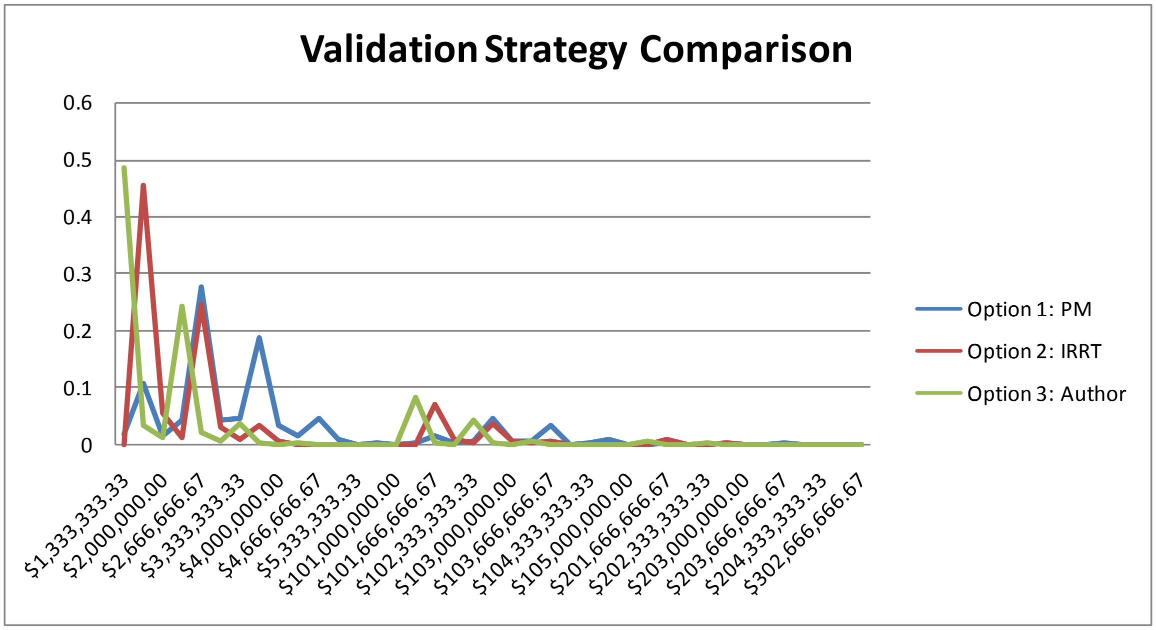


Figure 12: Validation Strategy Comparison

As we can see from the histogram in Figure 12, the median value for these validation strategies is between $1M and $3M. Comparing the median value for different validation strategies helps assess which strategy to choose. The average overall validation cost for each option is between $17M and $20M. Unfortunately, the average overall cost is not as useful for decision making in this situation because of the large range of overall validation costs. Figure 12 shows that there is not only a very large range within the possible overall validation costs, but also there is a large area where the overall validation costs did not “hit” in the simulation at all. This is an interesting phenomenon that is unique to unmanned spaceflight. Currently, if there is an irresolvable problem with satellite to ground system compatibility once the satellite is on-orbit, the mission is lost.

Three of the risks identified by our SMEs have impacts that are loss of mission. These impact costs equal the cost of the entire mission, approximately $100M dollars. If one of these risks is realized then the overall validation cost elevates to over $100M. If two of these risks are realized then the cost rises to above $200M and if all three risks are realized then the cost is over $300M. Because of these three risks, there are three large bins where there can be no overall validation costs.

We will present our findings and interpretations based on the sample program. Table 23 compares the three validation strategies examined for this sample program. This is done by comparing the cost of completing the validation strategy, the average overall validation cost, the standard deviation, the range of overall validation costs, and the median overall validation cost for each strategy.

Table 23: Comparison of Validation Strategies

	Validation Strategy Costs	Mean	Range	Standard Deviation	Median
Option 1 All: PM	$1,324,850.00	$18,970,647.13	$301,129,400.00	$40,253,166.62	$2,924,850.00
Option 2 All: IRRT	$1,517,150.00	$17,130,988.89	$202,071,000.00	$38,064,722.27	$1,817,150.00
Option 3 All: Author	$1,031,050.00	$18,179,638.00	$201,321,000.00	$40,144,600.32	$1,405,050.00

From looking at the median we can conclude that both Option 2 and 3 are superior to Option 1. Option 3 is displayed as the best option because it not only is the least expensive, but also mitigates all of the risks. As we compare this data in attempt to identify a desired validation strategy, it is important to note that there is no right answer.

Each program office needs to use the simulation provided and then evaluate their results based on the factors that are most important to them.

4.7 Program Manager's Input on Simulation

In order to demonstrate the accuracy of the simulation used to generate distributions on possible costs and risk outcomes that we developed during this thesis we provided the simulation to two program managers. We asked the program managers to run the simulation for their on-going programs and answer a series of questions. We asked them to also keep in mind past programs when answering the questions.

We sought out program managers that were separate from our Delphi group. We believe that this not only validated the simplicity and usability of our simulation program, but also helped to validate the CVM and SRM developed through the Delphi Method. Finally, we wanted to solicit input on the risks listed in Table 14. We wanted to ensure that these were the only risks that an R&D satellite program would encounter during the validation of its ground system to the satellite compatibility.

To validate the Delphi Method, we asked the program managers questions regarding the risks we identified in Table 14. We first asked them if the risks listed in the table provided (Table 14) encompassed all the risks on their current satellite program. Program manager #1, stated that their program risks and the program risks we identified were the same. They are currently tracking 12 risks, all of which can be found on our table. However, some of the wording for the risks is slightly different. The program manager for program #2 stated they combined some of their risks but they were found within our table.

We also asked both program managers if they had ever worked an R&D satellite program that tracked a risk concerning the compatibility of the satellite and its ground system not listed in Table 14. We received a unanimous no. We did get the comment that some of the risks we listed in the table would not be considered a high enough risk to track.

To evaluate the simulation, we asked the program managers their thoughts on the simulation. Specifically, what were the results using the simulation on their program? Can using the simulation save their programs cost, or schedule? Finally, how could utilizing the simulation help their program? Program manager #1 stated that utilizing the simulation could help them eliminate some validation steps to save schedule and cost while adequately mitigating risks to the program. They also believe that if they held a successful FCT, they could possibly save both cost and schedule associated with executing an LBCT. The program manager for program #1 stated that they lost a lot of schedule due to performing an LBCT on a past program that may not have been necessary due to the programs successful FCT. Overall, they thought they could eliminate costly testing with the aid of the simulation. Finally, program manager #1 believes that this simulation could help advocate for a more comprehensive set of tests that would cut down on more risks.

Program manager #2 felt very similarly to program manager #1. However, it should be noted that program manager #2 frequently discussed how with an unlimited budget, it is always best to complete as much testing as possible. Additionally, they made a number of statements indicating that any process (simulation) would need proper push from leadership to be effective. With these comments noted, they did state that the simulation could help defend skipping validation steps, which would save time and money. Program manager #2 believed that the simulation helped provide evidence to the team showing which steps in the validation process are absolutely necessary.

The program managers were allowed to make any addition comments to questions we asked them. Program manger #1 really liked the simulation program and was excited to use it in the future. Program manager #2 was slightly concerned that the simulation program often pointed to not completing LBCTs and saw this as a potential problem. This could be a potential problem because not conducting an LBCT is a very political issue. Not completing this test can be a very unpopular decision regardless of the lack of technical risk.

V. Conclusion and Recommendations

5.1 Introduction

When we started this thesis, we set out to create a simulation that would generate distributions of possible risk and cost outcomes. This simulation would in turn aid Research and Developmental (R&D) satellite program offices in analyzing the risks associated with the compatibility between satellites and their ground systems. We wanted to help these program offices decide which risks need to be mitigated and which risks can be accepted at their current level. We also wanted to help them decide the more efficient way to mitigate these risks through the validation process. Throughout this chapter we will be discussing the conclusions and significance of our research.

5.2 Conclusions of Research

This thesis examined readiness and on-orbit activities of R&D satellite programs and attempted to accurately define the process for validating the compatibility between a satellite and its ground system. Using historical program data together with Subject Matter Experts (SMEs), our thesis mirrors the method outlined by Engel & Barad in *A Methodology for Modeling VVT Risks and Costs*. Our thesis identified all of the steps in the process of validating the compatibility between a satellite and ground system. We created a simulation that can assist program offices in determining which steps in the validation process they should execute, and which they can skip based on the risks.

Through the Delphi Method we concluded that the final Canonical Verification Validation and Testing (VVT) Model (CVM) presented in section 4.2.2 is complete and correct CVM. We also concluded that the risks identified by our SMEs through the Delphi Method are a complete and accurate list of risks. The attributes and variables for these risks were identified via the Strategy Based Risk Model (SRM). This process allowed us to create a simulation that generates distributions of risk and cost outcomes. If this simulation is executed a large number of times, conclusions can be drawn about how much of the budget should be saved for contingency costs. If the simulation is executed with more than one validation strategy, it can be used as a comparison tool for selecting a desired validation method.

We gave the technique and simulation to two program managers. These program managers evaluated the technique and provided insight into the usefulness of the technique. In the future we will be distributing this technique and simulation to program offices to support tailoring a validation plan based on their budget. The technique and simulation will give decision makers insight into the expected risks and costs associated with the selected validation process so that they can make informed decisions. They will be able to understand and accept risks with reasonable probability and severity of impacts, and ensure that risks with unreasonable probability and severity of impacts are mitigated to the fullest extent possible.

5.3 Significance of Research and Recommendations for Action

The technique and simulation developed in this thesis will be invaluable to R&D satellite program offices. These program offices often deal with diminishing budgets.. The typical budget for an R&D satellite program office at Space Development and Test Wing (SDTW) is between $300K and $400M. Some operational satellites have budgets of more than $1B.

R&D satellites often do not have a dedicated launch vehicle. They often share a launch vehicle with as many as 6 other satellites. Because of this, they must be flexible with their schedules. If the R&D satellite is not the primary mission on a launch vehicle, they can have little influence on the launch date, and the launch can occur whether the R&D satellite is ready or not. Therefore it is important for R&D satellites to be flexible and responsive. These budget and schedule constraints present R&D program offices with the unique challenge of deciding which program risks to mitigate and which to accept.

Our technique and simulation allow program offices to make this assessment by providing them with the program risks, the steps in the validation process that mitigate these risks, and the impacts of these risks. The simulation allows the program offices to generate distributions of possible risk and cost outcomes based on their chosen validation strategy. Program offices can compare several validation strategies to help decide which strategy is best for them. Using our technique these program offices will be able to provide data to defend decisions. They will be able to explain why certain steps in the validation process are necessary and why other steps in the validation process are not. While our research was completed using R&D satellite programs; we feel there is another initiative currently in DoD that can apply our technique and simulation as well.

Operationally Responsive Space (ORS) is the vision for the future of military space. In future conflicts, military space forces will likely face challenges ranging from defending against opposing systems to dealing with rapidly changing technology and support needs. "The goal of ORS is to provide an affordable capability to promptly, accurately, and decisively position and operate national and military assets in and through space and near space." [Doggrell, 2006] Since the goals of ORS are to be affordable and responsive, we feel that our risk management and decision analysis technique is an excellent way to help accomplish their goals. Our recommendation for action is that all SDTW and ORS satellite program offices adopt this technique and associated simulation for on-going and future missions.

5.4 Recommendations for Future Research

The assumptions and scope of our thesis was limited to R&D satellite programs. As a result, we feel there is room for future research on the subject. We also feel that the technique presented by Engel and Barad is applicable to any situation where a series of steps is performed to mitigate risk. For example, we only looked at the compatibility between the satellite and ground system. The technique could also be applied to satellite environmental testing and launch vehicle testing as well as any number of subjects within and outside the space industry. First, this research can be expanded into domains such as ORS. Another area for future work is to expand the process to more accurately represent reality.

Our validation process is simplified and does not represent reality. There are certain things that should be added to our process in order to be more realistic. Our process assumes all testing will be successful. If the steps identified in this process are not successful further testing will need to be performed. In order the make our process more realistic further testing can be represented with feedback loops and logic boxes. Logic boxes can be included to ask whether the test is successful. If the test is successful the process can proceed to the next step. If the test is not successful the process will be repeated. This is an area that requires further research and can be expanded on in future work within this subject area.

Another assumption we made that limited our thesis was that a validation step can either be fully performed or not performed at all. Since testing can be partially completed, this is an area for future research. We also assumed that each step in the validation process mitigates the risk the same amount. Future work can examine if some validation steps mitigate risks more than others.

When applying our simulation we noted that there is not only a large range within the possible overall validation costs, but also there are is a large area where the overall validation costs did not “hit” at all. As discussed in our analysis, this is because the loss of mission impact, that has a significantly higher impact cost. This is unique to spaceflight. Future works should compare different validation strategies not considering the risks that result in loss of mission and/or only considering the risks that result in loss of mission. This will reduce the range and produce meaningful averages rather than averages that are skewed due to the large range of data.

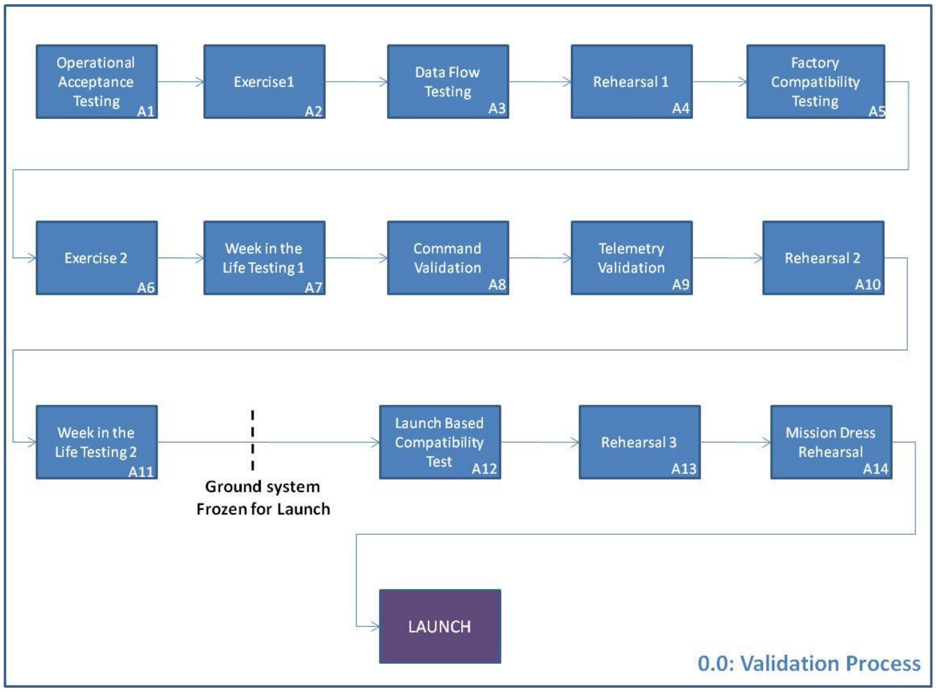
The final area for future research that we have identified is concentrating on reducing the severity of the impact of the risk. Currently the validation process only mitigates the probability of the risk being realized. Since both probability and severity of impact are risk variables, it would be useful to examine what steps can be accomplished to mitigate the severity of the risk in addition to the probability. All of the research can be accomplished by expanding on the work completed by Engel and Barad and by ourselves.

5.5 Summary

In summary we were able to develop a technique by using the Delphi Method to evaluate a validation process for compatibility between a satellite and its grounds system. Through the Delphi Method we were able to determine what risks were associated with ground system and satellite compatibility. We were able to provide a point estimate for the costs associated with each validation step and ascertain costs and severity of each risk identified. Finally through the Delphi Method we were able to determine what validation steps mitigated which risks. This technique was used to create a simulation that generates distributions of outcomes based on risk and cost.

The technique and simulation will be given to program offices. This will help them save time when determining what risks their program has for ground system and satellite compatibility. It will also allow them to determine the best validation process based on their program risks and budget and will allow them to go to their leadership with this process, showing risks before and after validation and the cost associated with the validation process.

Appendix A: Initial Validation Process



Operational Acceptance Testing: Operational Acceptance Testing (OAT) is performed by the organization that will be operating the satellite via the ground system. The operators have two main objectives when performing this testing. (1) Validate that the design is operationally suitable and (2) Evaluate the ground system under operationally realistic conditions.

Exercise 1: Exercise one is a training event, which is typically the first time the operators use the ground system. Exercises are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. The objectives of exercise one are usually to: (1) Familiarize the operations team with the ground system, (2) Assure the ground system design is feasible under realistic loading conditions, (3) Test of Concept of Operations, and (4) Familiarize operators with procedures and processes.

Data Flow Testing (DFT): Data flow testing is usually the first time the satellite and ground system are allowed to interact. It is the first opportunity to validate that the ground system can receive and process satellite telemetry and that the satellite receives and processes commands sent from the ground system. Problems are identified with the compatibility between the satellite and the ground system. The DFT often identifies problems before they impact the mission and schedule.

Rehearsal 1: Rehearsal 1 is the first chance to train the entire Launch and Early Orbit (LEO) operational team. The operational team is made up of the contractors that operate the satellite, the flight directors, the satellite operations crew commanders, the satellite (satellite) manufacturer technical advisors, the payload technical advisors and members of the program office or independent technical advisors. Rehearsals are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. The objective of the rehearsals is to certify the launch and early orbit operational team. Specifically, the objectives are: (1) Testing the ground system design under realistic loading conditions, (2) Testing of Concept of Operations and (3) Familiarizing the operator with procedures and processes. However, the first rehearsal is 90% training and only 10% certification.

Factory Compatibility Test: The FCT is performed by connecting the satellite to the ground system through an AFSCN test van or the Transportable Space Test and

Evaluation Resource (TSTR) van. TSTR is operated by the organization that provides test assets to the Space Community. This organization also has a variety of other equipment that can be used to perform this test, in an event that the TSTR van is not available. The TSTR van allows us to validate the AFSCN configuration (ARTS Inter-Range Operating Number (IRON) Databases). This is also a great opportunity to perform extensive satellite and ground system compatibility testing. The primary objective of the FCT is to validate the IRON databases. The FCT is completed by ensure that telemetry is received by the ground system and commands are received by the satellite. Many program offices add objectives to this test in order to maximize the testing opportunity. These objectives include: (1) Validation of all command types, (2) Validation that the flight software and ground software are compatible, and (3) Ensure that critical telemetry points are being properly processed and displayed by the ground system.

Exercise 2: The second exercise has the same objectives as the first exercise and typically only involves the operations contractor. Exercises are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions.

Week in the Life Tests 1&2: The Week in the Life Tests (WITL) are performed during the readiness phase of a mission. The WITL is used to ensure that the system can handle the loading of nominal operations. This test is also used to validate operational procedures. The WITL is most useful if it can be performed between the ground system and the satellite. However, often times the satellite and ground system perform WITL separately due to budgetary constraints.

Command Validation: The purpose of command validation (CV) is to ensure that the end product (the commands executed by the satellite) matches the input (the tasking file provided by the customer or the commands built by the operator). The specific objectives of command validation are: (1) Validate the customer provided tasking files are processed properly by the ground system, and (2) Validate the command database and validate that a specific command accomplishes the expected action on the satellite.

Telemetry Validation: Telemetry originates on the satellite, is transmitted to the ground, and is processed by the ground system. The objective of Telemetry Validation (TV) is to ensure that the end product (the raw, processed, and displayed telemetry) agrees with the data being produced on the satellite, as interpreted in accordance with the telemetry database provided by the contractor. The steps to ensure the telemetry is valid are as follows: (1) Validating the raw telemetry at the output, (2) Validating the processed telemetry products (EU converted files, etc.), (3) Validating the displayed telemetry (telemetry screens) is properly converted by the ground system and (4) Validating that of red, yellow, and green limits are handled correctly.

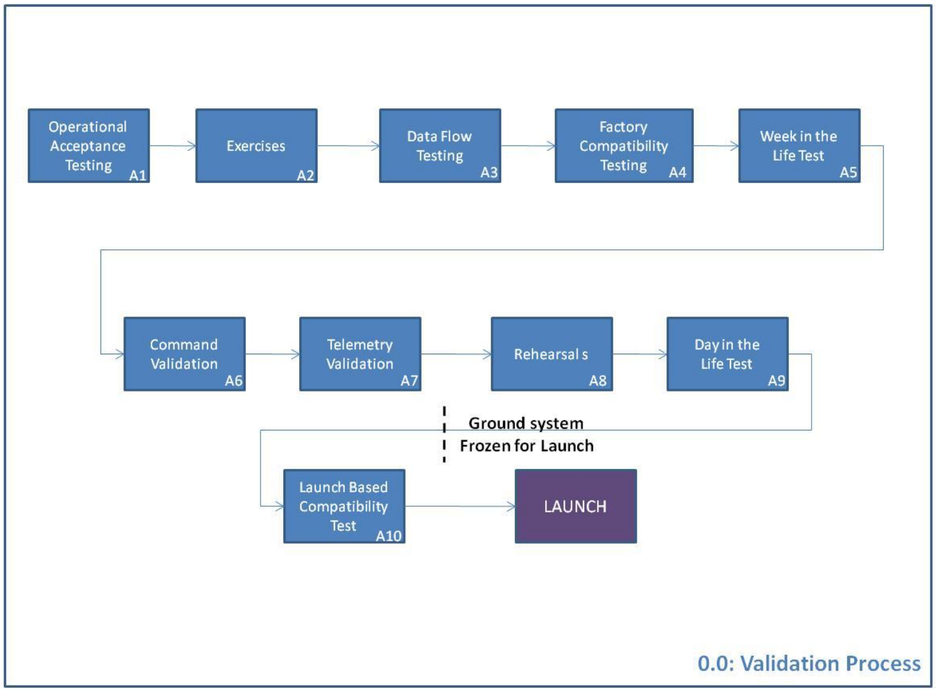
Rehearsal 2: For ground system validation, the second rehearsal has the same objectives as the first rehearsal. However, the second rehearsal is usually50% for training and 50% for launch certification. If a satellite simulator or a computer running the current version of the flight software is used for the rehearsal, then they are even more useful for satellite to ground system compatibility validation. This ensures that the satellite flight software and ground system software are indeed compatible.

Launch Based Compatibility Test: The launch based compatibility test (LBCT) is the final opportunity for the ground system and satellite to connect prior to launch. All of the objectives accomplished at FCT are revalidated during the LBCT. In addition to the main objectives from FCT, LBCT also ensures that the satellite transponder was not damaged during the shipment of the satellite to the launch site and that any previously encountered compatibility issues have been resolved. Since LBCT is the last chance to confirm compatibility, the ground system and satellite baseline are frozen after a successful test, and no software or hardware changes are allowed until after the satellite has launch and is in a safe configuration. Freezes prevent the team from inadvertently changing something that does not allow the ground system to contact the satellite.

Rehearsal Three: For ground system validation, the third rehearsal has the same objectives as the first and second rehearsals. Rehearsals are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. However, the third rehearsal is used 10% for training and 90% for launch certification.

Mission Dress Rehearsal (MDR): MDR is the final training/validation event that occurs before launch, usually less than 10 days prior to launch. Final procedure acceptance occurs during MDR. It is also the final validation for launch critical commands. This is completed either by sending this commands to a simulator during MDR, or if a simulator is not available, by bit busting. MDR is the final event that Mission Critical Personnel are evaluated and certified. It is also the final validation of system interoperability.

Appendix B: Final Validation



<u>Operational Acceptance Testing:</u> Operational Acceptance Testing (OAT) is performed by the organization that will be operating the satellite via the ground system. The operators have two main objectives when performing this testing. (1) Validate that the design is operationally suitable and (2) Evaluate the ground system under operationally realistic conditions.

<u>Exercises:</u> Exercises are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. Exercises are executed as needed throughout the validation process. Because of this, our SMEs concluded that they did not need to be individually called out in our

process. The number of exercises executed by an operations team is based on operator experience and uniqueness of the mission objectives and not on their secondary objectives of compatibility validation.

Data Flow Testing: DFT is usually the first time the satellite and ground system interact. It is the first opportunity to validate that the ground system can receive and process satellite telemetry and that the satellite can receive and process commands sent from the ground system. DFT is usually executed by connecting the satellite and ground system through a mobile communication system and a T-1 line. No RF functionality is tested during this step.

Factory Compatibility Test: The FCT is performed by connecting the satellite to the ground system through an AFSCN test van or the Transportable Space Test and Evaluation Resource (TSTR) van. TSTR is operated by the organization that provides test assets to the Space Community. This organization also has a variety of other equipment that can be used to perform this test, in an event that the TSTR van is not available. The TSTR van allows us to validate the AFSCN configuration (ARTS IRON Databases). This is also a great opportunity to perform extensive satellite and ground system compatibility testing. The primary objective of the FCT is to validate the IRON databases. The FCT is completed by ensure that telemetry is received by the ground system and commands are received by the satellite. Many program offices add objectives to this test in order to maximize the testing opportunity. These objectives include: (1) Validation of all command types, (2) Validation that the flight software and ground software are compatible, and (3) Ensure that critical telemetry points are being properly processed and displayed by the ground system.

Week in the Life Tests: WITLs are performed during the readiness phase of a mission. The WITL is used to ensure that the system can handle the loading of nominal operations. Our SMEs feedback was that typically only one WITL is performed for an R&D satellite mission, so we deleted the second WITL from our original process. A WITL is most successful with participation from the satellite contractor, the ground system contractor and the operator.

Command Validation: The purpose of command validation (CV) is to ensure that the end product (the commands executed by the satellite) matches the input (the tasking file provided by the customer or the commands built by the operator). The specific objectives of command validation are: (1) Validate the customer provided tasking files are processed properly by the ground system, and (2) Validate the command database and validate that a specific command accomplishes the expected action on the satellite.

Telemetry Validation: Telemetry originates on the satellite, is transmitted to the ground, and is processed by the ground system. The objective of Telemetry Validation (TV) is to ensure that the end product (the raw, processed, and displayed telemetry) agrees with the data being produced on the satellite, as interpreted in accordance with the telemetry database provided by the contractor. The steps to ensure the telemetry is valid are as follows: (1) Validating the raw telemetry at the output, (2) Validating the processed telemetry products (EU converted files, etc.), (3) Validating the displayed telemetry (telemetry screens) is properly converted by the ground system and (4) Validating that of red, yellow, and green limits are handled correctly.

Rehearsals: Like Exercises, Rehearsals are primarily used as training events, but they have a secondary mission of testing the ground system and operational concept under realistic loading conditions. Also Rehearsals are often executed as needed throughout the validation process. Because of this, our SMEs concluded that they did not need to be individually called out in our process.

Day in the Life Tests: Day in the Life Test (DITL) is the only step in the validation process that was added based on SME feedback. The DITL exercises the system based on a normal day's activities (not a Launch and Early Orbit (LEO) day's activities.) The main goal is to identify any deficiencies with the ground system that would prevent normal operations. A secondary goal is to examine the routine operations usability of the system at a point where there is still some ability to make modifications if a more efficient, or better process can be established. Routine procedures are run, post pass processing of data should be completed; everything should work as expected on-orbit or changes to the Concept of Operations (CONOPS) or the ground system need to be made. The focus is on the procedures, CONOPS, and the ground system's ability to perform the procedures and CONOPS. A DITL is most successful with participation from the satellite contractor, the ground system contractor and the operator.

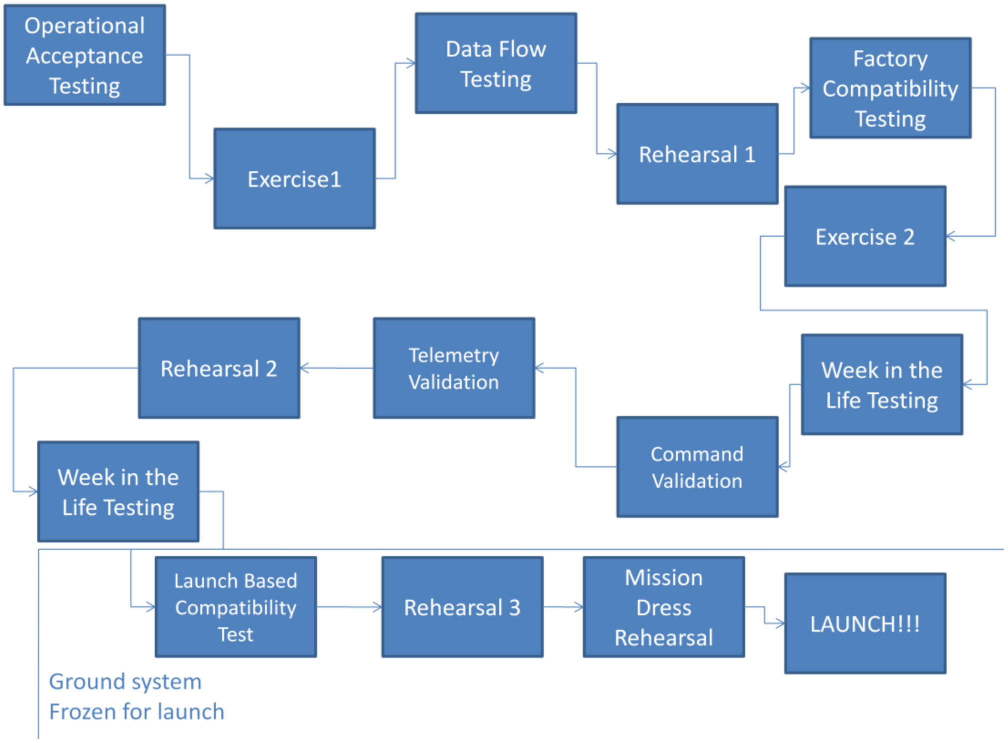
Launch Based Compatibility Test: The Launch Based Compatibility Test (LBCT) is the final opportunity for the ground system and satellite to connect prior to launch. All of the objectives accomplished at FCT are revalidated during the LBCT. In addition to the main objectives from FCT, LBCT ensures that the satellite transponder was not damaged during the shipment of the satellite to the launch site and that any previously encountered compatibility issues have been resolved. Since LBCT is the last chance to confirm compatibility, the ground system and satellite baseline are typically frozen after a successful test, and no software or hardware changes are allowed until after the satellite has launched and is in a safe configuration. Freezes prevent the team from inadvertently changing something that does not allow the ground system to contact the satellite.

Appendix C: Survey #1

STEP 1: Develop a Validation Cost Model

For the scope of our thesis we will be examining the compatibility between an R&D spacecraft and its associated ground system. We will specifically be looking at the process for validating this compatibility. Below is a model of the process. With this survey we also sent out this process with additional information. Please use this model process for answering the questions within our survey.

<u>Validation Process:</u> For the Validation process discussed throughout this survey, the model referenced, is the model shown below.



Define the validation process *This first subsection deals with the validation process identified on page 1 of this survey. Please review this process. After reviewing the process, please answer question 1-5. If you answer "NO" to any question, please explain in the comment section. Please include any additional comments you may have in this section. Additional information about the process model is included in the PowerPoint presentation sent out with this survey. Details include objectives for each step in the process.*	
Are these the right steps in the process? Comments:	Yes No
Are the steps in the right order? Comments:	Yes No
Is the process complete? Comments:	Yes No
If you answered no above, what steps in the process are missing? Comments:	
Are there any steps you don't feel are part of the validation effort? Comments:	Yes No
Assign appropriate cost to each activity *This second subsection deals with assigning a cost to each of the steps in the validation process. Please review the process model and answer questions1-5. Please incorporate any comments from above and include any comments you may have in the comments section.*	

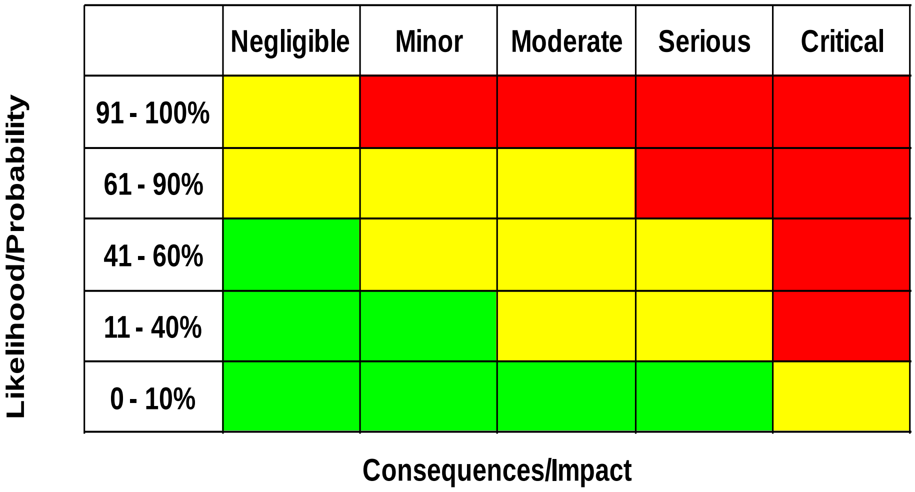
1	Assign a cost to each validation activity. *Please round to the nearest $10K* Comments:	Operational Acceptance Testing___________
		Exercise 1________
		Data Flow Testing___________
		Rehearsal 1_______
		Factory Compatibility Test_____________
		Exercise 2 ________
		Week In The Life Test 1_____________
		Command Validation_________
		Telemetry Validation__________
		Rehearsal 2________
		Week in the life test 2________________
		Launch Based Compatibility Test______________
		Rehearsal 3________
		Mission Dress Rehearsal_________
2a.	What are the assumptions and limitations used to assign the cost for the Operational Acceptance Testing? Comments:	
2b.	What are the assumptions and limitations used to assign the cost for the Exercises? Comments:	
2c.	What are the assumptions and limitations used to assign the cost for the Data Flow Test? Comments:	
2d.	What are the assumptions and limitations used to assign the cost for the Rehearsals? Comments:	
2e.	What are the assumptions and limitations used to assign the cost for the Factory Compatibility Test Comments:	

2f.	What are the assumptions and limitations used to assign the cost for the Week in the Life Test? Comments:
2g.	What are the assumptions and limitations used to assign cost for the Command Validation? Comments:
2h.	What are the assumptions and limitations used to assign cost for the Telemetry Validation? Comments:
2i.	What are the assumptions and limitations used to assign cost for the Launch Based Compatibility Test? Comments:
2j.	What are the assumptions and limitations used to assign cost for the Mission Dress Rehearsal? Comments:
3.	What past program information was used to ascertain this cost? Comments:
4.	What is the impact of not executing each activity? Comments:
5.	What other options are available for each step? Comments:

STEP 2: Identify the Risks Associated With the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks

The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility. Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, we would like to get your input.

Please use the following matrix to determine the probability and the consequences of the occurrence each risk identified.



		Negligible	Minor	Moderate	Serious	Critical
Likelihood/Probability	91 - 100%	🟨	🟥	🟥	🟥	🟥
	61 - 90%	🟨	🟨	🟨	🟥	🟥
	41 - 60%	🟩	🟨	🟨	🟨	🟥
	11 - 40%	🟩	🟩	🟨	🟨	🟥
	0 - 10%	🟩	🟩	🟩	🟩	🟨

Consequences/Impact

Identify the Risks Associated with the Compatibility between an R&D Satellite and its Ground System

The validation process is used to mitigate the risks associated with the compatibility between satellite and their ground systems. In this subsection, please describe all of the risks a typical program office would encounter on this subject

1 Identify the risks associated with the compatibility between R&D satellite and ground systems?

Assign Risks to Isolated Steps in the Validation Process

For each risk identified above, please answer the following:

1a.	Assign Risks to each step in the validation process? *For the first risk you identified above.* Comments:	
1b.	Assign Risks to each step in the validation process? *For the second risk you identified above.* Comments:	
1c.	Assign Risks to each step in the validation process? *For the third risk you identified above.* Comments:	
1d.	Assign Risks to each step in the validation process? *For the fourth risk you identified above.* Comments:	
1e.	Assign Risks to each step in the validation process? *For the fifth risk you identified above.* Comments:	
1f.	Assign Risks to each step in the validation process? *For the sixth risk you identified above.* Comments:	
1g.	Assign Risks to each step in the validation process? *For the seventh risk you identified above.* Comments:	
1h.	Assign Risks to each step in the validation process? *For the eighth risk you identified above.* Comments:	
1i.	Assign Risks to each step in the validation process? For the ninth risk you identified above. Comments:	
1j.	Assign Risks to each step in the validation process? *For the tenth risk you identified above.* Comments:	

Assign Probabilities and Impacts to Each Risk Identified Above

For each risk identified above, please answer the following:

If you don’t need to use each box, please leave the answer blank. If we did not provide enough spaces, please insert additional rows. If a risk has multiple impacts, please identify each impact as a separate line item.

1a.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the first risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	

1b.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the second risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1c.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the third risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1d.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the fourth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1e.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the fifth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1f.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the sixth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1g.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the seventh risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1h.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the eighth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
1i.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the ninth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	

1j.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the tenth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2a.	What is the probability of the risk occurring after performing the steps in the validation process? *For the first risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2b.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the second risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2c.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the third risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2d.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the fourth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2e.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the fifth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2f.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the sixth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2g.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the seventh risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	

2h.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the eighth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2i.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the ninth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
2j.	If none of the validation steps are performed, what is the probability of the risk occurring? *For the tenth risk you identified above.* Comments:	0-10% 11-40% 41-60% 61-90% 91-100%	
3a.	If the risk occurs, what are the impacts associated with it? *For the first risk you identified above.* Comments:		
3b.	If the risk occurs, what are the impacts associated with it? *For the second risk you identified above.* Comments:		
3c.	If the risk occurs, what are the impacts associated with it? *For the third risk you identified above.* Comments:		
3d.	If the risk occurs, what are the impacts associated with it? *For the fourth risk you identified above.* Comments:		
3e.	If the risk occurs, what are the impacts associated with it? *For the fifth risk you identified above.* Comments:		
3f.	If the risk occurs, what are the impacts associated with it? *For the sixth risk you identified above.* Comments:		
3g.	If the risk occurs, what are the impacts associated with it? *For the seventh risk you identified above.* Comments:		

3h.	If the risk occurs, what are the impacts associated with it? *For the eighth risk you identified above.* Comments:		
3i.	If the risk occurs, what are the impacts associated with it? *For the ninth risk you identified above.* Comments:		
3j.	If the risk occurs, what are the impacts associated with it? *For the tenth risk you identified above.* Comments:		
4a.	What is the severity of each impact? *For the first impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4b.	What is the severity of each impact? *For the second impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4c.	What is the severity of each impact? *For the third impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4d.	What is the severity of each impact? *For the fourth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4e.	What is the severity of each impact? *For the fifth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4f.	What is the severity of each impact? *For the sixth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	

4g.	What is the severity of each impact? *For the seventh impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4h.	What is the severity of each impact? *For the eighth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4i.	What is the severity of each impact? *For the ninth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
4j.	What is the severity of each impact? *For the tenth impact you identified above.* Comments	Negligible Minor Moderate Serious Critical	
Define costs Associated with Risk Impacts For the scope of this thesis we are assuming that each risk impact has a cost associated with it. Please assign a cost impact for each identified above. If there are multiple costs associated with a risk impact, please put the total down and explain the multiple costs in the comment section. If a risk has multiple impacts please track each impact as a separate line item.			
1a.	What are the cost associated with the impacts, if the risk occurs. *For the first risk you identified above.* Comments:	$________	
1b.	What are the cost associated with the impacts, if the risk occurs. *For the second risk you identified above.* Comments:	$________	
1c.	What are the costs associated with the impacts, if the risk occurs. *For the third risk you identified above.* Comments:	$________	
1d.	What are the costs associated with the impacts, if the risk occurs. *For the fourth risk you identified above.* Comments:	$________	

1e.	What are the costs associated with the impacts, if the risk occurs. *For the fifth risk you identified above.* Comments:	$________	
1f.	What are the costs associated with the impacts, if the risk occurs. *For the sixth risk you identified above.* Comments:	$________	
1g.	What are the costs associated with the impacts, if the risk occurs. *For the seventh risk you identified above.* Comments:	$________	
1h.	What are the costs associated with the impacts, if the risk occurs. *For the eighth risk you identified above.* Comments:	$________	
1i.	What are the costs associated with the impacts, if the risk occurs. *For the ninth risk you identified above.* Comments:	$________	
1j.	What are the costs associated with the impacts, if the risk occurs. *For the tenth risk you identified above.* Comments:	$________	
Open Ended Questions The following questions may or may not be formally used in our research. However, we would appreciate additional feedback.			
1.	Why is the compatibility between a small R&D satellite and its ground system so important? Comments:		
2.	Can we partially reduce the probability of a risk occurring by performing a cheaper/less extensive variation of a validation step? If so, please comment on which step and how. Comments:	Yes No	
3.	Does a step in the validation process reduce the portability of more than one risk occurring? If so which ones? Comments:	Yes No	
4.	Are there any risks that can occur, that require multiple validation steps? If so which ones? Comments:	Yes No	

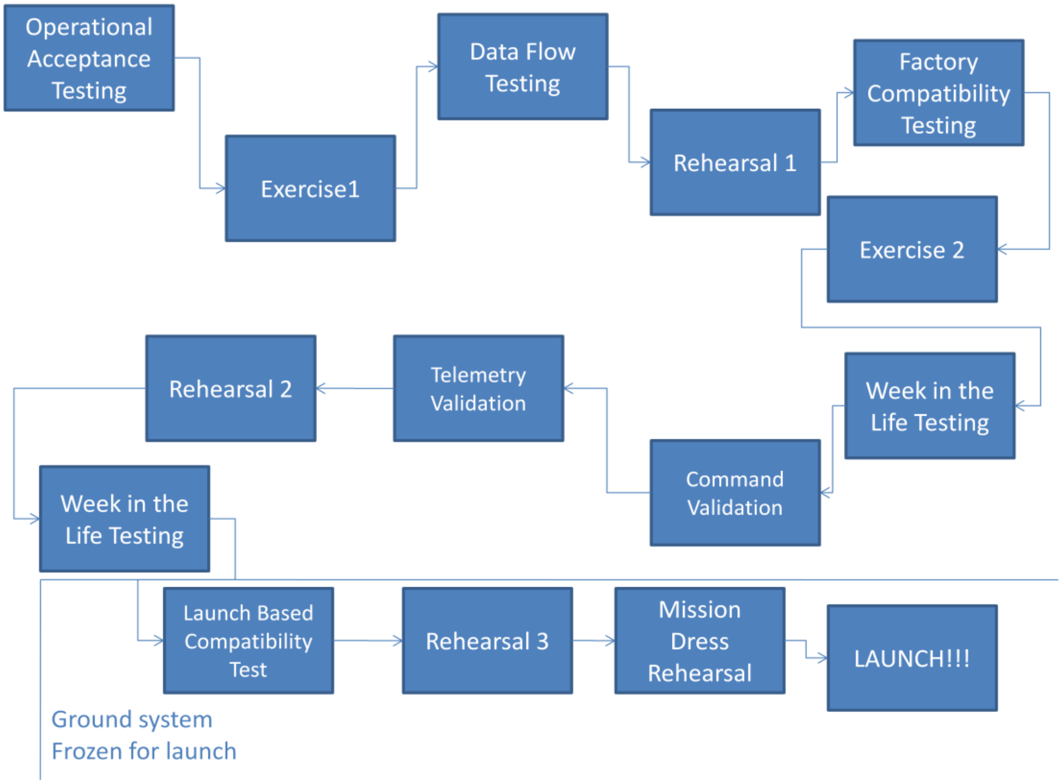
5a.	What tradeoffs are available in each of the risk areas? *For the first risk you identified above.* Comments:	
5b.	What tradeoffs are available in each of the risk areas? *For the second risk you identified above.* Comments:	
5c.	What tradeoffs are available in each of the risk areas? *For the third risk you identified above.* Comments:	
5d.	What tradeoffs are available in each of the risk areas? *For the fourth risk you identified above.* Comments:	
5e.	What tradeoffs are available in each of the risk areas? *For the fifth risk you identified above.* Comments:	
5f.	What tradeoffs are available in each of the risk areas? *For the sixth risk you identified above.* Comments:	
5g.	What tradeoffs are available in each of the risk areas? *For the seventh risk you identified above.* Comments:	
5h.	What tradeoffs are available in each of the risk areas? *For the eighth risk you identified above.* Comments:	
5i.	What tradeoffs are available in each of the risk areas? *For the ninth risk you identified above.* Comments:	
5j.	What tradeoffs are available in each of the risk areas? *For the tenth risk you identified above.* Comments:	

Appendix D: Survey #2

STEP 1: Develop a Validation Cost Model

For the scope of our thesis we will be examining the compatibility between an R&D spacecraft and its associated ground system. We will specifically be looking at the process for validating this compatibility. Below is a model of the process. With this survey we also sent out this process with additional information. Please use this model process for answering the questions within our survey.

Validation Process: For the Validation process discussed throughout this survey, the model referenced, is the model shown below.



Define the validation process This first subsection deals with the validation process identified on page 1 of this survey. Please review this process. The questions that we asked you are listed as Q1-5 and the responses given are listed as R1.x – R5.x. Please review the overall teams assessment and let us know whether you agree or disagree with their comments. All comments were reviewed, as some were very similar, we may have consolidated the overall comment, so you may not see your specific comment.			
Q1	**Are these the right steps in the process?**		
R1.1	Only one Week in the Life Test is needed	Agree Disagree	
R1.2	Rehearsal and training products are part of the training for the operational team and are not part of the overall ground system validation	Agree Disagree	
R1.3	Additional testing is required after each software drop and needs to be incorporated into the overall process	Agree Disagree	
Q2	**Are the steps in the right order?**		
R2.1	Telemetry validation needs to occur before command validation	Agree Disagree	
R2.2	Specific to missions, frequently operational testing occurs much later than you recommend	Agree Disagree	
R2.3	Command and telemetry validation should occur after each software drop (as mentioned in R1.3)	Agree Disagree	
R2.4	Operational acceptance testing is not a separate function, rather part of the entire process.	Agree Disagree	
R2.5	Telemetry and command validation should be done in conjunction with either data flow tests and/or with FCT and or LBCT	Agree Disagree	
R2.6	MDR should not be part of the validation effort	Agree Disagree	
R2.7	Prefers order – DT&E, FCT, OAT, Ex 1, DFT, C&T Validation, Reh 1, WITL	Agree Disagree	
R2.8	Rehearsals/Exercises have a tertiary mission of validation, but primarily used for operational training and thus do not need to come at any specific time in the process, but must be completed, and in fact due help validate the system (especially if a simulator is used for commanding)	Agree Disagree	
Q3	**Is the process complete?**		
R3.1	Add Day in the Life Test (DITL)	Agree Disagree	
R3.2	Call Operational Testing System Testing, which allows you to leave AFSPC out of the testing loop	Agree Disagree	
Q4	**If you answered no above, what steps in the process are missing?**		
R4.1	DT&E is missing	Agree	

		Disagree	
Q5	**Are there any steps you don’t’ feel are part of the validation effort?**		
R5.1	Mission Dress Rehearsal shouldn’t be a part of the validation process because the ground system has already been validated by this point.	Agree Disagree	

R5.3	Only steps that interface the ground system to the satellite are required	Agree Disagree	
R5.5	LBCT should not be part of the validation effort	Agree Disagree	
R5.6	Rehearsals 2,3,etc and exercises 2,3, etc. should not be a part of the validation effort	Agree Disagree	
R5.7	Launch should not be a part of the validation effort	Agree Disagree	

Assign appropriate cost to each activity

This second subsection deals with assigning a cost to each of the steps in the validation process. Please review the process model and answer questions1-5. Please review the costs that were provided by the other subject matter experts and let us know if you agree with the cost or disagree. If you only feel comfortable commenting on costs from your experience/contract, please indicate that to us.

The questions were wrapped together in this section to be easier for you to read, and hopefully eliminate page flipping.

Q1/2a.	**What is the cost of Operational Acceptance Testing? What assumptions and limitations were used in this response?**	
R1/2a.		

Operational Acceptance Testing (OAT)		
Contract	Hours	Dollars
Ground System Development Contractor	0	$0.00
Operations Contractor	168	$12,600.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$12,600.00

Assumptions and Limitations:

- Ground system is stable, satellite has good documentation for ground system,
- The ground system is complete to include MUS
- Each test is only conducted one time
- Based on operations contractor PE for STPSat-2

		Agree Disagree	

Q1/2b **What is the cost of Exercises?**
What assumptions and limitations were used in this response?
*If you complete your exercises connected to a simulator that runs flight software, they are used as a validation activity. The primary mission of a rehearsal is to train the MCF, however this is a function of the rehearsal.

R1/2b

Exercises		
Contract	Hours	Dollars
Ground System Contract	40	$4,000.00
Operations Contract	284	$21,300.00
Mobile Range Flight	0	$0.00
Satellite Developer	0	$0.00
		$25,300.00

Assumptions and Limitations:

- Exercises are internal, mostly used for operational training.
- Operations contractor participation – 3 days, 8hr/day, 7 people ~ $21K
- Ground system development contractor only provide SA support - $4K

Agree

Disagree

Q1/2c

What is the cost of Data Flow Tests?
What assumptions and limitations were used in this response?

R1/2c

Data Flow Testing

Contract	Hours	Dollars
Ground System Contract	702	$70,200.00
Operations Contract	252	$18,900.00
Mobile Range Flight	0	$0.00
Satellite Developer	454	$34,050.00
		$123,150.00

Assumptions and Limitations:

- Ground system/Satellite connectivity required, ground system and factory are remote from one another
- No deployables equipment is required (MRF)
- Mobile comm. system required ($50K per event)
- Deployment of mobile comm
- Ground System Communication is available
- Ground System Development Contractor Cost covers travel, setup and site surveys
- Other includes SV and payload TA support

Agree
Disagree

Q1/2d

What is the cost of Rehearsals?
What assumptions and limitations were used in this response?
**If you complete your rehearsals connected to a simulator that runs flight software, they are used as a validation activity. The primary mission of a rehearsal is to train the MCF, however this is a function of the rehearsal.*

R1/2d

Rehearsals		
Contract	Hours	Dollars
Ground System Contract	120	$12,000.00
Operations Contract	524	$39,300.00
Mobile Range Flight	0	$0.00
Satellite Developer	1200	$90,000.00
		$141,300.00

Assumptions and Limitations:

- Ground system/Satellite connectivity is not required
- All critical MCF personnel are required to be located at the RSC
- Operations contractor support 13 people 8 hours a day for 5 days
- Ground system development contractor will provide SA support only
- 24 hour Ground system development contractor support total ~$12K
- Other includes SV and payload TA support

Agree

Disagree

Q1/2e **What is the cost of Factory Compatibility Test?**
What assumptions and limitations were used in this response?

R1/2e.

Factory Compatibility Test (FCT) with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Flight Site Survey		$60,000.00
Test Asset Flight Operations		$220,000.00
Satellite Development Contractor	708	$53,100.00
		$393,600.00

FCT with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Flight Site Survey		$60,000.00

Test Asset Flight Operations		$160,000.00
Satellite Development Contractor	708	$53,100.00
		$333,600.00

Assumptions and Limitations:

- Ground System/Satellite connectivity required
- Ground System and satellite are remote from one another
- Tester is required ($220K)
- Tester Site Survey Required ($60K)
- Mobile comm. required already in place from DFT
- Mobile ground system already in place, travel added to ensure sys ready
- Other includes SV and payload TA support

		Agree Disagree

Q1/2f **What is the cost of WITL?**
What assumptions and limitations were used in this response?

R1/2f.

Week In The Life Test (WITL)

Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	360	$27,000.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$31,000.00

Assumptions and Limitations:

- Ground System Development Contractor SA Support Only
- Operations contractor internal exercise
- No one required to travel

		Agree Disagree

Q1/2g **What is the cost of Command Validation?**
What assumptions and limitations were used in this response?

R1/2g

Command Validation (CV)

Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00
Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00

<table>
<tr><td></td><td><table><tr><td></td><td></td><td>$19,900.00</td></tr></table>Assumptions and Limitations:
Minimal Ground system development contractor support
Primarily operations contractor, SV Contractor and Government Task
Other includes SV and payload TA support</td><td></td></tr>
<tr><td></td><td></td><td>Agree Disagree</td></tr>
<tr><td>Q1/2h</td><td colspan="2">What is the cost of Telemetry Validation?
What assumptions and limitations were used in this response?</td></tr>
</table>

R1/2 h

Telemetry Validation (TV)		
Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00
Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00
		$19,900.00

Assumptions and Limitations:

- Minimal Ground system development contractor support
- Primarily operations contractor, SV Contractor and Government Task
- Other includes SV and payload TA support

Agree
Disagree

Q1/2i. **What is the cost of LBCT?**
What assumptions and limitations were used in this response?

R1/2i.

Launch Based Compatibility Test (LBCT) at ARTS Site		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset	0	$0.00
Satellite Development Contractor	1000	$75,000.00
		$133,900.00

LBCT with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset		$220,000.00
Satellite Development Contractor	708	$53,100.00
		$333,600.00

LBCT at Launch Site with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset Operations	0	$160,000.00
Test Asset Flight Site Survey		$60,000.00

Satellite Development Contractor	1000	$75,000.00
		$353,900.00

LBCT at Factory with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset	0	$160,000.00
Satellite Development Contractor	708	$53,100.00
		$272,000.00

LBCT at Launch Site with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Operations		$220,000.00
Test Asset Flight Site Survey		$60,000.00
Satellite Development Contractor	1000	$75,000.00
		$415,500.00

Assumptions and Limitations:

- If launched somewhere w/o AFSCN, LBCT will be more
- If launched from either Cape Canaveral or Vandenberg, cost is minimal
- Ground system development contractor assumed no travel required and launch is at Cape or Vandenberg
- Other includes SV and payload TA support

		Agree Disagree
Q1/2j	**What is the cost of MDR?** **What assumptions and limitations were used in this response?**	
R1/2j	Assumptions and Limitations: • Ground System/Satellite connectivity not required • Full LEO capability • 3 days, 24 hr/day • Ground system development contractor will provide SA support only	
		Agree Disagree
Q3.	**What past program information was used to ascertain this cost?**	

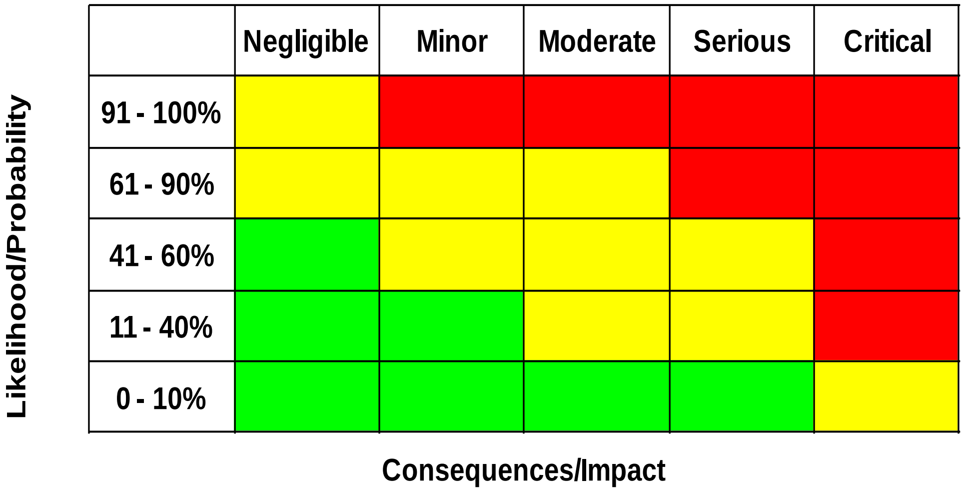
*we do not feel this question required response on subsequent surveys and only found it helpful for our knowledge.		
Q4.	**What is the impact of not executing each activity?**	
R4a	OAT- Ground system would not be validated and deemed acceptable to conduct operations meeting all requirements.	Agree Disagree
R4b	Exercises – Exercises provide a means to indentify project deficiencies related to the ground system or mission planning processes; without these events potential impacts to the project schedule and cost exist due to the discovery of the deficiencies later in the project schedule.	Agree Disagree
R4c	Data Flow Testing – Issues with ground system to satellite compatibility would not be identified at earliest opportunity.	Agree Disagree
R4d	Rehearsals – Inadequate preparedness of operations support staff to perform mission operations; unfamiliarity with the ground system being used to conduct operations. Operational impacts to functionality of ground system would not be assessed.	Agree Disagree
R4e	FCT – Inability to verify correct ARTS IRON database configuration; could potentially result in loss of mission.	Agree Disagree
R4f	WITL testing – Conducted to identify any shortcomings with data processing over an extended period of time and to assess the ground system stability over an extended period of time. For some missions this event has not been conducted without impact to the project.	Agree Disagree
R4h	Command validation – Significant risk of inability to properly command the satellite; could result in loss of mission or data.	Agree Disagree
R4g	Telemetry validation – Inability to adequately assess the health and safety of the satellite; could result in degraded performance or loss of mission.	Agree Disagree
R4i	LBCT – satellite could have been damaged during transport to the launch facility; could result in loss of mission.	Agree Disagree
R4j	MDR – Validation that mission operations team is prepared to support the satellite once on-orbit; failure to conduct this event could result in launching with a support staff that is unprepared for launch.	Agree Disagree
Q5	**What other options are available for each step?**	
R5	May be feasible to add more steps	Agree Disagree

STEP 2:

Identify the Risks Associated With the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks

The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility. Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, we would like to get your input.

Please use the following matrix to determine the probability and the consequences of the occurrence each risk identified.



Likelihood/Probability

	Negligible	Minor	Moderate	Serious	Critical
91 - 100%	🟨	🟥	🟥	🟥	🟥
61 - 90%	🟨	🟨	🟨	🟥	🟥
41 - 60%	🟩	🟨	🟨	🟨	🟥
11 - 40%	🟩	🟩	🟨	🟨	🟥
0 - 10%	🟩	🟩	🟩	🟩	🟨

Consequences/Impact

Identify the Risks Associated with the Compatibility between an R&D Satellite and its Ground System

The validation process is used to mitigate the risks associated with the compatibility between satellite and their ground systems. In this subsection, please describe all of the risks a typical program office would encounter on this subject

All questions in this section were wrapped into one. Therefore the new question will be spelt out at the beginning and is the same question for each risk.

Q	• Identify the risks associated with the compatibility between R&D satellite and ground systems? • Assign Risks to each Step in the Validation Process • If none of the validation steps are performed, what is the probability of the risk occurring? • What is the probability of the risk occurring after performing the steps in the validation process? • If the risk occurs, what are the impacts associated with it? • What is the severity of each impact? • What are the cost associated with the impacts, if the risk occurs.	
Each Risk below addresses the question above, the main idea is in bold		
Risk 1	**Risk:** RF Compatibility between SC and GS **Steps:** FCT and LBCT **Risk before validation step:** 41-60% **Risk after validation step**: 0-10% **Severity:** Critical – unable to cmd, possible loss of range, range rate or telem data **Cost associated with risk:** Possible loss of msn - $100M	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 2	**Risk:** Configuration incompatibility between RTS & SC (i.e., ARTS configuration, IRON Database) **Steps:** FCT and LBCT **Risk before validation step:** 41-60% **Risk after validation step**: 0-10% **Severity:** Critical – unable to cmd, possible loss of range, range rate or tlm data **Cost associated with risk:** Possible loss of msn - $100M	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 3	**Risk:** Cmd incompabilities and errors between SC &GS (i.e., GS cmd database problems) **Steps:** Command validation **Risk before validation step:** 41-60% **Risk after validation step**: 0 -10% **Severity:** Serious – some cmds may not work properly or at all **Cost associated with risk:** $1M	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 4	**Risk:** Telemetry incompatibilities and errors between SC and GS (i.e., GS telemetry database problems) **Steps:** Telemetry Validation **Risk before validation step:** 41-60%	Agree Disagree Agree Disagree Agree Disagree

	Risk after validation step: 0-10% **Severity:** Serious – some telemetry may be reported incorrectly, limits may be set incorrectly **Cost associated with risk:** $1M	Agree Disagree Agree Disagree Agree Disagree
Risk 5	**Risk:** Ground system software does not process and display satellite telemetry correctly **Steps:** Telemetry Validation, FCT, DFT **Risk before validation step:** 41-60% **Risk after validation step**: 0-10% **Severity:** Serious **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 6	**Risk:** Ground system software does not construct and release satellite command correctly **Steps:** Command Validation, FCT, DFT **Risk before validation step:** 11-20% **Risk after validation step**: 0-10% **Severity:** **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 7	**Risk:** Ground system is unable correctly post-pass process payload/mission data correctly **Steps:** WITL, FCT **Risk before validation step:** 41-60% **Risk after validation step**: 0-10% **Severity:** Moderate **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 8	**Risk:** Operational or data latency impacts based on relationship between ground system and satellite flight software (may add more complexity requiring more time or more resources based on flight software handling of data) **Steps:** Exercises and Rehearsals **Risk before validation step:** 41-60% **Risk after validation step**: 11-20% **Severity:** Serious **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 9	**Risk:** A satellite manufacture trying something new with command, format which causes compatibility problems between ground system and satellite. **Steps:** DFT, FCT, LBCT, Command Validation, Telemetry Validation **Risk before validation step:** 61-80% **Risk after validation step**: 11-20%	Agree Disagree Agree Disagree Agree Disagree Agree Disagree

	Severity: Serious – satellite will make numberous changes, adding cost and schedule (MUS development) **Cost associated with risk:** $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K)	Agree Disagree Agree Disagree
Risk 10	**Risk:** Documentation maturity on satellite – could have a great satellite, but documentation could be lacking **Steps:** DFT **Risk before validation step:** 61-80% **Risk after validation step**: 11-20% **Severity:** Minor – GS will be built poorly, and then will require cmd processing and rework, adding cost and schedule **Cost associated with risk:** $24K – dev $20K , test $4K	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 11	**Risk:** Documentation maturity on GS **Steps:** DFT **Risk before validation step:** 11-20% **Risk after validation step**: 0-10% **Severity:** Minor – satellite manufacture will build capability that ground system can't handle, ground system will need to be fixed. Adds cost and schedule **Cost associated with risk:** $24K – dev $20K , test $4K	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 12	**Risk:** Maturity of Satellite Development **Steps:** Command Validation and Telemetry Validation **Risk before validation step:** 11-20% **Risk after validation step**: 0-10% **Severity:** Serious – less mature satellite is more likely to have changes resulting in changes to the ground system **Cost associated with risk:** $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K)	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 13	**Risk:** Maturity of Ground System **Steps:** FCT, LBCT, DFT **Risk before validation step:** 11-20% **Risk after validation step**: 0-10% **Severity:** Moderate – Ground System may not meet Satellite schedule **Cost associated with risk:** $25K-$100K (dev – $20K-$80K, test $5-$20K	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 14	**Risk:** Lack of satellite with telemetry truth data **Steps:** DFT **Risk before validation step:** 41-60% **Risk after validation step**: 11-20% **Severity:** Minor – telemetry not processed correctly – rework required after FCT adding schedule and cost	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree

	Cost associated with risk: $6K (fix database - $5K + $1K test)	Agree Disagree
Risk 15	**Risk:** Lack of satellite command samples **Steps:** DFT **Risk before validation step:** 41-60% **Risk after validation step**: 11-20% **Severity:** Minor – commands not processed correctly – rework required after FCT adding schedule and cost **Cost associated with risk:** $6K (fix - $5K + $1K test)	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 16	**Risk:** System fails to support all operational requirements of the satellite **Steps:** Exercises, Rehearsals, WITL **Risk before validation step:** 11-20% **Risk after validation step**: 0-10% **Severity:** Moderate –late fix – schedule slip **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 17	**Risk:** System will lose/corrupt data **Steps:** Command & Telemetry Validation **Risk before validation step:** 41-60% **Risk after validation step**: 0-10% **Severity:** Minor – satellite commanding and telemetry will be erratic **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree
Risk 18	**Risk:** Delivered products will be improperly formatted (i.e. tasking files) **Steps:** Telemetry Validation **Risk before validation step:** 0-10% **Risk after validation step**: 0-10% **Severity:** Minor – results in increased ops costs, replan contacts, retransmit commands, increased maintenance costs, etc. **Cost associated with risk:**	Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree Agree Disagree

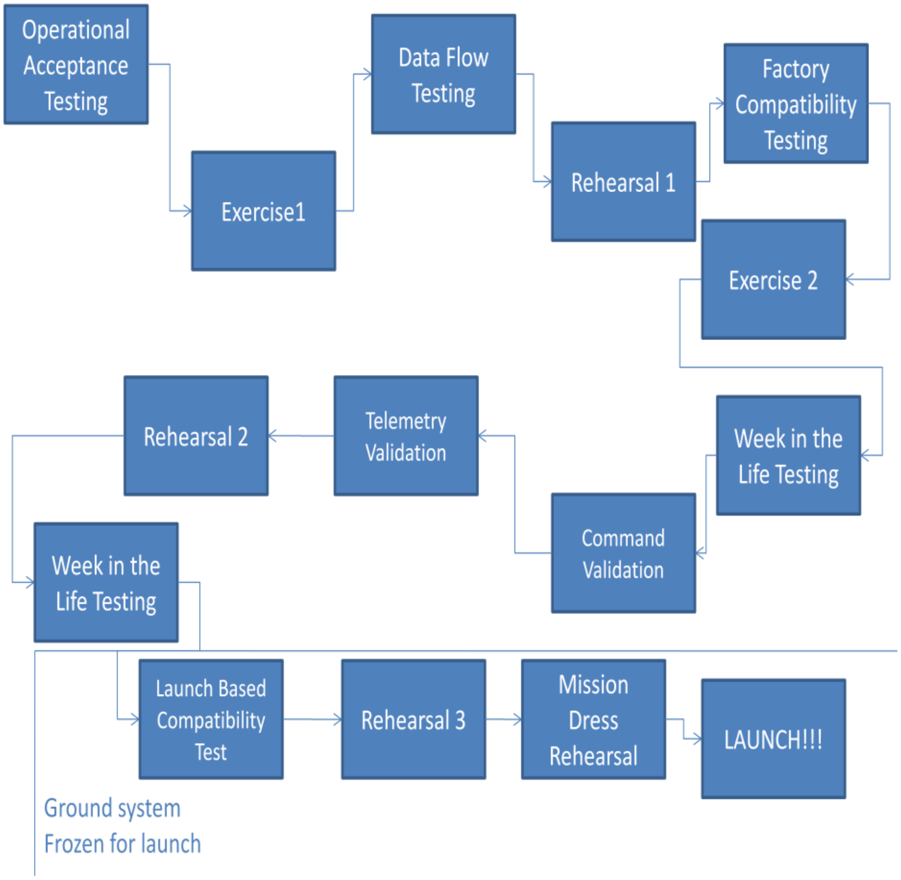
Appendix E: Survey #3

STEP 1: Develop a Validation Cost Model

For the scope of our thesis we will be examining the compatibility between an R&D satellite and its associated ground system. We will specifically be looking at the process for validating this compatibility. Below is a model of the process. With this survey we also sent out this process with additional information. Please use this model process for answering the questions within our survey.

Validation Process: THIS IS THE ORIGINAL VALIDATION PROCESS. THE FINAL PROCESS WILL BE CHANGED BASED ON ALL THE INPUTS.

For the Validation process discussed throughout this survey, the model referenced, is the model shown below.



Define the validation process At this point in the survey process, we eliminated all questions/responses that reached a consensus. Therefore only responses that we are looking for more insight have been included. The overall comments for/against have been included. Please respond to the comments in the right column.		
Are the steps in the right order?		
Operational acceptance testing is not a separate function, rather part of the entire process. Comment: If you wait for rehearsals you may be too late and this is why you need upfront testing. Do you agree with this? If you disagree, please note why.	Response:	
Prefers order – DT&E, FCT, OAT, Ex 1, DFT, C&T Validation, Reh 1, WITL Comment: Though this order is preferred by some, the actual order of validation testing will vary by mission and the availability of personnel, assets, etc. Do you agree with this belief?	Response:	
Is the process complete?		
Add Day in the Life Test (DITL) Why do you feel a DITL would be helpful?	Response:	
If you answered no above, what steps in the process are missing?		
DT&E is missing Comment: DT&E is part of verification and not validation. Do you agree with this comment:	Response:	

Assign appropriate cost to each activity

This second subsection deals with assigning a cost to each of the steps in the validation process. Please review the process model and answer questions1-5. Please review the costs that were provided by the other subject matter experts and let us know if you agree with the cost or disagree. If you only feel comfortable commenting on costs from your experience/contract, please indicate that to us.

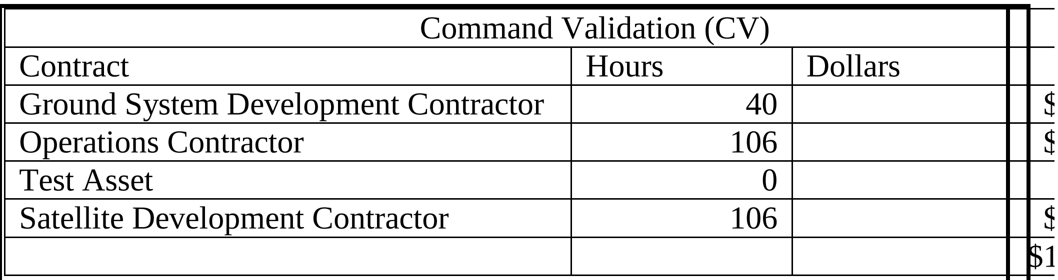
The questions were wrapped together in this section to be easier for you to read, and hopefully eliminate page flipping.

Do you agree with the statements the other experts made throughout this section and why?

<table>
<tr><td>Q1/2f</td><td colspan="2">What is the cost of WITL?
What assumptions and limitations were used in this response?</td></tr>
<tr><td>R1/2f.</td><td colspan="2">
<table>
<tr><th colspan="3">Week In The Life Test (WITL)</th></tr>
<tr><td>Contract</td><td>Hours</td><td>Dollars</td></tr>
<tr><td>Ground System Development Contractor</td><td>40</td><td>$4,000.00</td></tr>
<tr><td>Operations Contractor</td><td>360</td><td>$27,000.00</td></tr>
<tr><td>Test Asset</td><td>0</td><td>$0.00</td></tr>
<tr><td>Satellite Development Contractor</td><td>0</td><td>$0.00</td></tr>
<tr><td></td><td></td><td>$31,000.00</td></tr>
</table>
Assumptions and Limitations:
• Ground system development contractor SA Support Only
• Operations contractor internal exercise
• No one required to travel
</td></tr>
<tr><td></td><td>Comment: Suspect this is on the low side. Although systems and payload specialists may not be required to travel to the RSC, they may still be required to support from their home locations.

If you believe this is low, please state a better estimate. If you agree with this statement but don’t have an estimate, please state as such. If you disagree, please tell us why.</td><td>Response:</td></tr>
</table>

Q1/2g	**What is the cost of Command Validation?** **What assumptions and limitations were used in this response?**

<table>
<tr><td>R1/2g</td><td colspan="2">

<table>
<tr><td colspan="5">Command Validation (CV)</td></tr>
<tr><td>Contract</td><td>Hours</td><td>Dollars</td><td></td><td></td></tr>
<tr><td>Ground System Development Contractor</td><td>40</td><td></td><td></td><td>$</td></tr>
<tr><td>Operations Contractor</td><td>106</td><td></td><td></td><td>$</td></tr>
<tr><td>Test Asset</td><td>0</td><td></td><td></td><td></td></tr>
<tr><td>Satellite Development Contractor</td><td>106</td><td></td><td></td><td>$</td></tr>
<tr><td></td><td></td><td></td><td></td><td>$1</td></tr>
</table>

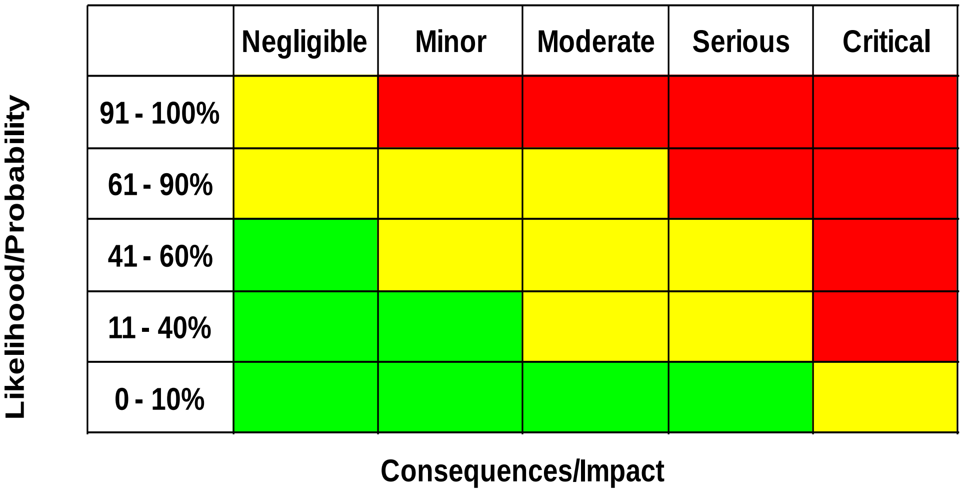
- Minimal Ground System Development Contractor Support
- Primarily operations contractor, SV Contractor and Government Task
- Other includes SV and payload TA support</td></tr>
<tr><td></td><td>Comment: Insufficient data to compute, and wouldn’t this be accomplished in conjunction with some other event that connects the GS & SV, or is a simulator being used, and do you trust simulators? What is the fidelity of the simulator?</td><td>Response:</td></tr>
</table>

Q4.	**What is the impact of not executing each activity?**		
R4e	FCT – Inability to verify correct ARTS IRON database configuration; could potentially result in loss of mission. There was some disagreement on this. Is there another impact that we are missing? Is this not an impact?	Response:	
R4i	LBCT – satellite could have been damaged during transport to the launch facility; could result in loss of mission. Comment: Although an LBCT might not be performed with AFSCN RTS resources, the SV manufacturer will verify the health and status of the SV at the launch site using the Factory Ground Support Equipment. Do you agree with the comment above? Are there other impacts?	Response:	

STEP 2: Identify the Risks Associated With the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks

The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility. Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, we would like to get your input. .

Please use the following matrix to determine the probability and the consequences of the occurrence each risk identified.



	Negligible	Minor	Moderate	Serious	Critical
91 - 100%	🟨	🟥	🟥	🟥	🟥
61 - 90%	🟨	🟨	🟨	🟥	🟥
41 - 60%	🟩	🟨	🟨	🟨	🟥
11 - 40%	🟩	🟩	🟨	🟨	🟥
0 - 10%	🟩	🟩	🟩	🟩	🟨

Identify the Risks Associated with the Compatibility between an R&D Spacecraft and its Ground System

The validation process is used to mitigate the risks associated with the compatibility between spacecraft and their ground systems. In this subsection, please describe all of the risks a typical program office would encounter on this subject

All questions in this section were wrapped into one. Therefore the new question will be spelt out at the beginning and is the same question for each risk.

<table>
<tr><td></td><td>• Identify the risks associated with the compatibility between R&D satellite and ground systems?
• Assign Risks to each Step in the Validation Process
• If none of the validation steps are performed, what is the probability of the risk occurring?
• What is the probability of the risk occurring after performing the steps in the validation process?
• If the risk occurs, what are the impacts associated with it?
• What is the severity of each impact?
• What are the cost associated with the impacts, if the risk occurs.</td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Risk 1: RF Compatibility between SC and GS
Steps: FCT and LBCT – Are any missing? Should some be added?
Risk before validation step: 41-60% Is this too high/low? Why?</td><td></td></tr>
<tr><td colspan="2">Risk 2: Configuration incompatibility between RTS & SC (i.e., ARTS configuration, IRON Database)
Steps: FCT and LBCT – Are any missing? Should some be deleted?
Risk before validation step: 41-60% Is this too high/low? Why?
Severity: Critical – unable to cmd, possible loss of range, range rate or tlm data. If you disagree why?
Cost associated with risk: Possible loss of msn - $100M – If you don’t agree with this number, what do you believe the risk is?</td><td></td></tr>
<tr><td colspan="2">Risk 3: Cmd incompabilities and errors between SC &GS (i.e., GS cmd database problems)
Cost associated with risk: $1M – If you disagreed, why?</td><td></td></tr>
<tr><td colspan="2">Risk 4: Telemetry incompatibilities and errors between SC and GS (i.e., GS telemetry database problems)
Cost associated with risk: $1M - If you disagreed, why?</td><td></td></tr>
<tr><td colspan="2">Risk 5: Ground system software does not process and display satellite telemetry correctly
Risk before validation step: 41-60% - Is this too high/low? Why?
Severity: Serious - If you disagreed, why?</td><td></td></tr>
<tr><td colspan="2">Risk 6: und system software does not construct and release satellite command correctly
Risk before validation step: 11-20% - Is this too high/low? Why?</td><td></td></tr>
<tr><td colspan="2">Risk 7: Ground system is unable correctly post-pass process payload/mission data correctly
Risk before validation step: 41-60% - Is this too high/low? Why?</td><td></td></tr>
<tr><td colspan="2">Risk 8: Operational or data latency impacts based on relationship between ground system and satellite flight software (may add more complexity requiring more time or more resources based on flight software handling of data)
Steps: Exercises and Rehearsals - Are any missing? Should some be deleted?</td><td></td></tr>
</table>

Risk before validation step: 41-60% - Is this too high/low? Why? **Risk after validation step**: 11-20% - Is this too high/low? Why? **Severity:** Serious - Is this too high/low? Why?
Risk 9: A satellite manufacture trying something new with command, format which causes compatibility problems between ground system and satellite. **Risk after validation step**: 11-20% Should validation steps reduce this further? thisfurther?Why/Why not.
Risk 10: Documentation maturity on vehicle – could have a great vehicle, but documentat lacking **Steps:** DFT – Should + FCT + LBCT be added? **Risk after validation step:** 11-20% - Should this risk be further reduced? Why/Why not. **Severity:** Minor – GS will be built poorly, and then will require cmd processing and ework, adding cost and schedule – does this seem too low of a risk for the impact**?**
Risk 11: Documentation maturity on GS **Steps:** DFT - Are any missing? Should some be deleted? **Risk before validation step:** 11-20% - Is this too high/low? Why? **Risk after validation step:** 0-10% - Is this too low? Why? **Cost associated with risk:** $24K – dev $20K, test $4K – Is this too high/low? Why?
Risk 12: Maturity of Vehicle Development **Steps:** Command Validation and Telemetry Validation - Are any missing? Should some be deleted? Ris**k before validation step:** 11-20% - Is this too high/low? Why? **Risk after validation step:** 0-10% - Is this too low? Why?
Risk 13: Maturity of Ground System **Risk before validation step:** 11-20% - is this too high/low? Why? **Risk after validation step:** 0-10% - is this too low?
Risk 14: Lack of vehicle with telemetry truth data **Steps:** DFT - should Tlm Val, FCT, LBCT be added? **Risk after validation step:** 11-20% - is this too high/low? Why? **Severity:** Minor – telemetry not processed correctly – rework required after FCT adding schedule and cost – Is this the incorrect impact or severity or both?
Risk 15: Lack of vehicle command samples **Steps:** DFT - Are any missing? Should some be deleted? **Risk before validation step:** 41-60% - is this too high/low? Why? **Risk after validation step:** 11-20% - is this too high/low? Why? **Severity:** Minor – commands not processed correctly – rework required after FCT adding schedule and cost - Is this the incorrect impact or severity or both?
Risk 16: System fails to support all operational requirements of the satellite **Risk before validation step:** 11-20% - is this too high/low? Why? **Risk after validation step:** 0-10% - is this too low? Why?

Risk 17: System will lose/corrupt data **Steps:** Command & Telemetry Validation – are others missing? Which ones? **Risk after validation step: 0-10% -** is this too low? Why? **Severity:** Minor – satellite commanding and telemetry will be erratic - Is this too low**? W**
Risk 18: Delivered products will be improperly formatted (i.e. tasking files) **Steps: Telemetry** Validation – should we add: WITL, ex, reh, and tasking files for commanding **Risk before validation step:** 0-10% - is this too low? Why?

Appendix F: Results of Survey #1

We received results for Survey #1 from the eight people: three military members, one government civilian, one operations contractor, two ground system contractors, and one independent technical advisor.

Step 1a: The Validation Process:
This first subsection of our survey dealt with the validation process identified on page in chapter three. This section consisted of five questions. Below are these questions and the responses.

Question 1: Are these the right steps in the process?

Responses: Most of the SMEs agreed that the steps in the process were correct. Three of the SMEs answered no and provided the following responses:

1. Only one Week in the Life Test is needed
2. Rehearsal and training products are part of the training for the operational team and are not part of the overall ground system validation
3. Additional testing is required after each software drop and needs to be incorporated into the overall process.

Question 2: Are the steps in the right order?

Responses: All of the SMEs had comments on the order of the process, many of these comments contradicted each other. We are hoping to get greater concurrence on Survey #2. The responses were as follows:

1. Telemetry validation needs to occur before command validation
2. Specific to missions, frequently operational testing occurs much later than recommended
3. Command and telemetry validation should occur after each software drop
4. Operational acceptance testing is not a separate function, rather part of the entire process
5. Telemetry and command validation should be done in conjunction with either data flow tests and/or with FCT and or LBCT
6. MDR should not be part of the validation effort
7. Prefers order – DT&E, FCT, OAT, Ex 1, DFT, C&T Validation, Reh 1, WITL
8. Rehearsals/Exercises have a tertiary mission of validation, but primarily used for operational training and thus do not need to come at any specific time in the process, but must be completed, and in fact due help validate the system (especially if a simulator is used for commanding)

Question 3 and 4: Is the process complete? If you answered no above, what steps in the process are missing?

Responses: Most of the SMEs agreed that the process was complete. However, two of the SMEs answered no and provided the following responses:

1. Add Day in the Life Test (DITL)
2. Call Operational Testing: System Testing, which allows you to leave AFSPC out of the testing loop
3. DT&E is missing

Question 5: Are there any steps you don't feel are part of the validation effort?

Responses: About half of the SMEs felt there were no steps that were not part of the validation process. However the other half felt there were steps that were unnecessary, they provided the following responses:

1. Mission Dress Rehearsal shouldn't be a part of the validation process because the ground system has already been validated by this point
2. Only steps that interface the ground system to the satellite are required
3. LBCT should not be part of the validation effort
4. Rehearsals 2, 3, etc and exercises 1, 2, etc. should not be a part of the validation effort
5. Launch should not be a part of the validation effort.

Overall the SMEs agreed that the validation process was basically complete. We did receive some comments that may drive changes in the validation process, but we won't make any of these changes until after the responses are confirmed by a majority of the SMEs.

Step 1b: Assign appropriate cost to each activity: This second subsection deals with assigning a cost to each of the steps in the validation process. For this section, we did not get very many responses. Because of this we used data from past programs to ascertain costs estimate for each of the steps in the validation process. We included these cost estimates in the second survey and are hoping to get concurrence, or identification of problems with the costs estimates. Below are the cost estimates we derived:

Operational Acceptance Testing (OAT)		
Contract	Hours	Dollars
Ground System Development Contractor	0	$0.00
Operations Contractor	168	$12,600.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$12,600.00

Exercises		
Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	284	$21,300.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$25,300.00

Data Flow Testing (DFT)		
Contract	Hours	Dollars
Ground System Development Contractor	702	$70,200.00
Operations Contractor	252	$18,900.00
Test Asset	0	$0.00
Satellite Development Contractor	454	$34,050.00
		$123,150.00

Rehearsals		
Contract	Hours	Dollars
Ground System Development Contractor	120	$12,000.00
Operations Contractor	524	$39,300.00
Test Asset	0	$0.00
Satellite Development Contractor	1200	$90,000.00
		$141,300.00

Week In The Life Test (WITL)		
Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	360	$27,000.00
Test Asset	0	$0.00
Satellite Development Contractor	0	$0.00
		$31,000.00

Command Validation (CV)		
Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00

Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00
		$19,900.00

Telemetry Validation (TV)		
Contract	Hours	Dollars
Ground System Development Contractor	40	$4,000.00
Operations Contractor	106	$7,950.00
Test Asset	0	$0.00
Satellite Development Contractor	106	$7,950.00
		$19,900.00

Mission Dress Rehearsal (MDR)		
Contract	Hours	Dollars
Ground System Development Contractor	24	$7,200.00
Operations Contractor	63.6	$23,580.00
Test Asset	0	$0.00
Satellite Development Contractor	720	$54,000.00
		$84,780.00

Factory Compatibility Test (FCT) with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Flight Site Survey		$60,000.00
Test Asset Flight Operations		$220,000.00
Satellite Development Contractor	708	$53,100.00
		$393,600.00

FCT with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Flight Site Survey		$60,000.00
Test Asset Flight Operations		$160,000.00
Satellite Development Contractor	708	$53,100.00
		$333,600.00

Launch Based Compatibility Test (LBCT) at ARTS Site		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset	0	$0.00
Satellite Development Contractor	1000	$75,000.00
		$133,900.00

LBCT with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset		$220,000.00
Satellite Development Contractor	708	$53,100.00
		$333,600.00

LBCT at Launch Site with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset Operations	0	$160,000.00
Test Asset Flight Site Survey		$60,000.00
Satellite Development Contractor	1000	$75,000.00
		$353,900.00

LBCT at Factory with STGS-T		
Contract	Hours	Dollars
Ground System Development Contractor	280	$28,000.00
Operations Contractor	412	$30,900.00
Test Asset	0	$160,000.00
Satellite Development Contractor	708	$53,100.00
		$272,000.00

LBCT at Launch Site with TSTR		
Contract	Hours	Dollars
Ground System Development Contractor	296	$29,600.00
Operations Contractor	412	$30,900.00
Test Asset Operations		$220,000.00
Test Asset Flight Site Survey		$60,000.00
Satellite Development Contractor	1000	$75,000.00
		$415,500.00

Along with costs, we asked our SMEs to assess the impacts of not executing each of the steps in the validation process. We consolidated these responses, they are below:

OAT- Ground system would not be validated and deemed acceptable to conduct operations. There would be no assurance that the ground system meets all operational requirements.

Exercises – Exercises provide a means to indentify project deficiencies related to the ground system or mission planning processes; without these events potential impacts to the project schedule and cost exist due to the discovery of the deficiencies later in the project schedule.

Data Flow Testing – Issues with ground system to satellite compatibility would not be identified at earliest opportunity. The later in the validation process, compatibility issues are identified, the more expensive it is to address them.

Rehearsals – Inadequate preparedness of operations support staff to perform mission operations; unfamiliarity with the ground system being used to conduct operations. Operational impacts to functionality of ground system would not be assessed.

FCT – Inability to verify correct ARTS IRON database configuration; could potentially result in loss of mission.

WITL test – Conducted to identify any shortcomings with data processing over an extended period of time and to assess the ground system stability over an extended period of time. For some missions this event has not been conducted without impact to the project.

Command validation – Significant risk of inability to properly command the satellite; could result in loss of mission or data.
Telemetry validation – Inability to adequately assess the health and safety of the satellite; could result in degraded performance or loss of mission.

LBCT – satellite could have been damaged during transport to the launch facility; could result in loss of mission.

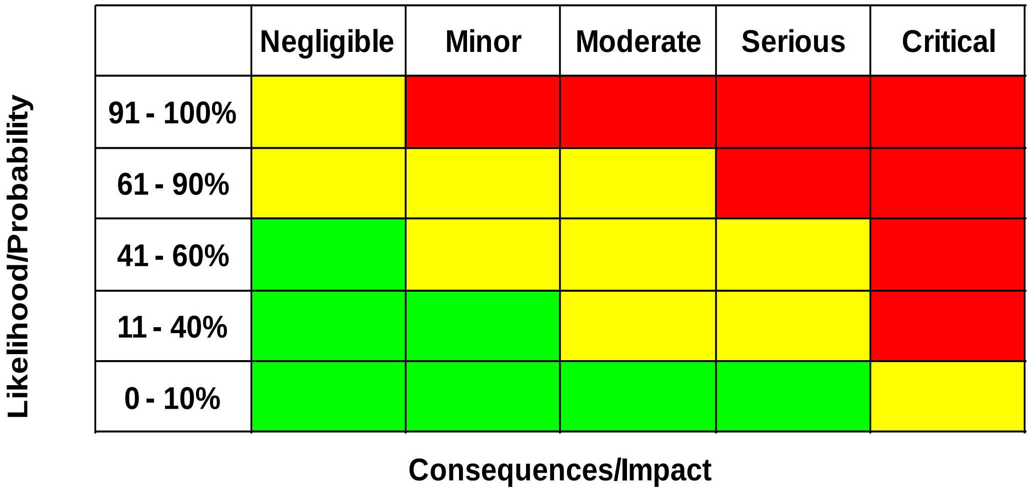
MDR – Validation that mission operations team is prepared to support the satellite once on-orbit; failure to conduct this event could result in launching with a support staff that is unprepared for launch.

All of the SMEs pretty much agreed on the impacts of not executing each of these steps. We have included these in the second survey to receive final concurrence. From the above responses, we have concluded that each of the steps in the validation process is very important.

STEP 2: Identify the Risks Associated With the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks:

The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility.

Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, our SMEs identified these risks. They also identified what steps in the validation process would be used to mitigate these risks. Below are the risks identified by the SMEs and the steps in the validation process to which the steps map. The SMEs also identified the probability of the risk occurring before performing the associated steps in the validation process, the probability after performing the steps and the impact of the risk being realized. The following table was used to assess the probabilities and impacts:



Likelihood/Probability

	Negligible	Minor	Moderate	Serious	Critical
91 - 100%	🟨	🟥	🟥	🟥	🟥
61 - 90%	🟨	🟨	🟨	🟥	🟥
41 - 60%	🟩	🟨	🟨	🟨	🟥
11 - 40%	🟩	🟩	🟨	🟨	🟥
0 - 10%	🟩	🟩	🟩	🟩	🟨

Consequences/Impact

Below are the risks the SMEs identified:

Risk 1: No RF Compatibility between the Satellite and Ground System
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Critical – Ground System is unable to command satellite, possible loss of range, range rate or telemetry data
Cost associated with risk being realized: Possible loss of msn - $100M

Risk 2: Configuration incompatibility between RTS & SC (i.e., ARTS configuration, IRON Database)
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Critical – unable to cmd, possible loss of range, range rate or telemetry data
Cost associated with risk: Possible loss of msn - $100M

Risk 3: Command database incompatibility and errors between SC &GS (i.e., cmd database problems)
Steps in the Validation Process that Mitigate this Risk: Command validation
Risk before validation step: 41-60%
Risk after validation step: 0 -10%
Severity: Serious – some commands may not work properly or at all
Cost associated with risk: $1M

Risk 4: Telemetry database incompatibility and errors between SC and GS (i.e., GS telemetry database problems)
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Serious – some telemetry may be reported incorrectly, limits may be set incorrectly
Cost associated with risk: $1M

Risk 5: Ground system software does not process and display satellite telemetry correctly
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation, FCT, DFT
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Serious – Would require additional software drop, could cause operator to incorrectly command satellite due to false telemetry processing
Cost associated with risk: $500K

Risk 6: Ground system software does not construct and release satellite command correctly
Steps in the Validation Process that Mitigate this Risk: Command Validation, FCT, DFT
Risk before validation step: 11-20%
Risk after validation step: 0-10%
Severity:
Cost associated with risk:

Risk 7: Ground system is unable correctly post-pass process payload/mission data correctly
Steps in the Validation Process that Mitigate this Risk: WITL, FCT
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Moderate
Cost associated with risk:

Risk 8: Operational or data latency impacts based on relationship between ground system and satellite flight software (may add more complexity requiring more time or more resources based on flight software handling of data)
Steps in the Validation Process that Mitigate this Risk: Exercises and Rehearsals
Risk before validation step: 41-60%
Risk after validation step: 11-20%
Severity: Serious
Cost associated with risk: $100K

Risk 9: A satellite manufacture trying something new with command format which causes compatibility problems between ground system and satellite.
Steps in the Validation Process that Mitigate this Risk: DFT, FCT, LBCT, Command Validation, Telemetry Validation
Risk before validation step: 61-80%
Risk after validation step: 11-20%
Severity: Serious – satellite will make numerous changes, adding cost and schedule (MUS development)
Cost associated with risk: $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K)

Risk 10: Documentation maturity on satellite – could have a great satellite, but documentation could be lacking
Steps in the Validation Process that Mitigate this Risk: DFT
Risk before validation step: 61-80%
Risk after validation step: 11-20%
Severity: Minor – GS will be built poorly, and then will require command processing and rework, adding cost and schedule
Cost associated with risk: $24K – dev $20K, test $4K

Risk 11: Documentation maturity on GS
Steps in the Validation Process that Mitigate this Risk: DFT
Risk before validation step: 11-20%
Risk after validation step: 0-10%
Severity: Minor – satellite manufacture will build capability that ground system can't handle, ground system will need to be fixed. Adds cost and schedule
Cost associated with risk: $24K – dev $20K, test $4K

Risk 12: Satellite is not mature enough in development to have important compatibility parameters defined.
Steps in the Validation Process that Mitigate this Risk: Command Validation and Telemetry Validation
Risk before validation step: 11-20%
Risk after validation step: 0-10%
Severity: Serious – less mature satellite is more likely to have changes resulting in changes to the ground system
Cost associated with risk: $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K)

Risk 13: Ground System is not mature enough in development to have important compatibility parameters defined.
Steps in the Validation Process that Mitigate this Risk: FCT, LBCT, DFT
Risk before validation step: 11-20%
Risk after validation step: 0-10%
Severity: Moderate – Ground System may not meet Satellite schedule
Cost associated with risk: $25K-$100K (dev – $20K-$80K, test $5-$20K

Risk 14: Satellite manufacturer does not provide telemetry truth data for ground system DT&E testing
Steps in the Validation Process that Mitigate this Risk: DFT
Risk before validation step: 41-60%
Risk after validation step: 11-20%
Severity: Minor – telemetry not processed correctly – rework required after FCT adding schedule and cost
Cost associated with risk: $6K (fix database - $5K + $1K test)

Risk 15: Satellite does not provide command samples for ground system DT&E testing
Steps in the Validation Process that Mitigate this Risk: DFT
Risk before validation step: 41-60%
Risk after validation step: 11-20%
Severity: Minor – commands not processed correctly – rework required after FCT adding schedule and cost
Cost associated with risk: $6K (fix - $5K + $1K test)

Risk 16: System fails to support all operational requirements of the satellite
Steps in the Validation Process that Mitigate this Risk: Exercises, Rehearsals, WITL
Risk before validation step: 11-20%
Risk after validation step: 0-10%
Severity: Moderate –late fix – schedule slip
Cost associated with risk: Anywhere between $200K and $2M –depending on where in the readiness process the problem is discovered

Risk 17: Ground System will lose/corrupt satellite data
Steps in the Validation Process that Mitigate this Risk: Command & Telemetry Validation
Risk before validation step: 41-60%
Risk after validation step: 0-10%
Severity: Minor – satellite commanding and telemetry will be erratic
Cost associated with risk: $100K

Risk 18: Customer delivered planning products will be improperly formatted (i.e. tasking files)
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation
Risk before validation step: 0-10%
Risk after validation step: 0-10%
Severity: Minor – results in increased ops costs, re-plan contacts, retransmit commands, increased maintenance costs, etc.
Cost associated with risk: $100K either for re-planning activities on a daily basis, or a software solution

All of this information was included in the second survey. We hope to gain statistical confidence that this is a correct and the complete list of risks. We hope to do this by gaining the majority of our SMEs concurrence. The second survey is a very different format than the first survey. Rather than asking our SMEs to give input, we provide the input received in Survey #1 and ask them to agree or disagree and then provide comments based in that. All subsequent surveys will be formatted like this.

Appendix G: Results of Survey #2

We received results for Survey #2 from the same eight people: three military members, one government civilian, one operations contractor, two ground system contractors, and one independent technical advisor.

Step1a: The Validation Process: This first subsection of each survey dealt with the validation process identified on page in chapter three. This section consisted of all of the same questions from Survey #1, and the comments provided by our SMEs. We asked each SME to either agree or disagree with the comments provided by other SMEs. Below are these questions and the responses.

Question 1: Are these the right steps in the process?

Responses for Survey #1 with Results from Survey #2:

1. Only one Week in the Life Test is needed – All SMEs agreed that only one WITL is required.
2. Rehearsal and training products are part of the training for the operational team and are not part of the overall ground system validation – All SMEs with Operational experience agreed that Rehearsal and Exercises are an important part of the validation process. One SME disagreed.
3. Additional testing is required after each software drop and needs to be incorporated into the overall process. – All SMEs agree that additional testing is needed after each software release.

Question 2: Are the steps in the right order?

Responses for Survey #1 with Results from Survey #2:

1. Telemetry validation needs to occur before command validation- Only one SME felt that Telemetry Validation needs to be completed first, the rest of the SMEs feel that CV and TV are usually completed together or it doesn't matter.
2. Specific to missions, frequently operational testing occurs much later than recommended - All SMEs but one believe that this is true; the one SME that disagreed commented: that he does not participate in OAT and therefore did not have an opinion.
3. Command and telemetry validation should occur after each software drop – All SMEs disagreed with this statement. Comments we got included that testing needs to be done, but understand that it cannot be as extensive and full command and telemetry validation.
4. Operational acceptance testing is not a separate function, rather part of the entire process – We did not get a consensus from our SMEs on this topic, we will evaluate further in Survey #3.

5. Telemetry and command validation should be done in conjunction with either data flow tests and/or with FCT and or LBCT – Only one SME disagreed with this statement. He is the independent technical advisor.
6. MDR should not be part of the validation effort – All SMEs agreed with this assessment
7. Prefers order – DT&E, FCT, OAT, Ex 1, DFT, C&T Validation, Rehearsal 1, WITL – We did not reach consensus on this order, however many SMEs commented that the order of the validation process will change depending on the mission. This is the comment we will be including Survey #3.
8. Rehearsals/Exercises have a tertiary mission of validation, but primarily used for operational training and thus do not need to come at any specific time in the process, but must be completed, and in fact due help validate the system (especially if a simulator is used for commanding) - All SMEs but one agreed that Rehearsal and Exercises are an important part of the validation process, one SME disagreed.

Question 3 and 4: Is the process complete? If you answered no above, what steps in the process are missing?

Responses for Survey #1 with Results from Survey #2:

1. Add Day in the Life Test (DITL) - We did not get a consensus from our SMEs on this topic, we will evaluate further in Survey #3.
2. Call Operational Testing: System Testing, which allows you to leave AFSPC out of the testing loop – All SMEs agreed with this assessment. However, we will not be changing the name. If programs wish to call this activity system testing that is fine, but the objectives are to ensure that the system meets all operational requirements.
3. DT&E is missing – Only one SME agreed with this statement. We feel that DT&E is a part of verification and not the validation process. We understand that DT&E is important but feel that it is not in the scope of this thesis. We will be posing this comment in Survey #3

Question 5: Are there any steps you don't' feel are part of the validation effort?

Responses for Survey #1 with Results from Survey #2:

1. Mission Dress Rehearsal shouldn't be a part of the validation process because the ground system has already been validated by this point - All SMEs but one agreed that MDR is not part of the Validation Process, one SME disagreed.
2. Only steps that interface the ground system to the satellite are required – All SMEs disagree with this statement
3. LBCT should not be part of the validation effort – Only one SME feels this is true….all other SMEs feel that LBCT is an important step in the validation process.

4. Rehearsals 2, 3, etc and exercises 1, 2, etc. should not be a part of the validation effort – Only one SME agrees with this assessment; all others disagree. From this SMEs comments, we feel that all Rehearsals and Exercises are an important part of validation, but we may combine them into one step in the validation process since they all serve the same function.
5. Launch should not be a part of the validation effort. – All SMEs but one feel that launch is not part of validation. We think that our SMEs misunderstood the reason for ending the process with launch. We did not intend to insinuate that launch is part of the validation process but simply that the validation process leads to launch. The one SME that disagreed with this statement did bring up a good point that some requirements cannot be tested until the satellite is on-orbit.

Step 1b: Assign appropriate cost to each activity: This second subsection deals with assigning a cost to each of the steps in the validation process. We included the cost estimate that calculated based on past and current program actuals in the second survey. Below are the cost estimates we derived and the SME comments:
1. OAT- All SMEs agreed with our cost estimate, assumptions and limitations for OAT
2. Exercises – All SMEs agreed with our cost estimate, assumptions and limitations for Exercises
3. DFT- All SMEs agreed with our cost estimate, assumptions and limitations for DFT
4. Rehearsals - All SMEs agreed with our cost estimate, assumptions and limitations for rehearsals
5. FCT - All SMEs agreed with our cost estimate, assumptions and limitations for FCT with the exception of one SME. He felt that this cost estimate was too high. We feel that although he is correct in theory many missions use the FCT as an opportunity to fully test the satellite and ground system compatibility end to end that therefore the test is more robust and more expensive.
6. WITL - All SMEs agreed with our cost estimate, assumptions and limitations for WITL
7. CV - All SMEs agreed with our cost estimate, assumptions and limitations for CV
8. TV - All SMEs agreed with our cost estimate, assumptions and limitations for TV
9. LBCT - All SMEs agreed with our cost estimate, assumptions and limitations for LBCT
10. MDR- All SMEs agreed with our cost estimate, assumptions and limitations for MDR

Along with costs, we asked our SMEs to assess the impacts of not executing each of the steps in the validation process. We consolidated these responses from Survey #1 and asked each SME to agree or disagree in Survey #2. The responses are below:

OAT- Ground system would not be validated and deemed acceptable to conduct operations. There would be no assurance that the ground system meets all operational requirements. – All SMEs agreed with the impacts of not executing OAT.

Exercises – Exercises provide a means to indentify project deficiencies related to the ground system or mission planning processes; without these events potential impacts to the project schedule and cost exist due to the discovery of the deficiencies later in the project schedule. - All SMEs agreed with the impacts of not executing exercises.

Data Flow Testing – Issues with ground system to satellite compatibility would not be identified at earliest opportunity. The later in the validation process, compatibility issues are identified, the more expensive it is to address them. - All SMEs agreed with the impacts of not executing DFT.

Rehearsals – Inadequate preparedness of operations support staff to perform mission operations; unfamiliarity with the ground system being used to conduct operations. Operational impacts to functionality of ground system would not be assessed. - All SMEs agreed with the impacts of not executing rehearsals

FCT – Inability to verify correct ARTS IRON database configuration; could potentially result in loss of mission. All SMEs agreed with the impacts of not executing FCT except one. He did not provide any comments as to why.

WITL test – Conducted to identify any shortcomings with data processing over an extended period of time and to assess the ground system stability over an extended period of time. For some missions this event has not been conducted without impact to the project. - All SMEs agreed with the impacts of not executing WITL.

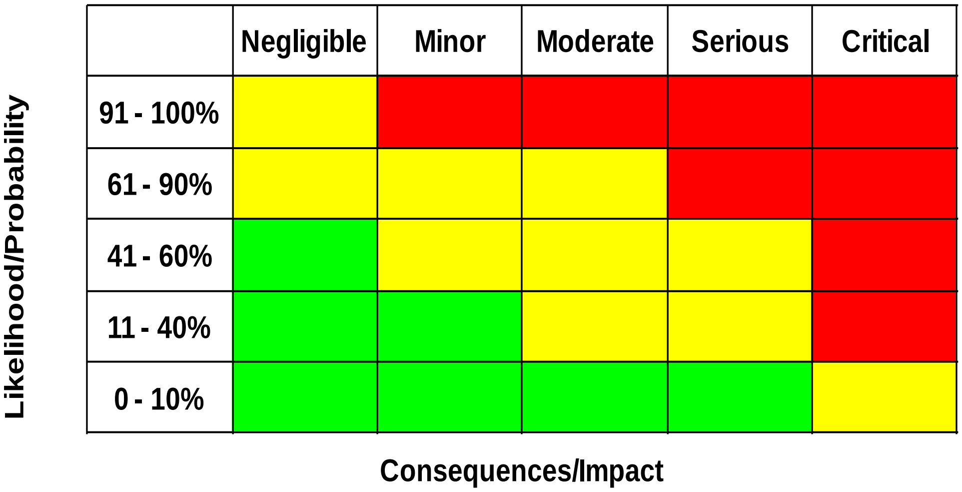
Command validation – Significant risk of inability to properly command the satellite; could result in loss of mission or data. - All SMEs agreed with the impacts of not executing CV.

Telemetry validation – Inability to adequately assess the health and safety of the satellite; could result in degraded performance or loss of mission. - All SMEs agreed with the impacts of not executing TV.

LBCT – satellite could have been damaged during transport to the launch facility; could result in loss of mission. - All SMEs agreed with the impacts of not executing LBCT.

MDR – Validation that mission operations team is prepared to support the satellite once on-orbit; failure to conduct this event could result in launching with a support staff that is unprepared for launch.- All SMEs agreed with the impacts of not executing MDR.

STEP 2: Identify the Risks Associated with the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks: The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility. Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, our SMEs identified these risks. They also identified what steps in the validation process would be used to mitigate these risks. Below are the risks identified by the SMEs and the steps in the validation process to which the steps map. The SMEs also identified the probability of the risk occurring before performing the associated steps in the validation process, the probability after performing the steps and the impact of the risk being realized. All of this information was gathered in Survey #1, in Survey #2 we asked the SMEs to either agree or disagree with the data. The following table was used to assess the probabilities and impacts:



Likelihood/Probability

	Negligible	Minor	Moderate	Serious	Critical
91 - 100%	🟨	🟥	🟥	🟥	🟥
61 - 90%	🟨	🟨	🟨	🟥	🟥
41 - 60%	🟩	🟨	🟨	🟨	🟥
11 - 40%	🟩	🟩	🟨	🟨	🟥
0 - 10%	🟩	🟩	🟩	🟩	🟨

Consequences/Impact

Below are the risks the SMEs identified:

Risk 1: No RF Compatibility between the Satellite and Ground System – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT– All SMEs agreed with exception of one; no comments provided.
Risk before validation step: 41-60%– All SMEs agreed with exception of one no comments provided.
Risk after validation step: 0-10%– All SMEs agreed
Severity: Critical – Ground System is unable to command satellite, possible loss of range, range rate or telemetry data– All SMEs agreed
Cost associated with risk being realized: Possible loss of msn - $100M – All SMEs agreed

Risk 2: Configuration incompatibility between RTS & SC (i.e., ARTS configuration, IRON Database) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT– All SMEs agreed with the exception of one.

Risk before validation step: 41-60% – All SMEs agreed with exception of one.
Risk after validation step: 0-10% – All SMEs agreed
Severity: Critical – unable to cmd, possible loss of range, range rate or telemetry data - All SMEs agreed with exception of one.
Cost associated with risk: Possible loss of msn - $100M - All SMEs agreed with exception of one.

Risk 3: Command database incompatibility and errors between SC &GS (i.e., cmd database problems) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Command validation– All SMEs agreed
Risk before validation step: 41-60% – All SMEs agreed
Risk after validation step: 0 -10%– All SMEs agreed with the exception of one.
Severity: Serious – some commands may not work properly or at all– All SMEs agreed
Cost associated with risk: $1M – All SMEs agreed with exception of one.

Risk 4: Telemetry database incompatibility and errors between SC and GS (i.e., GS telemetry database problems) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation– All SMEs agreed
Risk before validation step: 41-60% – All SMEs agreed
Risk after validation step: 0-10%– All SMEs agreed
Severity: Serious – some telemetry may be reported incorrectly, limits may be set incorrectly– All SMEs agreed
Cost associated with risk: $1M– All SMEs agreed with exception of one.

Risk 5: Ground system software does not process and display satellite telemetry correctly– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation, FCT, and DFT– All SMEs agreed
Risk before validation step: 41-60%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed
Severity: Serious – Would require additional software drop, could cause operator to incorrectly command satellite due to false telemetry processing – All SMEs agreed with exception of one
Cost associated with risk: $500K – All SMEs agreed with exception of one who thought that the impact would be more than $1M

Risk 6: Ground system software does not construct and release satellite command correctly– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Command Validation, FCT, and DFT– All SMEs agreed
Risk before validation step: 11-20% – All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed

Severity: Critical was added by one SME no one else commented; we hope to receive more concurrence in Survey #3
Cost associated with risk: Loss of mission; $100M was added by one SME no one else commented; we hope to receive more concurrence in Survey #3

Risk 7: Ground system is unable correctly post-pass process payload/mission data correctly – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: WITL, FCT– All SMEs agreed
Risk before validation step: 41-60%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed
Severity: Moderate– All SMEs agreed
Cost associated with risk: delay in mission data <$200K was added by one SME no one else commented; we hope to receive more concurrence in Survey #3

Risk 8: Operational or data latency impacts based on relationship between ground system and satellite flight software (may add more complexity requiring more time or more resources based on flight software handling of data) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Exercises and Rehearsals– All SMEs agreed
Risk before validation step: 41-60% – All SMEs agreed with exception of one
Risk after validation step: 11-20% – All SMEs agreed with exception of one
Severity: Serious– All SMEs agreed with exception of one
Cost associated with risk: $100K was added by one SME no one else commented; we hope to receive more concurrence in Survey #3

Risk 9: A satellite manufacture trying something new with command format which causes compatibility problems between ground system and satellite. – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: DFT, FCT, LBCT, Command Validation, and Telemetry Validation– All SMEs agreed
Risk before validation step: 61-80% – All SMEs agreed
Risk after validation step: 11-20% – All SMEs agreed
Severity: Serious – satellite will make numerous changes, adding cost and schedule (MUS development) – All SMEs agreed
Cost associated with risk: $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K) – All SMEs agreed

Risk 10: Documentation maturity on satellite – could have a great satellite, but documentation could be lacking– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed with exception of one
Risk before validation step: 61-80% – All SMEs agreed
Risk after validation step: 11-20%– All SMEs agreed with exception of one
Severity: Minor – GS will be built poorly, and then will require command processing and rework, adding cost and schedule– All SMEs agreed with exception of one

Cost associated with risk: $24K – dev $20K, test $4K– All SMEs agreed with exception of one

Risk 11: Documentation maturity on GS– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed with exception of one
Risk before validation step: 11-20%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed with exception of one
Severity: Minor – satellite manufacture will build capability that ground system can't handle, ground system will need to be fixed. Adds cost and schedule– All SMEs agreed
Cost associated with risk: $24K – dev $20K, test $4K– All SMEs agreed with exception of one who thinks the cost would be more.

Risk 12: Satellite is not mature enough in development to have important compatibility parameters defined. – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Command Validation and Telemetry Validation– All SMEs agreed with exception of one
Risk before validation step: 11-20%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed with exception of one
Severity: Serious – less mature satellite is more likely to have changes resulting in changes to the ground system– All SMEs agreed
Cost associated with risk: $60-$200K (MUS dev & test – Dev $50-$150K, Test $10-$50K) – All SMEs agreed

Risk 13: Ground System is not mature enough in development to have important compatibility parameters defined. – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: FCT, LBCT, and DFT– All SMEs agreed
Risk before validation step: 11-20%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed with exception of one
Severity: Moderate – Ground System may not meet Satellite schedule– All SMEs agreed
Cost associated with risk: $25K-$100K (dev – $20K-$80K, test $5-$20K– All SMEs agreed

Risk 14: Satellite manufacturer does not provide telemetry truth data for ground system DT&E testing– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed with exception of one
Risk before validation step: 41-60%– All SMEs agreed
Risk after validation step: 11-20%– All SMEs agreed with exception of one
Severity: Minor – telemetry not processed correctly – rework required after FCT adding schedule and cost– All SMEs agreed with exception of one.
Cost associated with risk: $6K (fix database - $5K + $1K test) – All SMEs agreed

Risk 15: Satellite does not provide command samples for ground system DT&E testing – All SMEs agreed with exception of one
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed with exception of one
Risk before validation step: 41-60%– All SMEs agreed with exception of one
Risk after validation step: 11-20%– All SMEs agreed with exception of one
Severity: Minor – commands not processed correctly – rework required after FCT adding schedule and cost– All SMEs agreed with exception of one
Cost associated with risk: $6K (fix - $5K + $1K test) – All SMEs agreed

Risk 16: System fails to support all operational requirements of the satellite– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Exercises, Rehearsals, WITL– All SMEs disagreed
Risk before validation step: 11-20%– All SMEs agreed with exception of one
Risk after validation step: 0-10%– All SMEs agreed
Severity: Moderate –late fix – schedule slip– All SMEs agreed
Cost associated with risk: Anywhere between $200K and $2M –depending on where in the readiness process the problem is discovered – All SMEs agreed

Risk 17: Ground System will lose/corrupt satellite data– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Command & Telemetry Validation– All SMEs agreed with exception of one
Risk before validation step: 41-60%– All SMEs agreed
Risk after validation step: 0-10%– All SMEs agreed with exception of one
Severity: Minor – satellite commanding and telemetry will be erratic– All SMEs agreed with exception of one
Cost associated with risk: $100K was added by one SME no one else commented; we hope to receive more concurrence in Survey #3

Risk 18: Customer delivered planning products will be improperly formatted (i.e. tasking files) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation – All SMEs disagreed
Risk before validation step: 0-10%– All SMEs disagreed
Risk after validation step: 0-10% – All SMEs agreed
Severity: Minor – results in increased ops costs, re-plan contacts, retransmit commands, increased maintenance costs, etc. – All SMEs agreed
Cost associated with risk: $100K either for re-planning activities on a daily basis, or a software solution$100K was added by one SME no one else commented; we hope to receive more concurrence in Survey #3

We got very few comments in the risk section. We will add any disagreements to Survey #3 and hope to receive more concurrence and clarification in Survey #3.

Appendix H: Results of Survey #3

We received results for Survey #3 from the same eight people: three military members, one government civilian, one operations contractor, two ground system contractors, and one and one independent technical advisor.

** The only comments we included in Survey #3 were ones that did not have unanimous concurrence on Survey #2.**

The Validation Process: This first subsection of each survey dealt with the validation process identified on page in chapter three. This section consisted of all of the same questions from Survey #2 with comments that did not receive 100% concurrence in Survey #2.

Question 1: Are these the right steps in the process?
No comments were included pertaining to this question in Survey #3 because we believe that we received adequate concurrence

Question 2: Are the steps in the right order?

1. Operational acceptance testing is not a separate function, rather part of the entire process – We still did not receive concurrence on this subject in Survey #3. In fact none of the SMEs changed their responses.

Response:

1. Only one SME felt strongly that OAT should not be accomplished as a separate test, therefore we will include it in the process.

2. Prefers order – DT&E, FCT, OAT, Ex 1, DFT, C&T Validation, Reh 1, WITL - All of our SMEs agreed that the order of the validation process will vary from mission to mission. Therefore we are going to continue with the original order (with the omissions and additions from our SMEs) and discuss this in our discussion.

Question 3 and 4: Is the process complete? If you answered no above, what steps in the process are missing?

1. Add Day in the Life Test (DITL)

Response: All SMEs agreed that a DITL should be added to the process.

Question 5: Are there any steps you don't' feel are part of the validation effort?

No comments were included pertaining to this question in Survey #3 because we believe that we received adequate concurrence.

Assign appropriate cost to each activity: This second subsection deals with assigning a cost to each of the steps in the validation process. We included the cost estimate that calculated based on past and current program actuals in the second survey. Below are the cost estimates we derived and the SME comments:

1. WITL - All SMEs agreed with our cost estimate, assumptions and limitations for WITL

Response: All SMEs felt that the cost was too low because we did not include satellite manufacturer hours and costs. We included these and here is the new WITL costs.

Week In The Life Test (WITL)		
Contract	Hours	Dollars
Ground System Contract	40	$4,000.00
Operations Contract	360	$27,000.00
Mobile Range Flight	0	$0.00
Satellite Developer	360	$27,000.00
		$58,000.00

2. CV - All SMEs agreed with our cost estimate, assumptions and limitations for CV

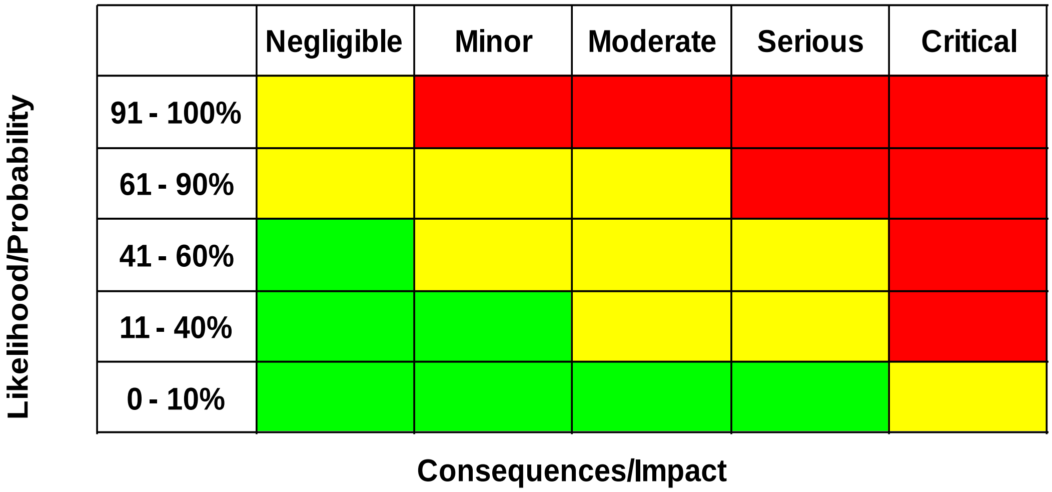
Response: Only SME comment was that this should take 3 people one week which is consist with our original estimate so we will keep our original estimate.

Along with costs, we asked our SMEs to assess the impacts of not executing each of the steps in the validation process. We only included the responses from Survey #2 in Survey #3 that did not have unanimous agreement.

FCT – Inability to verify correct ARTS IRON database configuration; could potentially result in loss of mission. All SMEs agreed with the impacts of not executing FCT

LBCT – satellite could have been damaged during transport to the launch facility; could result in loss of mission. - All SMEs agreed with the impacts of not executing LBCT.

STEP 2: Identify the Risks Associated With the Compatibility between R&D Satellite and their Ground Systems, Assign Risks to Isolated Steps in the Validation Process and Define Costs Associated with Impacts of Risks: The compatibility between a satellite and its ground system is very important. Every satellite program office assesses and monitors the risks associated with this compatibility. Each step in the validation process is performed in order to mitigate one of more risks associated with the compatibility between a satellite and its ground system. In this step, our SMEs identified these risks. They also identified what steps in the validation process would be used to mitigate these risks. Below are the risks identified by the SMEs and the steps in the validation process to which the steps map. The SMEs also identified the probability of the risk occurring before performing the associated steps in the validation process, the probability after performing the steps and the impact of the risk being realized. Only the comments without 100% agreement in Survey #2 were included in Survey #3.



Likelihood/Probability

	Negligible	Minor	Moderate	Serious	Critical
91 - 100%	🟨	🟥	🟥	🟥	🟥
61 - 90%	🟨	🟨	🟨	🟥	🟥
41 - 60%	🟩	🟨	🟨	🟨	🟥
11 - 40%	🟩	🟩	🟨	🟨	🟥
0 - 10%	🟩	🟩	🟩	🟩	🟨

Consequences/Impact

Below are the risks the SMEs identified:

Risk 1: No RF Compatibility between the Satellite and Ground System
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT– All SMEs agreed that this was a good list of steps
Risk before validation step: 41-60%– All SMEs agreed that this was a good assessment

Risk 2: Configuration incompatibility between RTS & SC (i.e., ARTS configuration, IRON Database)
Steps in the Validation Process that Mitigate this Risk: FCT and LBCT– All SMEs agreed however, we should include in our discussion that LBCT importance drops with a successful FCT.
Risk before validation step: 41-60% – All SMEs agreed risks probability is acceptable.
Severity: Critical – unable to command, possible loss of range, range rate or telemetry data - All SMEs agreed severity is acceptable.
Cost associated with risk: Possible loss of msn - $100M - All SMEs agreed the costs is acceptable.

Risk 3: Command database incompatibility and errors between SC &GS (i.e., command database problems) – All SMEs agreed
Cost associated with risk: $1M – All SMEs agreed with costs associated with this risk

Risk 4: Telemetry database incompatibility and errors between SC and GS (i.e., GS telemetry database problems)
Cost associated with risk: $1M– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.

Risk 5: Ground system software does not process and display satellite telemetry correctly
Risk before validation step: 41-60% – All SMEs agree this is correct
Severity: Serious – Would require additional software drop, could cause operator to incorrectly – All SMEs agree this is correct

Risk 6: Ground system software does not construct and release satellite command correctly
Risk before validation step: 11-40% – All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority

Risk 7: Ground system is unable correctly post-pass process payload/mission data correctly
Risk before validation step: 41-60%– All SMEs agreed with exception of one– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority

Risk 8: Operational or data latency impacts based on relationship between ground system and satellite flight software (may add more complexity requiring more time or more resources based on flight software handling of data) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Exercises and Rehearsals– SMEs agree that we should add DFT, FCT and LBCT
Risk before validation step: 41-60% – All SMEs agreed this is acceptable
Risk after validation step: 11-20% – All SMEs agreed this is acceptable
Severity: Serious– All SMEs agreed this is acceptable

Risk 9: A satellite manufacture trying something new with command format which causes compatibility problems between ground system and satellite.
Risk after validation step: 11-20% – All SMEs agreed this is acceptable

Risk 10: Documentation maturity on satellite – could have a great satellite, but documentation could be lacking
Steps in the Validation Process that Mitigate this Risk: DFT– SMEs feel we should add FCT and LBCT
Risk after validation step: 0-10%– All SMEs agreed with exception of one

Severity: Minor – GS will be built poorly, and then will require command processing and rework, adding cost and schedule– All SMEs agreed is acceptable

Risk 11: Documentation maturity on GS
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed this is acceptable
Risk before validation step: 11-40%– All SMEs agreed this is acceptable
Risk after validation step: 0-10%– All SMEs agreed this is acceptable
***Bad training, incorrect ops procedures and disillusioned operators can add to this problem. ***
Cost associated with risk: $24K – dev $20K, test $4K– All SMEs agreed this is acceptable

Risk 12: Satellite is not mature enough in development to have important compatibility parameters defined.
Steps in the Validation Process that Mitigate this Risk: Command Validation and Telemetry Validation– All SMEs agreed this is acceptable
Risk before validation step: 11-20%– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.
Risk after validation step: 0-10%– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.

Risk 13: Ground System is not mature enough in development to have important compatibility parameters defined.
Steps in the Validation Process that Mitigate this Risk: FCT, LBCT, and DFT– All SMEs agreed
Risk before validation step: 11-20%– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.
Risk after validation step: 0-10% – All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.

Risk 14: Satellite manufacturer does not provide telemetry truth data for ground system DT&E testing– All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: DFT– All SMEs agreed to add TV, FCT, and LBCT
Risk after validation step: 11-20%– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.
Severity: Minor – telemetry not processed correctly – rework required after FCT adding schedule and cost– All SMEs agreed this is acceptable.

Risk 15: Satellite does not provide command samples for ground system DT&E testing
Steps in the Validation Process that Mitigate this Risk: DFT– SMEs feel that we should add CV
Risk before validation step: 41-60%– All SMEs agreed this is acceptable
Risk after validation step: 11-20%– All SMEs agreed this is acceptable
Severity: Minor – commands not processed correctly – rework required after FCT adding schedule and cost– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.

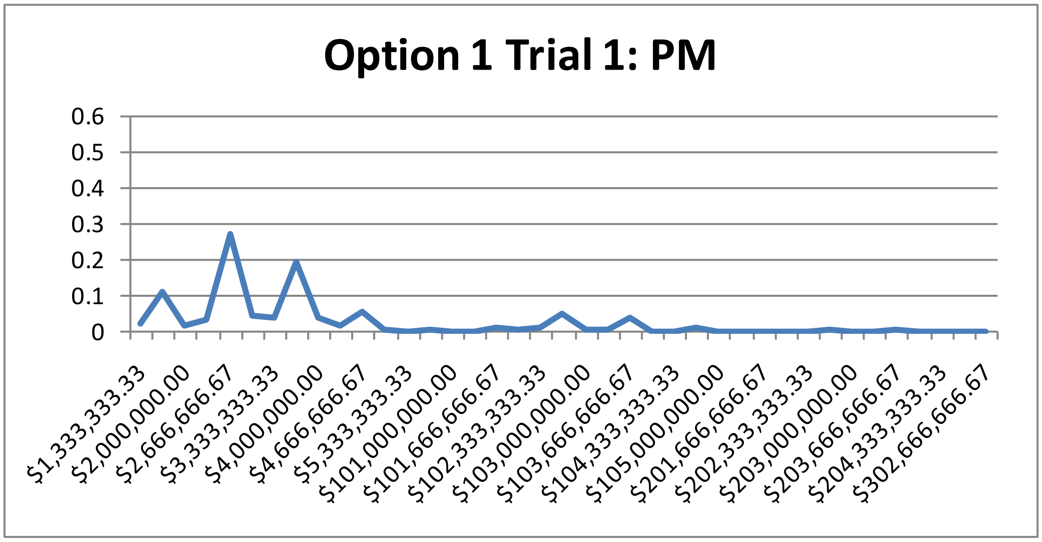
Risk 16: System fails to support all operational requirements of the satellite
Risk before validation step: 11-40%– All SMEs but one agree that this is appropriate; the one SME is not changing his opinion so we will go with the majority.
Risk after validation step: 0-10%– All SMEs agreed this is acceptable

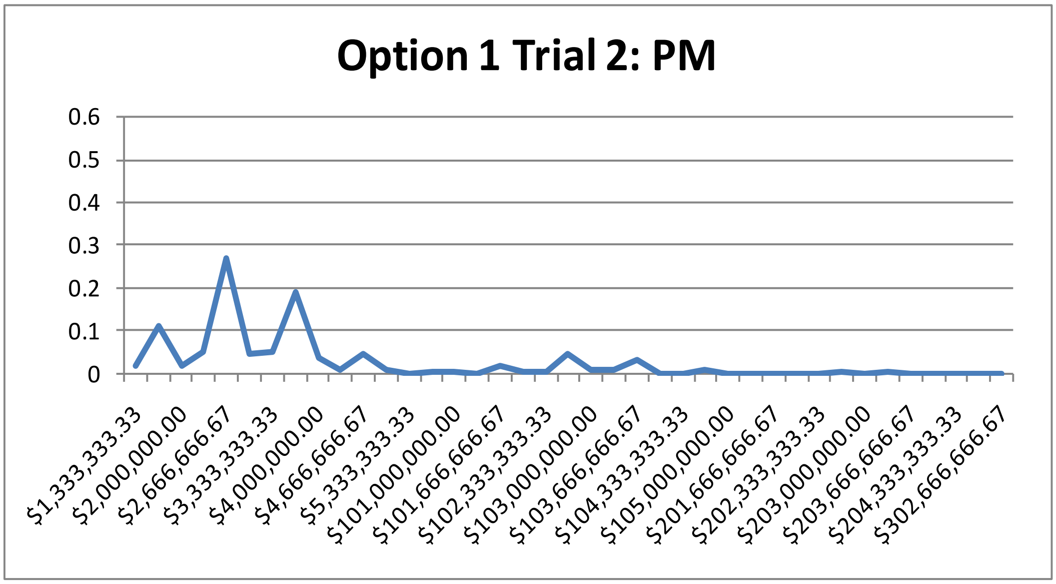
Risk 17: Ground System will lose/corrupt satellite data
Steps in the Validation Process that Mitigate this Risk: Command & Telemetry Validation– All SMEs agreed with exception of one; the one SME is not changing his opinion so we will go with the majority.
Risk after validation step: 0-10%– All SMEs agreed with exception of one the one SME is not changing his opinion so we will go with the majority
Severity: Minor – satellite commanding and telemetry will be erratic– All SMEs agreed this is acceptable

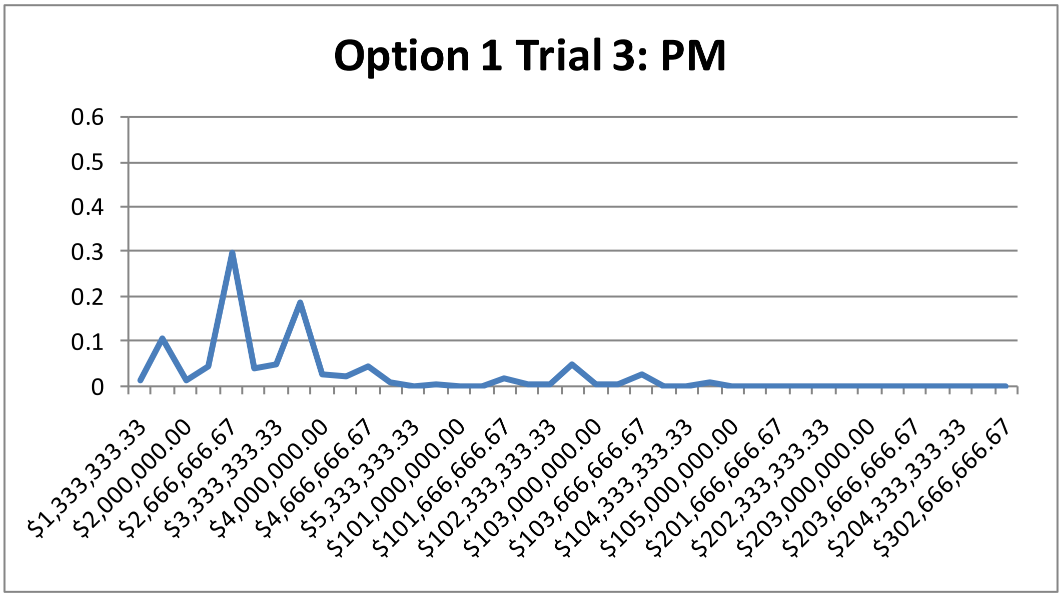
Risk 18: Customer delivered planning products will be improperly formatted (i.e. tasking files) – All SMEs agreed
Steps in the Validation Process that Mitigate this Risk: Telemetry Validation – All SMEs agreed that we should add WITL, TV, exercises and rehearsals
Risk before validation step: 0-10%– All SMEs felt this was acceptable

Appendix I: Results from Simulation Runs

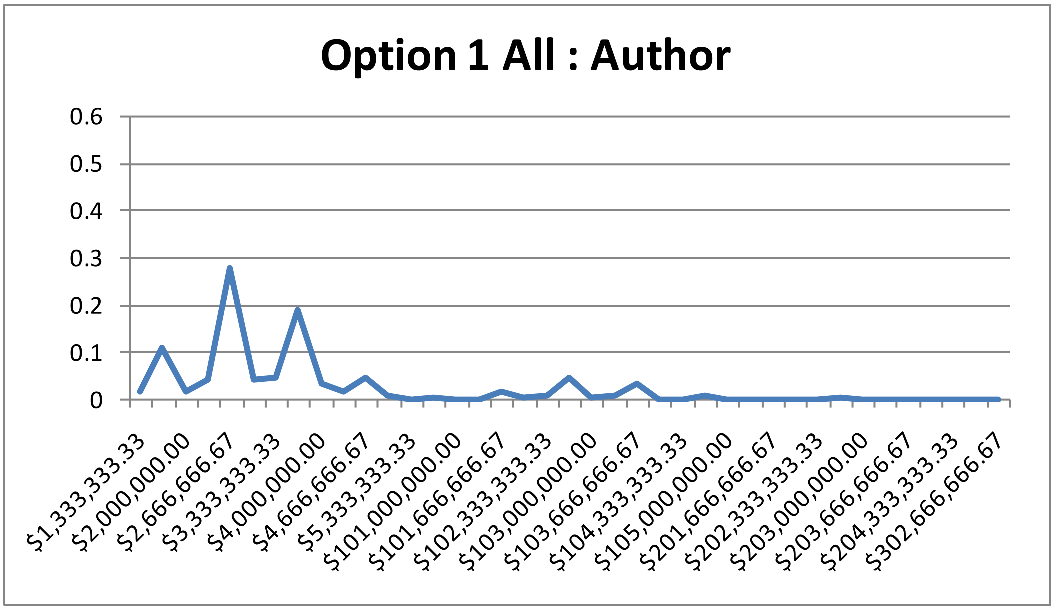
Program Office Proposed Validation Strategy





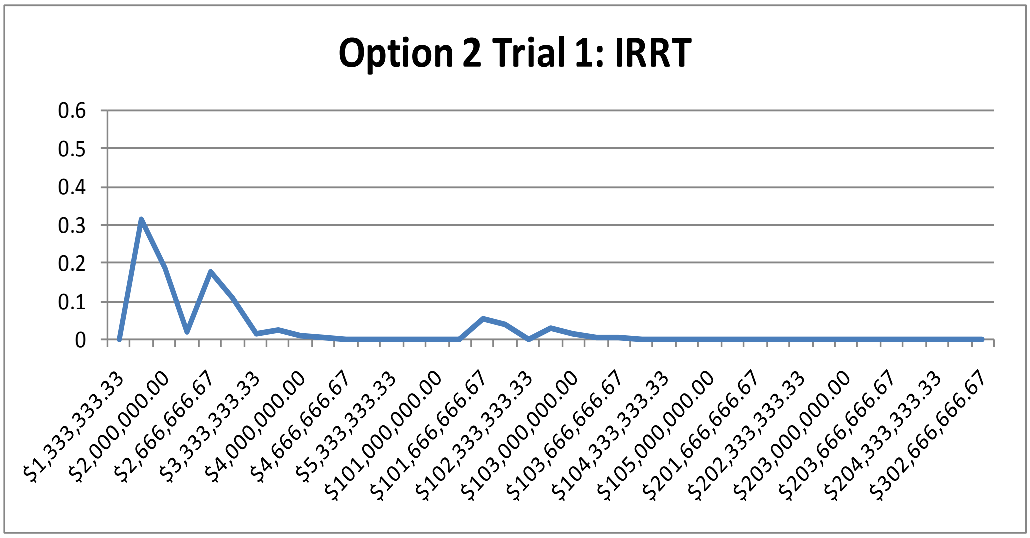


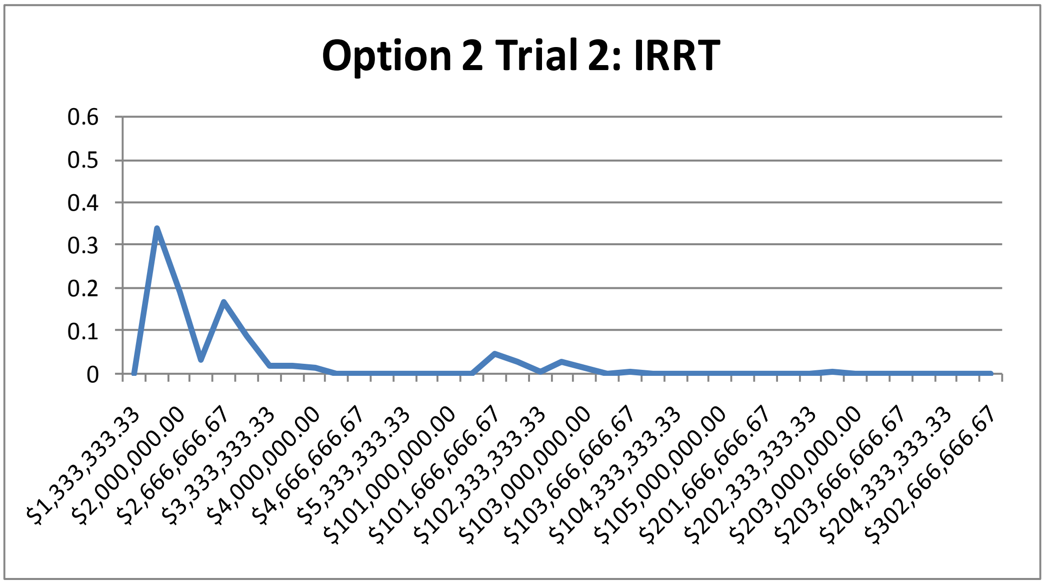
Option 1 Trial 3: PM

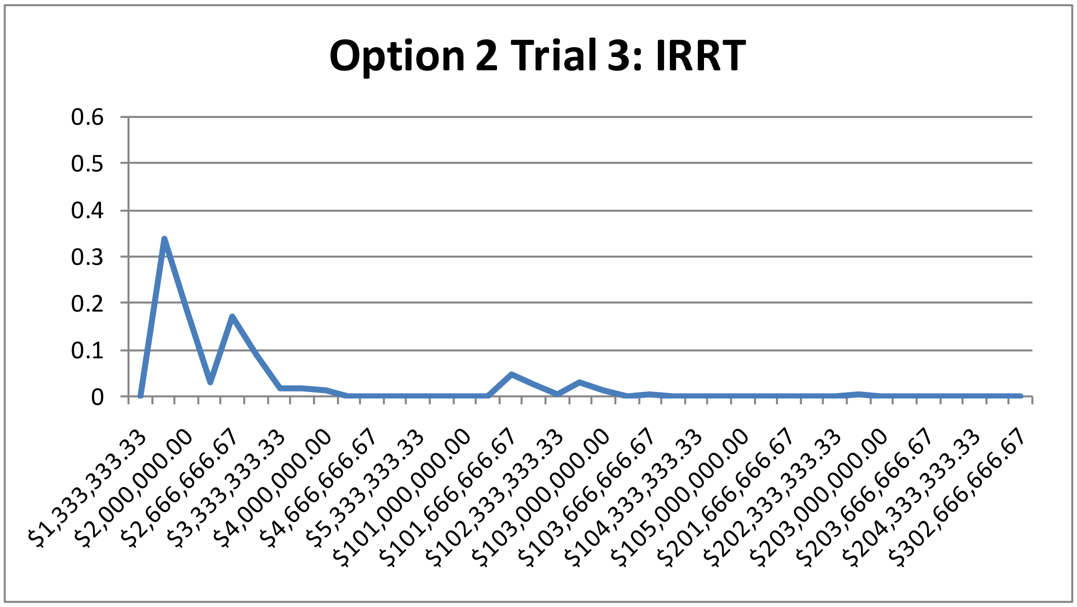


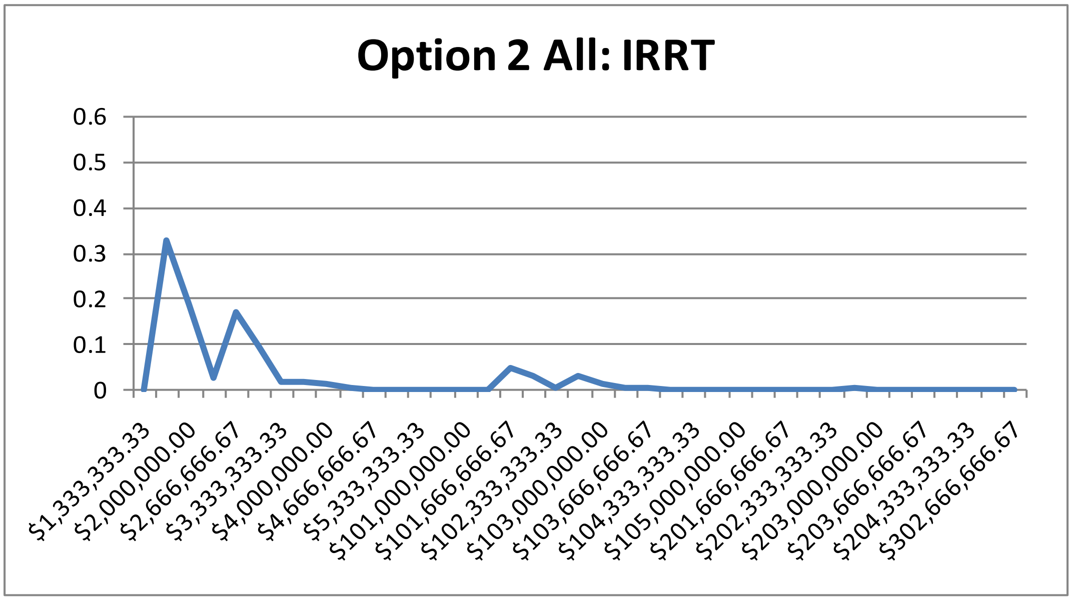
Option 1 All : Author

IRRT Proposed Validation Strategy



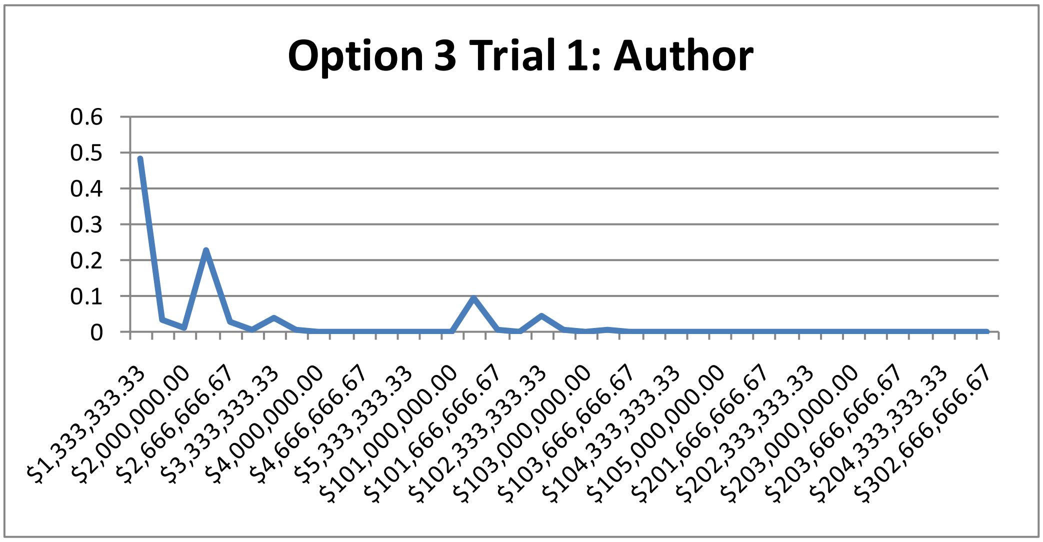


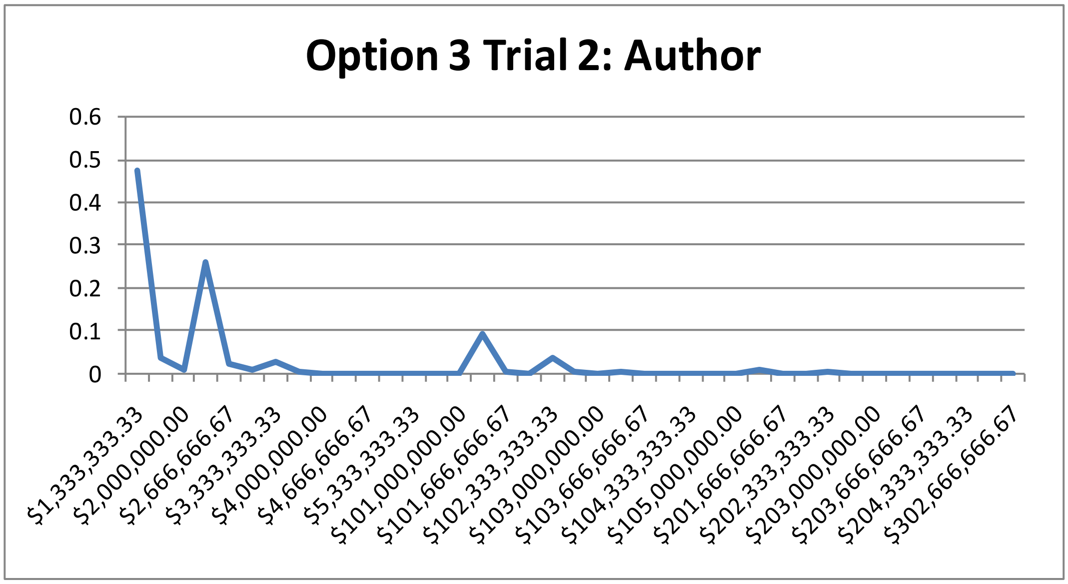


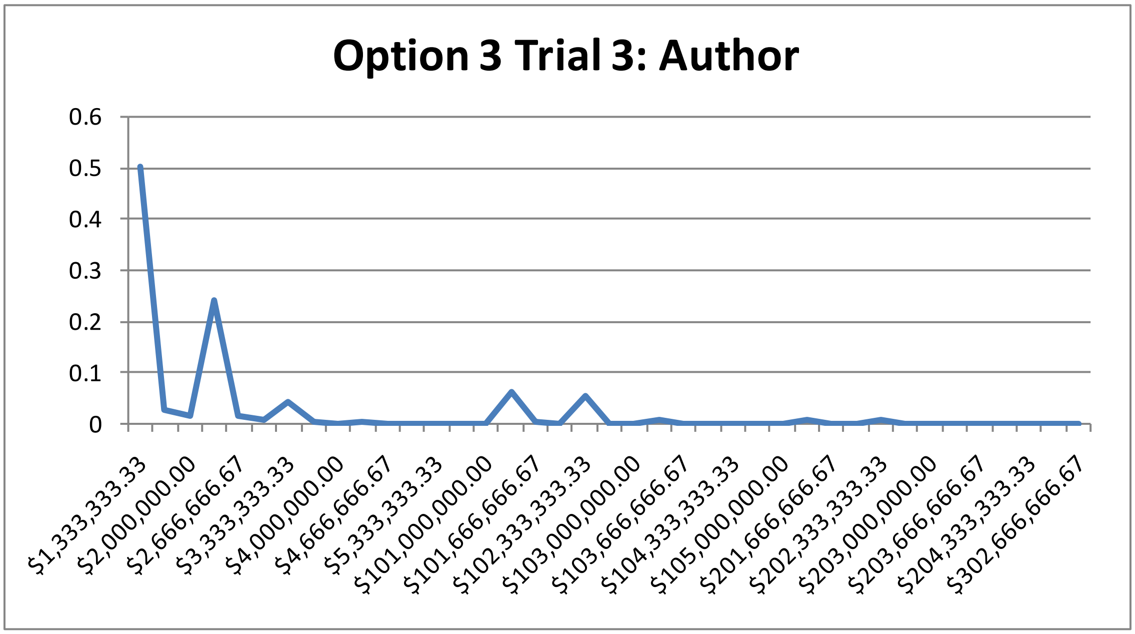


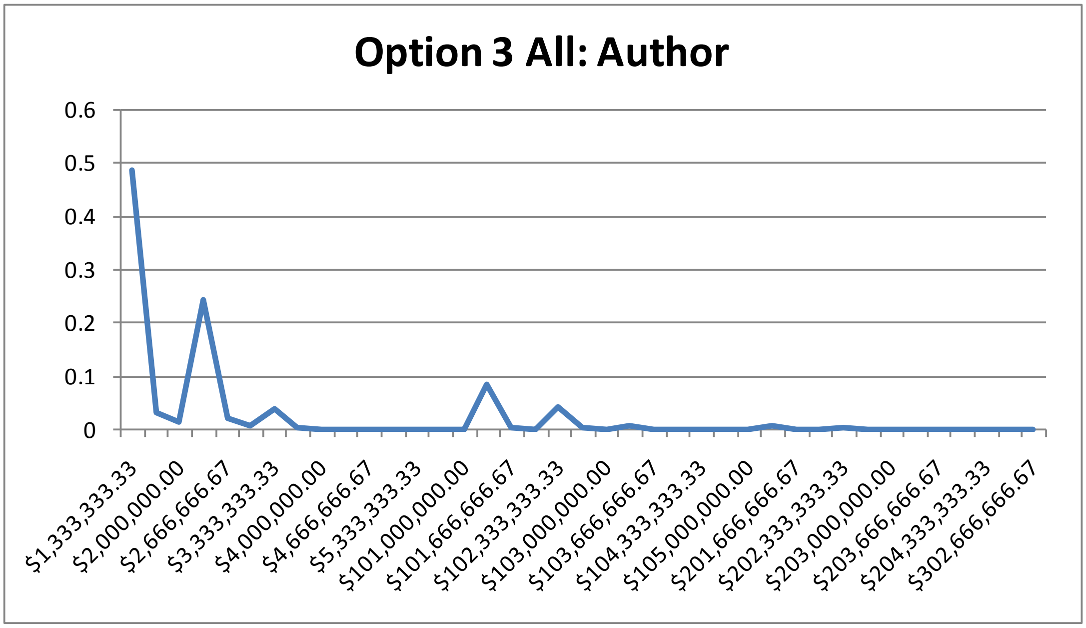
	Validation Strategy Costs	Mean	Range	Standard Deviation	Median
Option 2 Trial 1: IRRT	$1,517,150.00	$17,492,726.15	$201,000,000.00	$37,479,079.62	$2,017,150.00
Option 2 Trial 2: IRRT	$1,517,150.00	$16,981,410.52	$202,071,000.00	$38,403,474.14	$1,773,150.00
Option 2 Trial 3: IRRT	$1,517,150.00	$16,981,410.52	$202,071,000.00	$38,403,474.14	$1,773,150.00
Option 2 All: IRRT	$1,517,150.00	$17,130,988.89	$202,071,000.00	$38,064,722.27	$1,817,150.00

Author Proposed Validation Strategy



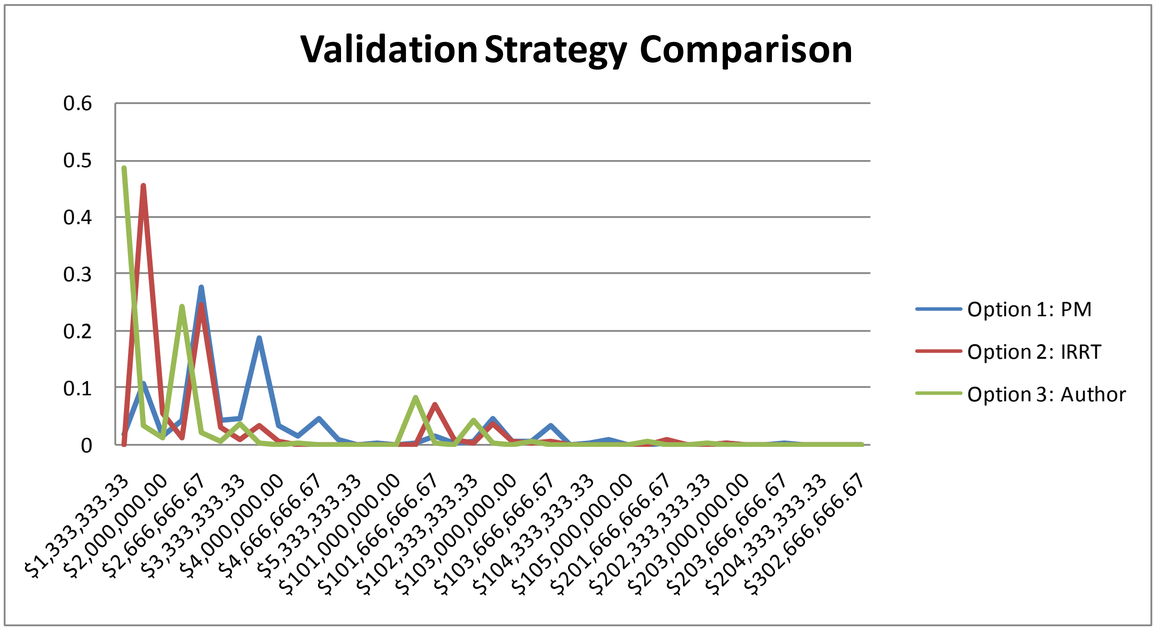


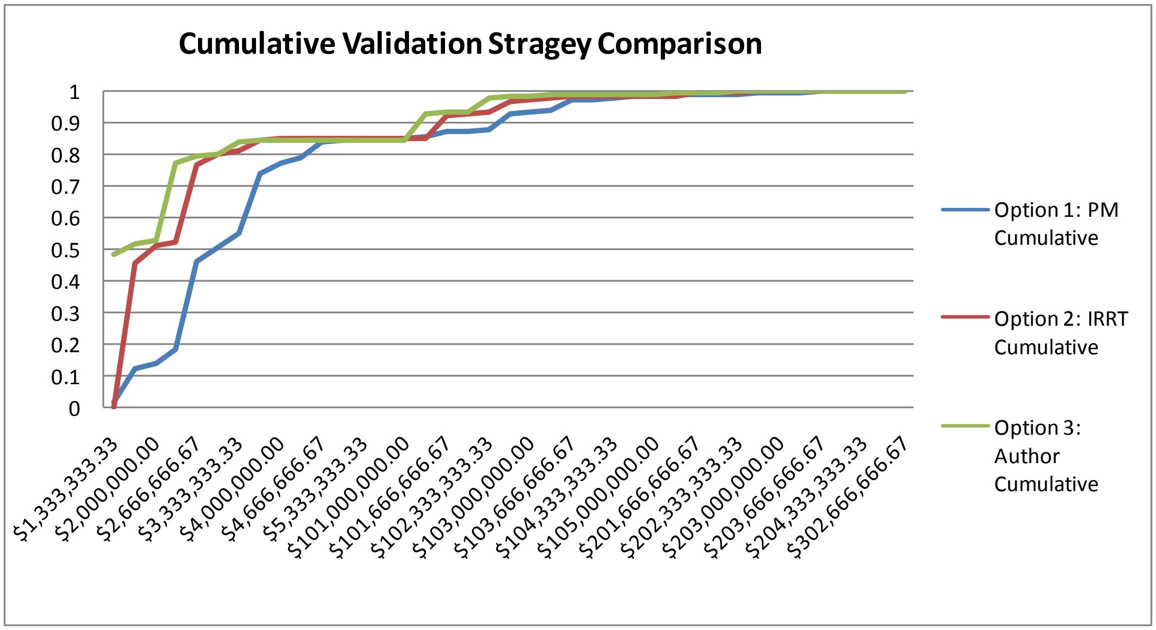




	Validation Strategy Costs	Mean	Range	Standard Deviation	Median
Option 3 Trial 1: Author	$1,031,050.00	$18,784,992.00	$201,321,000.00	$39,572,532.20	$1,405,050.00
Option 3 Trial 2: Author	$1,031,050.00	$18,770,949.00	$201,248,000.00	$41,266,558.94	$1,596,050.00
Option 3 Trial 3: Author	$1,031,050.00	$16,982,973.00	$201,165,000.00	$39,584,450.95	$1,331,050.00
Option 3 All: Author	$1,031,050.00	$18,179,638.00	$201,321,000.00	$40,144,600.32	$1,405,050.00

Validation Strategy Comparison





	Validation Strategy Costs	Mean	Range	Standard Deviation	Median
Option 1 All: PM	$1,324,850.00	$18,970,647.13	$301,129,400.00	$40,253,166.62	$2,924,850.00
Option 2 All: IRRT	$1,517,150.00	$17,130,988.89	$202,071,000.00	$38,064,722.27	$1,817,150.00
Option 3 All: Author	$1,031,050.00	$18,179,638.00	$201,321,000.00	$40,144,600.32	$1,405,050.00

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Vita

Captain Amanda J. Langenbrunner was born in Duluth, Minnesota. She entered undergraduate studies at the University of Washington in 1998, where she graduated with a Bachelor of Science degree in Ceramic Engineering in 2002. In August 2003, she commissioned through Officer Training School, Maxwell AFB, Alabama.

Her first assignment was at Luke AFB in August 2003 where she was assigned to the 56th Civil Engineering Squadron, Luke AFB, Arizona. While stationed at Luke, she deployed to Keesler AFB, Mississippi in support of Joint Task Force Katrina, providing humanitarian relief. In June 2006, she was assigned to the Space Development and Test Wing (SDTW) at Kirtland AFB, New Mexico. Since her arrival, she has held a variety of positions. She has worked as an Executive Officer for a Group Commander. She was the Operations Flight Commander for the Space Test Squadron leading 7 military directing a 125 member team operating 10 R&D satellite missions worth $1.2B. She currently works for the Department of Defense Space Test Program as the Chief Space Flight Mission Design Manager, helping find spaceflight for the DoD's R&D space missions. Her military honors include Air Force Achievement medal (2), Outstanding Units Award (2), Organizational Excellence Award (2), Armed Forces Service Medal, Humanitarian Service Medal, '07 AF Chief of Staff Safety Award, SDTW '07 Senior Company Grade Officer of the Year, along with numerous individual and team quarterly awards.

She entered the Graduate School of Engineering and Management, Air Force Institute of Technology in September 2006.

1st Lt Mary Trautwein was born in Fort Collins, Colorado. She entered undergraduate studies at the University of Massachusetts in 2001, where she graduated with a Bachelor of Science degree in Chemical Engineering in 2005 and was commissioned into the United States Air Force through the Reserved Officer Training Corps.

Her first assignment was the Space Development and Test Wing at Kirtland AFB, New Mexico. Lt Trautwein arrived at the Space Development and Test Wing in February of 2006.   Since her arrival, she has held a variety of positions. She was the on-orbit operations lead for a $430M DARPA on-orbit docking/refueling/maintenance demo. Lt Trautwein was the Test and Standardization and Evaluation lead for the Space Development and Test Wing's #1 mission in 2007. She directed 114 contractor personnel that developed plans, implements satellite ground system modifications, and managed the configuration of hardware and software baselines. Lt Trautwein currently leads the integration of Mission Unique Equipment and Software into the Multi-Mission Satellite Operations Center (MMSOC) Ground System Architecture (GSA)..

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)*
December 2009

2. REPORT TYPE
Master's Thesis

3. DATES COVERED *(From – To)*
Jan 2009 - Dec 2009

4. TITLE AND SUBTITLE
Extending the Strategy Based Risk Model Using the Delphi Method: An Application to the Validation Process for Research and Developmental Satellites

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GSE/ENV/09-03DL

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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10. SPONSOR/MONITOR'S ACRONYM (S)
SDTW/SDSG/RS C2

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The validation between a research and developmental satellite and its ground system is critical to ensuring the success on-orbit. However, the exact process for completing validation is not documented, frequently underfunded, and accomplished ad hoc. This leads to debate regarding maintenance of budget and schedule, while ensuring on-orbit success.

This thesis examines readiness and on-orbit activities within the U.S. Air Force Space Development and Test Wing's Research Development Test and Evaluation Support Complex. Combining historical data with the consultation of subject matter experts, a validation process was defined. Risks associated with this process were then analyzed using the Strategy Based Risk Model, and were evaluated based on the probability of occurrence and severity of impact. The validation process and associated costs were validated using the Delphi Method. Next, we transformed the results into a simulation that generates distributions of possible costs and risk outcomes. Finally we applied the simulation to a program, and distributed it to program managers for feedback. The simulation will be distributed to program offices to support tailoring a validation plan relative to their budget. The simulation will give decision makers greater fidelity into the expected risks and costs associated with the selected validation process.

15. SUBJECT TERMS
Research and Developmental Satellites and Ground System Validation, Strategy Based Risk Model, Canonical Verification Validation and Test Model, Delphi Method

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		
U	U	U	UU	177

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18