Analysis of UH-60 Blackhawk Safety
Controls Using Value Focused Thinking and
Monte Carlo Simulation

THESIS

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In the past few years, Army aviation accidents have been on the rise, due largely to increases in mission frequency and complexity, and diminishing resources. The magnitude of the resulting losses (casualties, dollars, equipment) has prompted the Commanding General of the Army Safety Center to demand a complete examination of the way safety hazards and subsequent safety controls are evaluated and selected. This project integrates value focused thinking, Monte Carlo simulation, and integer programming in response to this demand by developing and using a methodology that effectively identifies and evaluates portfolios of controls. An integer program generates portfolios of controls that maximize the reduction of hazards that contribute to Army aviation accidents. Monte Carlo simulation using the bootstrap method is used to simulate the number and types of losses resulting from accidents that occur in 100,000 UH-60 flying hours. A value model has been developed to quantify the severity of these losses. The expected performance of the portfolios of controls is calculated as the anticipated decrease in severity of losses resulting from implementation of those controls.

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Roger D. Gallan, Jr.

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Abstract

In the past few years, Army aviation accidents have been on the rise, due largely to increases in mission frequency and complexity, and diminishing resources. The magnitude of the resulting losses (casualties, dollars, equipment) has prompted the Commanding General of the Army Safety Center to demand a complete examination of the way safety hazards and subsequent safety controls are evaluated and selected. This project integrates value focused thinking, Monte Carlo simulation, and integer programming in response to this demand by developing and using a methodology that effectively identifies and evaluates portfolios of controls. An integer program generates portfolios of controls that maximize the reduction of hazards that contribute to Army aviation accidents. Monte Carlo simulation using the bootstrap method is used to simulate the number and types of losses resulting from accidents that occur in 100,000 UH-60 flying hours. A value model has been developed to quantify the severity of these losses. The expected performance of the portfolios of controls is calculated as the anticipated decrease in severity of losses resulting from implementation of those controls.

ANALYSIS OF UH-60 BLACKHAWK SAFETY CONTROLS

USING VALUE FOCUSED THINKING AND MONTE CARLO SIMULATION

1 Introduction

1.1 Background

Management of safety in the Army starts at the top, with the Secretary of the Army and the Chief of Staff, Army. Safety policy generated from this level is actively supported and promoted by all Army staff agencies. The Army operates "one of the largest, most comprehensive safety programs in the world" (US Army Safety Center Mission Statement). The USASC provides support to the Army staff and major subordinate commanders, assisting them in conserving manpower and materiel resources and in conducting effective operations. These programs are designed to help produce safe air and ground operations, as well as to promote safety both on and off duty (USASC Mission Statement).

In the past few years, Army aviation safety mishaps have been on the rise, due largely to the increases in mission frequency and complexity, coupled with diminishing resources (ASIST Brief, Aug 1999). In November 1998, the Under Secretary of Defense for Acquisition and Technology challenged the services to "...achieve a 3 sigma reduction in Class A accident rate in 5 years" (ASIST Brief, Aug 1999). In February 1999, the Army Safety Action Team reviewed Army aviation safety experiences in response to this challenge, and chartered the Army Safety Investment Strategy Team (ASIST). ASIST's strategy, endorsed by the Vice Chief of Staff, Army (VCSA) in April

1999, is to reduce by 50%, within the next ten years, the rate of fatal and disabling injuries, the Class A-C accident rate, and the total annual cost of aviation accidents (ASIST Brief, Aug 1999).

1.2 Risk Management

Approximately eleven years ago, risk management was formally introduced in the Army safety community, and has since evolved into the principal risk-reduction process to protect the force. By integrating risk management into all Army processes, lives can be saved and equipment spared. Risk management "is the process of identifying, assessing, and controlling risks arising from operational factors and making decisions that balance risk costs with mission benefits" (FM 100-14, 1998: 1-1). Risk has two components: probability and severity. Probability refers to the chance of something bad happening, or the chance of a hazard causing an event, while severity deals with the magnitude of consequences. Accidents are unplanned events causing personal injury or illness, or property damage. Historically, accidents have caused more losses than has enemy action (FM 100-14, 1998: 1-2). Proper application of risk management techniques will result in conservation of combat power and resources (FM 100-14, 1998: 1-1).

1.3 Problem Statement

The purpose of this project is to develop a methodology aimed at evaluating controls that reduce UH-60 Blackhawk helicopter hazards. A hazard is defined as "any actual or potential condition that can cause injury, illness, or death of personnel, damage to or loss of equipment, property or mission degradation" (FM 101-14, 1998: G-1). Controls are proposed actions intended to eliminate or reduce the severity and/or probability of a hazard contributing to an accident (FM 100-14, 1998: 2-13). ASIST developed the UH-60 hazard taxonomy and control listing in their proof of concept study. This project builds on ASIST's initial work with the UH-60 program.

1.4 Research Objectives

In the past, the United States Army Safety Center (USASC) used statistical analysis of data to identify safety-related hazards and controls. Some consider such an analysis approach to be too reactive. Using value-focused thinking and multiattribute preference theory concepts, Captain Brian J. Sperling, GOR/99M, US Army, developed a prescriptive decision analysis model to more proactively evaluate hazards (Sperling, 1999).

The focus of this project is to use decision and risk analysis theory and techniques, coupled with simulation and mathematical programming, to further develop a suite of tools to assist Army leadership with integrating risk management and Army processes.

The ASIST effort brought safety and aviation experts together to focus on eliminating Army aviation hazards. The initial project was limited to the UH-60 Blackhawk, with the intent of expanding out to all Army aviation platforms. This project will integrate and augment ASIST's work in developing a methodology for designing and proposing portfolios of controls intended to reduce or eliminate UH-60 Blackhawk hazards.

1.5 Research Approach

The first part of the project involves updating, verifying, and validating the Accident Severity model. Using the updated Severity of Losses Model, a severity score representing the losses due to accidents in 100,000 flight hours, is determined. A mathematical program uses the ASIST control list and hazard taxonomy to generate portfolios of controls for evaluation. Once accomplished, portfolios of controls designed to reduce UH-60 hazards can be assigned an expected performance score..

Updating included incorporating changes and additions to the hierarchy. The Accident severity model was designed for all Army aircraft. For every aspect of the model, the value hierarchy was reassessed to make sure the structure was still valid for the UH-60. The ranges for each level of evaluation consideration were determined. The single dimensional value functions were updated to reflect changes in perspective, preferences, and policy. Weights for all evaluation criteria and measures were confirmed or reassessed.

Verification assures the model is built properly by comparing the conceptual model to the computer implementation. It confirms the model properly represents all input parameters and structures by assuring the logic of the model is translated correctly into the computer program (Banks, et al.: 399).

Validation is the determination that a model is accurately representing the real world systems (Banks, et al.: 400). In this case, validation involves assuring the model is complete and nonredundant. Kirkwood (1997) states the conditions for a complete hierarchy as, "the evaluation considerations at each layer (tier) in the hierarchy, taken together as a group, must adequately cover all concerns necessary to evaluate the overall objective of the decision" (Kirkwood, 1997:16). In addition to completeness, the hierarchy should also be nonredundant.

A mathematical program has been developed for the purpose of generating portfolios, with the intent of identifying a group of controls that meet the 50% reduction goals at minimal investment costs. Once the portfolios were generated, the Monte Carlo simulation was run to determine the performance of the portfolios of controls associated with the UH-60 program. The hazard taxonomy and hazard assessments from ASIST, along with the control effectiveness assessments, are incorporated into the model at this point. Sensitivity analysis on the weight of the major uncertainty in the model was conducted to see how varying the weight affects the portfolio rankings.

1.6 Scope

The UH-60 Blackhawk was chosen as the focus of ASIST's initial study because of the maturity of the system and the massive amount of accident data available. This project was intended to parallel ASIST's initial study and is therefore limited to the UH-60. In the future, the methods and model from this project could be modified for other platforms. This project deals with only class A, B, and C accident categories. Class A accidents involve damages of more than $1M, and/or fatality or permanent total disability. Class B accidents result in damages between $200K and $1M, and/or permanent partial disability. Class C accidents have damages between $10K and $200K or loss of time from work (AR 385-40, 1994:2.2-2.4). Class D and E accident categories have insufficient data for meaningful analysis.

1.7 Thesis Overview

Chapter Two contains a brief description of Value Focused Thinking (VFT), Monte Carlo simulation, and the bootstrap method, along with some references to recent applications of these techniques. Chapter Three describes the Accident Severity Model, the Monte Carlo simulation methodology, and a discussion of the mathematical program used in developing the control portfolio. Chapter Four contains a description of the data, results, and sensitivity analysis of selected weights from the model. Chapter 5 discusses the project findings and recommendations for further related study. Data and other relevant information are included in the Appendices.

2 Literature Review

2.1 Introduction

This chapter provides a review of the literature pertinent to this research project as well as an introduction to basic decision analysis concepts. The discussion will also include the basic concepts of value focused thinking, which are used extensively in this research project. Monte Carlo simulation and the bootstrap method are briefly discussed. Finally, current applications using these techniques are reviewed.

2.2 Decision Analysis

2.2.1 Decision Analysis Concepts

Decision analysis is a methodology used to assist a decision maker in modeling a given decision situation, to include the structure of the problem, and his or her beliefs and preferences. Decision analysis is a prescriptive approach, designed to help intelligent people make difficult decisions (Clemen, 1996: 3). By using decision analysis techniques, real-world problems can be analyzed in order to gain insight and understanding (Clemen, 1996: xix).

Decisions can be difficult due to a number of factors. A decision may be considered hard because of its complexity or its uncertainty. By using decision analysis, the problem can be broken into manageable pieces and organized into an understandable structure. Decision analysis techniques can also help identify and represent key uncertainties in a useful manner (Clemen, 1996: 2-3). Decisions can also be difficult when there are multiple, competing objectives, or when different perspectives lead to different decisions. Decision analysis "provides both a framework and specific tools for dealing with multiple objectives" (Clemen, 1996: 4). When different perspectives lead to different decisions, decision analysis can help resolve these differences in a systematic way (Clemen, 1996: 4)

By using decision analysis techniques, a thorough understanding of the problem is formed and a better decision can be made (Clemen, 1996: 3). It is vital, however, to understand that a better decision does not necessarily result in a better outcome. Not every detail can be captured and incorporated into a decision situation, and occasionally unpredictable events happen. A good decision might be considered choosing an alternative that 'provides the ideal outcome given eventual circumstances', or one that comes 'from a thorough understanding of the problem' (Bunn, 1984: 9).

Decision analysis does not provide solutions. Instead, it is "best thought of as simply an information source, providing insight about the situation, uncertainty, objectives, and trade-offs, and possibly yielding a recommended course of action" (Clemen, 1996: 4). Decision analysis does not replace the decision maker. Rather, it works with the decision maker to help him or her thoroughly understand the problem. The responsibility for the decision, however, ultimately remains with the decision maker (Clemen, 1996: 4).

2.2.2 Decision Analysis Process

The decision analysis process applies the fundamental concepts in a systematic manner (see Figure 2.1). In each step, certain questions can be asked to help guide the process. The deliverables represent the type of results usually derived from a particular step.

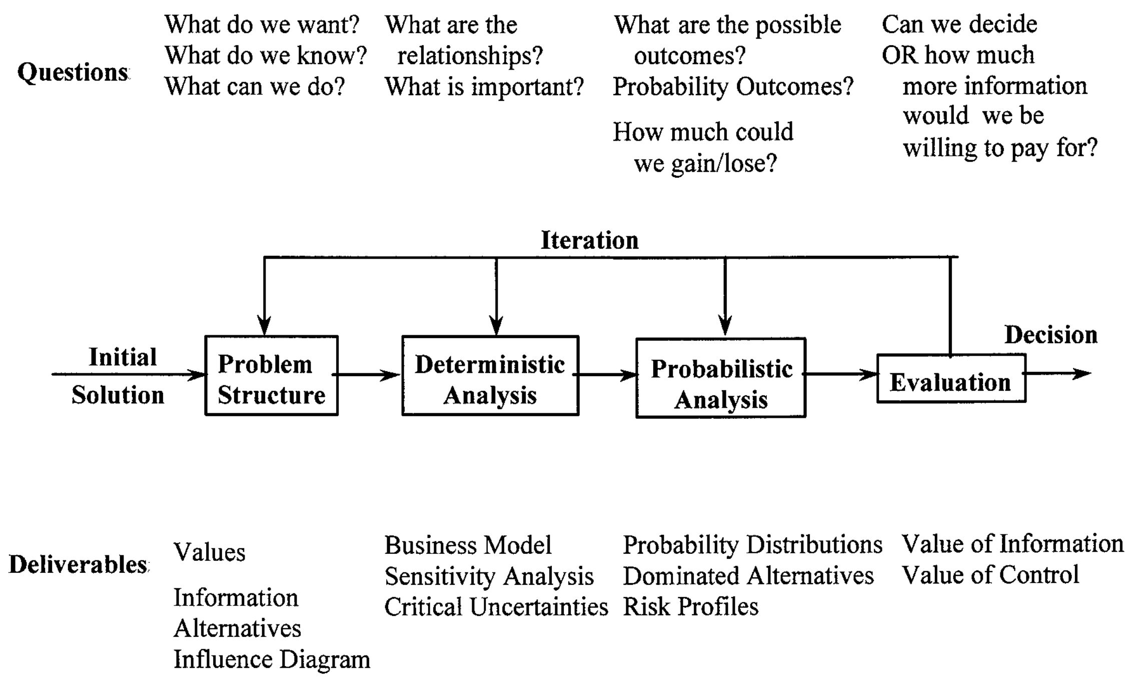

Figure 2-1 Decision Analysis Cycle (Clemen, 1996:6)

In structuring the problem, the goal is an understanding of the nature of the decision as well as the objectives in the current situation. In the next step, deterministic analysis, the problem is decomposed into manageable subproblems. Initial sensitivity analysis can help identify key uncertainties and influential parameters. In the probabilistic step, these uncertainties are incorporated into the model. The final step helps determine if a decision is ready to be made, or if further analysis is required (Clemen, 1996: 6-7).

Solving problems using a decision analysis approach is an iterative process. As the model is developed, new insight could require a restructuring of the problem. In addition, at each step along the way, the decision maker's preferences could change, or more information could become available, which would require a restructuring of the problem (Clemen, 1996: 7).

When dealing with complex decisions involving multiple competing objectives, reaching a conclusion can be difficult, especially when trying to account for the complexities involved with uncertainty, dependencies, and tradeoffs. When problems become complex, augmenting intuition with decision analysis methodologies can assist in making logical, supportable, and transparent decisions (Kirkwood, 1997: 1).

2.3 Value Focused Thinking

Hazards contribute to accidents that can cause loss of life or irreparable damage to equipment. Many interrelated factors might be considered when evaluating controls designed to eliminate hazards. Value focused thinking is an approach designed to deal with complex decisions having multiple, competing objectives, that involve tradeoffs; it is quite different from the alternative based way of addressing a problem. The most common way of attacking a complex problem is to focus on the available alternatives. This alternative based approach, which is reactive rather than proactive, places unnecessary limitations on the decision situation. Value focused thinking removes the artificial boundaries and allows creative thinking to augment the structuring of the decision problem (Keeney, 1992: viii).

"Values are what we care about" (Keeney, 1992: 3). Values are also things that are considered important in a decision situation. Given this, values should ultimately drive the decision. Objectives represent the "preferred direction of movement" with respect to the important aspects of the situation (Kirkwood, 1997: 12). Once the set of values is obtained, it can be organized into a hierarchy with the overarching objective at the top, and supporting objectives and measures of merit at subsequent levels (see Figure 2-2). The measures of merit, or evaluation considerations, measure the attainment of the higher objectives.

One of three approaches is typically used to identify and incorporate values into a value hierarchy. These are the gold, silver, and platinum standards (Parnell, et al, 1998). The gold standard development is a top-down method that clarifies and structures doctrine or strategic vision. Using strategic visions, doctrine, or other organizational documents can facilitate 'buy-in' to the process. Each objective is divided into sub-objectives, and each sub-objective is further divided in successively greater detail, until a measurable item is reached (Kirkwood, 1992: 21-22).

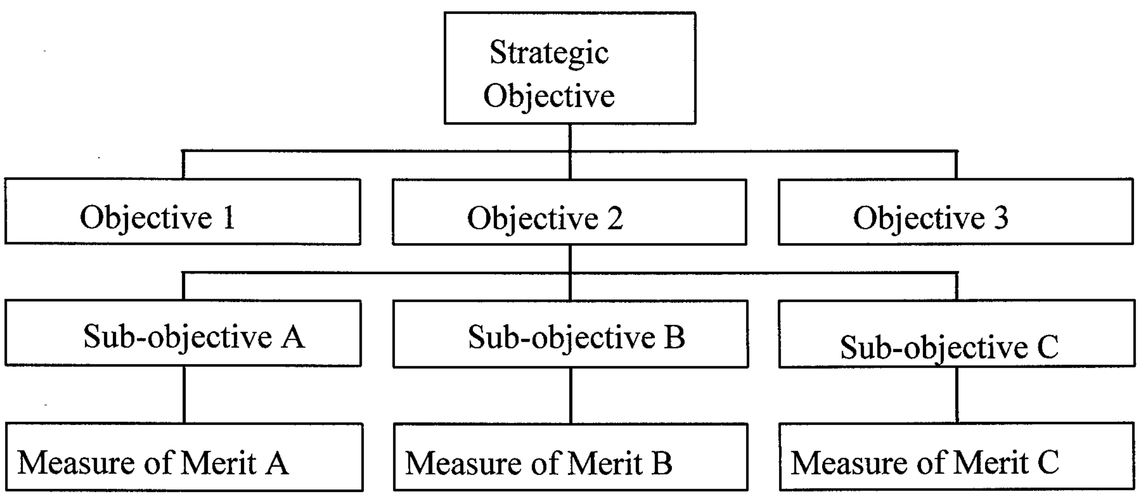

Figure 2-2 Sample Value Hierarchy

It is not always possible to use the gold standard development method. In situations where strategic objectives or doctrine are not known, or when the alternatives are already known, the silver standard development may be appropriate. The silver standard development method is a bottom-up approach that assists in creating new values. By using verbs that indicate action to describe the situation, a group of representatives can inductively develop a value hierarchy. This method typically requires a large group of people and a substantial amount of time to develop the hierarchy (Parnell, et al, 1998).

The third method is the platinum standard. In cases where the problem is ill defined, the platinum standard can help build the value hierarchy, inductively, through a series of interviews with the decision makers, representatives, and stakeholders. Combining the information gleaned from the interviews and existing doctrine can help establish the true nature of the problem (Parnell, et al, 1998).

Value hierarchies, regardless of the method used to develop them, should possess certain qualities. According to Kirkwood, these qualities should be *completeness, nonredundancy, decomposability, operability,* and *small size*.

Completeness of a hierarchy is a quality signifying that all evaluation concerns required to evaluate the higher objective are taken into account. It also means all evaluation concerns together "adequately cover all concerns necessary to evaluate the overall objective of the decision" (Kirkwood, 1992: 16). A *complete*, or *collectively exhaustive*, value hierarchy is needed to properly, and consistently, distinguish between different alternatives (Kirkwood, 1997: 17)

A value hierarchy should also be *nonredundant*, or *mutually exclusive*. No evaluation consideration should overlap another in the same level of the hierarchy. This means no two measures should be used in evaluating the degree of attainment for the same objective. *Nonredundancy* is needed to prevent double counting of an evaluation consideration (Kirkwood, 1997: 16-17)

Decomposability, or *independence*, requires that the preference for one level of an evaluation consideration should not depend on the level of another evaluation consideration. The lack of *decomposability* makes the model much more complicated and difficult to use (Kirkwood, 1997: 17-18)

"An operable value hierarchy is one that understandable for the persons who must use it" (Kirkwood, 1997: 18). Compromises, with respect to the other desirable qualities of a hierarchy, must sometimes be made in order to make the hierarchy operable. These compromises are certainly acceptable as long as the decision maker believes the hierarchy to be complete and understandable.

All things being equal, the smaller the hierarchy, the better. A smaller hierarchy is easier to communicate, and also requires fewer resources to evaluate the alternatives (Kirkwood, 1997: 18).

Having built the hierarchy, evaluation measures must also be developed. The scales for evaluation measures are first classified as natural or constructed:

- Natural scale - is in general use with a common interpretation
- Constructed scale – is developed for a specific decision situation, and generally used when a natural scale is not appropriate or does not exist

Evaluation measure scales are further classified as:

- Direct scale – directly measures degree of attainment of an objective
- Proxy scale - uses the attainment of an associated objective to measure the degree of attainment for the original objective (Kirkwood, 1997: 24).

The following example contains the types of evaluation measures.

	Natural	Constructed
Direct	Net Present Value Time to Remediate Cost to Remediate Bandwidth per second	Olympic Diving Score Weather Prediction Categories Project Funding Categories R&D Project Categories
Proxy	Gross National Product (Economic Growth) Number of Subsystems (System Reliability	Performance Evaluation Categories (Promotion Potential) Student Grades (Student Learning)

Figure 2-3 Evaluation Measure Types (Parnell, et al, 1998)

For a deterministic analysis, single dimensional value functions are developed for each evaluation measure. The value functions are created in a systematic manner so that they reflect the decision maker's and/or organizations values or beliefs. From interviewing the decision maker, or a representative, the value for a certain score for an evaluation measure is elicited by asking value increment questions (Kirkwood, 1997: 70). After covering the entire range of the evaluation measure, the value function represents how the decision maker feels about a given score.

For decisions involving tradeoffs among the objectives, the decision maker's preferences are included in the model by assigning weights to each evaluation measure (Kirkwood, 1997: 55). Once the weights are determined, the overall additive value function, which represents the weighted sum of single dimensional values, can be created.

2.4 The Bootstrap Method

The bootstrap method is a technique that uses computer intensive methods in making reliable statistical inferences, such as standard errors, confidence intervals, or other measures of uncertainties (Davison and Hinkley, 1997: 2). Using the bootstrap method, random samples are drawn, with repetition, from one or more *empirical* distributions. In complex situations where bootstrap statistics are awkward to compute, Monte Carlo samples can be used to approximate the parameters of interest (Efron and Tibshirani, 1993: 1).

The bootstrap method is useful in situations when there is no known well-defined probability distribution. Key advantages of using the bootstrap method are that it is easy to describe and apply to complicated situations, and that distribution assumptions, such as normality, are not needed (Efron and Tibshirani, 1993: 160). Precautions must be taken, however, to ensure appropriate design of the experiment, data analysis, and presentation of conclusions. Failing to do so could lead to either solving the wrong problem, or solving the right problem poorly (Davison and Hinkley, 1997: 4).

2.5 Monte Carlo Simulation

Monte Carlo simulation consists of some physical or mathematical system that can be described in terms of probability distribution functions. As a rule, the algorithm is to simply complete a single random trial. Then, the single random trial is repeated n times, each independent of the other (Sobol, 1984: 10). The final goal of the Monte Carlo method is to gather pertinent statistics of desired metrics based on the distribution of the n independent outcomes (Hammersby and Handscomb, 1964: 10).

The Monte Carlo method heavily employs the use of randomly generated numbers. Each random number used in the system is a potential source of uncertainty in the final result. Attempts should be made to replace uncertainties with exact, theoretically sound representations whenever possible (Hammersby and Handscomb, 1964: 5).

Monte Carlo simulation can be conducted in a variety of manners. One way is using the Crystal Ball add-in package for Microsoft Excel. Leaving the modeling of the system to the user, Crystal Ball provides common probability distributions than can be used in the simulation. Crystal Ball also gathers the results from each trial of the simulation and reports statistics upon termination. Microsoft Excel and Crystal Ball are used extensively in this project.

2.6 Portfolio Analysis

At various levels, government agencies and businesses are forced to make decisions regarding resource allocation. Two common procedures used in making these decisions are ranking schemes and mathematical programming. Ranking processes tend to be loosely structured, while mathematical programming is designed to find an optimal solution given an objective and a set of constraints (Byrd and Moore, 1982: 183). The knapsack, a specific type of mathematical program, is used in this study.

The knapsack problem is based on the premise that a hiker would like to take as many items as possible on a trip, but can only carry a specific weight in his or her knapsack. The idea is to choose items that maximize the total benefit while remaining under the weight restriction (Winston, 1994: 468). This approach can be used to identify the best mix of programs to fund that would give the maximum benefit for a specified investment budget (Byrd and Moore, 1982: 184).

2.7 Applications of Techniques in Current Literature

This section discusses a few applications of value focused thinking, as well as a recent application of Monte Carlo simulation using the bootstrap method.

Capt Brian K. Sperling, GOA-99M, developed a decision analysis model for the US Army Safety Center. Using value focused thinking, Capt Sperling developed an accident severity model, incorporating Army doctrine, commander preferences, and expert opinion. The model determined severity for accident and hazard categories. Using probability relationships, accident and hazard risks were also quantified. This research effort builds on Capt Sperling's work.

The CEO of British Columbia Hydro and Power Authority (BC Hydro), a publicly owned hydroelectric utility company, had a vision of making BC Hydro the best planned electric utility in North America. Ken Peterson, appointed as the director of planning, found little guidance in the published mission statement on how to attack this problem. He realized he needed to identify the organization's strategic objectives in order to achieve the long-term goal (Keeney, McDaniels, 1992).

Using a value focused thinking approach, Keeney and McDaniels helped Peterson develop a hierarchy of the company's strategic objectives. Information, from various points of view, was gathered on BC Hydro strategic objectives through a series of interviews with three key individuals. The nature of the interviews was unstructured and open, so as not to place any arbitrary limitations. Questions by the analysts, like "what does that objective really mean?", helped clarify relationships among the objectives. After a few follow-on meetings, a strategic objectives hierarchy was developed and utility functions were developed. BC Hydro continued to use this multiobjective structure in other contexts such as capital budget reductions and developing an its integrated electricity plan (Keeney, McDaniels, 1992)

In a thesis by Capt Donald F. Hurry, GOR-96M, various statistical techniques were used to determine the impact of Programmed Depot Maintenance on weapon system availability. Specifically, the technique of Monte Carlo simulation with the bootstrap method was used to estimate the downtime per truck per year. By independently sampling, with replacement, from two empirical distributions, time to failure and downtime after failure was estimated. These estimates validated conclusions drawn from other statistical analyses.

3 Methodology

3.1 Introduction

"The mission of the Army Safety Center is to enhance combat readiness through proactive risk management to prevent accidents" (USASC Mission Statement). The USASC accomplishes this by assisting the Army's major commands and the Army staff with the development and day-to-day management of safety policies. Commanders then execute those policies and procedures at the unit level (USASC Mission Statement).

A current tasking is to "...achieve a 3 sigma reduction in Class A accident rate in 5 years" (ASIST Brief, Aug 1999). The Army Safety Investment Strategy Team (ASIST) was chartered in response to this challenge. ASIST's strategy is to reduce by 50%, within the next ten years, the rate of fatal and disabling injuries, the annual cost of aviation accidents, and the Class A-C Accident Rate. Expanding on ASIST's work, this research incorporates risk management into the process by using a value focused thinking approach to tie together doctrine, commander preferences, expert opinion, and information from the Risk Management Information System.

3.2 Project Overview

The overarching objective of this project is to reduce losses due to aviation accidents. For this study, which is limited to the UH-60 program, the interpreted objective is to identify and implement a methodology that identifies and evaluates portfolios of controls intended to reduce the severity of losses by 50 percent over the next ten years.

The performance of a control is estimated by simulating the effect on losses due to implementing that control (see Figure 3-1). The Severity of Losses Model, based on value focused thinking, quantifies the severity of losses due to UH-60 accidents, while the Monte Carlo process accounts for probability in the model. Using the Severity of Losses Model and Monte Carlo simulation, accidents that occur in 100,000 flying hours, with and without controls, are simulated. Control performance is then defined as the expected decrease in losses after implementation of controls. Using the control performance and cost estimates, portfolios of controls are identified that meet Army Safety goals.

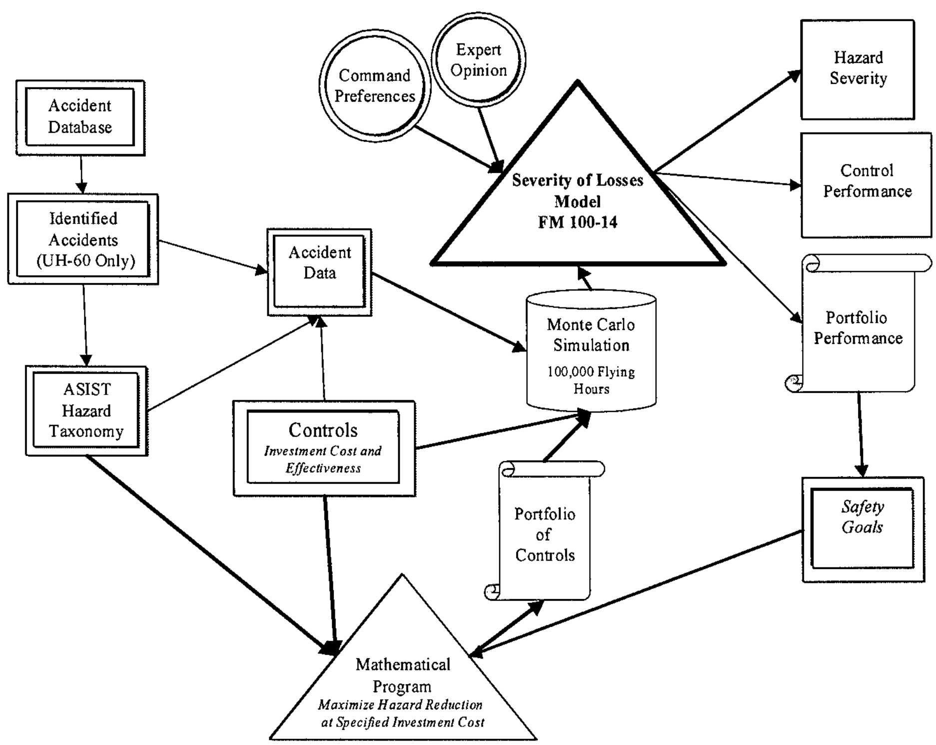

Figure 3-1 Project Framework

This chapter contains a description of the Severity of Losses Model, to include what it represents, its construction, data aggregation, and how ASIST's hazard taxonomy, hazards assessments, and controls assessments were implemented. The Monte Carlo simulation, using the bootstrap method, is described in detail. Finally, the mathematical program used to generate portfolios is discussed.

3.3 Severity of Losses Model

This model quantifies the severity of losses resulting from accidents in 100,000 flying hours. Accidents are unplanned events causing personal injury or illness, or property damage. Hazards are any actual or potential condition that can lead to an accident. For the purpose of analysis, it is assumed that reducing the frequency or severity of contributing hazards should reduce the overall losses associated with the accidents.

The Severity of Losses Model, incorporating expert opinion and commander preferences, quantifies the losses from UH-60 accidents. The components of the model are supported in Army doctrine and are representative of the important aspects in evaluating hazards and controls (Warren, 2000). FM 100-14, Army Risk Management, states four criteria to consider when assessing severity (FM 100-14, 1998: 2-9). The top tier of the Severity of Losses hierarchy represents *degree of injury or illness*, *other mission impairing factors, repair or replacement costs, other mission impairing factors*, and *environmental damage*. *Casualties* represents the degree of injury or illness, *unit readiness* represents other mission-impairing factors, and *total costs* represents loss of or damage to equipment or property. The top tier of the hierarchy is shown in Figure 3-2.

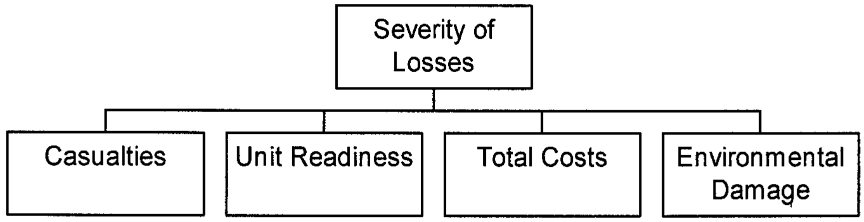

Figure 3-2 Top Tier Severity of Losses Hierarchy

The current Severity of Losses Model, based on the Accident Severity Model developed by Capt Brian Sperling (Sperling, 1999), quantifies the severity of losses resulting from accidents in 100,000 flying hours, rather than from a single accident or hazard. This change of viewpoint necessitated modification of the Accident Severity model. While the top tier of the hierarchy is outlined in FM 100-14 (see Figure 3-2), the questions of why and to whom are they important required investigation. Discussions with members of ASIST and USASC brought out the answers to these questions.

Accidents affect the Army as a whole, but an accident also impacts the owning unit. The effects of the severity of losses from *casualties* are felt at both the Army level and at the unit level. Similarly, the loss of an aircraft costs the Army millions of dollars, but perhaps even more severe is the decrease in unit readiness resulting from having fewer aircraft for training and mission execution (Semmens, 2000).

To represent these two levels, the evaluation measures in each tier focus on the appropriate level in Army command. *Casualties*, total costs, and environmental damage represent the severity of losses at an Army level perspective. Unit readiness looks at the impact of losses on the battalion. This distinct difference in the level of focus accounts for concerns at both the battalion unit and Army levels of command.

3.3.1 Evaluation Measures

This section describes the sub-criteria of the Severity of Losses Model. Each top level consideration is further broken down into evaluation considerations. As noted in Figure 2-3, the evaluation measures are classified as either natural-direct, natural-proxy, constructed-direct, or constructed-proxy. The metrics used to measure the evaluation considerations are also discussed.

3.3.1.1 Casualties

The *casualties* branch of the hierarchy measures the severity contribution of fatalities and injuries sustained in accidents. These considerations take an Army level perspective of determining severity. According to Army Risk Management, FM 100-14, and USASC leadership, the following evaluation considerations effectively measure *casualties*' contribution to severity (Warren, 2000).

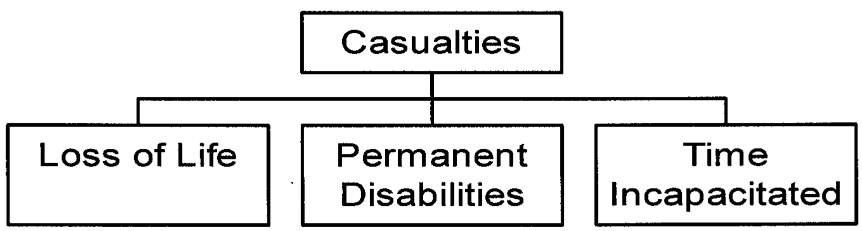

Figure 3-3 Severity of Losses: Casualties

3.3.1.1.1 Loss of Life

Loss of life is a natural-direct measure that assesses the severity of the number of fatalities in 100,000 flying hours. In this measure, all civilian and military deaths caused by UH-60 Blackhawk accidents are included.

3.3.1.1.2 Permanent Disabilities

There are two types of permanent disabilities tracked in the Risk Management Information Database (RMIS): total and partial. *Total disabilities* compromise any nonfatal injury that, in the opinion of competent medical authority, permanently and totally incapacitates a person to the extent that he or she cannot find any gainful employment (DA PAM 385-40, 1994: Glossary). The occurrence of this type of disability resulting from aviation accidents is extremely rare. No *permanent total disabilities* were found in the UH-60 five-year database, and, therefore, are not used in this study.

Permanent partial disability is a natural-direct measure used to assess the contribution to severity of losses from permanent disabilities. This type of injury occurs frequently enough to warrant inclusion in the model. A *permanent partial disability* is any injury (not resulting in death or *permanent total disability*) that, in the opinion of competent medical authority, results in the loss or permanent impairment of any part of the body, with the following exceptions:

a. Loss of teeth.
b. Loss of fingernails or toenails.
c. Loss of tip of fingers or tip of toe without bone involvement.
d. Inguinal hernia, if it is repaired.
e. Disfigurement
f. Sprains that do not cause permanent limitation of motion (DA PAM 385-40, Glossary).

3.3.1.1.3 Time Incapacitated

Time incapacitated is a natural-direct measure used to assess the total number of days of hospitalization resulting from aviation accidents. Hospitalization is defined as "admission to a hospital as an inpatient for medical treatment" (DA PAM 385-40, 1994: Glossary).

3.3.1.2 Unit Readiness

The effects of losses due to accidents are felt at both the Army and unit level. *Unit Readiness* measures the severity of losses in terms of impact on the battalion. The *Unit Readiness* branch of the hierarchy is shown in Figure 3-4. *Training execution, unit morale, and equipment availability* were identified as the major contributing factors to unit readiness (Semmens, 2000).

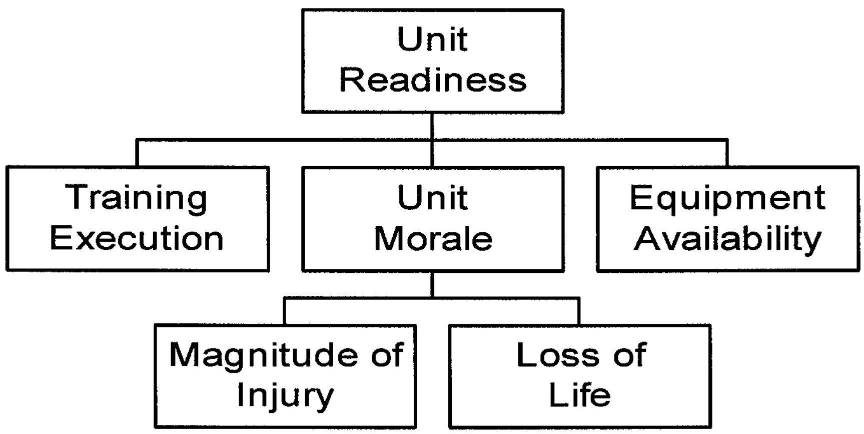

Figure 3-4 Severity of Losses: Unit Readiness

3.3.1.2.1 Training Execution

Training execution is a natural-proxy scale that assesses the battalion commander's change in mission planning and execution resulting from the number and class of recent accidents. The rationale is that, as more accidents occur in a unit, the commander is believed to become more risk averse. As a result, the commander may 'pull back' on the amount, complexity, realism, or sophistication of training, which reduces unit readiness. LTC Semmens expressed the opinion that the reduction in *training execution* due to recent accidents is most often the major cause of a decrease in unit readiness (Semmens, 2000).

3.3.1.2.2 Unit Morale

A decline in unit morale also has a detrimental effect on unit readiness. After discussing the many issues involved in assessing the impact on unit morale from aircraft accidents, two major influences were identified: *loss of life* and *magnitude of injury*. *Loss of life* is a natural-proxy measure that assesses the decrease in morale in terms of the number of fatalities in the unit. *Magnitude of injury* uses a constructed scale as a proxy measure to assess the effect on unit morale (Semmens, 2000).

3.3.1.2.3 Equipment Availability

Equipment availability is a natural-proxy measure to assess the impact on unit readiness resulting from fewer aircraft. An unavailable aircraft is defined as any aircraft requiring greater than 40 man-hours of repair time, or a total loss of an aircraft. The assumption is that repairs greater than 40 hours would not be accomplished at the unit level, requiring the aircraft to be fixed at the post or depot level (Semmens, 2000). If an aircraft is not economically repairable, it is considered a total loss (AR 385-40, 1994: 2-11).

Man-hours to repair are at first estimated in the accident report, then updated upon completion of the work. The final man-hour total includes time to estimate damage, repair and replace damaged components, and remove and replace parts not economically repairable (AR 385-40, 1994: 2-11).

3.3.1.3 Total Costs

Total costs is a natural-direct measure that assesses the severity of accidents in terms of the dollar cost to the Army. Army accident costs are computed, as describe in Army Regulation 735-11, using injury costs, repair/replacement costs, and other military and non-military damage costs resulting from accidents.

All aircraft damage costs are accounted for in repair/replacement cost. When the aircraft is a total loss, the aircraft acquisition cost is used. When the aircraft is repairable, the replacement cost is computed using the actual cost of replacement parts and man-hour costs (AR 385-40, 1994: 2-11).

Figure 3-5 Severity of Losses: Total Costs

Injury costs are used in calculating total accident cost, although they are not used in determining accident classifications. Injury costs include the cost of pay while away from work, medical treatment, hospitalization, dependent survival, unused training costs, gratuities, compensation, disability retirement, and burial. Injury costs do not include indirect costs associated with the accident such as wages lost to employees not injured (production loss) or cost of hiring and training new employees. The actual amount of time away from work may not be known at the time the accident report is submitted. If it is not known, an official estimate of lost workdays, made by a competent medical authority, is used in computing the cost (AR 385-40, 1994: 2-11).

3.3.1.4 Environmental Damage

The Army Risk Management manual identifies environmental damages as a necessary criterion in assessing severity. FM 20-400, the Military Environmental Protection Manual, states the applicable sub-criteria given in Figure 5-2. However, little data currently exists to allow a detailed assessment of environmental damage.

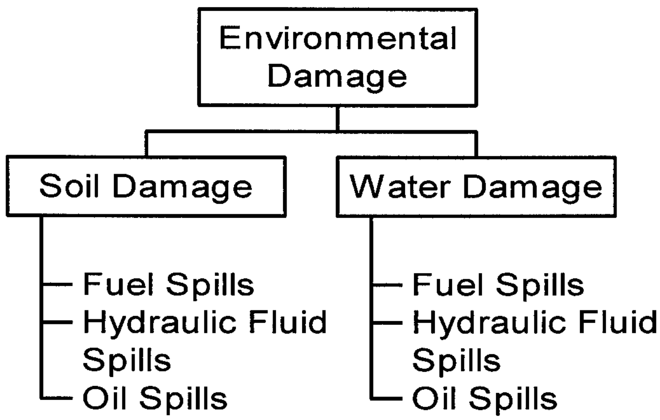

Figure 3-6 Severity of Losses: Environmental Damage

Constructed-direct measurements are used in assessing soil and water damage. The Army categorizes hazardous fluid spills based on the number of gallons spilled (see Table 3-7). In assessing the severity of environmental damages, effect on the environment and the amount of cleanup required are taken into account.

3.3.2 Severity Functions

This section provides a description of the process used to develop single dimensional severity functions for each evaluation measure. Single dimensional *value* functions are usually constructed so that the least preferred level receives a zero, and the most preferred level receives a one (Kirkwood, 1997: 61). In assessing the *severity* of the evaluation measures, the most preferred level is the least severe level. Therefore the least preferred level of the evaluation receives a severity of one (Sperling, 99: 3-26).

The expected range of each metric is determined through simulation based on accident data from FY94 through FY98. The range represents the lower and upper bounds that are needed in developing evaluation measures. Two different procedures were used in building the severity functions. In creating a piecewise linear severity function, relative severity increments between the possible evaluation measure scores were specified (Kirkwood, 1997: 62). Exponential severity functions are used where the severity increments are not linear. In these functions, a mid-severity score and its associated measure score were specified. The mid-severity score is the score in which the difference in severity between the lowest score and the mid-severity score is the same as the difference in severity between the mid-severity score and the highest score (Kirkwood, 1997: 66).

The severity functions were developed through interviews with appropriate representatives from the USASC. *Casualties* and *total costs* severity functions were developed with COL Warren, USASC Deputy Commander. *Unit readiness* severity functions were developed with a recent battalion commander, LTC Semmens, USASC Executive Officer. Finally, *environmental damage* severity functions were developed with an expert in environmental law, LTC Gleisberg, USASC Judge Advocate General.

3.3.2.1 Casualties

The following severity functions assess the severity of *casualties* occurring in 100,000 UH-60 Blackhawk flying hours, from an Army level perspective.

3.3.2.1.1 Loss of Life

The loss of any individual is tragic and could never be adequately quantified. However, from an Army perspective, the loss of each additional life due to aviation accidents is equally severe, resulting in a linear function (Warren, 2000). From fiscal year 1994 through 1998, the average number of fatalities per 100,000 flying hours was about 2.53. The maximum number occurring in a single accident in that timeframe was eight. Results from 10,000 simulation runs suggest an expected range of 0 to 27 *fatalities* in 100,000 UH-60 flying hours.

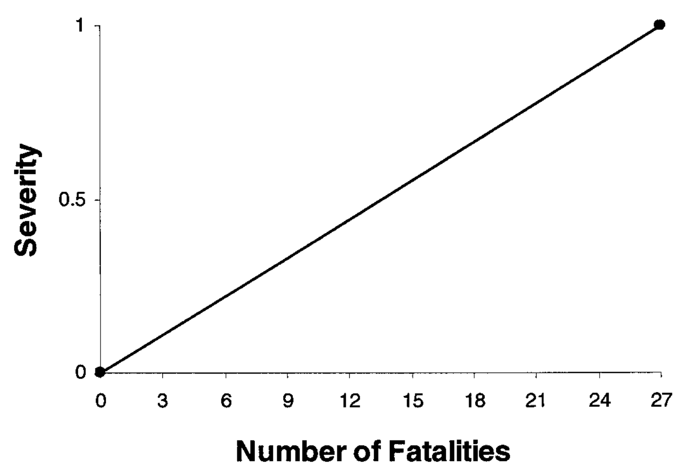

Figure 3-7 Severity Function: Loss of Life

3.3.2.1.2 Permanent Partial Disabilities

Similar to *loss of life*, the effect of *permanent partial disabilities* is also tragic. In terms of severity to the Army, each occurrence is equally severe (Warren, 2000). Again, a linear severity function is used. The only occurrence in the accident database of *permanent partial disabilities* was a single accident with two *permanent partial* *disabilities*. Simulation results suggest an expected range of 0 to *6 permanent partial disabilities.*

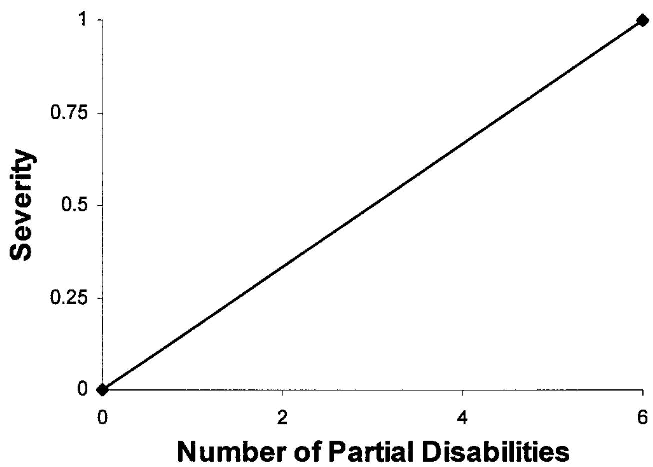

Figure 3-8 Severity Function: Partial Disabilities

3.3.2.1.3 Time Incapacitated

Time incapacitated is scored in terms of total days in the hospital as a result of UH-60 accidents in 100,000 flying hours. A linear severity function is used because, from an Army perspective, each day of hospitalization is equally severe (Warren, 2000). Using past accident data and the Monte Carlo simulation an expected range of *time incapacitated* is 0 to 52 days of hospitalization (see Figure 3-9).

3.3.2.2 Unit Readiness

Unit readiness focuses on the battalion level. The severity of losses in each measure is for each individual unit, but is representative of 100,000 total UH-60 flying hours, or roughly six months for the current UH-60 program. The information used in developing the severity functions for *training execution*, *unit morale*, and *equipment availability* was elicited from LTC Semmens, a recent aviation battalion commander.

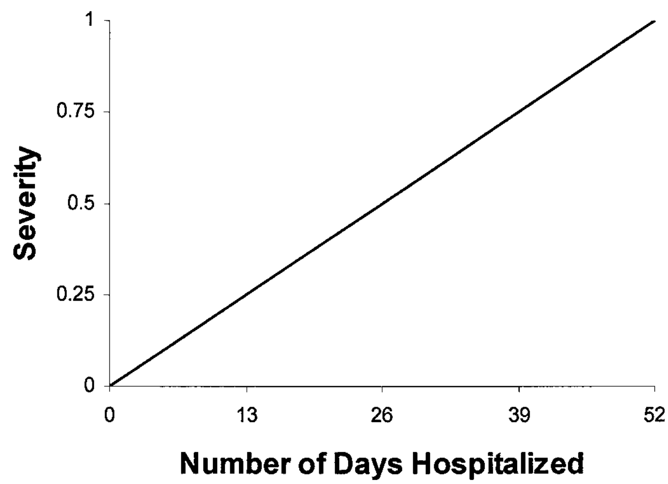

Figure 3-9 Severity Function: Time Incapacitated

Throughout the interview, he emphasized that more aviation commanders need to be interviewed to better capture the nature of these severity functions. Because of this, the severity functions used in this study are based upon guidance from LTC Semmens rather than explicit data points.

3.3.2.2.1 Training Execution

Training execution assesses the impact on unit readiness resulting from a reduction in training frequency, complexity, and realism. This measure combines both the number and class of accidents occurring in a single unit within a range of 0 to 3 accidents. This range was determined through simulation and is an realistic representation (Semmens, 2000). From the battalion commander's viewpoint, the effect on risk aversion is about the same for three Class C accidents as it is for one Class A accident. The following scale, designed to account for the class and the number of accidents, is used in measuring *training execution*:

Class A accident = 3
Class B accident = 2
Class C accident = 1

For example, if a unit had two Class A accidents in the time span of 100,000 UH-60 flying hours (approximately six months), the *training execution* category would be six. Two Class Cs and one Class B accident would be a Category 4 (Semmens, 2000). The largest increase in severity occurs between two and four on the accident-class category scale. After a single Class-A, or two Class-B or -C accidents, commanders may become more risk-averse and 'pull back' on the amount of flying. Severity increases slowly after category six, representing a threshold above which the unit would most likely have already reduced flying dramatically (Semmens, 2000).

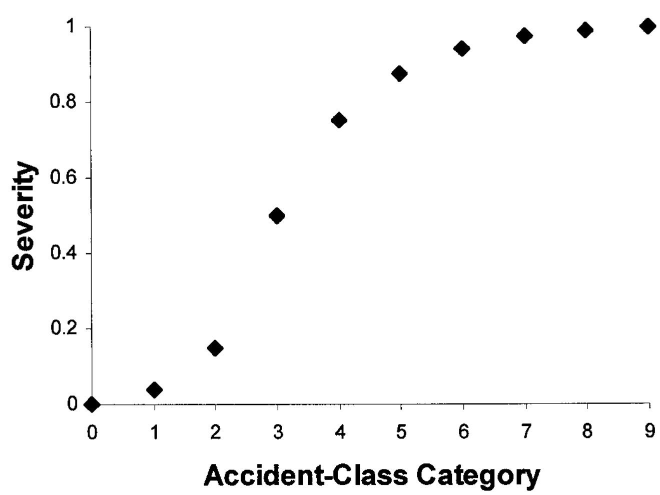

Figure 3-10 Severity Function: Training Execution

3.3.2.2.2 Unit Morale

A decrease in *unit morale* can affect unit readiness. For the purpose of this analysis, *unit morale* is subdivided into *lives lost in unit* and *magnitude of injury.*

3.3.2.2.2.1 Lives Lost in Unit

Constructing a severity function for *lives lost in unit* is complicated because each commander will have a different viewpoint on the matter. LTC Semmens had experience in developing severity functions and was familiar with the concept of evaluating increments in severity. In the interview, LTC Semmens was shown a curve with a range of 0 to 9 and a midvalue of 3. He felt that a unit could cope with the first few fatalities, after which each additional lost life increasingly affects the unit. The *lives lost in unit* severity function described by LTC Semmens is shown in Figure 3-11. Nine fatalities in a single unit during a six-month timespan would be a rare occurrence, but possible. This range was determined through Monte Carlo simulation using UH-60 accident data for fiscal years 1994 through 1998. The severity represents the impact on unit morale because of the fatalities rather than the value or importance of lives lost.

Figure 3-11 Severity Function: Lives Lost in Unit

3.3.2.2.2.2 Magnitude of Injury

Magnitude of injury, shown in Figure 3-12, uses the following scale in assessing severity:

Category 0:	No injuries requiring hospitalization
Category 1:	Injuries requiring less than 7 days hospitalization
Category 2:	Injuries requiring more than 7 days hospitalization, but no permanent disabilities
Category 3:	Injuries resulting in permanent disabilities

Category 1 represents minor injuries, which rarely affect the morale of the unit. Unit morale is affected slightly more when personnel sustain more serious injuries, represented by Category 2. Permanent disabilities, Category 3, are considered much more severe in comparison and tend to have a lingering effect in the minds of unit personnel (Semmens, 2000).

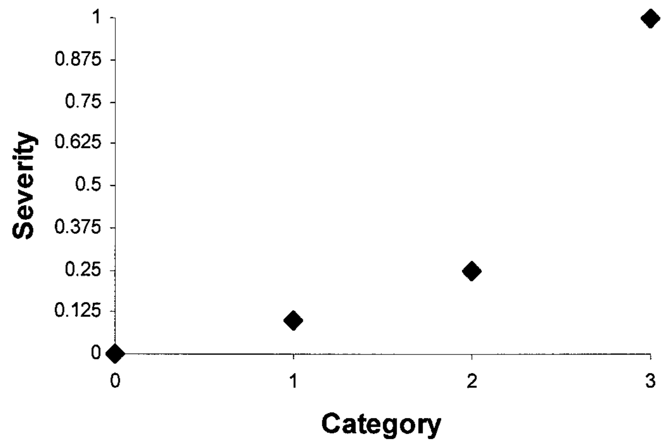

Figure 3-12 Severity Function: Magnitude of Injury

3.3.2.2.3 Equipment Availability

The *number of unavailable aircraft in a unit* is defined as any aircraft requiring more than 40 hours of maintenance, or not economically repairable, as a result of an accident. Using past accident data and Monte Carlo simulation, the expected range for the *number of unavailable aircraft in a unit* was determined to be 0 to 5 unavailable aircraft.

The severity function in Figure 3-13 shows a major increase in severity between two and three unavailable aircraft. This threshold represents the level where a typical unit would begin to feel the impact of fewer aircraft (Semmens, 2000).

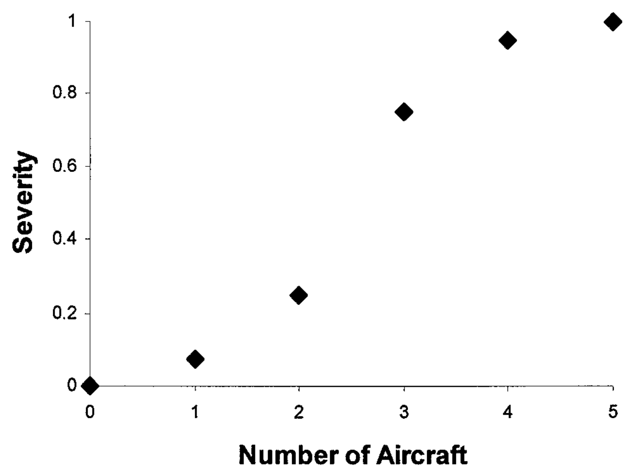

Figure 3-13 Severity Function: Aircraft Availability

3.3.2.3 Total Costs

Total Costs assesses the severity of UH-60 accidents in terms of dollar cost to the Army. Repair/replacement, injury, and damage costs in 100,000 flying hours are totaled. Looking at the range of costs generated by simulation using past accident data, 0.1 to 52 million, there is no threshold that warrants a significant jump in severity (Warren, 2000). When considering the fact that the UH-60 is only one fleet of aircraft in the Army inventory, this makes even more sense. Therefore, the *total costs* severity function is linear.

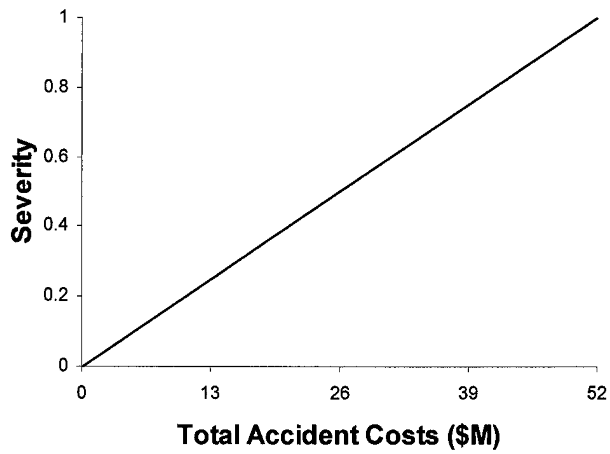

Figure 3-14 Severity Function: Total Costs

3.3.2.4 Environmental Damage

Specifically, this measure uses the maximum occurrence of spill category in 100,000 flying hours. Based on Army Regulation 385-40, fuel, hydraulic fluid, and oil, fluid spills are estimated as follows:

Category 0:	No hazardous fluid spilled
Category 1:	Less than 1 gallon of hazardous fluid spilled
Category 2:	More than 1, but less than 2 gallons
Category 3:	More than 2, but less than 10 gallons
Category 4:	More than 10, but less than 20 gallons
Category 5:	More than 20 gallons spilled

For example, if there were three accidents with recorded spillage in 100,000 UH-60 Blackhawk flying hours, the maximum spill category for all types of hazardous fluids (fuel, hydraulic fluid, and oil) from the three accidents would be used in the severity function.

3.3.2.4.1 Soil Damage

Severity of damage to the soil is assessed in amount of hazardous fluids spilled in an accident. From an Army perspective, UH-60 hazardous fluid spills are generally of little concern. In considering soil damage, there is little difference in the type of hazardous fluid spilled. Therefore, the same severity function is used for fuel, hydraulic fluid, and oil. The severity of a Category 5 spill was estimated to be 3 times as severe as a Category 4 (Gleisberg, 2000).

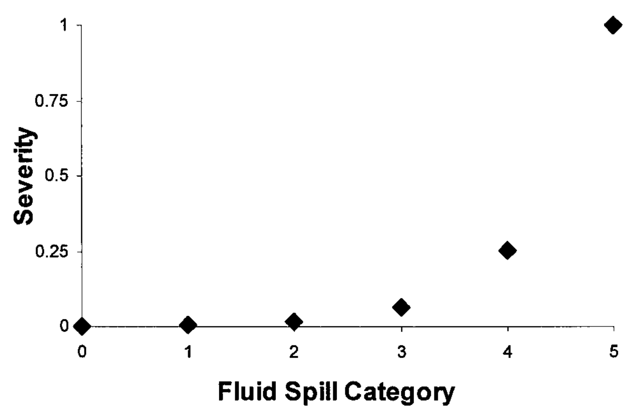

Figure 3-15 Severity Function: Soil Damage

3.3.2.4.2 Water Damage

Severity of damage to water sources is dependent on the type of fluid spilled. *Fuel spills* tend to dissipate easily, except in large quantities. In these cases, the severity of a Category 5 spill was estimated to be 10 times as severe as a Category 4. Once in the water, hydraulic fluid and oil tend to clump near the surface. For these types of water spills, a Category 5 is judged to be 3 times as severe as a Category 4 (Gleisberg, 2000).

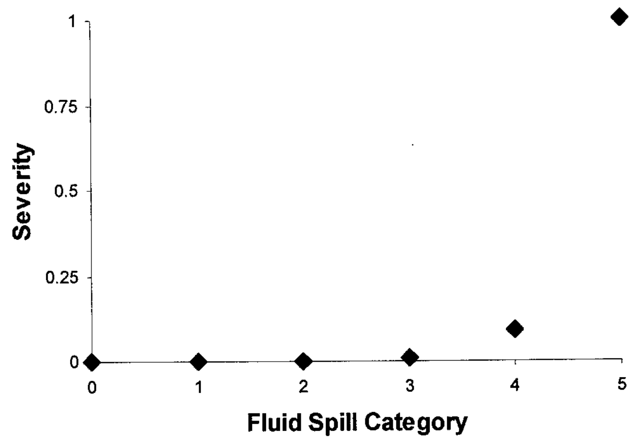

Figure 3-16 Severity Function: Water Damage - Fuel

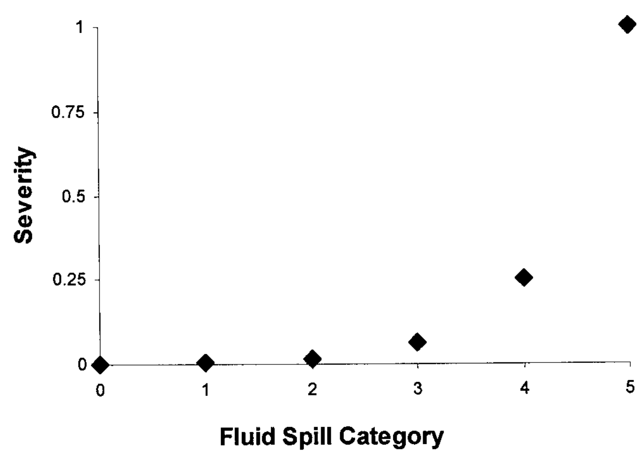

Figure 3-17 Severity Function: Water Damage – Hydraulic and Oil

3.3.2.5 Severity of Losses Hierarchy

The criteria and evaluation considerations in this were validated with ASIST and the decision maker's representative, COL Warren (AFIT Brief, 2000). Further research, if warranted, may improve upon the current hierarchy by incorporating changes or additions as required. Figure 3-18 displays the entire hierarchy.

3.3.3 Weight Assessment

Before describing the process used to determine the weights for the Severity of Losses Model, it is necessary to review the subtle difference between value functions and severity functions. Single dimensional value functions are usually constructed so that the *least preferred level* receives a zero, and the most preferred level receives a one. In assessing the severity of the evaluation measures, the most preferred level is the least severe level. For this reason the *least preferred level* of the evaluation receives a severity of one.

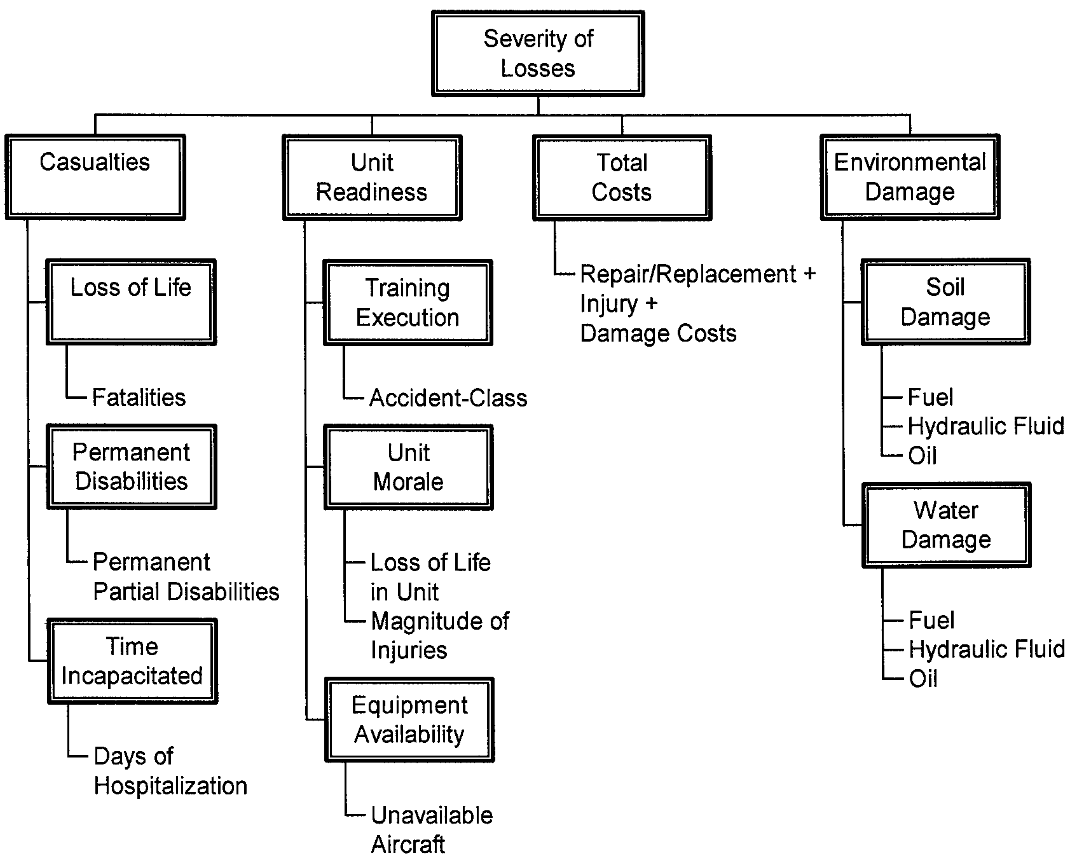

Figure 3-18 Severity of Losses Hierarchy

The severity scores from each evaluation measure are combined to generate an overall severity of losses score. One way of combining the severity scores, perhaps the simplest, might be to average them. In most situations involving tradeoffs, however, average scores fail to take into account any tradeoffs that may exist. Attaching weights to the evaluation measures alleviates this problem (Kirkwood, 1997:59).

Weights, normally elicited from the decision maker or a designated representative, represent the importance placed over the range of each evaluation measure. Combining the weights and the severity functions yields the overall additive severity function (Kirkwood, 1997: 230): $\text{severity of losses}(X) = \sum_{i=1}^{n} w_i s_i(x_i)$, where X represents the set of attributes under consideration, w is the weight, and $s()$ is severity.

3.3.3.1 Local Weights

Local weights, derived from pairwise comparisons of evaluation measures, represent the relative importance of each measure in a single branch of a hierarchy (Kirkwood, 1997: 71). Using the ranges for each evaluation measure, the local weights for each branch of the hierarchy were elicited from the appropriate experts and representatives.

3.3.3.1.1 Local Weights - Casualties

Weights in the *casualties* branch of the hierarchy were assessed using information elicited from COL Warren. Using hypothetical situations representing extreme situations, he was able to compare the severity of measurable ranges from evaluation measures and establish their relative importance (Kirkwood, 1997: 71).

The first hypothetical situation involved having a control that eliminated all losses due to accidents except for *loss of life*, which remained at its most severe level of 52 *fatalities*. Next, he was asked to imagine a different control that eliminated all losses except for permanent disabilities, which remained at its most severe level of *6 permanent partial disabilities*. When asked which control he would rather implement, COL Warren chose the second. This response indicated that, within the given ranges, *loss of life* should be weighted more than *permanent disabilities*. A similar situation comparing *permanent disabilities* with *time incapacitated* resulted in a greater emphasis placed on *permanent disabilities*.

Using the same hypothetical situations, COL Warren was next asked to determine a level on the *loss of life* scale with which, when compared with the highest level of *permanent partial disabilities*, he would be indifferent between the two controls. The level of *loss of life* stated was two. One way to view this statement is that the severity increment of going from no *fatalities* to two is equal to the severity increment of going from no partial disabilities to six. In comparing the severity of *permanent disabilities* with *time incapacitated*, the level of indifference for the *permanent partial disability* measure was three disabilities. These relationships result in the following equations:

$$weight_{\text{loss of life}} * severity_{\text{loss of life}}(2) = weight_{\text{permanent disabilities}}$$

$$weight_{\text{loss of life}} + weight_{\text{permanent disabilities}} + weight_{\text{time incapacitated}} = 1$$

$$weight_{\text{permanent disabilities}} * severity_{\text{permanent disabilities}}(3) = weight_{\text{time incapacitated}}$$

Solving this group of equations results in the following local weights:

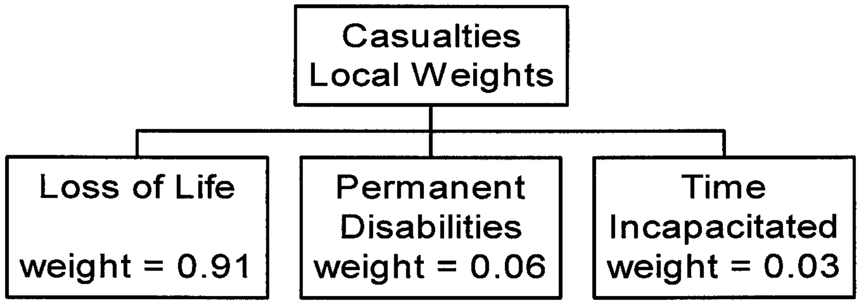

Figure 3-19 Local Weights - Casualties

3.3.3.1.2 Local Weights - Unit Readiness

In determining the weights for unit readiness, LTC Semmens, the most recent aviation battalion commander at the Army Safety Center, again recommended interviewing more battalion commanders to attain a more diverse representation. Rather than give explicit severity comparisons, he provided general guidance on the nature of the weights. On the upper level, he said if *equipment availability* was given a one, then unit morale would be a two, and *training execution* would be a three. These answers represented ratios of severity increments, but he stressed that these were guides for weights. Within unit morale, he stated that, at the unit level, *magnitude of injuries* have a slightly higher effect than *fatalities*. His estimation was about a 1.2 to 1 ratio of *magnitude of injury* to *lives lost* (Semmens, 2000). A note was made to conduct sensitivity analysis of these weights as part of the overall analysis. These estimations result in the following local weights for unit readiness:

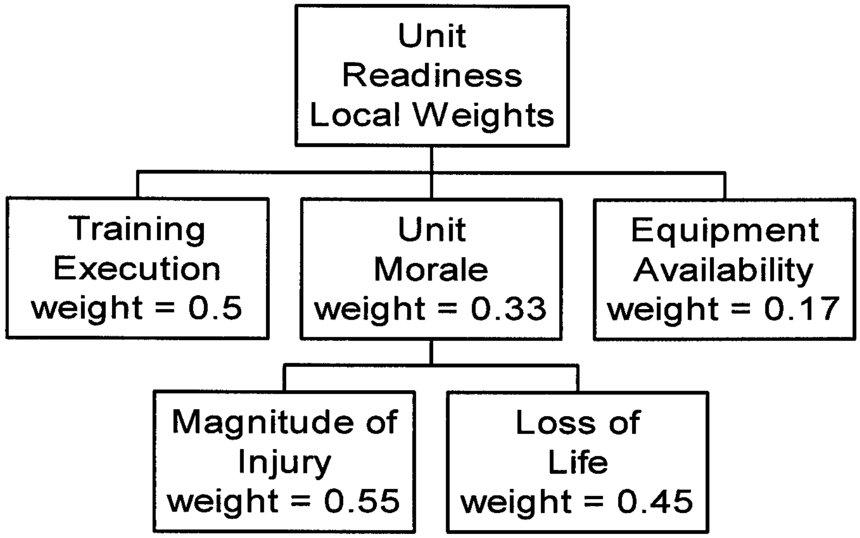

Figure 3-20 Local Weights – Unit Readiness

3.3.3.1.3 Local Weights Environmental Damage

In interviewing LTC Gleisberg, hypothetical situations similar to those presented to COL Warren were used to determine the local weights of the evaluation measures. For *soil damage*, the increment in severity going from a Category 0 to a Category *5 hydraulic fluid spill* is equivalent to going from a Category 0 to a Category 4 *fuel spill*. Similarly, the increment in severity from a Category 0 to a Category 5 *oil spill* is equivalent to going from a Category 0 to a Category 4 *fuel spill*.

For *water damage*, LTC Gleisberg commented that an oil spill is much more damaging than a fuel spill. Fuel dissipates rapidly in water, while oil tends to clump and stick to rocks and wildlife. In comparing oil with fuel, going from a Category 0 to a Category 5 *fuel spill* is equivalent in severity to going from a Category 0 to a Category 3 *oil spill*. Hydraulic fluid spills in water are worse than fuel, but not as bad as oil (Gleisberg). The increment in severity from a Category 0 to a Category 5 *hydraulic spill* is equivalent in severity of going from a Category 0 to a Category 4 *oil spill* in terms of *water damage*. In comparing the severity of *soil damage* versus *water damage*, LTC Gleisberg stated that going from a Category 0 to a Category 5 *fuel soil spill* is equivalent in severity to going from a Category 0 to a Category 5 *oil spill* in water. Using these relationships the following local weights were derived:

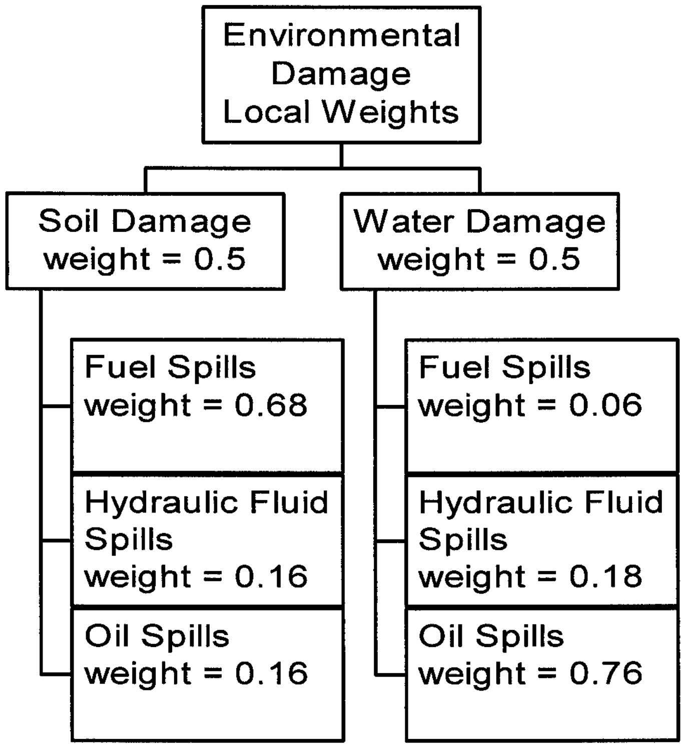

Figure 3-21 Local Weights – Environmental Damage

3.3.3.2 Global Weights

Having determined the local weights in each branch of the hierarchy, the higher level weights in the hierarchy were assessed in the same manner. COL Warren made severity comparisons, at Army level, between evaluation measures in different branches of the hierarchy. Similar to the hypothetical situations used in assessing local weights, he was asked to imagine controls that eliminate all losses except for one, which remained at its most severe level.

The first hypothetical situation involved selecting between a control that eliminated all losses except for a Category 5 *hazardous fluid spill*, and a control that removed all losses except for \$52 million of *total accident costs*. COL Warren stated that, in this hypothetical situation, he would choose the first control. For him to be indifferent between the two controls, the level would have to be \$1 million of *total costs* (Warren, 2000).

The next hypothetical situation involved a control that removed all losses except for \$52 million of total accident costs, and a control that removed all losses except that it left *training execution* at its most severe level. *Training execution* is focused at the battalion level, while *total costs* is at Army level. The way *training execution* is defined, the most severe level would be three Class-A accidents in **each** unit. This would be equivalent to 78 total Class-A accidents in 100,000 flying hours, since the model assumes there are 26 UH-60 battalions. COL Warren chose the first control, stating that, while \$52 million is a lot of money to the Army, it does not compare to the effect on *training execution* that many accidents would have. To feel indifferent about the two controls, *training execution* would have to be at a level of two. This level would be equivalent to each unit sustaining a single Class-B accident in 100,000 flying hours. In comparison, an average *training execution* level of 2 across all 26 battalions is, in terms of severity, equivalent to \$52 million in total accident costs (Warren, 2000).

The next hypothetical situation involved a control that removed all losses except for \$52 million of total accident costs, and a control that removed all losses except that it left *loss of life* at its most possible severe level of 52 *fatalities*. While it is hard to place a dollar value on a life, this type of tradeoff must be made. Looking at both *loss of life* and total accident costs from an Army perspective, COL Warren stated he would rather implement the first control. For him to feel indifferent between the severity of the two controls, the level of *loss of life* would have to be four. Thus at an Army level this would mean the severity of four *fatalities* is equivalent to the severity of \$52 million in *total accident costs*. It is recognized that other key leaders may express different tradeoff preferences, which would then require the top portfolio to be checked for sensitivity to this change.

By using the following relationships, as well as the previously determined local relationships, the global weights for the Severity of Losses Model were calculated (see Figure 3-22).

$$weight_{\text{Training Execution}} * severity_{\text{Training Execution}}(2) = weight_{\text{Total Accident Costs}}$$

$$weight_{\text{Total Accident Costs}} * severity_{\text{Total Accident Costs}}(1) = weight_{\text{fuel soil damage}}$$

$$weight_{\text{loss of life}} * severity_{\text{loss of life}}(4) = weight_{\text{Total Accident Costs}}$$

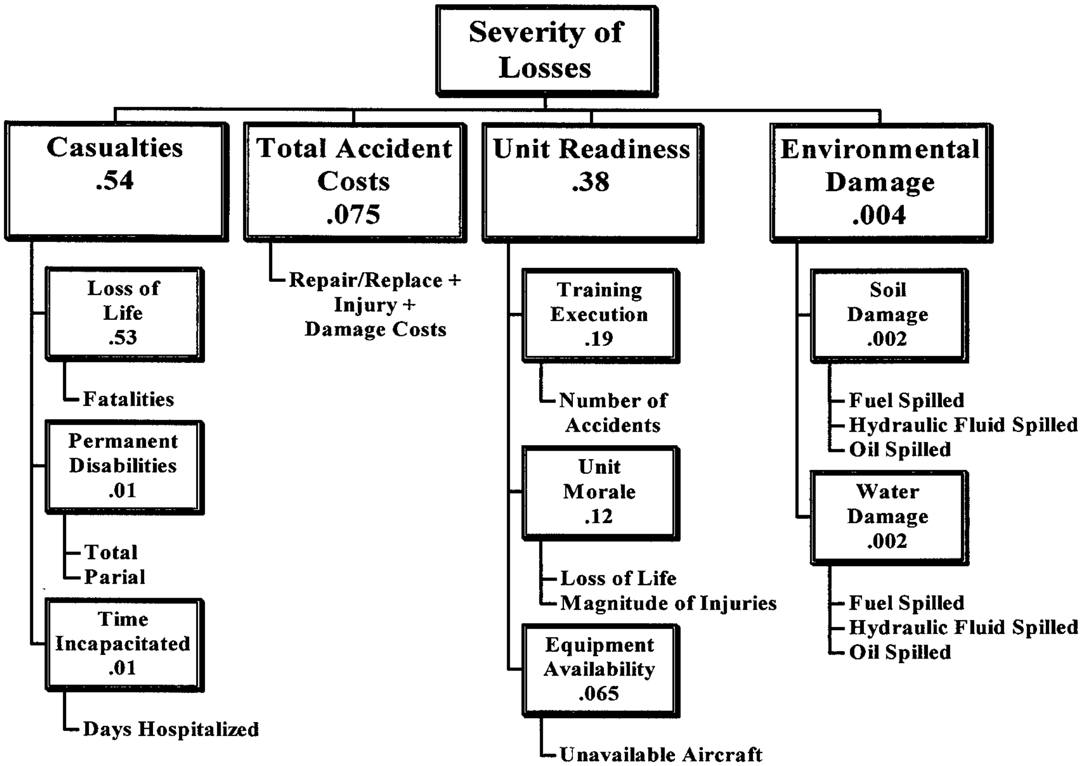

Figure 3-22 Severity of Losses Global Weights

The weights elicited and used in this model represent the values and preferences of the current leadership at the USASC and may not represent the official US Army preferences. The entire Severity of Losses Model should be reassessed periodically to ensure it remains representative.

3.4 Hazards

The current model, as described above, quantifies the severity of losses resulting from UH-60 accidents occurring in 100,000 flying hours. Controls have been developed to eliminate or reduce the effects of the hazards that contribute to the cause or severity of the accidents. This section describes the hazard taxonomy and the hazard contribution assessments from ASIST.

3.4.1 ASIST Hazard Taxonomy

In developing the new hazard taxonomy, members of the ASIST team conducted a thorough review of all UH-60 accident narratives. Using the definition that a hazard is made up human, materiel, and environmental factors, they developed a detailed list of 67 hazards, which is included in Appendix A. This taxonomy represents a breakthrough as a focus on the different parts of the man-machine-environment system that worked together to produce a hazard. Emphasis was taken off of who made a mistake or which engine part failed in favor of a more holistic and preventative approach (ASIST Brief, 1999).

3.4.1.1 ASIST Hazard Assessments

ASIST estimated hazard contribution assessments for three areas: casualty, cost, and frequency. *Casualty* refers to *injuries* and *fatalities*, *cost* refers to *total accident costs*, and *frequency* refers to the cause of the accident. Each assessment estimates the percent contribution of the hazard in an accident in the areas of *casualty, cost*, and *frequency*. For an accident, any number of hazards may contribute to these areas, but the total contribution of all hazards in each area must be 100 percent. Table 3-1 contains an example of hazard assessments for two accidents.

Table 3-1 Hazard Assessment

Accident	Contributing Hazards	Casualty Contribution	Cost Contribution	Frequency Contribution
19940304	AVN-05	0.333	0.333	0.333
	H60-05	0.667	0.667	0.667
	Total	1.000	1.000	1.000
19951110	AVN-01	0.364	0.364	0.400
	AVN-03	0.181	0.181	0.200
	H60-18	0.364	0.364	0.400
	H60-20	0.091	0.091	0.000
	Total	1.000	1.000	1.000

Accident 19940304 had two contributing hazards. Across all three categories, AVN-05 was responsible for 1/3 of the accident losses and H60-05 was responsible for 2/3. In the second example, even though H60-20 contributed to the *severity* of the accident, its frequency contribution was zero, indicating it had nothing to do with the actual *cause* of the accident.

3.5 Controls

Value models are typically used to evaluate and develop alternatives. In this study, controls or portfolios of controls, are the alternatives. ASIST developed a list of 49 controls designed to attack various hazards in the UH-60 Blackhawk program. Similar to the hazard contribution assessments, each control has an assessed percent effectiveness against each hazard. Even though the controls were developed with a particular hazard in mind, many controls affect more than a single hazard. Experienced Army aviators and members of ASIST spent hundreds of hours to develop the control effectiveness assessments which represent the estimated hazard reduction at the end of ten-years, and apply to the casualty, cost, and frequency areas of the hazard (ASIST Control Calculations Brief, 1999). Investment costs for the ten-year period were also estimated (see Table 3-2). While a massive and time-consuming effort, ASIST's efforts were invaluable to this thesis. A complete control listing, including description, affected hazards, and estimated investment costs, is included in Appendix B.

Table 3-2 H60-C09 Control Effectiveness

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.6
H60-09	0.6
H60-18	0.6
H60-58	0.5

3.6 Control Evaluation Using Monte Carlo Simulation

The Severity of Losses Model quantifies the losses from accidents occurring in 100,000 UH-60 flying hours. Since the Army reports the rate of accidents per 100,000 flying hours, this same block of time is used to simulate accident losses.

Control performance is defined as the decrease in expected severity resulting from implementation of that control. This is evaluated by combining the control effectiveness assessments with the hazard contribution assessments to influence the frequency and outcomes of the accidents in a 100,000 flying hour operational period.

The Monte Carlo simulation approach used produces a distribution of expected severity scores. The expected performance of a control, or group of controls, is defined as the expected decrease in the *severity of losses* resulting from the implementation of the controls.

Using Monte Carlo and the bootstrap method helps in dealing with difficulties involved in randomly generating accident data. Since there is no accident distribution to draw from, past accidents are used as the type of UH-60 accidents likely to occur in the future. In this case, bootstrap sampling accounts for correlation of accident data. As mentioned in chapter two, the bootstrap method is useful in situations in which there is no well-defined underlying probability distribution. Using the UH-60 accident database is just such a situation.

3.6.1 Monte Carlo Simulation

Monte Carlo simulation and the bootstrap method are used to generate data that represents the losses that might occur from accidents in 100,000 UH-60 flying hours. The methodology consists of conducting B independent samples, with replacement, each consisting of n data points (Efron and Tibshirani, 1993: 47). Each of the n data points represents the severity of losses from the accidents that might occur in 100,000 flying hours.

To generate a single data point, or one severity score, accidents are randomly drawn, with replacement, from an empirical distribution of accidents. The distribution of accidents used in this study are all Class A-C UH-60 accidents that occurred in fiscal years 1994 through 1998. The number of draws in each replication is binomial random variable with 30 trials and $p = 0.29$. The distribution is based on UH-60 Class A-C accident rates from the same five years.

The data set used in the simulation represents 5 years of accident data, or about 10 blocks of 100,000 flying hours. For this reason n=10 data points are generated in each of the B replications. It is important to note that a data point is not the severity of **an** accident but the severity of a collection of accidents that may have occurred over 100,000 flying hours of the UH-60. This simulation was implemented using Microsoft Excel and the commercial add-in software package Crystal Ball. Crystal Ball uses Monte Carlo simulation to provide forecasting and risk analysis capabilities. A description of the Monte Carlo simulation is included in Appendix C.

3.6.2 Accident Rate Adjustment

The effect of implementing a control is estimated by modifying the accident data. The expected frequency reduction is used to reduce the number of accidents occurring in the simulation. Data from the randomly selected accidents is then transformed and aggregated to the appropriate level for input to the Severity of Losses Model. This produces a single score representing the severity of losses for 100,000 flying hours. The number of accidents in each run of the Monte Carlo simulations is a random number based on historical accident rates. Controls can be designed to reduce the probability of a hazard contributing to an accident or the severity of hazards, or both. The simulation model accounts for the probabilistic aspects of the control by reducing the number of accidents in the run. The extent of the reduction of the raw accident data is determined by calculating the casualty, cost, and frequency reduction totals. Each control has a list of hazards it affects along with the estimated percent effectiveness. Each accident has a list of percent contribution of each hazard. When an accident is selected in the simulation, each hazard contribution assessment is combined with the control effectiveness estimate to determine the amount of frequency reduction.

3.6.3 Accident Data Transformation

In the base case, fiscal year 1994 through 1998 accident data is simply aggregated and input into the Severity of Losses Model. This action returns the base case expected severity, which represents the expected severity of UH-60 losses in 100,000 flying hours if no controls are implemented. The simulation is then run again with the control effects included. The difference between the base case severity and a score with a control implemented is the control performance score.

To simulate the effect of implementing a control, the same empirical data set is transformed based on the hazard and control assessments. The adjustment percentage is determined by calculating the casualty, cost, and frequency reduction totals. Each control has a list of hazards it affects along with the estimated percent effectiveness. Each accident has a list of percent contribution of each hazard. The ASIST casualty, cost, and frequency assessments are applied to the various evaluation measures. It would be best to individually assess the hazard contribution for each evaluation measure in the Severity of Losses Model, which would require convening the ASIST experts for another long and expensive session. Since the hazard assessments developed by ASIST were readily available and had consensus approval by the ASIST members, a method was found that would allow their use in this application.

3.6.3.1 Hazard Contribution Assessments

Hazard contribution to casualty assessments are applied to all evaluation measures in the *casualties* branch, as well as the *unit morale* evaluation measures under *unit readiness*. The unit morale evaluation measures deal with *fatalities* and *magnitude of* *injury* and clearly had the most direct ties to effectiveness against *casualties* (see Figure 3-23).

Hazard contribution to cost assessments are applied to *total costs* and to the evaluation measures in *equipment availability* in *unit readiness*. *Equipment availability,* measured in terms of man-hours to repair, is a component of the total accident costs. It is therefore assumed the hazards that are effective in reducing cost are equally effective in reducing repair effort.

Hazard contribution to frequency is used for *training execution* and *environmental damage*. Hazard frequency contribution is assessed as the degree (percent) to which that hazard is responsible for causing the accident. Since *training execution* uses number of class A-C accidents, it was logical to use the frequency reduction assessment as the effect on this measure. Hazard contribution assessments for environmental damage do not currently exist. It is assumed that the hazard frequency assessments, at this point, are adequate to approximate the infrequent occurrence of environmental damage due to spills (Warren, 2000). This may be an area to consider in the further development of the model. The frequency assessments are also used to simulate the reduction in the number of accidents.

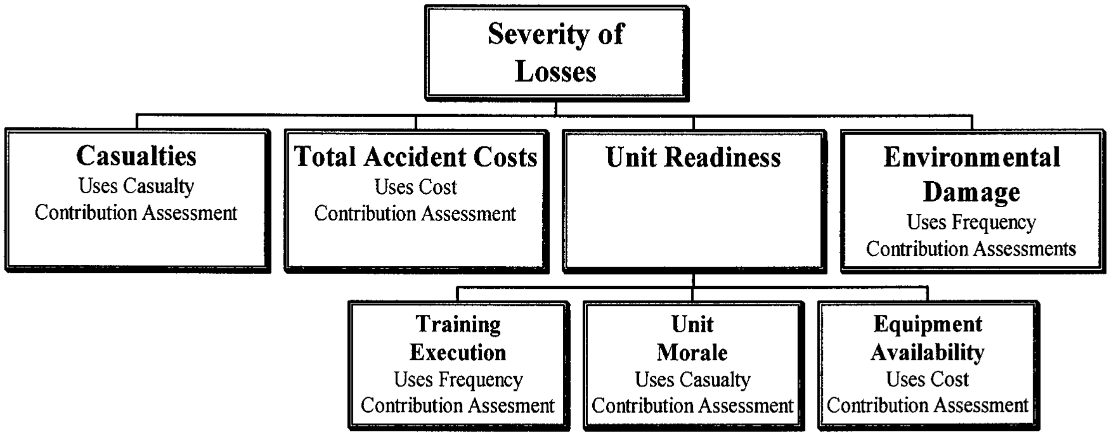

Figure 3-23 Application of Hazard Contribution Assessments

3.6.3.2 Accident Data Calculations

When an accident is randomly selected in the simulation, each hazard contribution assessment is combined with the control effectiveness estimate to determine the casualty, cost, and frequency reduction amount.

To illustrate this process, consider the following hypothetical accident, hazards, and controls:

Table 3-3 Sample Accident Data

Case	Total Costs	Fatalities	Repair Hrs	Oil
19940205	65,000	0	292	1.5 Gallons

Hazard	Casualty	Cost	Frequency
1	1	0.5	0.5
2	0	0.25	0.5
3	0	0.25	0

Now assume Control 1 is 40 percent effective on Hazard 1, Control 2 is 30 percent effective on Hazard 2, and 60 percent effective on Hazard 3. If Control 1 is implemented, and case 19940205 is drawn during a simulation run, the amount of frequency reduction would be 20 percent. A Bernoulli trial (success or failure) is conducted to decide if the accident data should be aggregated. This simulates reduction of the accident rate due to implementing controls. If the Bernoulli trial is a success, the accident occurs, and the accident data would be changed to:

Table 3-4 Control Effectiveness

Control	Hazard 1	Hazard 2	Hazard 3
1	0.40	0	0
2	0	0.30	0.60

Because Hazard 1 is 50 percent responsible for the costs, and Control 1 is 40 percent effective on Hazard 1, this amounts to a 20 percent reduction in *total accident costs.*

*new total accident costs = [1 – (0.5 * 0.4)] * 65000*

Table 3-5 Control 1 Data calculation

Total Costs	Fatalities	Repair Hrs	Oil	Fuel
52,000	0	233.6	1.28 Gallons	0

Repair hours are reduced in the same fashion. To transform the amount of *oil spilled*, using the frequency assessment, Hazard 1 is 50 percent responsible. Again, this is a 20 percent in reduction in *oil spilled.* In the Severity of Losses Model, the new oil amount is categorized for use in the oil severity function.

For Control 2, assuming the Bernoulli trial passes, Hazards 2 and 3 are affected and each contribute 25 percent to the cost. Given that Control 2 is 30 percent effective on Hazard 2, and 60 percent effective on Hazard 3, this amounts to a 22.5 percent overall reduction in *total costs*. Given that *repair hours* uses the same hazard cost contribution assessment, it is also reduced 22.5 percent.

*new total costs = [1 – (0.25 * 0.3) + (0.25 * 0.6)] * 65000*

Hazard 3 did not contribute to the frequency of the accident, and therefore has no effect on *oil spilled.* However, because of the contribution of hazard 2 to the reduction of frequency, the overall control reduction of *oil spilled* is 15%.

*new oil spilled = [1 – (0.5 * 0.3)] * 1.5*

Table 3-6 Control 2 Data Transformation

Total Costs	Fatalities	Repair Hrs	Oil	Fuel
50,375	0	226.3	1.2 Gallons	0

3.6.4 Data Aggregation

After the accident data is transformed to account for implementation of the control, it is aggregated with data from the other randomly selected accidents. For evaluation measures in the *casualties* and total costs branch of the hierarchy, the respective data is summed over the 100,000 flying hours. The severity functions assign a severity score to each of these totals. The key here is to assess the weights, making sure the key experts or decision makers are completely aware of the levels of aggregation of the measures being compared. For example, *training execution* and *total costs* are aggregated at different levels. Comparing these two could be confusing without a detailed description of the differences.

3.6.4.1 Unit Readiness Data Aggregation

Each severity function in unit readiness is focused at the unit level. Individually, the maximum severity for a unit in each of these measures is one. It is not feasible, however, for every unit to have the highest level of a measure in 100,000 flying hours. For example, if there are 15 accidents in 100,000 flying hours and the maximum in the range for *training execution* represents 3 Class-A accidents, then at most there would only be 5 out of the 26 units with this maximum. The maximum expected severity

for all units combined was determined through Monte Carlo simulation. The average severity for the units in each run is normalized to the maximum expected severity.

$$Training\ Execution\ Severity = \frac{\frac{1}{num\_units}\sum severity_{unit}(training\_execution)}{\text{maximum expected severity of training execution}}$$

3.6.4.2 Environmental Damage Data Aggregation

Environmental damage assesses the severity of the maximum occurrence of a hazardous fluid spill category in 100,000 flying hours. In the accident database, spills are documented in categories. When an accident is selected the amount of spillage is estimated using the following conversion:

Table 3-7 Environmental Categories

Category	Description	Estimation
0	No Spills	0
1	0-1 Gallons	.5 Gallons
2	1-2 Gallons	1.5 Gallons
3	2-10 Gallons	6 Gallons
4	10-20 Gallons	15 Gallons
5	> 20 Gallons	30 Gallons

The estimated amount of spillage is then reduced, as described in section 3.9.2, to simulate the implementation of the control. The reduced amount is re-categorized and compared with the current maximum category for that type of spill in the simulation. The maximum categorical occurrence for fuel, hydraulic fluid, and oil is the level used in the environmental damage severity functions.

3.7 Expected Severity

Having developed the severity functions, determined the weights, and aggregated the data, determining expected severity is straightforward. Using the additive value function, each severity score is multiplied by its respective weight (Kirkwood, 1997: 72). The sum of the weighted severity scores is the severity for UH-60 accidents in the 100,000 flying hours. In the Monte Carlo simulation, this process is repeated $n=10$ times in each of the B replications, creating a distribution of B expected severity scores.

3.7.1 Control Performance Scoring

Initially, the simulation is run with no controls selected. This is referred to as the *base case*. The *base case* represents the current situation, assuming no new controls have been implemented. The simulation is then run incorporating the effectiveness of a given control. Control performance is the difference between the base case expected severity and the expected severity with the control implemented. Each control performance score is representative of the expected severity reduction resulting from implementing that individual control. The expected effect of implementing multiple controls is not necessarily additive. The assessed percent effectiveness on the affected hazards could add up to more than 100 percent when implementing more than one control. If this were the case, the expected decrease in the severity of losses would be overestimated. Because of this distinction, individual performance scores cannot be simply added.

To evaluate the expected decrease in severity resulting from implementing a "group" or portfolio of controls, the effectiveness of each control on each hazard is combined, up to a maximum of 100 percent. Using the portfolio effectiveness in place of individual control effectiveness, portfolio performance is calculated as the difference between the base case expected severity and the expected severity with the portfolio implemented. For example, if controls in Table 3-7 were combined into a portfolio, the actual effect on the hazards would be the combined effect, not the additive effect.

Table 3-8 Sample Portfolio Effectiveness

Control No	AVN-01	AVN-02	AVN-03	AVN-04	AVN-05	H60-02	H60-08	H60-44	H60-59
H60-C02	25%	25%	25%	5%	5%	5%	5%	5%	
H60-C05	60%		30%						
H60-C34	70%						60%		70%
H60-C41	70%								
Added % Effective	225%	25%	55%	5%	5%	5%	65%	5%	70%
Combined % Effective	100%	25%	55%	5%	5%	5%	65%	5%	70%

3.8 Portfolio Analysis

Each control has an estimated cost and estimated effectiveness percentages on its associated hazards. Each portfolio will have a total cost and its combined effectiveness on hazards. A method of determining which controls to include in a portfolio was required. One way of modeling such problems is with integer programming where each control is judged either yes or no for inclusion in the portfolio. The objective function could be to minimize cost, with the constraints defined as the achievement of 50 reduction in severity. However, in order to demonstrate cost versus effectiveness, cost was used as a constraint. The objective was to select controls that have the highest percentage effect on the most hazards, or maximize the coverage on the hazards. Solving the integer program at various cost levels generated a variety of portfolios to consider.

This integer program does not consider the severity of the individual hazards when maximizing coverage. Thus, there is no guarantee that the 'optimal' generated portfolio will achieve the best-simulated performance. However, this heuristic is very quick and coverage should correspond nicely with total control effectiveness. An iterative process is used to generate portfolios, which are simply starting points in the search for the best performing portfolio for specified cost threshold. Each iteration of generating maximal coverage portfolios involves adding constraints to force the integer program to choose a different mix of controls. This process creates a diverse group of portfolios whose performance is then estimated using the Monte Carlo simulation described above.

The integer program is implemented in Microsoft Excel using Premium Solver add-in package from Front-line Systems (1999). A complete description of the formulation of this integer program is included in Appendix D.

3.9 Summary

The Severity of Losses Model, which integrates doctrine, expert opinion, and commander preferences, quantifies the severity of losses resulting from 100,000 UH-60 Blackhawk flying hours. A zero/one integer program generates portfolios by selecting controls that maximize hazard coverage for a given maximum cost. The Monte Carlo simulation using the bootstrap method simulates the effect of implementing a control or portfolio of controls by using the ASIST control effectiveness percentages and hazard contribution assessments. Lastly, the Severity of Losses Model quantifies the expected decrease in *severity of losses* by comparing the difference before (base case) and after implementing controls. The framework in Figure 3-1 summarizes the methodology used in this study. Results and analysis from this methodology are discussed in the next chapter.

4 Results and Analysis

4.1 Introduction

This chapter contains analysis and discussion of the results from Severity of Losses Model developed in Chapter 3. The first section compares the ten most severe UH-60 Blackhawk hazards identified from this analysis with ASIST's ranking. Next, control performance scores and portfolio composition and scores are discussed. After reviewing all portfolios, six portfolios of controls that meet the 50 percent reduction goal are further analyzed. Some final thoughts on the findings of this project conclude the chapter.

4.2 Monte Carlo Replications

Prior to evaluating hazards, controls, or portfolios of controls, the number of replications for the simulation needed to be determined. Efron and Tibshirani state that 200 replications are sufficient for estimating the mean, but generally need to be increased by a factor of ten when computing bootstrap confidence intervals (Efron and Tibshirani, 1993:15).

The confidence interval half-length is used to determine the number of replications necessary to generate confidence intervals with specified precision ϵ. The number of replications R necessary for a 95 percent confidence interval with precision of 0.01is the smallest integer such that $R \geq R_0$ and satisfies the following equation, where R_0 replications were used to obtain the sample variance, S_0^2 (Banks, et al., 1999: 449)

$$R \geq \left(\frac{t_{\alpha/2, R-1} S_0}{\varepsilon} \right)$$

Using this method, with an initial sample size of 20, the required number of replications was 41. Therefore, the number of replications used in this study was 410 (based on the factor of ten rule of thumb) (Efron and Tibshirani, 1993:15).

4.3 Hazard Severity

Determining which hazards are the most severe is useful when considering control performance. One way of defining hazard severity is the amount of contribution from the hazard to the overall severity of losses. Consider a hypothetical control that eliminates 100 percent of a hazard. If this hypothetical control were implemented, the decrease in the overall expected severity of losses in 100,000 flying hours would represent that hazard's severity.

Table 4-1 contains a comparison of the top ranking hazards from the Severity of Losses Model and from ASIST. The table is sorted by severity, with AVN-04 ranked as the most severe hazard. While there is some consistency in the makeup of the two rankings, the differences are worth noting. The major contributing factor to the difference in the two rankings is due to the accounting of the frequency of the hazards. ASIST includes the number of occurrences of a hazard as a variable in its objective function, while the Severity of Losses Model uses the hazard frequency contribution to accidents as a probability for that accident occurring. For example, H60-04 is 100 percent accountable for the frequency of every accident in which it occurs. Its severity ranking is high because all H60-04 accidents are omitted when calculating the severity of losses. Assuming the entire hazard is eliminated, each time a H60-04 accident is drawn its associated accident data is not aggregated.

Table 4-1 Hazard Ranking Comparison

Hazard	**Hazard Definition**	**Severity Rank**	**ASIST Rank**
AVN-04 (13)	Commanders selectively enforce standards (published standard is not the same as the accepted standard)	1	1
H60-10 (9)	Performing maintenance procedures incorrectly can result in flight hazards.	2	6
H60-04 (12)	Aft cyclic input or main rotor blade flex may cause main rotor blade contact with aircraft components when landing.	3	11
AVN-02 (13)	Commander or unit lack experience, wisdom, or seasoned leadership to apply risk management	4	3
H60-58 (1)	Aircraft operations in close proximity under high workload conditions may result in loss of situational awareness and a multi-aircraft collision.	5	5
H60-18 (9)	Materiel failure of engine components may result in a loss of engine power	6	2
H60-08 (2)	Attempting maneuvers (due to a lack of understanding) which require more power or lift available will result in loss of control of the aircraft	7	7
AVN-01 (8)	Commander lacks factual and timely information for managing high risk behavior	8	9
H60-03 (6)	Aircraft operations in close proximity to unimproved surfaces may result in degraded visual environment leading to loss of situational awareness and damage to aircraft	9	12
H60-09 (2)	Crew may be unable to identify a failed engine resulting in shutdown of a properly operating engine in flight.	10	13
H60-06 (22)	Loss of situational awareness (as a result of distance estimation, varying workload, environmental, and visual issues) while maneuvering in close proximity to trees or objects may result in the aircraft striking the trees or objects	11	10
H60-23 (1)	Occupants may be exposed to post-crash fire by use of ferry tanks (ERFS) with less crashworthiness than main fuel tanks.	12	4
H60-46 (1)	Miscommunication between aircrew and jumpmaster (heilocast) may cause early exit from aircraft resulting in injury to jumpers.	13	16
H60-24 (1)	External fuel tank structural integrity may be exceeded by crash forces in otherwise survivable crashes.	14	20
H60-01 (3)	The aircrew's ability to visually acquire and avoid all wires may be reduced when crossing known wires between the poles under a degraded visual environment, which may result in a wire strike	15	15
H60-55 (1)	Personnel or equipment may be struck by main rotor blades if adequate ground clearance does not exist during hot refuel.	16	8
H60-16 (3)	Failure of the tail strut	17	22
H60-05 (8)	Loss of situational awareness (as a result of distance estimation, fixation and scanning issues) while ground taxiing in close proximity to objects may result in blade strikes.	18	27
H60-49 (1)	Aircraft operations in degraded visual environment (night aided over water) may result in loss of situational awareness resulting in the aircraft striking an object	19	19
(number of accidents in which hazard contributed)			

4.4 Control Performance

Control performance is defined as the expected decrease in severity of losses, in 100,000 flying hours, resulting from the implementation of a control. As described in Chapter 3, each control may affect a number of hazards contributing to accidents, as assessed by ASIST. Using the control effectiveness and hazard contribution assessments, the performance of the control is approximated. The definitions of the controls are in Appendix B.

Table 4-2 contains the top 15 individual controls ranked by expected decrease in severity. Controls C34 and C47 have moved up dramatically in ranking compared with the original ASIST Ranking.

Table 4-2 Top 15 Control Performance Results

Control	Investment Costs ($Millions)	Expected Severity Decrease	Percent Expected Decrease	Severity of Losses Rank	ASIST Rank
H60-C34	200	0.0230	17.99%	1	8
H60-C09	19	0.0187	14.66%	2	1
H60-C10	90	0.0178	13.94%	3	5
H60-C44	19	0.0156	12.21%	4	10
H60-C11	200	0.0136	10.62%	5	2
H60-C47	19	0.0128	9.99%	6	24
H60-C07	19	0.0126	9.83%	7	3
H60-C01	19	0.0113	8.83%	8	14
H60-C42	19	0.0109	8.55%	9	11
H60-C08	90	0.0100	7.81%	10	6
H60-C40	19	0.0093	7.23%	11	13
H60-C43	19	0.0084	6.58%	12	12
H60-C17	19	0.0080	6.23%	13	17
H60-C31	200	0.0078	6.09%	14	19
H60-C03	19	0.0074	5.77%	15	22

Major contributing factors to these control performance scores are the decreases in *casualties* and *unit readiness*. Figure 4-1 shows how the top controls break out into each area. Note the y-axis is only shown to 50 percent to increase readability and indicate the Army's goal of 50 percent reduction.

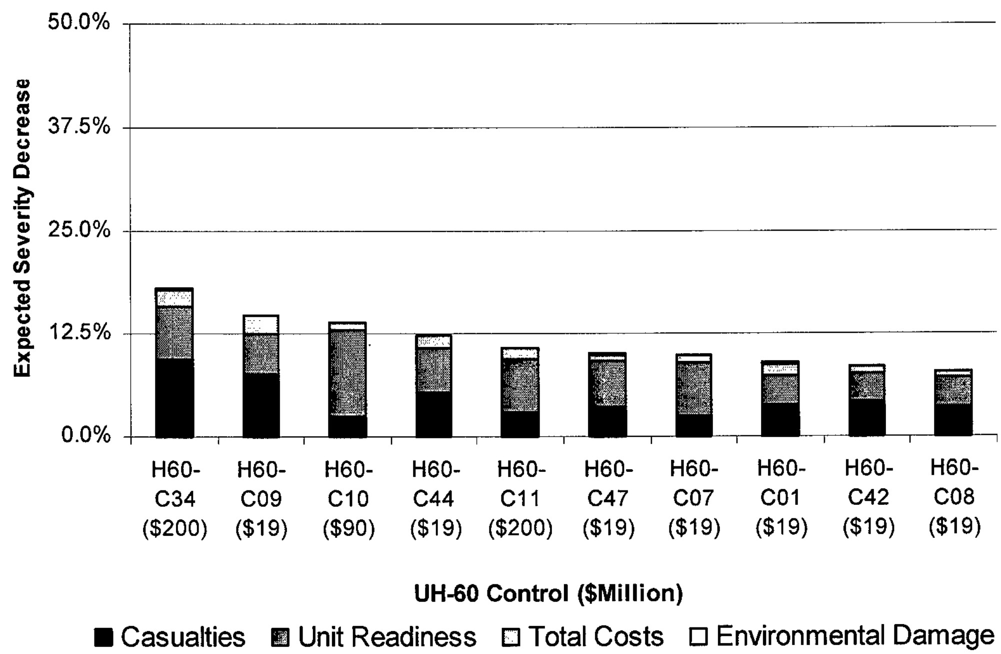

Figure 4-1 Control Performance Breakdown

While it appears as if environmental damage is not included in the Figure 4-1, upon closer inspection, the dark line at the top of some bars represents the contribution from environmental damage to reduction in severity. This small effect is due to the low weight assigned to that branch of the hierarchy. While environmental damage would decrease after implementing controls, the resulting decrease in severity is very small.

No single control can achieve the Army's goal of 50 percent reduction of losses, therefore portfolios of controls must be considered if the goal is to be achieved.

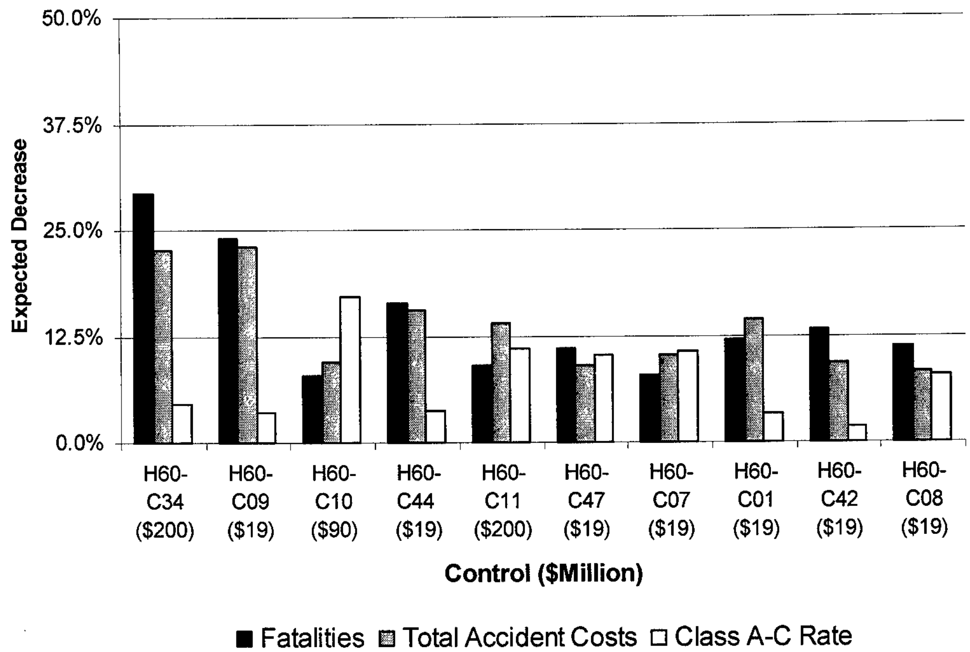

Figure 4-2 Expected Reduction in Accident Losses

In considering the control performance results, the question of what severity decrease means in terms of fatalities, accident costs and accident rate often arises. The expected decrease in each of these areas for the top controls is shown in Figure 4-2. The black bar represents the expected decrease in fatalities in 100,000 UH-60 flying hours after implementing the control. It takes approximately six months to accumulate 100,000 flying hours. Over the past five years, the Army has averaged 8.9 Class A-C accidents, 2 fatalities, and $85 million lost per 100,000 flying hours. Using these averages, a 10 percent expected decrease in these categories would be about 1 or 2 fewer accidents per year. *Fatalities* would be reduced to 1.8 per 100,000 flying hours, or approximately 1 less fatality in a two year timespan. Annual accident cost savings would be approximately $17 million. It appears that if the 50 percent reduction in severity of losses goal is reached, so too will a 50 percent reduction in fatalities and total accident costs. Again, the y-axis is shown to 50 percent to increase readability.

4.5 Portfolio Analysis

Using the mathematical program developed and described in Chapter 3, portfolios of controls were developed. A frontier of portfolios was generated by using the program to develop a varied number of portfolios at $20 million increments. The purpose is to give a graphical representation of the best 'bang for the buck'. $20 million increments were chosen to allow for the addition of a single low cost control (approximately $19 million) at each higher level. With more accurate cost estimates, smaller increments could be investigated.

Figure 4-3 contains a sample of portfolios along with a description of the controls and costs included. For example, Portfolio of Controls 138 (Portfolio 138) costs an estimate $60 million, and contains UH-60 controls 2, 7, 9, 18, 19, 22, 23, 38, and 44. Using the Severity of Losses Model, the expected decrease in severity having implemented all controls in the portfolio was calculated.

4.5.1 Portfolio Performance

Portfolios are evaluated in the same manner as individual controls by combining the assessed effectiveness of each control in a portfolio. The maximum reduction amount for a portfolio on a single hazard was limited to 100 percent. The mathematical program generated portfolios by selecting controls to maximize coverage on the hazards. Other portfolios were generated by manually selecting a mix of controls based on a benefit/cost ratio. A complete listing of the portfolios is included in Appendix E, ranked by expected reduction in severity.

		Control Number																																		
	Cost ($M)	1	2	3	4	5	6	7	8	9	11	12	13	14	16	18	19	22	23	25	27	28	33	34	35	37	38	40	41	42	43	44	46	47	48	49
PC130	$3.6		X									X				X	X	X	X				X		X		X									
PC131	$20.0		X							X							X																			
PC132	$20.0	X	X														X																			
PC133	$20.0		X					X									X																			
PC134	$20.0		X														X															X				
PC135	$40.0		X					X		X							X	X									X									
PC136	$40.0	X	X					X								X	X	X																		
PC137	$40.0	X	X													X	X	X														X				
PC138	$60.0		X					X		X						X	X	X	X								X					X				
PC139	$60.0	X	X					X								X	X	X	X								X					X				
PC170	$60.6		X					X		X		X				X	X	X	X				X		X		X					X				
PC162	$79.6	X	X					X				X	X			X	X	X	X				X		X		X					X				
PC163	$79.6		X							X		X	X			X	X	X	X				X		X		X					X		X		
PC141	$98.6	X	X					X				X	X			X	X	X	X				X		X		X					X		X		
PC143	$98.6	X	X					X				X	X			X	X	X	X				X		X		X					X		X		
PC142	$116.6	X	X					X		X			X			X	X	X							X		X					X		X		
PC10	$154.6		X	X				X		X		X	X			X	X	X									X	X	X	X				X		
PC11	$173.6	X	X	X				X		X		X	X			X	X	X									X	X	X	X				X		
PC12	$173.6	X	X	X				X		X		X	X			X	X	X									X	X	X	X						X
PC144	$212.6	X	X	X		X		X		X		X				X	X	X	X				X		X		X			X	X	X		X	X	X
PC145	$340.6	X	X	X	X	X	X	X		X		X	X			X	X	X	X				X		X	X	X			X		X		X	X	X
PC146	$1,140.6	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X		X	X	X	X	X	X	X			X		X		X	X	X
	Cost ($M)	19	1	19	90	19	19	19	90	19	200	0.05	19	90	90	0.5	0.5	0.5	0.5	19	200	200	0.5	200	0.05	19	0.5	19	19	19	19	19	19	19	19	19

Figure 4-3 Portfolio Composition Matrix

The following chart plots portfolio performance versus cost. The highlighted point at a cost of approximately $1180 million represents a portfolio containing all controls necessary to maximize hazard coverage, with no limit on costs.

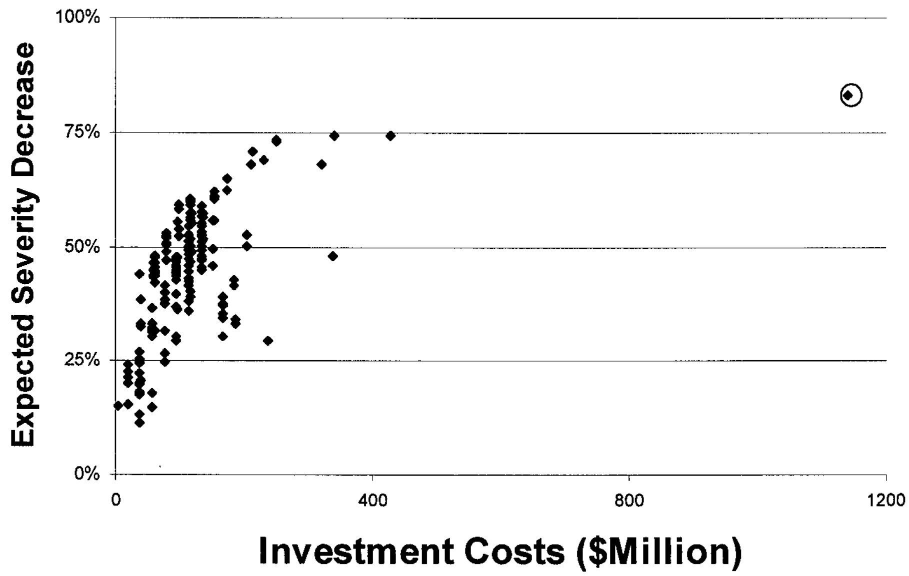

Figure 4-4 Portfolio Performance vs. Cost

Figure 4-5 is a similar look at portfolio performance, with the focus limited to $200 million. The dark curve on the upper portion of the graph represents the simple, but mathematically incorrect, performance sum of the individual controls in the portfolio. Since the effect on a hazard is limited to 100 percent, this sum could be a false representation of what is actually calculated when the controls are combined. Additionally, all interactions between controls are also ignored. The thinner line cutting across the middle of the chart shows the calculated best available frontier. The various points on the graph represent calculated portfolio performance scores.

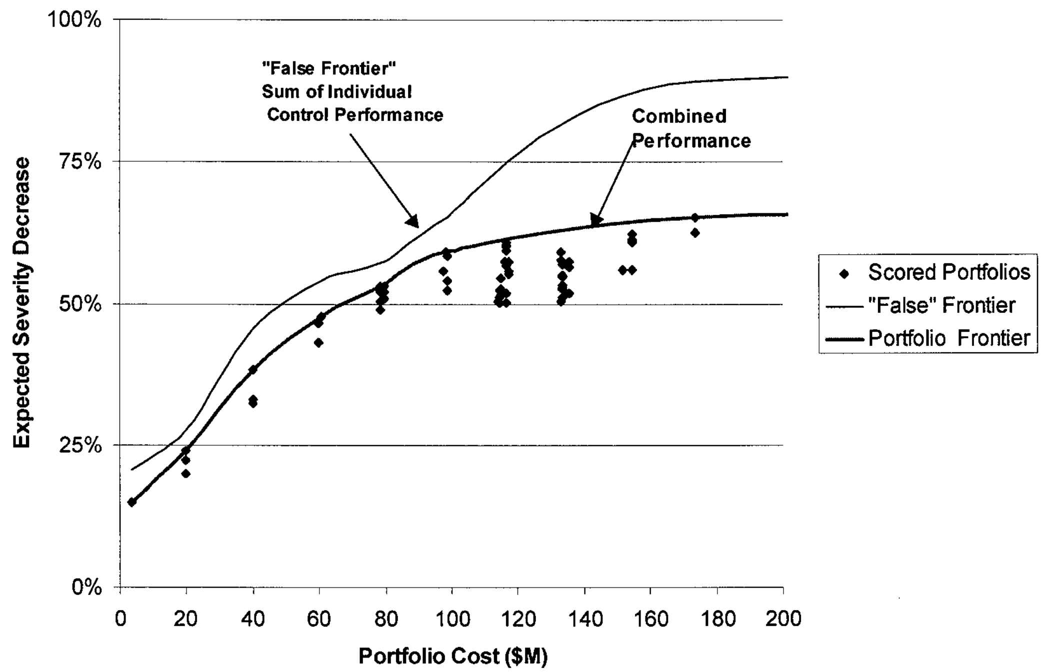

Figure 4-5 Portfolio Performance Frontier

4.5.2 Safety Goals Results

A stated objective of this project is to identify portfolios of controls that would help reduce losses by 50 percent over the next ten years at minimal investment costs. Table 4-3 contains a selection of portfolios each with an expected decrease in *severity of losses* of 50 percent. While the graph in Figure 4-5 portrays the 50 percent threshold being reached at just above $60 million, this can be misleading. A portfolio containing three low cost controls at $19 million each as well as all controls that cost less than $1 million each would total $60.6 million. Every portfolio evaluated with this level of investment cost fell below the 50 percent expected reduction of severity level. Adding one more control to the portfolio incurs an additional cost of $19 million. Figure 4-6 displays the control composition of each portfolio that met the reduction threshold for the lowest investment costs.

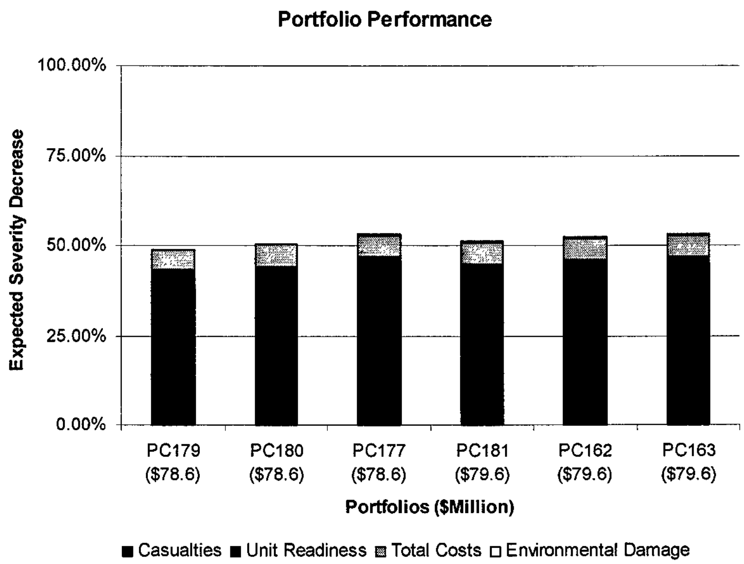

Figure 4-6 Portfolio Performance Breakdown – 50% Reduction of Losses

The primary differences between the portfolios shown above are a change in one $19 million control and one or two less expensive controls. For example, the difference between Portfolio 161 and Portfolio 162 is that control 9 is swapped with control 13, and controls 23 and 33 are added, which accounts for the million dollar difference in portfolio costs.

Considering the composition of the portfolios and their closeness in performance scores, it follows that the breakdown of the scores also show similarities (see Figure 4-7). The breakdown of portfolio performance scores parallels the breakdown of individual control performance scores with *casualties* and unit readiness as the major contributors.

Table 4-3 Portfolios - 50% Reduction of Losses

Portfolio	Cost	95 % Confidence Interval		
		From	Average	To
Portfolio 179	**78.6**	48.4%	49.0%	49.5%
Portfolio 180	**78.6**	50.0%	50.5%	51.6%
Portfolio 177	**78.6**	52.6%	53.1%	53.7%
Portfolio 181	**79.6**	51.6%	51.0%	52.7%
Portfolio 162	**79.6**	51.8%	52.2%	52.7%
Portfolio 163	**79.6**	52.7%	53.0%	53.7%

	Cost	Control Number																																	
	($M)	1	2	3	4	5	6	7	8	9	11	12	13	14	16	18	19	22	23	25	27	28	33	34	35	37	38	40	41	42	43	44	46	47	48	49
PC179	78.6	X	X					X		X		X				X	X	X							X		X							X		
PC180	78.6	X	X							X		X	X			X	X	X							X		X					X				
PC177	78.6	X	X					X		X		X				X	X	X							X		X					X				
PC181	79.6	X	X									X	X			X	X	X	X				X		X		X					X		X		
PC162	79.6	X	X					X				X	X			X	X	X	X				X		X		X					X				
PC163	79.6		X							X		X	X			X	X	X	X				X		X		X					X		X		
	Cost ($M)	19	0.5	19	90	19	19	19	90	19	200	0.05	19	90	90	0.5	0.5	0.5	0.5	19	200	200	0.5	200	0.05	19	0.5	19	19	19	19	19	19	19	19	19

Figure 4-7 Portfolio Composition – 50% Reduction of Losses

The expected decreases in terms of fatalities, costs, and accident rate for the top controls are shown in Figure 4-8. As with the individual controls, the major decreases are in fatalities and total costs. Given that the expected decrease in overall severity is so close for each portfolio this breakdown into fatalities, costs, and accident rate may provide additional insight to the decision maker.

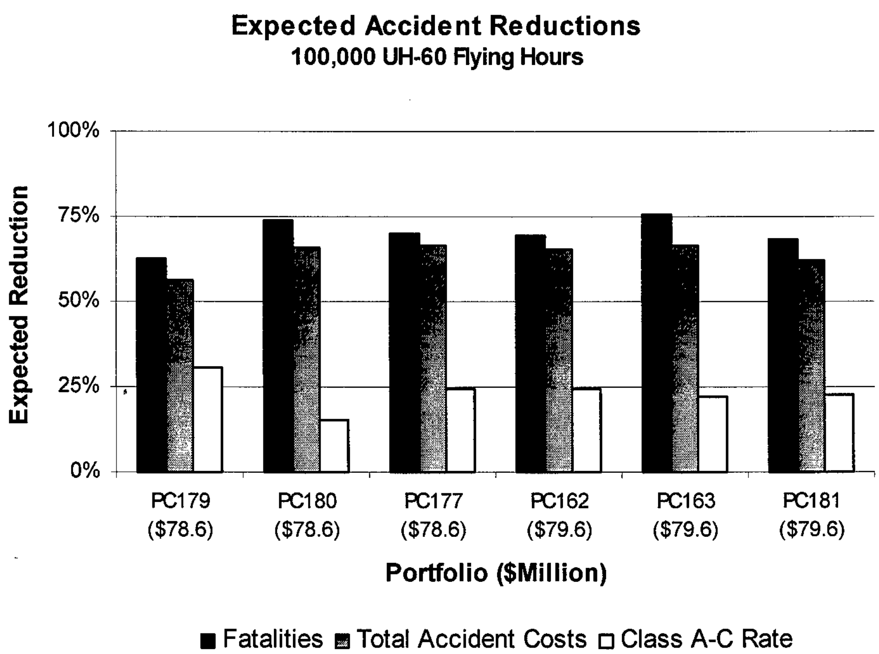

Figure 4-8 Portfolio Expected Reduction in Accident Losses

4.6 Unit Readiness Weight Sensitivity

A major uncertainty in this project is the composition of the *unit readiness* severity functions, as stated in the development phase of the severity hierarchy. Sensitivity analysis was performed by varying the weight of *unit readiness* to see what impact it would have on the results. The current weight *of unit readiness* is 0.378. The weight was varied from 0.25 to 0.45 with the results shown in Figure 4-9.

While it would be difficult to make out the rank order differences graphically in a scaled graph, the rank order of the portfolios does indeed change, as shown in Figure 4-9. The change in rank order of the top three portfolios, however, should not be of statistical concern. Using the Mann-Whitney *U* test with an α of 0.05 to compare the two means, it is shown that, with the current weight of 0.378, there is no statistical difference between the average decrease in severity of the first and third ranked portfolios (see Appendix F). Having no statistical difference between the averages implies mathematical indifference between performance scores of the two portfolios. With the weight below 0.378, the same three portfolios remain at the top with the only statistical difference among them occurring when the weight equals 0.35. In this case, the top portfolio, Portfolio 163, and the third ranked portfolio, Portfolio 177, is statistically different. Above the current weight, the same three portfolios remain at the top, with a difference in the means of the first and third ranked portfolios when the weight is 0.45

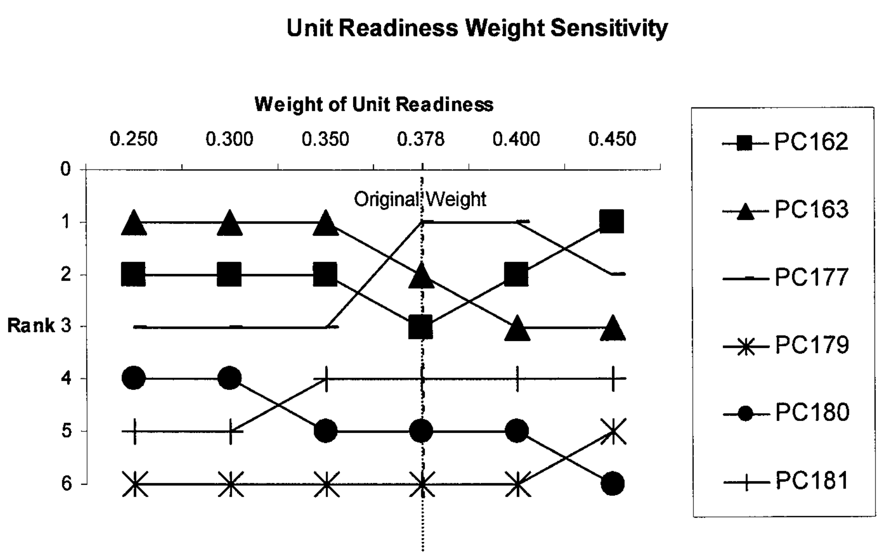

Figure 4-9 Unit Readiness Sensitivity – Rank Order

Sensitivity analysis results show that, for the current group of portfolios, varying the weight of *unit readiness* from 0.25 to 0.45 does change the ranking of the top two portfolios. Statistical testing shows this change is not significant at the 0.10 level.

Table 4-4 Unit Readiness Sensitivity – Portfolios Expected Decrease in Severity

Unit Severity Weight

	0.25	0.30	0.35	(Original Weight) 0.378	0.40	0.45
Portfolio 162	61.4%	58.4%	54.3%	52.2%	51.3%	47.5%
Portfolio 163	62.5%	58.5%	54.9%	53.0%	50.4%	45.8%
Portfolio 177	61.3%	57.8%	52.6%	53.1%	51.4%	47.2%
Portfolio 179	58.5%	54.7%	51.2%	49.0%	47.6%	45.4%
Portfolio 180	61.1%	57.1%	52.2%	50.5%	48.4%	44.4%
Portfolio 181	60.1%	55.6%	52.5%	51.0%	48.9%	45.6%

4.7 Summary

Using the Severity of Losses Model, the severity of hazards, and performance of controls and portfolios of controls has been quantified. This chapter presented the results from the model and a one-way sensitivity analysis on the weight of the major uncertain area of the model.

The chapter also focused on a group of portfolios that achieved the 50 percent reduction of losses threshold while minimizing investment costs. These six portfolios were very similar in composition; each containing four low cost and five to seven very low cost controls. Of these six, Portfolio 162 and Portfolio 163 remained the top two when the weight of *unit readiness* stayed between 0.25 and 0.45.

Generally speaking, there are a number of different portfolios of controls that total about $80 million in investment costs and will meet the 50 percent expected reduction in severity goal. Reaching the 75 percent expected decrease level would require a total of about $180 million, and attaining an 85 percent expected reduction, which would require selecting all possible contributing controls, would be about $1.2 billion.

5 Conclusions and Recommendations

5.1 Conclusions

Over the past few years the Army aviation accident rate has been on the rise. ASIST was chartered to reverse this trend with the overall goal of reducing the losses by 50 percent, interpreted as reducing the number of fatal and disabling injuries, accident costs, and the Class A-C accident rate by 50 percent over the next ten years. Focusing on the UH-60 Blackhawk initially, ASIST created a hazard taxonomy and a list of controls designed to reduce those hazards. This taxonomy has now been completed for the active fleet of Army air vehicles. The methodology developed and demonstrated in this project takes full advantage of ASIST's efforts by building a severity hierarchy, appropriate measures to quantify severity, and a method for aggregating preferences of key decision makers. This effort incorporated the hazard taxonomy into a Monte Carlo simulation. The Severity of Losses Model quantifies the effect of implementing a control or portfolio of controls and calculates the expected reduction in severity of losses due to accidents.

The Severity of Losses Model is based on doctrine and incorporates command preferences as well as expert opinion. The mathematical program, while simple at this stage, focuses the simulation effort by generating initial portfolios that maximize the hazard coverage for a given investment cost threshold. Using the mathematical program, the Severity of Losses Model, and Monte Carlo simulation, portfolios of controls that meet the goal of 50 percent reduction in losses have been identified. A number of portfolios were generated at various cost levels. Figure 5-1 displays the results for the top three performing portfolios and results for the three lowest cost portfolios that meet the 50 percent reduction goal.

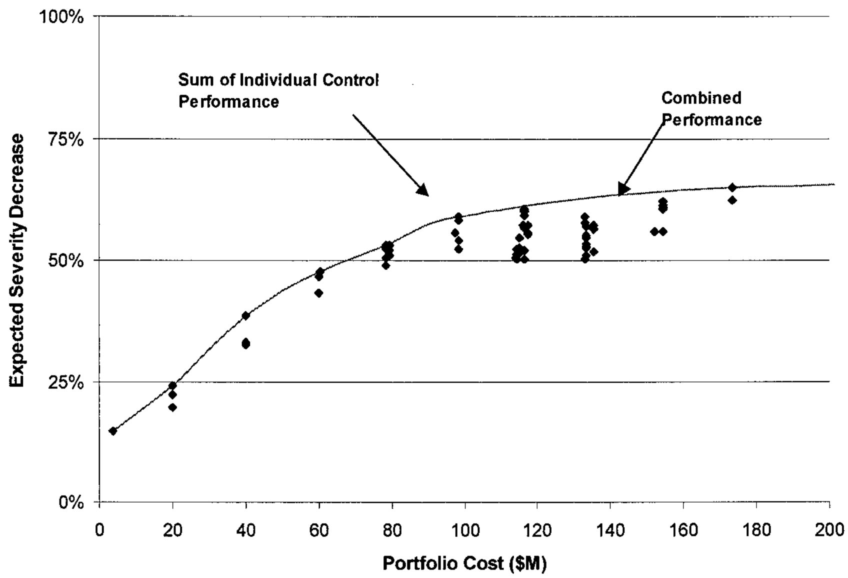

Figure 5-1 Portfolio Performance Frontier

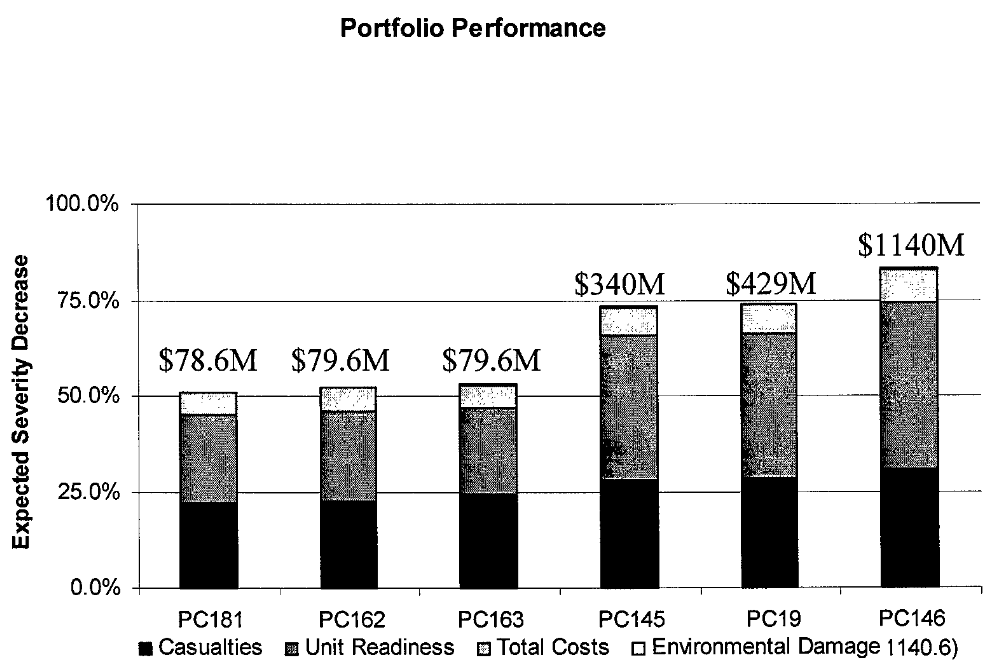

Figure 5-2 Portfolio Performance

5.2 Recommendations

The methodology used in this project has been incorporated into ASIST. ASIST personnel were involved throughout the research in providing data, clarification, and guidance. Plans are underway to integrate the portfolio evaluation simulation model with the entire maturing ASIST database. Opportunities to improve the model exist, but have yet to be explored. Future efforts may include considering some of the following recommendations.

5.2.1 Mathematical Program

The mathematical program used in this project to generate portfolios is based on the assumption that the more hazard coverage, the better the portfolio will perform. The intent is not to guarantee optimal portfolios, but rather to find a good starting point, or suggest a mix of controls that is expected to perform well.

In Chapter Four, hazard severity was estimated by running the simulation with 100 percent of the hazard eliminated. A better way to generate initial starting portfolios could be to maximize the total amount of hazard severity reduction. It may even turn out that portfolios generated in this manner maintain the same rank order as the simulated results. Such an occurrence is referred to as *strategic equivalence*. If the two methods result in strategically equivalent portfolios, the simulation would only be required to initially determine hazard severity. Highly focused portfolios could be simulated to determine the expected severity reduction. This type of improvement will be needed as the fleet of aircraft considered and the scope of the safety effort involved with it grows.

Search techniques and heuristics can be used to improve the speed and results of the portfolio search.

5.2.2 Severity of Losses Model

The Severity of Losses Model developed in this project is a continuation of the efforts of Captain Brian Sperling. As the methodology evolves, so too should the Severity of Losses Model.

The unit readiness branch of the hierarchy is the prime candidate for further development. LTC Semmens stressed the need to interview as many battalion commanders as possible to accurately capture the impact on unit readiness. A leadership conference is held annually at Ft. Rucker and is attended by many battalion commanders. Future efforts should coordinate with this conference and exploit this opportunity to meet with the attendees. Another vehicle for interviewing many commanders is at the Command and General Staff College at Ft. Leavenworth, Kansas. Improving the accuracy of the tradeoff preferences and severity functions of this area, which is very important to current leadership, will improve the overall quality of the model. Additionally, this would communicate the intent and capability of the methodology, thus improving its credibility within the aviation community.

Another opportunity to improve upon the quality of the model would be to elicit the severity functions and weights from an even higher level of Army Leadership. The current weighting reflects the values of the USASC Deputy Commander, COL Warren. Perhaps the Chief of Staff of the Army or the Secretary of the Army's preferences could be elicited to accurately represent the values and preferences of a 500,000 soldier organization.

The final comment on the Severity of Losses Model has to do with the environmental damage aspects of the hierarchy. FM 100-14 clearly states that damage to the environment must be considered when evaluating hazards. FM 20-400 describes the components of environmental damage (see Figure 5-2). Environmental damage, while considered, is not highly weighted in the Severity of Losses Model. If more data were collected, the actual severity of environmental damage could be better represented. A more developed depiction of environmental damage may result in higher weighting. The cost of environmental cleanup could also be included in the total accident costs.

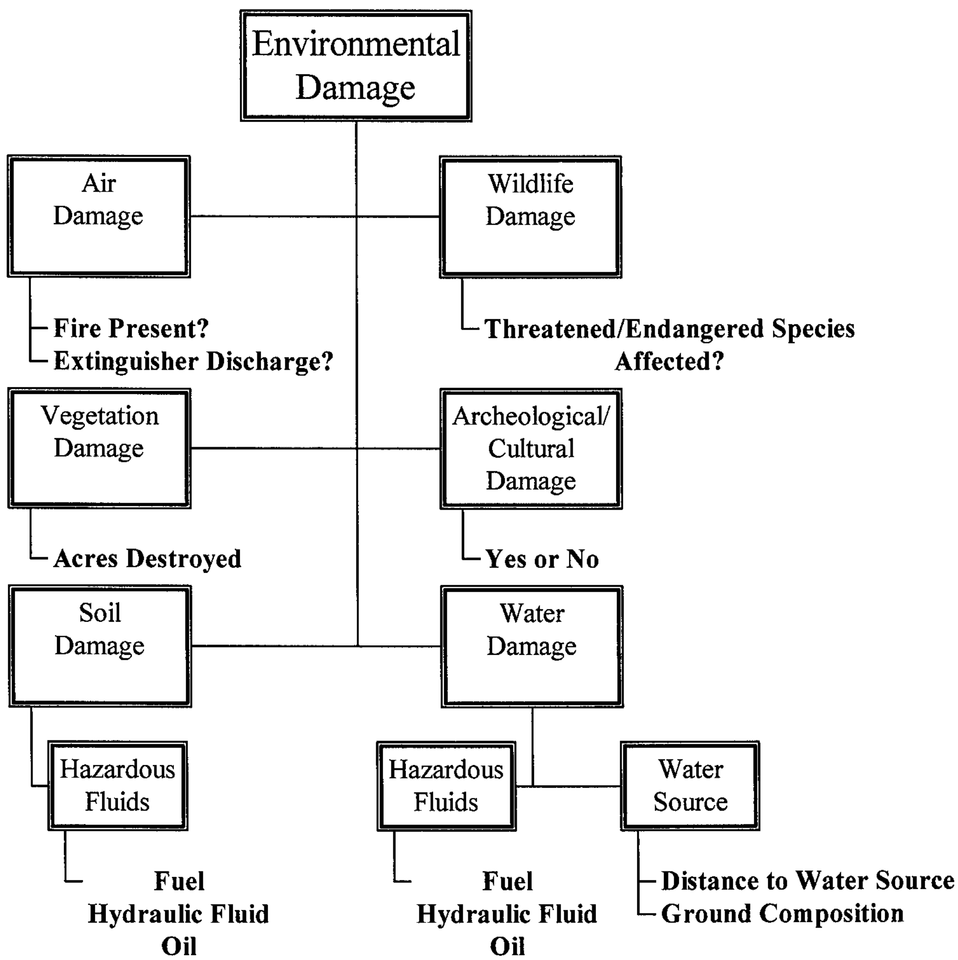

Figure 5-3 Proposed Environmental Considerations

5.2.3 Control Interactions and Dependencies

The Monte Carlo simulation uses the control effectiveness assessments to adjust the raw accident data, thus simulating the effect of a control. When portfolios are created, control effectiveness assessments for a hazard are assumed to be additive, up to 100 percent. Depending on the controls, this may be an accurate representation. In reality, the actual effects may not truly be additive. Individually, two controls may each reduce a given hazard by 50 percent. Together, the assessed effectiveness may turn out to be 75 percent. Developing the effectiveness relationships will involve a great deal of effort on the part of the ASIST team that created the control list but should add value to the overall project.

Along the same line, dependencies between controls might also be reinvestigated. This model includes several of the most critical dependencies (see Appendix D), but more exist and should be incorporated.

5.2.4 Monte Carlo Simulation

The model is built in an Excel Spreadsheet and uses Crystal Ball to run the Monte Carlo Simulation. Running the entire process, however, is interactive and somewhat time-consuming. Future efforts may include a purely coded program that would be automated for the user. The goal of this research, however, was to find a methodology that would accomplish the objectives set forth in Chapter One. If simulation is used in future efforts, the entire process could be automated.

5.2.5 Future Efforts

This project focused on the evaluation of portfolios of controls. Future efforts may choose to consider the actual budgeting and scheduling for implementation of the selected portfolio. Incorporating these issues into the model will produce an even more representative product for the Army.

5.3 Contributions

The combination of value focused thinking, mathematical programming, and Monte Carlo simulation has been well received by the safety community at large. As previously mentioned, ASIST plans on incorporating the Severity of Losses Model into their efforts.

This project has also sparked the interest of members of the Joint Programs Opportunities Board (JPOB). The methodology can be modified to work with any aircraft system, as well as ground systems (more lives are lost on the ground in accidents than are lost each year in the air). The eventual use of the Severity of Losses Model in the joint arena is uncertain, but the potential is exciting. The methodology will be briefed to the Joint Aeronautical Commanders Group in April 2000 for possible use by all services and/or the FAA and NASA.

Appendix A UH-60 Hazard Taxonomy

The Aviation Safety Investment Strategy Team (ASIST) developed the hazards described in this appendix. This taxonomy is the result of an exhaustive investigation into the detailed accident reports for all UH-60 Blackhawk accidents from fiscal years 1994 through 1998. Aviation (AVN) -code hazards cross aviation platforms, while H60-hazards are specific to the Blackhawk.

Hazard Code	Hazard Statement
AVN-01	Commander lacks factual and timely information for managing high risk behavior
AVN-02	Commander or unit lack experience, wisdom, or seasoned leadership to apply risk management
AVN-03	Commander lacks understanding of the available range of controls to manage high-risk behavior
AVN-04	Commanders selectively enforce standards (published standard is not the same as the accepted standard)
AVN-05	Commanders are unable to enforce standards because of reduction in resources
H60-01	The aircrew's ability to visually acquire and avoid all wires may be reduced when crossing known wires between the poles under a degraded visual environment, which may result in a wire strike
H60-02	Unanticipated fraying and breaking of hoist cable may result in casualty
H60-03	Aircraft operations in close proximity to unimproved surfaces may result in degraded visual environment leading to loss of situational awareness and damage to aircraft
H60-04	Aft cyclic input or main rotor blade flex may cause main rotor blade contact with aircraft components when landing

Hazard Code	Hazard Statement
H60-05	Loss of situational awareness (as a result of distance estimation, fixation and scanning issues) while ground taxiing in close proximity to objects may result in blade strikes
H60-06	Loss of situational awareness (as a result of distance estimation, varying workload, environmental, and visual issues) while maneuvering in close proximity to trees or objects may result in the aircraft striking the trees or objects
H60-07	Loss of airframe components may cause damage to aircraft during flight
H60-08	Attempting maneuvers (due to a lack of understanding) which require more power or lift available will result in loss of control of the aircraft
H60-09	Crew may be unable to identify a failed engine resulting in shutdown of a properly operating engine in flight
H60-10	Performing maintenance procedures incorrectly can result in flight hazards
H60-11	Unsecured tools, doors, or objects on or around the aircraft may cause damage during run up
H60-12	Unsecured objects within the aircraft can increase personnel injuries in the event of a crash
H60-13	Untimely emergency response to hazardous conditions may result in increased aircraft damage
H60-14	Crew will unnecessarily expose personnel to injury by allowing non-essential personnel on board aircraft
H60-15	Aircrew's ability to maintain powered flight is reduced by lack of fuel to the engine caused by air bubbles in the fuel system
H60-16	Failure of the tail strut
H60-17	Jettison of load above the ground may result in damage to the load
H60-18	Materiel failure of engine components may result in a loss of engine power
H60-19	Crew may be unable to properly react to in flight emergencies due to lack of proficiency with NVGs

Hazard Code	Hazard Statement
H60-20	Crew may voluntarily elect to continue flight after experiencing an emergency condition which could result in injury or further aircraft damage
H60-21	Personnel may receive unnecessarily severe injuries when personal protection equipment is not utilize
H60-22	Crew may be unable to perform rescue/survival/injury treatment due to inaccessibility of ALSE
H60-23	Occupants may be exposed to post-crash fire by use of ferry tanks (ERFS) with less crashworthiness than main fuel tanks
H60-24	External fuel tank structural integrity may be exceeded by crash forces in otherwise survivable crashes
H60-25	Crew may not utilize available power due to false indications from MH-60K voice warning system which does not automatically reset after Main rotor rpm is regained
H60-26	Fire extinguishing system failed to activate in a crash sequence for unknown reasons
H60-27	Crew may misjudge altitude by relying on the MH-60K aircraft radar altimeter information displayed on the multifunctional display, which, because of latency, can give incorrect information
H60-28	Crew may experience dual engine rollback loss of power
H60-29	Aircrew seat seatback may fail prematurely during accident sequence resulting in increased severity of injuries
H60-30	Crew chief/gunner's ability to remain securely positioned in a crash sequence is degraded by use of the gunner's harness
H60-31	Crew's ability to maintain safe body position in a crash sequence may be degraded by use of a single-mode inertia reel
H60-32	When flying into known deteriorating weather, crew may lose ability to maintain a safe flight path as a result of loss of situational awareness
H60-33	Fatigue failure of tail rotor gearbox bevel gear can cause loss of control resulting in forced landing and aircraft damage

Hazard Code	Hazard Statement
H60-34	Foreign object blown by aircraft rotor down-wash can damage aircraft components causing loss of aircraft control and result in aircraft crash
H60-35	Loss of situational awareness during flight in degraded visual cues may result in striking of objects in flight path
H60-36	Crew loss of situational awareness during aircraft operations (left engine cover in vicinity of main rotor system) may result in damage to the aircraft
H60-37	Breakaway fuel fitting failure contributed to fire and resulting aircraft damage. Note: Further investigation of this accident by aviation systems needed to validate the hazard
H60-38	Flight in the vicinity of lightning may result in aircraft being struck by lightning
H60-39	Combining training with mission operations (sling load) in a high workload environment can cause loss of situational awareness (divided attention) resulting in aircraft/equipment damage
H60-40	Use of an aircraft configured with full ERFS tanks will decrease load-carrying capability in sling load operations and may result in a low-rotor rpm condition
H60-41	Inadvertent release (caused by trying to remove excess 550 cord from cargo hook system manual release lever) may result in damage to the load
H60-42	Unauthorized testing of new procedures (sling load self hook-up method) may result in aircraft/load damage
H60-43	Combining multiple stressors (fatigue, OPTEMPO, family situation) with mission operations (sling load) in a high workload environment can cause LOSA (divided attention) resulting in aircraft/equipment damage
H60-44	Mis-assessing the risk of an identified hazard (ditch in landing area) may result in aircraft damage
H60-45	Exiting aircraft during jump operations at high altitude and airspeed can result in injury to jumpers
H60-46	Miscommunication between aircrew and jumpmaster (heilocast) may cause early exit from aircraft resulting in injury to jumpers

Hazard Code	Hazard Statement
H60-47	Hovering aircraft over areas with loose objects can cause injury to ground personnel
H60-48	Hovering aircraft in close proximity to parked aircraft can cause aircraft damage
H60-49	Aircraft operations in degraded visual environment (night aided over water) may result in loss of situational awareness resulting in the aircraft striking an object
H60-50	Aircraft operations in a degraded visual cue (night aided) may result in loss of situational awareness resulting in the aircraft striking an object
H60-51	Lack of survival radios
H60-52	Non-working emergency beacon
H60-53	No overdue aircraft procedures
H60-54	No risk assessment or briefing
H60-55	Personnel or equipment may be struck by main rotor blades if adequate ground clearance does not exist during hot refuel
H60-56	Gusty winds may affect the crew's ability to hold the aircraft steady during a one wheel landing to a slope along a ridgeline
H60-57	Keeping the unisex vent valve closed during refueling may result in overpressurization causing damage to aircraft
H60-58	Aircraft operations in close proximity under high workload conditions may result in loss of situational awareness and a multi-aircraft collision
H60-59	Hazards unknown
H60-60	The unprepared ELT would have contributed to the extent of the injuries if the crash had taken place in an unpopulated area
H60-61	Not Enough Information
H60-62	Tabled for lack of data

Appendix B Control Listing

The controls included in this appendix were developed by ASIST for the UH-60 Blackhawk aviation program.

H60-C01 Add mandatory scenario training in simulator (brownout) to include resourcing of TDY

Estimated Cost (in $Millions)
$19.0

Affected Hazards	Effectiveness
H60-03	0.1
H60-08	0.4
H60-09	0.4
H60-18	0.5

H60-C02 Book of hazards and controls

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-01	0.25
AVN-02	0.25
AVN-03	0.25
AVN-04	0.05
AVN-05	0.05
H60-02	0.05
H60-08	0.05
H60-44	0.05

H60-C03 Change ATM to establish new flying hour category for individual task flight training hours (not collective training)

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
H60-03	0.4
H60-06	0.25

H60-C04 Develop external crashworthy fuel tanks consider suction fuel system

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-23	0.75
H60-24	0.75

H60-C05 Establish a command information system which tracks all forms of high risk behavior and marginal performance

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
AVN-01	0.6
AVN-03	0.3

H60-C06 Establish and sustain crewchief's "school house" training program

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-06	0.35
H60-58	0.35

H60-C07 Establish crew coordination sustainment program

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-03	0.5
H60-06	0.5
H60-32	0.2
H60-58	0.4

H60-C08 Establish standards for and resource a 4th crewmember for multi-ship operations. Include in

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-06	0.45
H60-58	0.45

H60-C09 Expand AQC training (emergency procedures/emergency diagnosis)

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.6
H60-09	0.6
H60-18	0.6
H60-58	0.5

H60-C10 Implement a change to the flight control system to improve aircraft stability and control in low speed flight (Attitude Command Attitude Hold)

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-03	0.65
H60-04	0.5
H60-06	0.5
H60-58	0.2

H60-C11 Increase the available aircrew experience

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
AVN-02	0.05
H60-01	0.4
H60-03	0.2
H60-06	0.5
H60-32	0.5
H60-45	0.2
H60-46	0.2
H60-58	0.35

H60-C12 Modify AR 95-XX to require that mission planning time is considered as mandatory topic for risk determination and establish risk management standards for mission planning time

Estimated Cost (in $Millions)
$0.05

Affected Hazards	Effectiveness
AVN-01	0.01
H60-01	0.01
H60-03	0.01
H60-08	0.01

H60-C13 Provide commanders a better ability for selection, mission tailoring, and balancing of resources to do the mission

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-02	0.4
H60-08	0.5
H60-32	0.5
H60-58	0.4

H60-C14 Develop a wire strike protection system that covers more of the aircraft

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-01	0.15

H60-C15 Enhance NVG field of view

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-06	0.25

H60-C16 Develop and field a proximity warning system (Virtual Rotor Disk)

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-06	0.7

H60-C17 Fund and install flight data recorder (FDR)

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-59	0.7

H60-C18 Increase command emphasis (Advance Course) on safety incentives

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-03	0.15

H60-C19 Modify AR 95-3 or TC 1-210 to require 2 hours annually of actual instruments for each PIC

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
H60-32	0.7

H60-C20 Develop and field an adjustable proximity warning system/collision avoidance.

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-58	0.7

H60-C21 Develop a terrain following / terrain avoidance radar

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-32	0.8

H60-C22 Develop standardized training support package for use at unit level targeted on ERFS operations to include simulator scenario training, jettison stores, a/c performance characteristics

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
H60-23	0.5

H60-C23 Manual changes to describe handling characteristics

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.05

H60-C24 Develop and install new Night Vision Systems

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-06	0.5

H60-C25 Improve aircraft controllability with tanks installed (pitch bias actuator, digital stabilator amp)

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.1

H60-C26 Improve IFR/IMC infrastructure in selected parts of the world (ABSO define)

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-32	0.02

H60-C27 Wire detection system using laser radar or HF radar technology

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-01	0.6

H60-C28 Resource aviation maintenance IAW reference XYX to match requirements of complex aircraft. (link to USAALS needed to consider dedicated crews to aircraft)

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-10	0.7

H60-C29 Full authority DEC automatically causes engine shutdown

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-09	0.9

H60-C30 Improve engine diagnostics and improve cueing of correlation of PCL handle to engine

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-09	0.7

H60-C31 Accelerate addressing materiel failures

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
H60-18	0.9

H60-C32 Improve crew's ability to for premission planning by implementing electronic data management from Air Warrior

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-08	0.1

H60-C33 Enforce rules through leadership commitment

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.05

H60-C34 Digital Source Collector (DSC) and envelope cueing (exceedences) and notice to pilot of exceedences/crew monitor

Estimated Cost (in $Millions)
$200.00

Affected Hazards	Effectiveness
AVN-01	0.7
H60-08	0.6
H60-59	0.7

H60-C35 Increase minimum distance between aircraft for multiship operations

Estimated Cost (in $Millions)
$0.05

Affected Hazards	Effectiveness
H60-58	0.01

H60-C36 Modify manual to establish method of calculating lateral CG

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-08	0.15

H60-C37 Establish model RM training program, starting with DAIG evaluation of all institutional training schools for integration of risk management training into curriculum

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-02	0.5

H60-C38 Establish or enforce selection criteria for advanced aviator training

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-04	0.1

H60-C40 Develop a standardized methodology for conducting mission risk assessments with the objective for identification of all hazards and associated controls to be presented in the mission brief

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-02	0.6

H60-C41 Increase the system specific instruction in the UH-60 IP course. Emphasize what system specific instruction should be imparted by IP's to other aviators during subsequent assignments

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-01	0.7

H60-C42 Expand leader development training to emphasize enforcement of aviation maintenance and operations standards (integration into advanced course, an exportable training package, and modifying BOC and AOC)

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-04	0.4

H60-C43 Integrate risk management training into aviation officer/WO/NCO development programs (use accident experience as part of the training)

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
AVN-02	0.65

H60-C44 Install Flight Data Recorders (FDRs) and develop procedures for use of FDR data by commanders for aircrew training

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
AVN-01	0.7
H60-59	0.7

H60-C45 Evaluate H-60 maintenance force structure.

Estimated Cost (in $Millions)
$0.50

Affected Hazards	Effectiveness
AVN-05	0.0001

H60-C46 Investigate improving H-60 handling qualities by implementing strakes to improve airflow over the tailboom

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-03	0.1

H60-C47 Develop a smooth deflection device on top of ALQ-144

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-04	0.9

H60-C48 Relocate /redesign ALQ-144 (substitute ATIRCMS)

Estimated Cost (in $Millions)
$90.00

Affected Hazards	Effectiveness
H60-04	0.5

H60-C49 Develop and distribute an exportable training package for unit level Aviation refuelers and mandate training requirement prior to assignment as aviation refueler

Estimated Cost (in $Millions)
$19.00

Affected Hazards	Effectiveness
H60-55	0.4

Appendix C - Severity Monte Carlo Simulation Description

This appendix provides an overall description of the Visual Basic program used to conduct the data aggregation and severity score calculations. A description of the complete process to evaluating a portfolio of controls is included.

The Visual Basic code is included in Appendix G.

In conducting the simulation, the first function called is 'do_a_rep'. This function is responsible for calculating an expected severity score representing *n* samples of severity scores. Each sampled severity score comes from the function 'rand_draw'. This function is where everything takes place. The function call is as follows:

rand_draw(num_draws, haznum, percent_eff, control_num, number_of_hazards)

where num_draws = the number of accidents (randomly generated) for that 100,000 flying hour period

haznum = the list of hazards affected by the current control list

percent_eff = the ordered list of combined effectiveness estimates

control_num = the unique number of the control or portfolio – used for tracking raw and severity totals

number_of_hazards = the number of hazards affected

The function executes as follows:

For i = 1 to number of draws

- randomly pick an accident
- randomly assign a unit to the accident

- based on the hazards and the accident, determine the amount of casualty, cost, frequency and environmental reduction for the current accident
- based on the amount of frequency reduction determine if the accident occurred
- happen = random uniform variable (0,1)

  If happen > frequency reduction, then the accident happened – continue with function. If not, the accident didn't happen – go to the next draw i
- if the accident did happen, reduce the raw data and aggregate accordingly
- Unit data is tracked by unit in arrays
- Environmental data is tracked as the maximum occurrence of a category of spill
- After all of the draws, the aggregated data is processed.
  - Unit readiness data is sent to the severity functions and then averaged over all the units
  - The rest of the data is sent to their respective severity functions
- If tracked, raw and severity totals are written
- Finally, each branch is summed up and the function returns the severity score representing the losses from accidents occurring in 100,000 UH-60 flying hours

The process of running the simulation can be broken down into three phases:

1) Pre-simulation setup
2) Running the simulation
3) Post-simulation information gathering

Pre-simulation setup is fairly straightforward and involves verifying the data in the spreadsheets are correct and the parameters in the Visual Basic code (see Appendix G) are correct.

1) Pre-simulation setup
   - Verify the cells referenced by the Visual Basic code are correct. This would only need to be done if the severity functions change or if hazards are added.
   - Verify the weights on the top of the 'Accident Data' worksheet are correct
   - Verify all global constants in the VB code(num_units, num_reps, etc)

   - If the raw and severity totals are going to be tracked, the global arrays must not be commented out and the num_controls needs to be set to the number of controls that is going to be tracked

2) Running the simulation
   - Using Crystal Ball, set the run preferences to the desired settings
   - Using Crystal Ball, declare an assumption cell – the cell is not used in any calculations. Defining an assumption cell though, is a Crystal Ball requirement
   - All portfolios are on the 'Control Calcs' page – if additional portfolios are generated, just add information to the bottom of the current list
   - Set up the function call in a cell
     =do_a_rep(*assum_cell,hazlist,percent_effective,control_track_number*)
       where *assum_cell* represents the cell where the assumption is defined
       hazlist is a range of cells containing the names of the hazards affected by the controls in the portfolio
       percent_effective is the range of cells containing the percent effective on its corresponding hazard.
       NOTE: the order of the hazards and their corresponding percent_effectiveness must be the same. For example, if hazard 10 is the third hazard in the range, the percent effectiveness number must be the third one in the range of percent_effective

Control_track_number is used when recording the raw or severity totals, and must be a unique integer value for each control being tracked

  - Define the cell containing the function call as a forecast cell

3) Post-simulation information gathering

  - After the simulation has completed, use Crystal ball to gather desired information (forecast values or statistics)
  - If raw and severity totals were tracked, run the macro 'macro_get_totals' to retrieve the data.

Appendix D: Mathematical Program

The mathematical program used to generate portfolios was implemented in Microsoft Excel using the premium Solver add-in. The objective function simply maximizes the coverage on the hazards by selecting the best mix of controls for the given cost level. Other constraints considered are listed below. The problem is formulated as follows:

$$Max \sum_{i=1}^{49\,controls} \sum_{j}^{67\,hazards} e_{ij} * x_i$$

where e_{ij} is the percent effectiveness for control$_i$ on hazard$_j$, and $x_i = 1$ if control i is selected.

Subject to: $\sum_{i=1}^{49\,controls} c_i * x_i \leq Max\ Investment\ Costs$ $\quad$ c_i is the cost of control i

$x_{10} = 0$ $\quad$ Control 10 is a no longer under consideration

$x_{34} - x_{44} \leq 0$ $\quad$ C-34 Requires C44 (C44 DOES NOT Require)C-34

$x_{25} + x_{46} \leq 1$ $\quad$ C-25 and C-46 accomplish same function

$x_{16} + x_{20} \leq 1$ $\quad$ C-16 and C-20 Accomplish Same Function

$x_{20} + x_{21} \leq 1$ $\quad$ C-20 and C-21 Accomplish Same Function

$x_{24} + x_{15} \leq 1$ $\quad$ C-24 and C-15 Accomplish Same Function

$x_{17} + x_{44} \leq 1$ $\quad$ C-17 and C-44 Accomplish Same Function

Appendix E: Portfolio Results

The charts in this appendix show the results of the project in tabular format. The portfolios are ranked from best to worst expected performance score. The checked boxes indicate the corresponding control is included in the portfolio.

					Control																																		
Rank		% Decr	Cost	Benefit/Cos	1	2	3	4	5	6	7	8	9	11	12	13	14	16	18	19	22	23	25	27	28	33	34	35	37	38	40	41	42	43	44	46	47	48	49
1	PC146	83.2%	1140.6	7.3	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X		X	X	X	X	X	X	X			X		X		X	X	X
2	PC19	74.0%	429.55	17.2	X	X	X	X	X	X	X		X		X	X	X		X	X	X									X	X	X	X		X		X		X
3	PC17	73.9%	320.55	23.1	X	X	X	X	X		X		X		X	X			X	X	X									X	X	X	X		X		X		X
4	PC145	73.3%	340.6	21.5	X	X	X	X	X	X	X		X		X	X			X	X	X	X				X		X	X	X			X		X		X	X	X
5	PC144	71.1%	212.6	33.5	X	X	X		X		X		X		X				X	X	X	X				X		X		X			X	X	X		X	X	X
6	PC16	68.8%	249.55	27.6	X	X	X		X	X	X		X		X	X			X	X	X									X	X	X	X		X		X		X
7	PC18	68.2%	339.55	20.1	X	X	X	X	X	X	X		X		X	X			X	X	X									X	X	X	X		X		X		X
8	PC15	67.9%	230.55	29.5	X	X	X		X	X	X		X		X	X			X	X	X									X	X	X	X				X		X
9	PC14	66.9%	211.55	31.6	X	X	X			X	X		X		X	X			X	X	X									X	X	X	X				X		X
10	PC12	65.6%	173.55	37.8	X	X	X				X		X		X	X			X	X	X									X	X	X	X						X
11	PC13	62.3%	211.55	29.4	X	X	X		X		X		X		X	X			X	X	X									X	X	X	X				X		X
12	PC10	62.2%	154.55	40.2		X	X				X		X		X	X			X	X	X									X	X	X	X				X		
13	PC11	62.0%	173.55	35.7	X	X	X				X		X		X	X			X	X	X									X	X	X	X				X		
14	PC9	61.9%	154.6	40.0	X	X	X						X		X	X			X	X	X							X		X	X	X	X				X		
15	PC8	61.8%	154.6	40.0	X	X	X				X				X	X			X	X	X							X		X	X	X	X				X		
16	PC154	61.7%	116.6	52.9	X	X					X		X		X				X	X	X							X		X				X	X		X		
17	PC147	61.4%	116.6	52.7	X	X					X		X		X				X	X	X							X		X				X	X		X		
18	PC152	60.3%	116.6	51.7	X	X					X		X		X				X	X	X							X		X				X	X		X		
19	PC142	59.9%	116.55	51.4	X	X					X		X			X			X	X	X							X		X					X		X		
20	PC121	59.3%	133	44.6	X						X					X															X		X		X		X		
21	PC159	58.4%	98.55	59.2		X					X		X		X	X			X	X	X	X				X				X					X		X		
22	PC143	58.3%	98.6	59.1	X	X					X				X	X			X	X	X	X				X		X		X					X		X		
23	PC123	58.2%	133	43.7	X								X			X															X		X		X		X		
24	PC148	57.5%	117.6	48.9	X	X	X				X				X	X			X	X	X	X				X		X		X					X		X		
25	PC151	56.9%	116.6	48.8	X	X	X						X		X	X			X	X	X							X		X					X		X		
26	PC155	56.9%	116.1	49.0	X						X		X		X				X	X	X							X		X				X	X		X		
27	PC89	56.7%	154.6	36.7		X	X						X		X	X			X	X	X							X	X	X	X	X	X				X		
28	PC7	56.6%	154.55	36.6	X	X	X				X		X		X	X			X	X	X									X	X	X	X						
29	PC5	56.3%	135.6	41.5	X	X	X						X		X	X			X	X	X							X		X	X	X	X						
30	PC92	56.2%	133.5	42.1		X			X		X		X			X															X		X				X		
31	PC153	56.1%	117.55	47.7		X	X				X		X		X	X			X	X	X	X				X				X					X		X		
32	PC6	56.0%	135.6	41.3	X	X	X				X				X	X			X	X	X							X		X	X	X	X						
33	PC108	55.9%	152	36.8	X				X	X	X					X															X		X				X		
34	PC149	55.9%	117.6	47.5	X	X	X			X					X	X			X	X	X	X				X		X		X					X		X		
35	PC97	55.5%	133.5	41.6	X	X			X				X			X															X		X				X		
36	PC156	55.0%	97.6	56.3	X	X					X		X		X				X	X	X							X		X					X		X		
37	PC157	54.6%	115	47.5	X						X		X							X	X													X	X		X		
38	PC91	54.2%	133.5	40.6		X				X	X		X			X															X		X				X		
39	PC122	53.5%	204	26.2	X						X	X				X															X		X				X		
40	PC93	53.3%	115	46.3		X					X		X			X						X									X		X				X		
41	PC177	53.1%	78.6	67.6	X	X					X		X		X				X	X	X							X		X					X				
42	PC163	53.0%	79.6	66.6		X							X		X	X			X	X	X	X				X		X		X					X		X		
43	PC90	52.8%	133.5	39.5		X					X		X			X															X		X	X			X		
44	PC68	52.5%	135.6	38.8		X	X						X		X	X			X	X	X							X	X	X	X	X	X						
45	PC182	52.5%	78.6	66.8	X	X					X		X		X				X	X	X							X		X					X				
46	PC141	52.4%	98.6	53.1	X	X					X				X	X			X	X	X	X				X		X		X					X		X		
47	PC2	52.4%	116.6	44.9	X	X	X								X	X			X	X	X							X		X	X	X	X						
48	PC59	52.3%	114.5	45.7		X					X		X			X															X		X				X		
49	PC162	52.2%	79.6	65.6	X	X					X				X	X			X	X	X	X				X		X		X					X				
50	PC140	52.1%	78.6	66.3	X	X					X		X		X				X	X	X							X		X					X				
51	PC105	51.8%	133.5	38.8	X				X				X			X						X									X		X				X		
52	PC3	51.6%	116.6	44.3		X	X				X				X	X			X	X	X							X		X	X	X	X						
53	PC28	51.3%	152	33.8			X				X		X			X													X		X	X	X						
54	PC96	51.3%	133.5	38.4	X	X				X			X			X															X		X				X		
55	PC161	51.1%	78.6	65.0	X	X					X		X		X				X	X	X							X		X					X				
56	PC181	51.0%	79.6	64.1	X	X									X	X			X	X	X	X				X		X		X					X		X		
57	PC98	51.0%	115	44.3	X	X							X			X						X									X		X				X		
58	PC35	50.8%	114.5	44.4		X							X			X															X	X	X				X		
59	PC95	50.8%	133.5	38.1	X	X							X			X															X		X	X			X		

					Control																																		
Rank		% Decr	Cost	Benefit/Cos	1	2	3	4	5	6	7	8	9	11	12	13	14	16	18	19	22	23	25	27	28	33	34	35	37	38	40	41	42	43	44	46	47	48	49
60	PC94	50.8%	114.5	44.4	X	X							X			X															X		X				X		
61	PC38	50.7%	114.55	44.3		X							X		X	X													X			X	X				X		
62	PC180	50.5%	78.6	64.2	X	X							X		X	X			X	X	X							X		X					X				
63	PC84	50.3%	114.5	44.0	X	X							X			X															X		X				X		
64	PC158	50.2%	97.6	51.4	X	X			X		X		X		X				X	X	X							X		X							X		
65	PC124	50.1%	204	24.5	X							X	X			X															X		X				X		
66	PC118	49.9%	114	43.8	X								X			X															X		X		X				
67	PC106	49.8%	133	37.4	X						X					X															X		X	X			X		
68	PC104	49.5%	133	37.2	X								X			X															X		X			X	X		
69	PC179	49.0%	78.6	62.3	X	X					X		X		X				X	X	X							X		X							X		
70	PC119	48.9%	114	42.9							X					X															X		X		X		X		
71	PC138	48.8%	60	81.3		X					X		X						X	X	X	X								X					X				
72	PC21	48.7%	133.55	36.5		X	X						X		X	X													X		X	X	X						
73	PC170	48.5%	60.6	80.1		X					X		X		X				X	X	X	X				X		X		X					X				
74	PC107	48.5%	133.5	36.3	X				X		X					X						X									X		X			X			
75	PC150	48.4%	117.6	41.2	X	X	X		X	X					X	X			X	X	X	X				X		X		X							X		
76	PC26	48.1%	114.05	42.2							X		X		X	X															X	X	X						
77	PC27	48.1%	133	36.2									X			X													X		X	X	X				X		
78	PC24	48.0%	133.5	35.9		X	X						X			X													X		X	X	X						
79	PC31	47.9%	115.05	41.6		X	X				X				X	X														X		X	X				X		
80	PC178	47.8%	79.6	60.1	X	X					X				X	X			X	X	X	X				X		X		X					X				
81	PC160	47.7%	98.6	48.4	X	X				X					X	X			X	X	X	X				X		X		X					X		X		
82	PC29	47.6%	134.05	35.5		X	X						X		X	X				X									X		X	X				X			
83	PC37	47.0%	114.5	41.1		X							X			X													X		X		X				X		
84	PC165	46.9%	60.6	77.4		X					X		X		X				X	X	X	X				X		X		X					X				
85	PC164	46.6%	95	49.1	X						X		X																					X	X				
86	PC103	46.4%	152	30.6	X				X	X			X			X															X		X	X					
87	PC88	46.4%	95.1	48.8							X		X		X	X												X					X				X		
88	PC87	46.2%	95.1	48.6	X						X				X	X												X					X				X		
89	PC57	46.1%	115.05	40.1		X							X		X	X					X										X	X	X				X		
90	PC168	46.1%	60.6	76.1		X							X		X	X			X	X	X	X				X		X		X					X				
91	PC173	46.1%	60.6	76.0		X							X		X	X			X	X	X	X				X		X		X					X				
92	PC111	46.0%	95	48.4									X			X															X		X		X				
93	PC34	45.9%	95.55	48.1		X							X		X	X															X	X					X		
94	PC60	45.7%	95.5	47.9		X							X			X															X		X				X		
95	PC4	45.7%	135.6	33.7		X	X				X		X		X	X			X	X	X							X		X	X	X	X						
96	PC41	45.5%	114.05	39.9			X				X		X		X	X													X				X						
97	PC167	45.5%	60.6	75.1	X	X					X				X				X	X	X	X				X		X		X					X				
98	PC33	45.5%	114.5	39.7		X							X			X													X		X	X					X		
99	PC36	45.4%	95.55	47.5		X							X		X	X															X		X				X		
100	PC22	45.4%	133.05	34.1			X						X		X	X													X			X	X	X					
101	PC171	45.3%	59.6	76.0	X	X					X		X		X				X	X	X							X		X									
102	PC40	45.1%	133.05	33.9	X								X		X	X													X		X	X	X						
103	PC172	45.1%	60.6	74.4	X	X					X				X				X	X	X	X				X		X		X					X				
104	PC86	44.8%	95.1	47.2							X		X		X	X												X			X						X		
105	PC109	44.7%	95	47.0	X											X															X		X		X				
106	PC32	44.6%	95.55	46.7									X		X	X														X		X	X				X		
107	PC85	44.6%	95.1	46.9	X						X				X	X												X			X						X		
108	PC139	44.2%	60	73.7	X	X					X								X	X	X	X								X					X				
109	PC174	44.2%	60.6	72.9	X	X									X	X			X	X	X	X				X		X		X					X				
110	PC23	44.1%	114.55	38.5		X							X		X	X													X		X	X	X						
111	PC166	43.8%	59.6	73.4	X	X					X		X		X				X	X	X							X		X									
112	PC117	43.4%	185	23.5	X							X	X			X															X		X						
113	PC169	43.3%	60.6	71.4	X	X									X	X			X	X	X	X				X		X		X					X				
114	PC110	43.1%	95	45.4							X					X															X		X		X				
115	PC25	43.1%	114.5	37.6		X							X			X													X		X	X	X						
116	PC39	42.5%	114.55	37.1		X							X		X	X															X	X	X	X					
117	PC54	42.4%	77.5	54.7		X							X			X				X	X										X		X						
118	PC175	42.1%	60.6	69.5	X	X									X	X			X	X	X	X				X		X		X							X		

					Control																																	
Rank		% Decr	Cost	Benefit/Cos	1	2	3	4	5	6	7	8	9	11	12	13	14	16	18	19	22	23	25	27	28	33	34	35	37	38	40	41	42	43	44	46	47	48	49
119	PC30	41.7%	114.05	36.5									X		X	X															X	X	X			X			
120	PC120	41.0%	185	22.1							X	X				X															X		X				X		
121	PC62	40.5%	76.1	53.2							X		X		X	X												X									X		
122	PC58	39.7%	76.55	51.9	X										X	X					X												X				X		
123	PC63	39.5%	116.6	33.9		X	X								X	X			X	X	X							X	X	X	X	X	X						
124	PC56	39.4%	115.5	34.1	X	X										X					X		X						X	X	X	X							
125	PC113	39.4%	166	23.7	X							X				X															X		X						
126	PC126	38.1%	166	23.0								X				X															X		X		X				
127	PC1	38.1%	116.6	32.7		X	X						X		X	X			X	X	X							X		X	X	X	X						
128	PC115	38.0%	166	22.9								X	X			X															X		X						
129	PC55	37.9%	76.55	49.5		X							X			X												X	X				X						
130	PC99	37.6%	114.55	32.8												X												X	X	X	X	X	X		X				
131	PC135	37.3%	40	93.3		X					X		X							X	X									X									
132	PC129	37.3%	95	39.2												X															X		X		X			X	
133	PC127	36.9%	166	22.3												X		X													X		X		X				
134	PC112	36.7%	95	38.7												X															X		X		X		X		
135	PC100	36.5%	115.05	31.7												X					X							X	X	X	X	X	X		X				
136	PC114	36.4%	166	21.9							X	X				X															X		X						
137	PC51	36.4%	96	37.9		X	X									X					X										X	X	X						
138	PC61	35.5%	57	62.4							X		X																								X		
139	PC101	34.2%	186.05	18.4								X				X					X							X	X	X	X	X	X						
140	PC116	33.7%	166	20.3								X				X															X		X				X		
141	PC79	33.6%	57.1	58.8	X								X		X	X												X											
142	PC81	33.5%	57.1	58.7									X		X	X												X									X		
143	PC80	33.4%	57.1	58.6									X		X													X					X				X		
144	PC137	33.1%	40	82.8	X	X													X	X	X														X				
145	PC136	32.7%	40	81.8	X	X					X								X	X	X																		
146	PC83	32.6%	57.1	57.0	X						X				X	X												X											
147	PC102	32.5%	186.05	17.5												X		X			X							X	X	X	X	X	X						
148	PC48	31.7%	77	41.2		X	X									X					X										X		X						
149	PC43	31.6%	95.6	33.1		X									X	X												X	X		X	X	X						
150	PC50	31.0%	95.55	32.5		X	X									X												X	X		X	X							
151	PC176	30.8%	60.6	50.8		X									X	X			X	X	X	X				X		X		X					X		X		
152	PC78	30.6%	57.1	53.6	X								X		X													X					X						
153	PC128	30.1%	166	18.2								X				X															X		X					X	
154	PC82	28.7%	57.1	50.3	X						X				X													X					X						
155	PC47	28.2%	77.5	36.4		X										X			X		X								X		X		X						
156	PC72	27.7%	38	73.0									X																								X		
157	PC45	27.5%	77.1	35.7		X									X	X					X							X	X		X		X						
158	PC125	27.3%	237	11.5								X				X		X													X		X						
159	PC65	25.8%	38.1	67.7									X		X	X												X											
160	PC131	25.2%	20	126.2		X							X							X																			
161	PC52	24.9%	38	65.5									X			X																							
162	PC71	24.5%	38	64.6									X																					X					
163	PC73	24.2%	38	63.6	X						X																												
164	PC75	24.1%	38	63.6							X																										X		
165	PC69	23.6%	38	62.1	X								X																										
166	PC64	23.3%	38.1	61.1									X		X													X					X						
167	PC132	22.1%	20	110.7	X	X														X																			
168	PC134	22.0%	20	110.0		X														X															X				
169	PC49	21.9%	38.5	56.9		X										X													X										
170	PC133	20.1%	20	100.7		X					X									X																			
171	PC67	20.0%	38.1	52.5							X				X	X												X											
172	PC44	18.9%	19.55	96.6		X									X	X																							
173	PC42	18.6%	57	32.6																											X	X	X						
174	PC70	17.6%	38	46.4							X		X																										
175	PC74	16.4%	38	43.1							X																							X					
176	PC46	15.6%	57	27.4																									X		X		X						
177	PC77	15.5%	38	40.7																														X			X		
178	PC66	15.0%	38.1	39.4							X				X													X					X						
179	PC76	14.3%	38	37.7	X																													X					
180	PC130	13.4%	3.6	373.4		X									X				X	X	X	X				X		X		X									
181	PC53	11.8%	38	31.2																											X		X						

Appendix F: Mann-Whitney *U* Test

The Mann-Whitney *U* test is used to determine the statistical significance between two portfolio expected severity distributions.

Ho: The population relative frequency distributions for A and B are identical (means are equivalent)

Ha: The two populations' relative frequency distributions are shifted in respect to their relative locations (means are not equivalent)

$$U_A = n_1 n_2 + \frac{n_1(n_1+1)}{2} - W_A$$

Where n_1 = number of observations in Sample A

n_2 = number of observations in Sample B

W_A = ranked sum for Sample A

Test Statistic:

$$Z = \frac{U_A - \left(\frac{n_1 n_2}{2}\right)}{\sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}}$$

Rejection Region:
Reject Ho if
$Z > z_{\alpha/2}$ or $Z < -z_{\alpha/2}$
(two-tailed)

Assumptions: Samples were randomly and independently selected. Ties in observations are handled by averaging the weights.

The results of these tests are shown on the following page. The charts are read in a row-column manner. For example, to check the result of comparing Portfolio 163 with Portfolio 177, find the last occurrence of the two in the left hand column and follow that row over until it intersects the column of the other. If the code SD is in the box, the null has been rejected and the two means are statistically different. Otherwise, Not SD in the box indicates u1 = u2. If the weight of unit readiness equals 0.25, comparing Portfolio 177 and Portfolio 163 reveals they do not have the same mean.

Results from varying the weight of Unit Readiness:

Weight of Unit Readiness = 0.25							
Statistics	Rank	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	2						
PC163	1	**Not SD**					
PC177	3	**Not SD**	SD				
PC179	6	SD	SD	SD			
PC180	4	**Not SD**	SD	**Not SD**	SD		
PC181	5	SD	SD	**Not SD**	SD	**Not SD**	
Weight of Unit Readiness = 0.30							
Statistics	Costs	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	2						
PC163	1	**Not SD**					
PC177	3	**Not SD**	**Not SD**				
PC179	6	SD	SD	SD			
PC180	4	SD	SD	**Not SD**	SD		
PC181	5	SD	SD	SD	**Not SD**	SD	
Weight of Unit Readiness = 0.35							
Statistics	Rank	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	2						
PC163	1	**Not SD**					
PC177	3	SD	SD				
PC179	6	SD	SD	SD			
PC180	5	SD	SD	**Not SD**	**Not SD**		
PC181	4	SD	SD	**Not SD**	**Not SD**	**Not SD**	
Weight of Unit Readiness = 0.378				Base Case			
Statistics	Rank	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	3						
PC163	2	**Not SD**					
PC177	1	**Not SD**	**Not SD**				
PC179	6	SD	SD	SD			
PC180	5	SD	SD	SD	SD		
PC181	4	**Not SD**	SD	SD	SD	**Not SD**	
Weight of Unit Readiness = 0.40							
Statistics	Rank	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	2						
PC163	3	**Not SD**					
PC177	1	**Not SD**	**Not SD**				
PC179	6	SD	SD	SD			
PC180	5	SD	SD	SD	**Not SD**		
PC181	4	SD	SD	SD	**Not SD**	**Not SD**	
Weight of Unit Readiness = 0.45							
Statistics	Rank	**PC162**	**PC163**	**PC177**	**PC179**	**PC180**	**PC181**
PC162	2						
PC163	3	SD					
PC177	1	**Not SD**	**Not SD**				
PC179	6	SD	**Not SD**	SD			
PC180	5	SD	SD	SD	**Not SD**		
PC181	4	SD	**Not SD**	SD	**Not SD**	**Not SD**	

Appendix G: Severity Si mulation Visual Basic Code

This Appendix contains a listing of the Visual Basic for Applications code created for this project.

```
'Severity of Losses Simulation Visual Basic Code

'Global Declarations
'max eu's pre-determined used in unit readiness severity calcs
Public Const max_train_exec_eu = 0.2
Public Const max_unit_fat_eu = 0.125
Public Const max_unit_mag_inj_eu = 0.45
Public Const max_unit_unavail_acft_eu = 0.03

'num constants used for arrays
Public Const num_reps = 410          'B number of reps
Public Const num_cases = 110         'total number of UH-60 cases
Public Const num_hazards = 67         ' UH-60 hazards
Public Const num_controls = 6        ' number of controls being recorded as sim runs
Public Const draws_in_a_rep = 10       'n draws in a rep
Public Const num_units = 26          'estimate of number of UH-60 battalions

Public cas_matrix(1 To num_cases, 1 To num_hazards) As Double   'stores haz casualty matrix
Public cost_matrix(1 To num_cases, 1 To num_hazards) As Double  ' cost haz
Public freq_matrix(1 To num_cases, 1 To num_hazards) As Double  ' freq
Public env_matrix(1 To num_cases, 1 To num_hazards) As Double   ' same as freq matrix
Public accident_data_matrix(1 To num_cases, 1 To 11) As Double '11 data points
Public weights(1 To 14) As Double                    'weights for 14 sev funcs
Public std_err(1 To num_reps, 1 To num_controls)            'keeps track of std err
Public sev_totals(1 To num_controls, 1 To 4) As Double        'keeps track of sev scores
Public raw_totals(1 To num_controls, 1 To 3) As Double        'raw - fatalities, $, AC
Public run_number As Integer                         'sim run number

'*********************************************************************************

Function do_a_rep(cbvar, hazlist, percent_eff, control_num)
'cbvar is just a dummy variable to force crystal ball to recored this as a forecast
'hazlist is the range of cells containing the hazards
' percent eff is that portfolio (or control) effectiveness on the corresponding hazard

Dim x(draws_in_a_rep - 1) As Double 'stores the n draws
 Dim haznum(67) As Integer


   'fill the matrices if necessary
   If weights(1) = 0 Then
   fill_matrices_and_arrays
   End If

   'if crystal ball isn't running a sim, this cell is 0 and the function bombs out
```

```
  'the conditional takes care of that situation
   run_number = Worksheets("Control Calcs").Cells(6, 11)
  If run_number = 0 Then
  GoTo quitit
  run_number = 1
  End If

  number_of_hazards = hazlist.Count
' search through the hazard list to identify which hazards are
  ' currently being evaluated
  For j = 1 To number_of_hazards
     haznum(j) = findhaznum(hazlist(j))
  Next j


  'do n draws
  For i = 1 To draws_in_a_rep
     num_draws = get_rand_number_of_draws(i) 'number between 5 and 21
     x(i - 1) = rand_draw(num_draws, haznum, percent_eff, control_num, number_of_hazards)
  Next i

  avg = Application.Average(x)
  std_err(run_number, control_num) = Application.StDev(x)
  do_a_rep = avg
quitit:
End Function

'*******************************************************************************

Function rand_draw(number_draws, haznum, percent_eff, control_num, number_of_hazards)

Const num_units As Integer = 26
Dim unit_fat(num_units) As Double
Dim unit_train_exec(num_units) As Double
Dim unit_mag_inj(num_units) As Double
Dim unit_unavail_acft(num_units) As Double

'automate matrices population

  actual_num_accidents = 0


  For i = 1 To number_draws
     ' number of draws represents the number of accidents in 100,000
     'flight hours.  Each draw is one accident.
     ' initialize reduction totals
     cas_reduction = 0#
     cost_reduction = 0#
     freq_reduction = 0#
     env_reduction = 0#

     ' pick the accident
     casenum = Int((110 * Rnd) + 1)    ' 110 cases
     'pick the unit
```

```
    unit_num = Int((num_units * Rnd) + 1) '  num_units declared at top

    ' determine %reduction for the hazard combination
    ' for each hazard in the hazard list, see if it contributed to
    ' the current accident and record amount.
    For j = 1 To number_of_hazards
      If haznum(j) <> 0 Then
        cas_reduction = cas_matrix(casenum, haznum(j)) * percent_eff(j) + cas_reduction
        cost_reduction = cost_matrix(casenum, haznum(j)) * percent_eff(j) + cost_reduction
        freq_reduction = freq_matrix(casenum, haznum(j)) * percent_eff(j) + freq_reduction
        env_reduction = env_matrix(casenum, haznum(j)) * percent_eff(j) + env_reduction
      End If
    Next j

    ' does the accident occur
    ' Controls (or hazard combination) may have reduced the probability of occurrence.
    ' if this amount of reduction is significant, the accident is skipped.
    happen = Rnd
  If (happen > freq_reduction) Then
     actual_num_accidents = actual_num_accidents + 1
       ' if it does occur, adjust case data accordingly and add to running totals

      'get fatalities for the current accident
      current_fatalities = (1 - cas_reduction) * accident_data_matrix(casenum, 1)
      'add to total fatalities for current block of 100,000 fliying hours
      fatalities = current_fatalities + fatalities

    'perm_tot_dis commented out because there are none in this project
      'perm_tot_dis = (1 - cas_reduction) * accident_data_matrix(casenum, ???) + perm_tot_dis
      ' permanent partial disabilities

      'get current permanent partial disabilities
      current_ppd = (1 - cas_reduction) * accident_data_matrix(casenum, 2)
      'add to totals
      perm_part_dis = perm_part_dis + current_ppd

      'days in the hospital
      current_dh = (1 - cas_reduction) * accident_data_matrix(casenum, 3)
      days_hospital = current_dh + days_hospital

    ' accident data matrix has accident costs (meaning no injury or damage) in the 4 spot

      current_accident_costs = (1 - cost_reduction) * accident_data_matrix(casenum, 4)
    'total accident costs are in the 5 spot and include injury and damage costs as well
      total_costs = (1 - cost_reduction) * accident_data_matrix(casenum, 5) + total_costs

      ' unit training execution.  metric used is Accident occurrence * class
      ' a Class A is worth 3, B -> 2, C->1
      ' this is per unit
      ' first the pertinent raw accident data is transformed, then the new data is used
      ' to determine the 'new' class of the accident
      unit_train_exec(unit_num) = unit_train_exec(unit_num) +
get_class_number(current_accident_costs, current_fatalities, current_ppd)
```

```
'fatalities in the unit - the unit was randomly drawn above
unit_fat(unit_num) = current_fatalities + unit_fat(unit_num)

' magnitude of injury - categorical
' looks like a mess, but it really isn't.
' use the 'new' data points to determine the magnitude of injury
newcat = get_mag_inj_cat(current_ppd, current_dh)
' take the maximum occurrence of magnitude of injury for each unit
If newcat > unit_mag_inj(unit_num) Then
   unit_mag_inj(unit_num) = newcat
End If


' an aircraft is unavailable to the unit, either because
' it was totalled, or is gone for repair
' the data isn't adjusted with frequency
' because it has already been determined that the accident
' has occurred.  Cost reduction is used to represent the amount of
' reduction in severity for repair hours.

unit_unavail_acft(unit_num) = unit_unavail_acft(unit_num) + determine_loss((1 - cost_reduction) *
accident_data_matrix(casenum, 6)) + accident_data_matrix(casenum, 7)

' these blocks adjust the environmental spillage estimates
' after the adjustment, the get_cat function re-categorizes
' the data - using the max category as a proxy to severity of env damage.
'
' Assumes worse case of both water and soil being affected


   f = get_cat((1 - env_reduction) * accident_data_matrix(casenum, 8))
   h = get_cat((1 - env_reduction) * accident_data_matrix(casenum, 9))
   o = get_cat((1 - env_reduction) * accident_data_matrix(casenum, 10))

'only bother checking the spillage if there was some

If f > 0 Then
   ' if there was some fuel spilled, record it if is the max occurrence.
   If f > fuels Then
      fuels = f
   End If
   If f > fuelw Then
      fuelw = f
   End If
End If

If h > 0 Then
 If h > hydraulics Then
      hydraulics = h
   End If
 If h > hydraulicw Then
      hydraulicw = h
   End If
End If
```

```
        If o > 0 Then
          If o > oils Then
            oils = h
          End If

         If o > oilw Then
          oilw = h
           End If
        End If


      End If  ' end of the if block of  - did it happen?

      Next i ' go draw the next accident


   For j = 1 To num_units
     'get expected utility for unit variables
     'this sums the severity of each measure for each unit
     'after the loop, the average is taken - implying each unit is equally weighted

     ' two if statemets for unit_traiin exec because of S curve
     If (unit_train_exec(j) < 3 And unit_train_exec(j) > 0) Then
        train_exec_subtotal = train_exec_subtotal + (valueE(unit_train_exec(j), Worksheets("Training
Execution").Range("K35"), Worksheets("Training Execution").Range("K37"), "I", Worksheets("Training
Execution").Range("M35")) * 0.5)
     Else
     If (unit_train_exec(j) >= 3) Then
        train_exec_subtotal = train_exec_subtotal + (valueE(unit_train_exec(j), Worksheets("Training
Execution").Range("K37"), Worksheets("Training Execution").Range("K39"), "I", Worksheets("Training
Execution").Range("M36")) * 0.5 + 0.5)
     End If
     End If

     'make the function call to get unit fatalities severity only if there was one in the unit
     If unit_fat(j) > 0 Then
       unit_fat_subtotal = unit_fat_subtotal + valueE(unit_fat(j), Worksheets("Lives Lost in Unit
(Morale)").Range("K35"), Worksheets("Lives Lost in Unit (Morale)").Range("K37"), "I",
Worksheets("Lives Lost in Unit (Morale)").Range("M35"))
     End If

     If unit_mag_inj(j) > 0 Then
       unit_mag_inj_subtotal = unit_mag_inj_subtotal + valuePL(unit_mag_inj(j), Worksheets("Magnitude
of Injury").Range("K35:K38"), Worksheets("Magnitude of Injury").Range("L35:L38"),
Worksheets("Magnitude of Injury").Range("K38"))
     End If

     If unit_unavail_acft(j) > 0 Then
     unit_unavail_acft_subtotal = unit_unavail_acft_subtotal + valuePL(unit_unavail_acft(j),
Worksheets("Unavailable Aircraft").Range("K35:K40"), Worksheets("Unavailable
Aircraft").Range("L35:L40"), Worksheets("Unavailable Aircraft").Range("K40"))
     End If
   Next j  ' end of unit expected utility calcs
```

```
 ' average the unit scores
 train_exec_eu = train_exec_subtotal / num_units
 unit_fat_eu = unit_fat_subtotal / num_units
 unit_mag_inj_eu = unit_mag_inj_subtotal / num_units
 unit_unavail_acft_eu = unit_unavail_acft_subtotal / num_units

 ' run the measures through the severity functions
 ' severity multiplied by the weights in the function calls

 'casualties
 c = casualty_severity(fatalities, perm_tot_dis, perm_part_dis, days_hospital)

 ' unit_readiness
 ur = unit_severity(train_exec_eu, unit_fat_eu, unit_mag_inj_eu, unit_unavail_acft_eu)

 'costs
 tc = cost_severity(total_costs)

 ' environmental damage
 env = env_severity(fuels, hydraulics, oils, fuelw, hydraulicw, oilw)


  'take the comments away from the next lines to store raw totals for a run.
  raw_totals(control_num, 1) = fatalities + raw_totals(control_num, 1)
  raw_totals(control_num, 2) = total_costs + raw_totals(control_num, 2)
  raw_totals(control_num, 3) = actual_num_accidents + raw_totals(control_num, 3)
  '
  '
sev_totals(control_num, 1) = c + sev_totals(control_num, 1)
  sev_totals(control_num, 2) = ur + sev_totals(control_num, 2)
  sev_totals(control_num, 3) = tc + sev_totals(control_num, 3)
  sev_totals(control_num, 4) = env + sev_totals(control_num, 4)


 ' rand draw = casualties + costs + unit_readiness + env damage
 '  rand_draw = unit_mag_inj_eu
 rand_draw = c + ur + tc + env
End Function

'*********************************************************************************

Function casualty_severity(f, ptd, ppd, dh)
 ' if the value functions change, these HARDCODED cells need to be updated!
 ' the IF statements are there to save run time when the parameters are 0
 ' all information for severity functions start in cell K35
 If (f > 0) Then
   fatalities = valuePL(f, Worksheets("Lives Lost").Range("K35:K36"), Worksheets("Lives
Lost").Range("L35:L36"), Worksheets("Lives Lost").Range("K36"))
 End If

 ' no permanent total disabilities in this project
 'If (ptd > 0) Then
```

```
  '   perm_tot_dis = valuePL(ptd, Worksheets("Total Disabilities").Range("K35:K37"), Worksheets("Total Disabilities").Range("L35:L37"), Worksheets("Total Disabilities").Range("K37"))
  'End If

  If (ppd > 0) Then
    perm_part_dis = valuePL(ppd, Worksheets("Partial Disabilities").Range("K35:K36"), Worksheets("Partial Disabilities").Range("L35:L36"), Worksheets("Partial Disabilities").Range("K36"))
  End If

  If (dh > 0) Then
    days_hospital = valuePL(dh, Worksheets("Time Incapacitated").Range("K35:K36"), Worksheets("Time Incapacitated").Range("L35:L36"), Worksheets("Time Incapacitated").Range("K36"))
  End If

  casualty_severity = (fatalities * weights(1)) + (perm_part_dis * weights(2)) + (days_hospital * weights(3))

End Function

'*************************************************************************************

Function cost_severity(c)

' no if statements here because there is (almost) always a cost
'cost severity function is in millions of dollars
costs = valuePL(c / 1000000, Worksheets("Total Costs").Range("K35:K36"), Worksheets("Total Costs").Range("L35:L36"), Worksheets("Total Costs").Range("K36"))

cost_severity = costs * weights(4)

End Function

'*************************************************************************************

Function unit_severity(ute_eu, uf_eu, umi_eu, uua_eu)

  ' normalize all of the expected utility based on the predetermined
  ' maximums - would need updating if severity functions change

  a = (ute_eu / max_train_exec_eu) * weights(5)
  b = (uf_eu / max_unit_fat_eu) * weights(6)
  c = (umi_eu / max_unit_mag_inj_eu) * weights(7)
  d = (uua_eu / max_unit_unavail_acft_eu) * weights(8)

unit_severity = a + b + c + d
End Function

'*************************************************************************************

Function env_severity(fs, hs, os, fw, hw, ow)

' severity functions are different for water and soil
' only make funtion call when > 0
```

```
  If (fs > 0) Then
     fuel_severity = valuePL(fs, Worksheets("Fluid Spills").Range("K35:K40"), Worksheets("Fluid
Spills").Range("L35:L40"), Worksheets("Fluid Spills").Range("K40"))
  End If

  If (hs > 0) Then
     hydraulic_severity = valuePL(hs, Worksheets("Fluid Spills").Range("K35:K40"), Worksheets("Fluid
Spills").Range("L35:L40"), Worksheets("Fluid Spills").Range("K40"))
  End If

  If (os > 0) Then
     oil_severity = valuePL(os, Worksheets("Fluid Spills").Range("K35:K40"), Worksheets("Fluid
Spills").Range("L35:L40"), Worksheets("Fluid Spills").Range("K40"))
  End If
'soil total
total = (fuel_severity * weights(9)) + (hydraulic_severity * weights(10)) + (oil_severity * weights(11))

If (fw > 0) Then
     fuel_severity = valuePL(fw, Worksheets("Fluid Spills").Range("K45:K50"), Worksheets("Fluid
Spills").Range("L45:L50"), Worksheets("Fluid Spills").Range("K50"))
  End If

  If (hw > 0) Then
    hydraulic_severity = valuePL(hw, Worksheets("Fluid Spills").Range("K35:K40"), Worksheets("Fluid
Spills").Range("L35:L40"), Worksheets("Fluid Spills").Range("K40"))
  End If

  If (ow > 0) Then
     oil_severity = valuePL(ow, Worksheets("Fluid Spills").Range("K35:K40"), Worksheets("Fluid
Spills").Range("L35:L40"), Worksheets("Fluid Spills").Range("K40"))
  End If

'wate total + soil total
env_severity = (fuel_severity * weights(12)) + (hydraulic_severity * weights(13)) + (oil_severity *
weights(14)) + total

End Function

'*************************************************************************************

Function findhaznum(haz)
'crude way of doing it, but it works
findhaznum = 0
 For j = 3 To 69 ' number of hazs, starting in col 3
      If Worksheets("Haz Env Matrix").Cells(4, j) = haz.Value Then
         findhaznum = j - 2
         Exit For
      End If
 Next j
 End Function

'*************************************************************************************

Function get_cat(a)
```

```
'get environmental damage category

If a <= 0 Then
get_cat = 0
GoTo exitit
End If

If (a > 0 And a < 1) Then
   get_cat = 1
GoTo exitit
End If

If (a >= 1 And a < 2) Then
   get_cat = 2
GoTo exitit
End If

If (a >= 2 And a < 10) Then
   get_cat = 3
GoTo exitit
End If

If (a >= 10 And a < 20) Then
   get_cat = 4
GoTo exitit
End If

If a >= 20 Then
   get_cat = 5
End If

exitit:
End Function

'*********************************************************************************

Function get_mag_inj_cat(perm_part_dis, days_hospital)
'magnitude of injury category
'from interview with LTC Semmens, USASC

If perm_part_dis > 0 Then
   get_mag_inj_cat = 3
   GoTo exitit
End If

If days_hospital > 0 Then
   If days_hospital < 7 Then
      get_mag_inj_cat = 1
   Else
      get_mag_inj_cat = 2
   End If
Else
get_mag_inj_cat = 0
End If
```

```
exitit:
End Function

'*********************************************************************************

Function get_class_number(current_accident_costs, current_fatalities, current_ppd)
'accident class number
'Class C accident
' has to have no perm part dis, no fat, and costs < 200K
If current_ppd < 1 And current_fatalities < 1 And current_accident_costs < 200000 Then
   get_class_number = 1
   GoTo exitit
End If

'Class B accident
' involves 1 or more perm part dis or has no fatalities and is less than 1Million
If (current_ppd >= 1) Or (current_fatalities < 1 And current_accident_costs < 1000000) Then
   get_class_number = 2
   GoTo exitit
End If

' if not a C or B, must be an A
get_class_number = 3

exitit:

End Function

'*********************************************************************************

Function determine_loss(mhr)
' see if the aircraft is lost to the unit
' if it requires more than 40 hours to repair, it is sent away and therrefore lost to the unit

If mhr > 40 Then
determine_loss = 1
Else
determine_loss = 0
End If
End Function

'*********************************************************************************

'This routine must be run before the rand_draw function will work
'Here, the data is dumped into the matrices that are referenced in the rand_draw function

Sub fill_matrices_and_arrays()
run_number = 0

'for each accident
For i = 1 To num_cases
   'for each hazard
      For j = 1 To num_hazards
      'data starts in row 5 and column3
```

```
    cas_matrix(i, j) = Worksheets("Haz Casualty Matrix").Cells(4 + i, 2 + j)
    cost_matrix(i, j) = Worksheets("Haz Cost Matrix").Cells(4 + i, 2 + j)
    freq_matrix(i, j) = Worksheets("Haz Frequency Matrix").Cells(4 + i, 2 + j)
    env_matrix(i, j) = Worksheets("Haz Env Matrix").Cells(4 + i, 2 + j)
    Next j


  'fill the accident data matrix
   'fatalities
   accident_data_matrix(i, 1) = Worksheets("Accident Data").Cells(4 + i, 2)

   'permanent partial disabilities
   accident_data_matrix(i, 2) = Worksheets("Accident Data").Cells(4 + i, 4)

   'days in hospital
   accident_data_matrix(i, 3) = Worksheets("Accident Data").Cells(4 + i, 5)

   'Accident damage costs
   accident_data_matrix(i, 4) = Worksheets("Accident Data").Cells(4 + i, 6)

   'Total Accident costs
   accident_data_matrix(i, 5) = Worksheets("Accident Data").Cells(4 + i, 9)

 For k = 6 To 10
   'man hours to repair
   'total loss of acft
   'fuel spilled
   'hydraulic spilled
   'oil spilled
   accident_data_matrix(i, k) = Worksheets("Accident Data").Cells(4 + i, k + 8)
  Next k
Next i

  'get the global weights
  'fatalities weights
  weights(1) = Worksheets("Accident Data").Cells(3, 2)

  'perm part dis weight
  weights(2) = Worksheets("Accident Data").Cells(3, 4)

  'days hospital weight
  weights(3) = Worksheets("Accident Data").Cells(3, 5)

  For k = 4 To 14
   If k < 9 Then
     'Total Costs Accident weight
     'Class # weight
     'Fatalities_Unit_Morale weight
     'Magnitude of Injury weight
     'Acft Unavailable weight

     weights(k) = Worksheets("Accident Data").Cells(3, k + 5)
   Else
     'fuel soil weight
```

```
        'hydraulic soil weight
        'oil soil weight
        'fule water weight
        'hydraulic water weight
        'oil water weight
        weights(k) = Worksheets("Accident Data").Cells(3, k + 7)
    End If
Next k

End Sub

'*********************************************************************************

Function valueE(x, low, high, monotonicity, rho)
' Determines the value score for an exponential value function
' Kirkwood, pg 81
    If x < low Then
     valueE = 0
     GoTo exitit
     End If
    If x > high Then
    valueE = 1
    GoTo exitit
    Else
    Select Case UCase(monotonicity)
        Case "I"
            delta = x - low
        Case "D"
            delta = high - x
    End Select

    If UCase(rho) = "INF" Then
        valueE = delta / (high - low)
    Else
        valueE = (1 - Exp(-delta / rho)) / (1 - Exp(-(high - low) / rho))
    End If
    End If
exitit:

End Function

'*********************************************************************************

Function valuePL(x, Xi, Vi, high)
' Determines the value score for a piecewise linear value function
' Kirkwood, pg 81
    If x > high Then
    valuePL = 1

  GoTo exitit
      End If

      If x < Xi(1) Then
     valuePL = 0
```

```
 Else
 i = 2
 Do While x > Xi(i)
   i = i + 1
 Loop
 valuePL = Vi(i - 1) + (Vi(i) - Vi(i - 1)) * _
        (x - Xi(i - 1)) / (Xi(i) - Xi(i - 1))
 End If
exitit:
End Function

'*************************************************************************************

Function fluid_cat_to_amount(category)
'used for estimated amount of haz fluid spilled
Select Case (category)
  Case 0:  fluid_cat_to_amount = 0
  Case 1:  fluid_cat_to_amount = 0.5
  Case 2:  fluid_cat_to_amount = 1.5
  Case 3:  fluid_cat_to_amount = 6
  Case 4:  fluid_cat_to_amount = 15
  Case 5:  fluid_cat_to_amount = 30

End Select

End Function

'*************************************************************************************

Sub clear_totals()
Dim Message, Title, Default, MyValue

        For j = 1 To num_controls
          For k = 1 To 4
          sev_totals(j, k) = 0
          Next k
          For k = 1 To 3
          raw_totals(j, k) = 0
          Next k
          For k = 1 To num_reps
          std_err(k, j) = 0
          Next k
        Next j
End Sub

'*************************************************************************************

Sub get_totals()
'this is used when I write out severity breakdowns
' to work



'for severities
```

```
Worksheets("Severity Totals").Cells(1, 2) = "Casualties"
Worksheets("Severity Totals").Cells(1, 3) = "Unit Readiness"
Worksheets("Severity Totals").Cells(1, 4) = "Total Costs"
Worksheets("Severity Totals").Cells(1, 5) = "Environmental Damage"

'for aggregated totals

Worksheets("Severity Totals").Cells(1, 9) = "Fatalities"
Worksheets("Severity Totals").Cells(1, 10) = "Total Accident Costs"
Worksheets("Severity Totals").Cells(1, 11) = "Number of Accidents"

  For j = 1 To num_controls
    For k = 1 To 4
      Worksheets("Severity Totals").Cells(j + 1, k + 1) = sev_totals(j, k) / (num_reps * draws_in_a_rep)
      Next k
      For k = 1 To 3
        Worksheets("Severity Totals").Cells(j + 1, k + 8) = raw_totals(j, k) / (num_reps *
draws_in_a_rep)
      Next k
  Next j

   get_std_err
End Sub

'*********************************************************************************

Function get_rand_number_of_draws(dummy)
'binomial distribution n = 30, p = .295
num = 0
Randomize
For i = 1 To 30
  j = Rnd
    If j <= 0.295 Then
      num = num + 1
    End If
Next i
If num < 5 Then
  num = 5
End If
If num > 21 Then
  num = 21
End If
get_rand_number_of_draws = num
End Function

'*********************************************************************************

Sub get_std_err()
'recorded macro used to print out stderrs
With Application
    .Calculation = xlManual
    .MaxChange = 0.001
  End With
  ActiveWorkbook.PrecisionAsDisplayed = False
```

```
    Sheets("Std Err Wksheet").Select
    Cells.Select
    Range("C13").Activate
    Selection.ClearContents
    Range("A1").Select
  For i = 1 To num_reps
    For j = 1 To num_controls
        Worksheets("Std Err Wksheet").Cells(i + 1, j) = std_err(i, j)
    Next j
Next i

End Sub

'*********************************************************************************

Sub macro_get_totals()
'
' macro_get_totals Macro
' Macro recorded 2/17/00 by rgallan
'

'
    With Application
        .Calculation = xlManual
        .MaxChange = 0.001
    End With
    ActiveWorkbook.PrecisionAsDisplayed = False
    Sheets("Severity Totals").Select
    Cells.Select
    Selection.ClearContents
    Range("A1").Select
    get_totals
    With Application
        .Calculation = xlAutomatic
        .MaxChange = 0.001
    End With
    ActiveWorkbook.PrecisionAsDisplayed = False
End Sub

'*********************************************************************************

Sub macro_get_std_errs()
'
' macro_get_totals Macro
' Macro recorded 2/17/00 by rgallan
'

    With Application
        .Calculation = xlManual
        .MaxChange = 0.001
    End With
    ActiveWorkbook.PrecisionAsDisplayed = False
    Sheets("Std Err Wksheet").Select
    Cells.Select
```

```
    Range("C13").Activate
    Selection.ClearContents
    Range("A1").Select
    get_std_err

End Sub
```

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