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Total Ownership with Lifecycle Cost Model Under Uncertainty

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TOTAL OWNERSHIP WITH LIFECYCLE COST MODEL UNDER UNCERTAINTY: ELECTRO-OPTICAL INFRARED SENSORS

by

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In this research, we look at answering the following primary question: Would an advanced analytical model be a more effective metric to estimate total ownership cost (TOC) with life-cycle cost under uncertainty and risk than the current method of life-cycle cost estimates for Surface EO/IR Sensors? To accomplish this, the research developed and analyzed a computational model for Total Ownership with Life-Cycle Cost Model Under Uncertainty for Surface Electro-Optical Infrared Sensors. During the development of the model, we identified the required data and examined the current Department of Defense (DoD) method for determining system life-cycle costs for defense systems and determined that the proposed model is a useful alternative to the current method of determining the life-cycle costs for EO/IR Sensors on surface ships. Finally, we concluded that the developed model can be applied to cost estimating in other sectors of DoD cost projections.

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Total Ownership with Lifecycle Cost Model Under Uncertainty

Model Manual and Instructions (Electro-Optical Infrared Sensors)

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List of Deliverables

The following are the deliverables for the project:

Total Ownership Cost - Final Report.doc. This is the current file, with the detailed report of the analysis, methodologies, examples, models, and analytical discussions.

TOC Model Worksheet (Final) - nps.xlsx. This file contains the TOC model template that can be reused.

TOC Model - Example Only (Repeated Data and Locked Sheets).xlsx. This file contains an example set of nominal values such that the methodology and application can be seen in action.

TOC.mp4. This file contains a video recording of the step-by-step approach on using the model and methodologies.

Software Download. Please contact the author, Dr. Johnathan Mun, at jcmun@nps.edu for the latest updated link to the software application in order to run simulations and other advanced analytics on the TOC models.

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1. INTRODUCTION TO THE TOTAL OWNERSHIP WITH LIFECYCLE COST MODEL

Introduction

This report provides a detailed description of the associated "TOC Model Worksheet (Final).xlsx" model and instructions on running it. This model was developed by Dr. Johnathan Mun at the Naval Postgraduate School (jcmun@nps.edu) for the purposes of modeling the lifecycle and total ownership cost (TOC) of Surface Electro-Optic Infrared (EO/IR) sensors for NAVSEA. This document is meant to get the user of the model started with applying the basics of TOC modeling over the life cycle of the EO/IR, including the inception phase of Acquisition Costs, followed by annual Operations and Maintenance (O&M) expenses, and a final set of Disposition Costs at the end of life of the sensor. This document is not meant as guidance on design specifications, but, rather, as a guide to the decision analytics modeling of the costs of said sensors for the purposes of use in subsequent cost comparisons across sensor platforms, return on investment analysis, portfolio allocation of resources, and analysis of alternatives.

Research Purpose

The purpose of this thesis is to develop a model to estimate total ownership with life-cycle costs under uncertainty associated with Surface Electro-Optic Infrared (EO/IR) sensors. We will examine the basics of Total Ownership Cost modeling over the life cycle of the EO/IR sensors, including the inception phase of Acquisition Costs, followed by annual Operations and Maintenance (O&M) expenses, along with a final set of Disposition Costs at the end of life of the sensor. This model will allow managers to have better decision analytics of the costs of said sensors for use in subsequent cost comparisons across sensor platforms, return on investment analysis, portfolio allocation of resources, and analysis of alternatives.

Research Focus

In this research, we will answer the following primary question: Would an advanced analytical model be a more effective metric to estimate total ownership with life-cycle cost under uncertainty than the current method of life-cycle cost estimates for Surface EO/IR Sensors? To accomplish this, we will develop and analyze a Total Ownership with Life-Cycle Cost Model Under Uncertainty for Surface Electro-Optical Infrared Sensors. In the development of the model, we will determine what data is required to implement our proposed model for surface ship EO/IR sensors. We will also examine the current Department of Defense (DoD) method for determining system life-cycle costs for defense systems and will consider whether the proposed model is a useful alternative to the current method of determining the life-cycle costs for EO/IR Sensors on surface ships. Lastly, we will consider whether the developed model can be applied to cost estimating in other sectors of DoD cost projections.

Research Summary

While executing a standard life-cycle-based total ownership cost analysis, we assume that before the system is operational, there are substantial acquisition costs. These costs are usually referred to as Year 0, followed by the operational years where operation and maintenance costs will apply. The final price analyzed is the salvage cost, or the cost to properly dispose of, sell, or render the system inoperable. The sum of these three expenses is called the life-cycle cost.

Unfortunately, the accurate calculation of these costs is not as straightforward as their descriptions. To accurately incorporate these three factors, it is essential to consider economic theory. The elements of time valuation of money are critical in the analysis of alternatives. The economic growth, the annual discount rate, inflation, and opportunity cost of investing in a specific system are essential to our study. Other factors include budgetary cutbacks and changes in technology. The model will allow the user to input these changes to manually adjust for each of these. Utilizing this model will serve as a proof of concept to understand how this approach could be used to reduce cost overflow and prevent budget overruns. It will provide greater insight into the true nature of the cost of cash outflow and the life cycle of the product and its associated costs. These results would give leaders a more effective metric to analyze total ownership cost under uncertainty, therefore allowing leadership to make more informed decisions in the DoD acquisition process.

2. LITERATURE REVIEW

Introduction

This background and literature review provide a comprehensive overview of the topics pertinent to our project. We first examine the concepts and best practices in the field of cost and cost estimation, and their application inside of the DoD. We then look into the DoD's acquisition process as a whole to analyze how the DoD can utilize cost estimation to influence decision-making. After covering basic cost estimation and the acquisition system, we then discuss total ownership cost and life-cycle cost estimations, and how these factors play a role in calculating the overall cost of a system.

The review also covers the topics of risk and uncertainty to explain the relationship and the differences between the two, as well as to highlight the importance of properly accounting for both factors. We conclude with an overview of our model's subject, the electro-optical infrared sensor (EO/IR). We give a brief rundown of the capabilities as well as the applications that these sensors have on Navy surface vessels, along with their rapidly changing technology, and state why it is imperative that the Navy continues to buy these sensors while ensuring the cost stays at a rational price point.

Cost Estimation

The DoD receives a limited amount of funds every fiscal year and must decide how those funds are used in support of U.S. national strategies and goals. Specifically, those decisions fall into one of three categories: long-term planning, budgeting, and choosing among alternatives (Mislick & Nussbaum, 2015). The government is tasked with spending taxpayers' dollars effectively and efficiently. This means that the DoD decision makers must ensure they make strategic investments, including the acquisition of new programs and systems. Before a program is implemented or system purchased, decision makers must understand the full cost that will be incurred and its effect on the DoD's limited budget.

The projected costs of major acquisitions are produced through a process known as cost estimation. Cost estimation is defined as "the process of collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases in order to predict an estimate of the future cost of an item, product, or task" (Mislick & Nussbaum, 2015, p. 11). In basic terms, cost estimation is performed by running relevant data from the past through a model or database to predict what an item will cost in the future. It is important to note that reliable historical data is fundamental to this process.

In order to produce cost estimates, we must first gather available historical data. Collecting data is often the most time-consuming and costly step of the entire cost estimation process (Mislick & Nussbaum, 2015). Only after the historical data has be obtained can the cost analyst start the "organization, normalization, and management of that historical data" (Mislick & Nussbaum, p. 11). Normalization refers to taking the historical data and "applying adjustments to that data to gain consistent, comparable data to be used in your estimates" (Mislick & Nussbaum, p. 78). Normalizing the data set allows the analyst to compare data across different periods of time by adjusting for different factors. The data set must be normalized three different ways: for content, for quantity, and for inflation (Mislick & Nussbaum). Normalizing for content ensures you are comparing the same category or type of data (Mislick & Nussbaum). Normalizing for quantity ensures you are comparing data at the same point on the learning curve of production and you are comparing equal quantities (Mislick & Nussbaum). Lastly, the data is adjusted to account for inflation when comparing data from different years (Mislick & Nussbaum).

The second component of cost estimation is the quantitative model that is used to turn normalized historical data into a future cost estimate. Mislick and Nussbaum (2015) explain that the "profession of cost estimating is scientifically grounded by using transparent, rationally defensible and reviewable quantitative methods" (p. 12). The development of a high-quality quantitative model is key in cost estimation. If a poor quantitative model is used, then the quality and reliability of the cost estimate will also be poor. This axiom highlights the importance of the development of quality cost models for EO/IR sensors.

The third part of Mislick and Nussbaum's (2015) definition of cost estimation is to predict. The ultimate goal of cost estimation is to predict a future cost. The prediction is based on the information available at the time. We can only "estimate the conditions that will pertain later when the project is executed" and must rely on the information available in the present (Mislick & Nussbaum, p. 12). While no one can forecast the future with one hundred percent accuracy, through historical data and quantitative models we are able to provide a more accurate prediction that, while not perfect, is still a useful tool for decision makers in the acquisition process.

Mislick and Nussbaum (2015) explain that the overall objective of the cost estimation is to provide a complete, reasonable, credible, and analytically defensible estimation of future costs—a quality estimate—that can be used by decision makers. They provide a breakdown of characteristics essential to a quality cost estimate, and we explore some of these characteristics in the following paragraphs.

One of most important characteristics of a quality cost estimate is that it must be understandable to the user or decision maker (Mislick & Nussbaum, 2015) in order to be an efficient decision-making tool. To this end, a complex approach to cost estimation should be avoided and a simpler approach should be used (Mislick & Nussbaum). An understandable estimate also clearly lays out the assumptions and ground rules that were used in the process (Mislick & Nussbaum). With the diversity among people's background and experiences, there can be differing underlying assumptions in the cost estimation process. Therefore, the assumptions used must be clearly stated and a sensitivity analysis should be performed to accommodate additional variations of assumptions (Mislick & Nussbaum).

Another characteristic of a quality cost estimate is that it is "anchored in historical program performance" (Mislick & Nussbaum, 2015, p. 13). We previously stated that cost estimations use historical data to predict future cost. Therefore, an important aspect of the historical data is its relation to the future costs we are trying to predict. The cost estimation must be based on data from a similar system or program (Mislick & Nussbaum). For example, if we are trying to estimate the cost of a new class of surface ship, we should not be using historical data from a submarine program as such data would not produce a quality estimate. Instead, we should use the historical data from a past class of surface ship that has features similar to the new class. Although we are using historical data as a base, we must also account for "current and potential future process and design improvements" (Mislick & Nussbaum, p. 13). We are trying to predict the cost of a new future system, which may have updated designs and processes with no historical data. These updates and improvements still need to be accounted for in our estimation and are often accomplished by subject matter experts (SMEs) and their professional judgement (Mislick & Nussbaum).

Lastly, cost estimates are about predicting the future, and with the future comes uncertainty. In order to produce quality estimates, cost analysts must address the uncertainties and risk associated with the program (Mislick & Nussbaum). We go into more detail about how risk and uncertainties are addressed in cost estimation later.

Cost Overview

Before comprehending cost estimation methods, it is important to become familiar with the terms associated with cost estimation. To begin with, an understanding of "cost" provides a solid foundation in the cost estimation process. If we do not understand what we are trying to predict, then we will not produce a quality or credible estimation. The term cost is often used interchangeably with the term price; however, they do not have the same meaning. There is an important distinction between the two terms. Mislick and Nussbaum (2015) define cost as the total amount of money needed to produce a certain item, or a quantitative measurement that accounts for all resources needed to produce an item. However, they refer to price as the amount of money that a person must pay for an item. When we go into a store, we normally ask the salesperson "What does this item cost?" Answering the literal question of what an item costs would encompass every resource that went into the development and production of that item. Instead, the accurate question is, "what's the item's price?" or, "how much money I must exchange to receive that item?" In cost estimation, we are focused on the question of what a program or project costs.

Because the term cost can refer to a number of different types or categories, the type of cost is important to understand during the cost estimation process. One of the first distinctions is between recurring and nonrecurring costs. A recurring cost is "repetitive and occurs each time a company produces a unit" (Mislick & Nussbaum, 2015, p. 26).

When a bottling company produces a bottled beverage, each bottle cap has an associated cost. The cost of each bottle cap is recurring. In contrast, a nonrecurring cost is "not repetitive and cannot be tied to the quantity of the items being produced" (Mislick & Nussbaum, p. 26). The cost associated with purchase of the bottling machine would be consider nonrecurring. Closely related to recurring and nonrecurring costs are fixed and variable costs. Variable costs are associated and vary with the level of production (Mislick & Nussbaum). The more units produced, the more the total variable cost. However, fixed costs are unaffected by the level of production and are "generally associated with nonrecurring costs" (Mislick & Nussbaum, p. 27). No matter how many units are produced the fixed cost will remain unchanged.

Another distinction between types of cost is direct and indirect costs. A direct cost can be "reasonably measured and allocated to a specific output, product, or work activity" (Mislick & Nussbaum, 2015, p. 26). The material used to produce an item is a direct cost. An indirect cost "cannot be attributed or allocated to a specific output, product, or work activity" (Mislick & Nussbaum, p. 27). The maintenance required for the upkeep of a machine used in production is indirect. Operating costs that are not direct labor or material, such as electricity and property taxes, are classified as overhead costs (Mislick & Nussbaum).

Other cost classifications are sunk costs and opportunity costs. A sunk cost is a cost that has already been incurred, as it occurred in the past. These costs are considered irrelevant to decision makers, as the money spent cannot be retrieved (Mislick &

Nussbaum, 2015). If you walk into a car dealership and purchase a car, the cost of that car is not used in considering future upkeep or upgrades. You cannot get the money you spent back and reallocate it; therefore, it is sunk. Opportunity cost arises when there is more than one option to be considered. Opportunity cost is the measure of the value lost when you choose one alternative over another (Mislick & Nussbaum). In the car dealership scenario, you have the option of buying several different cars. Each of those cars has different features and value. In order to buy one car, you have to decide not to buy the others. This means you are giving up some features or value. Opportunity costs are important for decision makers when determining the best available option among multiple alternatives. Lastly, we consider the classification of life-cycle cost.

Life-Cycle Cost

In developing a cost estimate, we first must understand a program's or project's life cycle. A life cycle follows the project or program from its inception to its disposal, or "cradle to grave." It includes "the various stages of activity or phases through which the project progresses on its way from beginning to completion" (Rendon & Snider, 2008, p. 3). The life cycle starts at a program's development, flows through its production, operation, and maintenance, and finally concludes after proper disposal. The costs associated with this process are classified as the program's life-cycle cost (LCC).

The Defense Acquisition University defines LCC as the direct cost of the acquisition program, as well as the indirect cost that can be logically attributed to the program over the entire life cycle (DAU, n.d.-b). It includes the cost to the government to "acquire, operate, support (to include manpower), and where applicable, dispose" of a system or program (DAU, n.d.-b). There are multiple stakeholders in the DoD, such as Congress, the program manager and office, and contractors, that view a program's life-cycle cost from different perspectives. These multiple perspectives have led to three different methods of breaking down and displaying LCC.

The first method is breaking down program life-cycle costs by five different appropriation categories (DAU, n.d.-b): Research, Development, Test, and Evaluation (RDT&E); Procurement; Operations and Maintenance (O&M); Military Construction (MILCON); and Military Personnel (MILPERS). This method is used to develop and submit budget requests to Congress (DAU, n.d.-b).

However, program managers and program offices would not find the first method as useful as Congress does. Instead, they utilize program life-cycle costs that are broken down by Work Breakdown Structure (WBS) (DAU, n.d.-b). The DAU describes a WBS as a framework that displays "the total system as a product-oriented family tree composed of hardware, software, services, data, and facilities" (DAU, n.d.-b). The WBS relates all of the work elements to each other and eventually to the final product (DAU, n.d.-b). A WBS encompasses all of the work necessary to produce a product (Huynh & Snider, 2008). This breakdown shows the relationship between costs and different elements of a system, which is a useful tool for program managers and contractors.

The Office of the Secretary of Defense (OSD) for Cost Assessment and Program Evaluation (CAPE) outlines the third display method in their *Operating and Support Cost-Estimating Guide* (DoD, 2014). OSD-CAPE defines a program's life-cycle cost as the summation of four different cost categories or phases: Research and Development (R&D), Investment, Operating and Support, and Disposal. Figure 1 provides a graphical representation of the four cost categories over a program's life cycle.

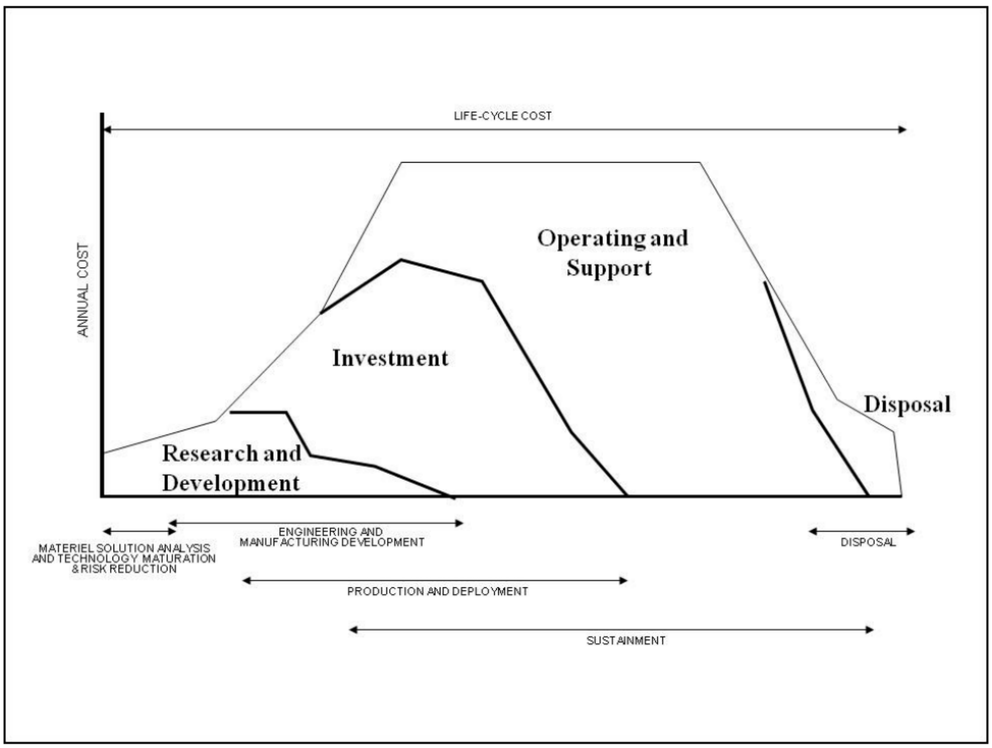


Figure 1. Notional Profile of Annual Program Expenditures by Major Cost Category over the System Life Cycle. *Source:* OSD CAPE (DoD, 2014).

R&D is the initial cost category or phase in a program's life cycle. These costs are the first incurred in the research, design, and development of a new system or program. They can also include the "system design and integration; development, fabrication, assembly, and test of hardware and software for protypes and/or engineering development models" (DoD, 2014, p. 2–3).

Following R&D is the Investment cost category. These costs are incurred from "procurement and related activities from the beginning of low rate initial production (LRIP) through completion of deployment" (DoD, 2014, p. 2–3). LRIP refers to the production of the minimal number of a product or system that is required for initial operational test and evaluation (IOT&E) (DAU, n.d.-c). Investment costs can include program management, initial spares, technical publications, and equipment training (DoD, 2014).

The Operating and Support (O&S) phase is the third phase in the OSD-CAPE definition of LCC. The O&S phase normally accounts for a majority of a project's life-cycle costs (DoD, 2014). O&S consists of all of a system's operation and sustainment cost from initial deployment to the end of its operational life. This includes the all costs associated with "operating, maintaining, and supporting a fielded system" (DoD, p. 2–3). Specifically, costs can include "personnel, equipment, supplies, software, and services associated with operating, modifying, maintain, supplying, and otherwise supporting a system" (DoD, p.2-3).

The fourth and final OSD-CAPE cost category is Disposal. Disposal costs are those associated with the proper disposal or demilitarization at the end of a system's operational life (DoD, 2014). These costs can include "disassembly, materials processing, decontamination, collection/storage/disposal of hazardous materials and/or waste, safety precautions, and transportation of the system to and from the disposal site" (DoD, p. 2–5). However, disposal costs can also be incurred during the sustainment phase due to unplanned system losses. (DoD, 2014). We revisit this method of life-cycle costing in our discussion of total ownership costing.

Department of Defense Acquisition Process

To comprehend how life-cycle costs and cost estimations are used in the DoD, we first must have a basic understanding of the DoD acquisition process. *DoD Directive 5000.01* defines the purpose of the acquisition process as the ability to "acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price" (DoD, 2007, p.3) In acquiring a new system or program, the DoD uses the Defense Acquisition System (DAS), which is defined in *Directive 5000.01* as a "management process by which the Department of Defense provides effective, affordable, and timely systems to the users" (DoD, p. 2). However, the DAS is not the only part of the acquisition process. It is used in conjunction with two other DoD decision support systems (Ambrose, 2017a): the Joint Capabilities Integration and Development System (JCIDS) and the Planning, Programing, Budgeting, and Execution process (PPBE). These support systems identify and document the operational requirements or needs and guide the program's financing process. We are providing a brief overview of both support systems because they are fundamental to the overall DoD acquisition process.

Dealing with identifying, assessing, and prioritizing military operational requirements, JCIDS represents the foundation of the defense acquisition program process. It uses a top-down approach stemming from the National Military Strategy and flows into joint concepts and joint capabilities. The Defense Acquisition University describes the process as a "collaborative effort that uses joint concepts and integrated architectures to identify prioritized capability gaps and integrated doctrine, organization, training, material, leadership and education, personnel, and facilities (DOTmLPF) solutions (materiel and non-materiel) to resolve those gaps" (DAU, n.d.-a). The JCIDS process starts with the identification of an operational capability gap and the requirements needed to fill the associated gap. This can be achieved through a capabilities-based assessment (CBA) and two different potential solutions: materiel or non-materiel (DAU, n.d.-a). If a materiel solution is decided on, then the DoD acquisition process proceeds.

As an example, if a Commander discovers his or her Sailors are unable to combat a new threat with the ship's current systems, a capability gap has been identified. The DoD will address this gap and the need for a solution through the JCIDS process. If the solution is a new or updated system, then a new program will be developed through the defense acquisition process. Once the need for a new system or program has been identified, we can transition to the financing side of the acquisition process.

The Planning, Programing, Budgeting, and Execution process (PPBE) is the second acquisition support system. The DAU defines the process as the DoD's "internal methodology used to allocate resources to provide capabilities deemed necessary to accomplish the Department's missions" (DAU, n.d.-d). The process focuses on how resources are allocated in the DoD to support both current and future acquisition programs, more specifically, on how the DoD finances those programs. The PPBE process is broken down into four phases.

In the first phase, planning, the required capabilities to support and complete the missions outlined in the national policy are developed. This phase produces the Joint Programming Guidance (JPG), which provides guidance and establishes priorities for the Program Objective Memorandum (POM) (Candreva, 2008). However, the JPG does not account for any fiscal constraints. The next phase in the PPBE process is programming. This phase entails applying fiscal constraints to the objects produced in the planning phase and results in the production of the POM, which outlines the plan for the allocation of funding to programs (Candreva). The third part of the PPBE process in the budgeting phase. The goal of this phase is converting the information contained in the POM into the budget format required by Congress and Office of Management and Budget (OMB) (Candreva). The budget outlines what the money is for, why is it needed (justification), and the monetary amount. The budget represents a request for spending authority. The appropriations from Congress grant that authority and give the power to obligate funds from the U.S. Treasury to an objective (Candreva). After the Authorization and

Appropriations Bill has been signed, we can enter the execution phase, the fourth phase of the PPBE process (Candreva). Execution refers to the act of exercising the authority granted by the appropriation or the spending of the money (Candreva). The PPBE is an important part acquisition process. Without the "funding" piece, the DoD would not be able to acquire the new programs and systems that have been identified as a "need" through the JCIDS process.

Now that the two support systems, JCIDS and PPBE, have identified capability need and established program funding, we can turn to the DAS. The DAS is governed by the DoD's Instruction 5000 series, which provides policy and principles, as well as a foundation of management for the DAS. The DAS serves a five-phase framework for defense acquisition programs. It takes the capability need identified through the JCIDS process and develops it into a working system. The process follows the system from the program's conception, through its operational phase, and ends with its disposal. Figure 2 from the *DODI 5000.02* (DoD, 2015) shows the DAS process for a hardware-intensive product.

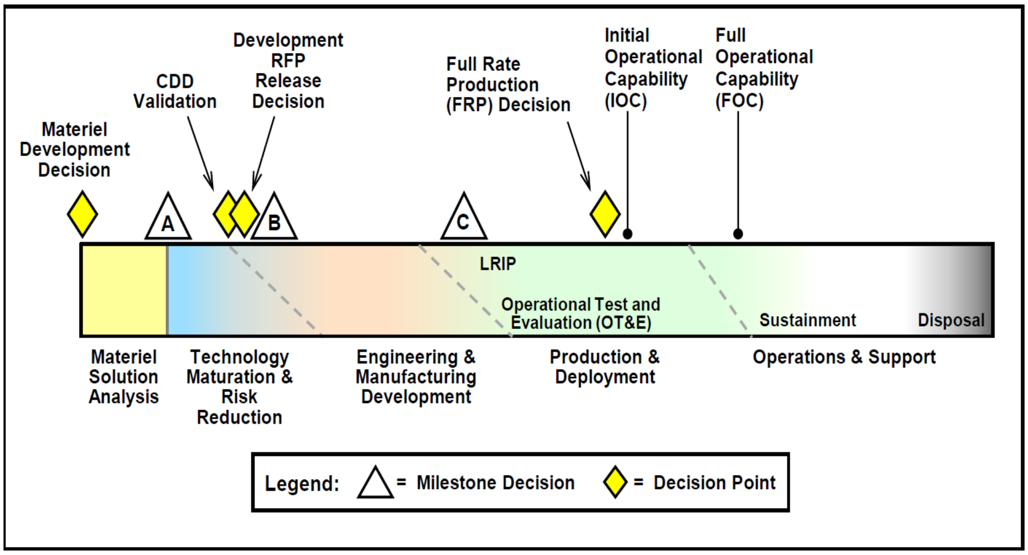


Figure 2. Hardware-Intensive DAS. *Source:* DoD (2017).

Material Solution Analysis (MSA) is the first phase of the DAS. *DODI 5000.02* describes the MSA's purpose as "conduct[ing] the analysis and other activities needed to choose the concept for the product that will be acquired, to begin translating validated capability gaps in system-specific requirements" (DoD, 2017, p.18). This phase takes the identified capability gaps and needs from the JCIDS process and translates them into the requirements for the desired acquisition. Then numerous technologies are analyzed and evaluated to determine which one best fulfills those needs and requirements (Ambrose, 2017b).

The second phase of the DAS is Technology Maturation and Risk Reduction (TMMR). The purpose of this phase, as defined by DAU, is "to reduce technology, engineering, integration, and life-cycle cost risk to the point that the decision to contract for Engineering and Manufacturing Development (EMD) can be made with confidence for the successful program execution of development, production, and sustainment" (DAU, n.d.-e). The goal of this phase is to reduce the risks associated with the product that will be developed (DoD, 2017).

Following the TMMR phase, the process enters the EMD phase of the DAS. The goal of this phase is to develop, build, and test a product in order to verify that all the operational and other requirements have been fulfilled (DoD, 2017). The hardware and software designed are being completed and prototypes are built during this phase. These prototypes will undergo a Developmental Test and Evaluation (DT&E) to verify that the capability requirements have been met (DoD, 2017). These results will support the decision to enter into the next phase.

Production and Development (P&D) is the fourth phase the DAS. The purpose of this phase is "to produce and deliver requirements-compliant products to receiving military organizations" (DoD, 2017, p. 30). In this phase, the product undergoes testing, including Operational Test & Evaluation (OT&E), to verify that the product meets the operational requirements before full production and deployment (DoD, 2017). After successful testing, the product can be produced and then fielded for use by operational forces. The phase also encompasses Low Rate Initial Production, Limited Deployment, Full-Rate Production Decision, and eventually full-rate production and deployment (DoD, 2017).

The last phase of the DAS is Operation and Support (O&S). Its purpose is to "execute the product support strategy, satisfy materiel readiness and operational support performance requirements, and sustain the system over its life cycle (to include disposal)" (DoD, 2017). The phase consists of two main stages, sustainment and disposal. Sustainment continues the full-rate production, deployment, and operational support of the product throughout its life (DoD, 2017). This phase also includes proper disposal at the end of the product's operational life, at which time it will be "demilitarized and disposed of in accordance with all legal and regulatory requirements" (DoD, 2017, p. 32). After a product's disposal the DAS is complete.

Cost Estimation in the Department of Defense

Cost estimation is an important and required tool used by decision makers in defense acquisitions. The requirement for a cost estimation is outlined in the *Department of Defense Instruction 5000.02, Operation of the Defense Acquisition System.* Specifically, the instruction mandates that the "DoD Component will develop a DoD Component Cost Estimate that covers the entire life cycle of the program for all Major Defense Acquisition Programs (MDAPs) prior to Milestone A, B, and C reviews and the Full-Rate Production Decision; and for all Major Automated Information System (MAIS) programs at any time an Economic Analysis is due" (DoD, 2017, p. 135). This means that before the acquisition process can move beyond the MSA, TMRR, and EMD phases and ultimately continue on to full production, a cost estimate encompassing the entire program life cycle must be produced. In addition to the DoD's Component Cost Estimate, a separate, independent cost estimate is also required. *DODI 5000.02* requires the Milestone Decision Authority to consider an "independent estimate of the full life-cycle cost of a program, prepared or approved by the Director of Cost Analysis and Program Evaluation (DCAPE)" (DoD, 2017, p. 135). The DoD Component and DCAPE cost estimates are typically classified as Life-Cycle Cost Estimations (LCCEs). Mislick and Nussbaum (2015) describe an LCCE as a "a cost estimate for the totality of the resources that will be necessary throughout the product's life cycle" (p. 18).

There are four main cost estimating techniques used in the DoD to develop an LCCE, and they can be used in different phases of a program's life cycle (Ambrose, 2017a). The first method is parametric cost estimating and involves the use of statistical inferences to generate an estimate based on system performance and design (Ambrose). Using historical data from similar systems, cost estimation relationships (CERs) and patterns are identified. Those patterns are assumed to hold true in the future and are used to predict cost (Mislick & Nussbaum, 2015). The second method is analogy cost estimating whereby a new system is compared to a similar existing system. The analogy method is a relatively quick and inexpensive method; however, it may not be as precise as other methods (Ambrose). The parametric and analogy methods are normally used early on in the acquisition process during the MSA, TMMR, and EMD phases (Ambrose). The third and most time-consuming method is engineering cost estimation. In this method the system is broken down into its WBS elements in which individual detail estimates are conducted. These estimates are then summed together to create the overall estimate (Mislick & Nussbaum). The engineering method is used during the TMRR phase and through the remaining acquisition process (Ambrose). The last main method used by the DoD is actual costing. This method uses the actual costs from a system that were incurred in the past to predict the cost of producing that system in the future (Ambrose). This method can be used after a program has entered the P&D Phase.

Total Ownership Cost

While LCCEs are a useful tool for decision makers, they present a narrower scope when a broader perspective may be more beneficial (Kobren, 2014). Thus, we introduce the concept of total ownership cost (TOC). The DAU defines TOC as including the "elements of life-cycle cost as well as other infrastructure or business process costs not normally attributed to the program" (Kobren). Infrastructures refers to "all military department and defense agency activities that sustain the military forces assigned to the combatant and component commanders" (Kobren). The major infrastructure categories are support to equipment, support to military personnel, and support to military bases (Kobren). Not normally included in a traditional LCCE, other support activities to consider in a cost estimate are recruiting, environmental and safety compliance, management headquarters functions, and logistics infrastructure activities (Kobren).

DoD Directive 5000.01 states that "DoD Components shall plan programs based on realistic projections of the dollars and manpower likely to be available in future years. To the greatest extent possible, the MDAs shall identify the total costs of ownership, and at a minimum, the major drivers of total ownership costs" (DoD, 2007). This requires the DoD to expand beyond the basic life-cycle cost estimation and include the support activities and infrastructure costs. To support the DoD directive, the Department of the Navy (DoN) issued its *Total Ownership Cost (TOC) Guidebook* in which it describes "new departmental and naval processes" that support the DoD policy of the identification of total costs of ownership (DoN, 2014, p. 6). Specifically, the guidebook assists the DoN and its organizations in developing, understanding, and applying the TOC requirements of the DoD.

The DoN outlines the importance of TOC: "As the DoD (and Navy) funding remains constant or declines, and as Navy's purchasing power declines as a result, increasing the decision weight priority for alternatives that can mitigate and reduce TOC becomes our clearest path to a capable an optimally affordable Fleet" (DoN, 2014, p. 8). For this reason, we focus on our model on TOC instead of a standard life-cycle cost.

Risk and Uncertainty

A key point that we need to understand in cost estimating is that the future is uncertain. Therefore, an essential pillar in developing a defensible and credible cost estimate is ensuring that risk and uncertainty are incorporated. A cost estimate can be severely affected by factors such as technological maturity, schedule slips, software requirements, or any other unforeseen event (Mislick & Nussbaum, 2015). Unknown factors make any "point estimate" or any exact answer extraordinarily unlikely (Mislick & Nussbaum). A more accurate estimate uses a central tendency centered on the original point estimate and a range both higher and lower to define the bounds of the estimate.

Though similar and related, risk and uncertainty are not synonymous. In the simplest terms, risk is the "probability" of the occurrence of a negative or unfavorable event, while uncertainty is the lack of certainty, or the realization that definitively knowing the outcome of any future event is completely impossible (Mislick & Nussbaum, 2015). Unlike risk, with uncertainty we are not able to predict the possibility of any future outcome. In Dr. Johnathan Mun's book, *Readings in Certified Quantitate Risk Management (CQRM),* he states "The concepts of risk and uncertainty are related but different. Uncertainty involves variables that are unknown and changing, but uncertainty will become known and resolved through the passage of time, events and action. Risk is something one bears and is the outcome of uncertainty. Sometimes risk may remain constant while uncertainty increases over time" (Mun, 2015, p. 28).

A good way to think about risk and uncertainty is to imagine going on a sky diving trip with a friend. As the plane takes off you and your friend realize that there is only one parachute and that parachute is looking like it is somewhat past its service life. Your friend, being slightly more adventurous than you, decides to grab the parachute and take the jump. Both you and your friend share the same level of uncertainty about whether the parachute will open, and if your friend will live to tell the story. However, only your friend will assume the risk of jumping out of the plane and falling to his death.

Though better than ignoring risk altogether, incorrect treatment of risk can significantly affect the estimate. Cost-estimating risk, schedule or technical risk, requirements risk, and threat risk are the four types of risk that will play a factor in the cost estimation for a life-cycle cost. Cost-estimating risk is the risk attributed to cost estimating error and uncertainty due to the numerical methodology used (Mislick & Nussbaum, 2015). Next, schedule or technical risk is the risk associated with the inability to accomplish schedule or technical objectives of the design or current specification, which stretches the timeline of the program completion (Mislick & Nussbaum). Requirements risk is the risk of the original requirements being shifted due to shortfalls in the original requirements documentation or due to the current design failing to complete the requirement. The final category, threat risk, is the risk of a new unforeseen threat due to a complete change in the original problem (Mislick & Nussbaum).

Even after a cost estimator does due diligence in looking at historical data, and normalizing data to build an analogy, parametric, engineering, or actual estimate, the multiple sources of uncertainty can still play a large factor in the estimate. Consider the figure below on the simplest way to take data and produce a cost estimate. Because cost estimators do not have a magic ball that they can use to tell the exact future, they must use assumptions.

Electro-Optical Infrared Sensors

Electro-optics (EO) are the field systems that convert electrons into photons (Driggers, Friedman & Nichols, 2012). These systems are designed to respond to wavelengths within the 0.4–.07 micrometer wavelength (Driggers et al.). These systems deliver images that are analogous to human vision; some EO systems are even capable of processing the near or short infrared spectral region (Driggers et al.). Figure 3 shows the basic components of an EO/IR sensor system.

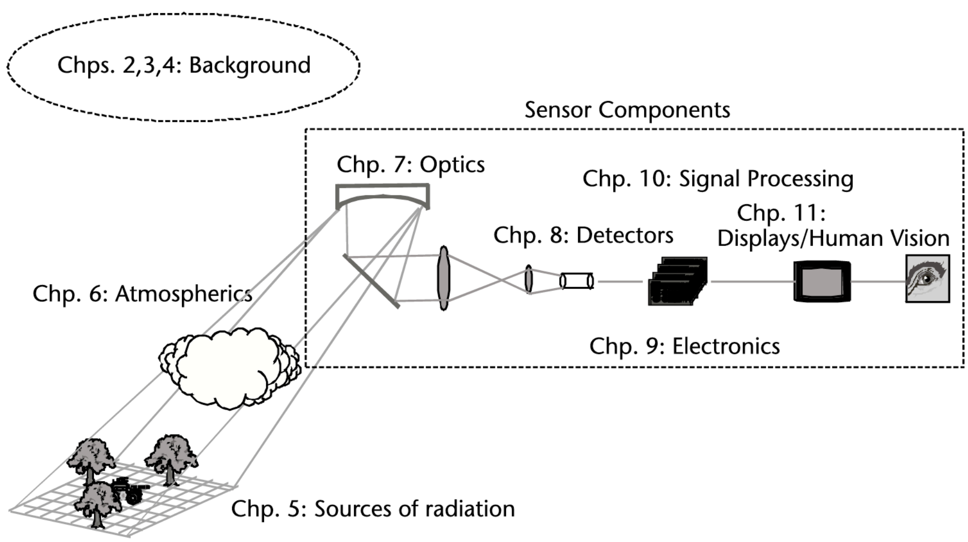


Figure 3. EO and IR Sensors. *Source:* Driggers et al. (2012).

The term "target" is used to describe the desired image that we are looking for with an EO sensor. The signal from a target usually has a large reflective component typically in the EO wavelength band. The target is provided this reflection component by moonlight, starlight, sunlight, or any artificial light source (Driggers et al.). The light sources reflecting off of the background and the target are known as external radiation. Radiation reflected by targets and background does not go directly to the EO sensor. The reflected radiation must first transition through the atmosphere, where it experiences scattering, before being processed by the EO sensor (Driggers et al.). Scattering is a phenomenon where particles in the atmosphere such as smoke, smog, or mist interfere with the reflection. Once the reflected radiation meets the EO sensor, it is passed through the sensing element, which could be detectors, tubes, or image intensifiers (low light situations) (Driggers et al.). Next, the output of the sensor element is digested by the electronics and sent to a human interface for the operator (human) to gather some information from the process. This information could take a myriad of shapes such as detection, recognition, or identification of targets such as a warship. In short, EO sensors are essentially products of the light reflected from the scene (Driggers et al.). Figure 4 represents a typical EO sensor scenario.

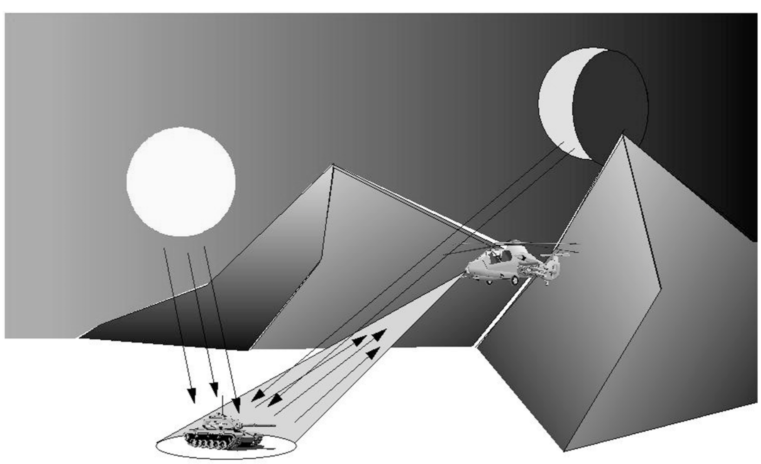


Figure 4. Typical EO Sensor Scenario. *Source:* Driggers et al. (2012).

Infrared is able to digest the spectral region from .7 to 14 micrometer wavelengths. Infrared is divided into four subregions The near-infrared (NIR) region is from 0.7 to 1.1 mm, the short-wave infrared (SWIR) region is from 1.1 to 3 mm, the midwave infrared (MWIR) region is from 3 to 5 mm, and the long-wave infrared (LWIR) region is from 8 to 14 mm. (direct Quote) Infrared is primarily used in night operations (Driggers et al., 2012). The science of infrared is based on the science supporting Planck's law, which states that all bodies above the temperature of absolute zero emit electromagnetic radiation. The electromagnetic radiation is exploited to uncover the electromagnetic signatures given off that do not correlate to the wavelengths visible by the human eye or EO sensors. "As the temperature of the object gets hotter, the peak wavelength moves to shorter wavelengths so that at very hot temperatures the radiation is perceived by the eye as light. The emissive surface characteristics of the hot object determine the spectral emission weighting of the radiation. The radiation emitted travels through the atmosphere, where it will then meet the aperture of the sensor" (Driggers et al., p. 7). Most IR sensors provide situational awareness for very low light situations such as night vision, surveillance of low-lit areas, and navigating through smoke-filled compartments (Driggers et al.). Figure 5 shows the basics of an infrared sensor scenario.

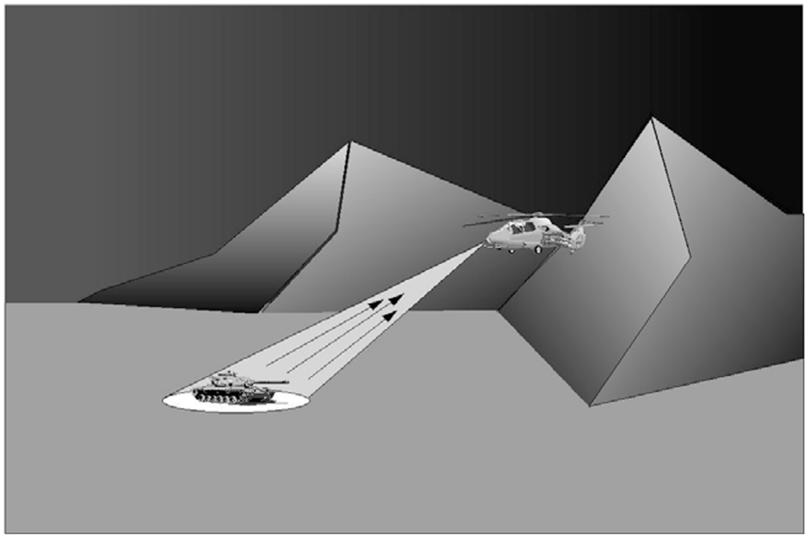


Figure 5. Typical IR Sensor Scenario. *Source:* Driggers et al. (2012).

The design of and EO and or IR imaging is very dependent on the purpose of the sensor, and the performance of the system is predicated on the functions of the wavelength (Driggers et al., 2012). Factors such as the characteristics of the scene and the atmosphere will determine the quality of the image obtained by the sensor. For EO sensors the largest factor is reflectivity, or how much of the external radiation from the scene is going to make it back to the sensor (Driggers et al.). For IR sensors the question is far more focused on the emissivity of the target or how much electromagnetic radiation is the target creating that will get back to the sensor (Driggers et al.).

EO/IR Sensors on Surface Ships

Before the advent of electro-optics, direct optics were a commander's main resource in support of tactical decision making. Binoculars, stadimeters, and periscopes were the keys to situational awareness and obtaining fire control solutions for torpedoes and gun engagements (Davidson, 2015). With the invention of EO, warfighters are no longer restricted to the limitations of the human eye. The application of using television cameras and the discovery of light-sensitive semiconductor materials allow images to be converted into electrical signals that are fed into displays for humans to process information. EO sensors paired with the ability of infrared detection allow warfighters to discern a target in the most vast and unlit environments (Davidson, 2015).

In Stefan Nitschke's (2007) article, New Generation Naval Electro Optics, he states, "Electro Optical/Infrared technology is an invaluable aid for the 21st century battlespace arena. It provides surface warships, submarines, and maritime aviation operating in the varying naval environment with extensive image gathering, navigational, and targeting capabilities " (p. 87). The constant advances in EO/IR systems have developed sensors with integral lasers that are used to measure distances with extreme accuracy and are a fraction of the size of the range finders of legacy ships (Davidson, 2015). In the report given by the Institute of Defense Analyses entitled "A Tutorial on Electro-Optical/Infrared (EO/IR) Theory and Systems," it is stated that "[t]he performance of an

EO/IR sensor depends on the optics, detector, display, target-background contrast and the intensity of the illumination source" (Koretsky, Nicoll & Taylor, 2013, p. 5)

Technological advances have emphasized the importance of the opportunity and the necessity to re-invest in the newest technologies and systems. These advances in technology will drive future EO/IR systems purchases by the DoD. These system acquisitions will require credible and reliable cost estimations to ensure the DoD manages its budget effectively. With the complexity and uniqueness of EO/IR systems, an efficient cost estimation model is needed to account for all life-cycle costs. The additional aspect of uncertainty should also be considered for in the estimation. The cost estimation model we are proposing takes into account total ownership costs and uncertainty for the acquisition of EO/IR systems for U.S. Navy surface ships. This model will serve as a proof of concept to help future DoD decision makers understand the cost associated with EO/IR systems so they can make strategic investments.

3. TOTAL OWNERSHIP COST MODEL OVERVIEW

In standard lifecycle-based TOC analysis, a basic set of assumptions includes that there are significant acquisition costs prior to the system being operational, usually denoted as Year 0, followed by subsequent operational years (e.g., Year 1 to Year 10 in Figure 1.1), where O&M costs apply. In the last year of operations, additional disposition or salvage costs may be incurred to either dispose of the system or render it inoperable (e.g., Year 10 in Figure 3.1). Furthermore, the total costs can be computed as a simple summation of all expenses incurred and to be incurred throughout the life cycle of the system. Conversely, applying economic theory, these costs can be *discounted* annually at some prespecified discount rate to account for the time value of money (i.e., a dollar tomorrow is not equivalent in purchasing power to a dollar today, due to various factors such as economic growth rates, purchasing power parity, inflation, and interest rates, as well as opportunity cost of holding money). Finally, the O&M costs may be themselves subject to changes over time (e.g., due to inflationary pressures, budgetary cutbacks, periodic technology insertions, cost inflation, and the like), and the model allows for such manual adjustments.

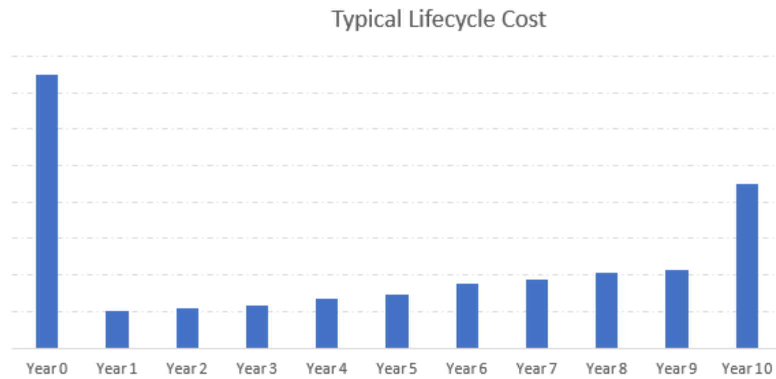


Figure 3.1 – Typical Lifecycle Cost Over Time

Before getting started, this manual assumes that the reader is somewhat familiar with the basics of Microsoft Excel and understands the rudiments of Risk Simulator for running Monte Carlo simulations to capture the future uncertainties of the cost structure. While this current chapter discusses the basics of the model, the next chapter covers the basic applications of Risk Simulator's Monte Carlo simulation techniques. Note that Risk Simulator does not have to be used in the model to obtain reasonable results. It is only used when uncertainty or risk analysis needs to be applied in the model, and when Monte Carlo simulations are applied to obtain the empirical probability distributions of the results.

The Excel model is divided into multiple worksheets. The first five worksheets are named System A to System E. These are five identical worksheets prepopulated with standard EO/IR generic cost structures (Figure 1.2). By default, each worksheet is delivered to NAVSEA as locked and protected to avoid any accidental tampering with the formulae. If needed, the user can unlock the worksheets by entering the following keyboard strokes: ALT+T, P, P and using the password ***nps*****.** The worksheet can be locked again with the same keystrokes.

Select Uncertainty Range: Use Small +/- 5% Range

Name: **System A** | *Discount Rate:* 3.00% | *Economic Life:* 20 Years

Notes:

Annual Growth or Decline Curve: 1.50%

Categories	Number of Units per System	Number of Platforms	Acquisition Cost (Unit)	%	Operational Costs (Unit) Per Year	%	Maintenance Per Year	%	Replacement Per Year	%	Total Acquisition Cost	%	Total Annual O&M	%
Grand Total			**$125.00**		**$125.00**		**$125.00**		**$125.00**		**$125.00**		**$375.00**	
Narrow-Medium Field of View (NFOV) Sensors	**17**	**17**	**$17.00**	**13.6%**	**$17.00**	**13.6%**	**$17.00**	**13.6%**	**$17.00**	**13.6%**	**$17.00**	**13.6%**	**$51.00**	**13.6%**
NF-DIR (NFOV Director)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-TIS (Thermal Imaging Sensor) - TIS #1	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-TIS (Thermal Imaging Sensor) - TIS #2	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-EOS (Electro-Optic Sensor) - EOS #1	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-EOS (Electro-Optic Sensor) - EOS #2	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-EOS (Electro-Optic Sensor) - EOS #3	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LRF (Laser Rangefinder)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LDR (Laser Designator/Rangefinder)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LDRFI (Laser Designator/Rangefinder/Illuminator)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LP (Laser Pointer)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LOI (Laser Optical/Ocular Interrupter)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-LI (Laser Illuminator)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-IRU (Inertial Reference Unit)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-BSM (Boresight Module)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
NF-EU (Electronics Unit)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
Ancillary Material (cabling, mounting hardware, etc.)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
Other: ___________	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
Wide Field of View (WFOV) Sensors	**7**	**7**	**$7.00**	**5.6%**	**$7.00**	**5.6%**	**$7.00**	**5.6%**	**$7.00**	**5.6%**	**$7.00**	**5.6%**	**$21.00**	**5.6%**
WF-DIR (Director)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%
WF-TIS (Thermal Imaging Sensor)	1	1	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$1.00	0.8%	$3.00	0.8%

Figure 3.2 – Input Worksheet

Unlocking the worksheets allows the user to make modifications to the equations and model, alter the model structure, and audit the model's calculations. However, for regular use, it is recommended that the worksheets remain locked to prevent insertions of any accidental and erroneous changes to the model.

Figure 3.2 illustrates the first two dozen rows of the model while Figures 3.3 and 3.4 show the last two dozen rows of the model. The following provides additional clarity and guidance to this worksheet:

- The Excel file has five worksheets (System A–E) where each worksheet is meant for a different system, or one of these can be set as the current or baseline system. If additional systems need to be included for analysis, we recommend creating a new file (simply perform a File | Save As to create a duplicate file).
- The figures in this document show a sample dataset where all unit and dollar inputs are set to 1 or $1, respectively. This was done intentionally to illustrate the location of data entry cells as well as to have some sample results to show how the model works. You can access the same results either by manually entering these unitary values or by opening the associated "TOC Model - Example Only (Repeated Data and Locked Sheets).xlsx" file to follow along.
- Row 1 is where you enter the name of the System. You can enter the system name in cell D1. Then, enter any discount rate value ≥ 0%. The discount rate is used to calculate the present value of all future cash flows. Use 0% if no present valuation

is needed, or enter the annualized cost of money (e.g., from 3% for inflationary adjustments only to 15% to account for risks and reinvestment opportunity costs of the cash flows). Also, here you can select the economic or operational life of this current system. These inputs can be unique for each of the five systems under analysis.

- Row 2 allows you to select the uncertainty range on which to perform risk-based Monte Carlo simulations. You can select to not run any simulations, a small ±5% range, standard ±10% to ±20% range, wide ±25% to ±40%, or a highly uncertain ±45% to ±50% range. These ranges will be automatically computed and applied as probability distributions on the inputted costs (see the following bullet points) in order to run simulations. There is also a section where you can enter notes about the system under analysis (cells D2:O2).

- Row 3 allows you to enter an annual positive growth rate or an annual negative decline rate to be applied to the O&M over time, starting in the second year. This allows the user to increment the O&M over time or perform a similar reduction in costs over the lifetime of the system.

- The data input grid starts from row 6 to row 187, around columns B to P. All *white colored cells with borders* are user input cells. You can also make modifications to subsection headers (e.g., rows 6, 24, etc.) and line item titles (e.g., cells B7:B23).

The subsections and line item titles are generic inputs and can be changed as required. There is also an "Other:" line item that can be used as required.

- Because the model has been structured to run simulations and other advanced analytics, it is highly recommended that the user does not make any structural adjustments and modifications (i.e., please do not delete worksheets or insert rows and columns unnecessarily). Also, the model has been optimized for printing and any major modifications will muddle the printing capabilities.

- The number of units per system and number of platforms (columns C and D) have to be ≥ 0 and are self-explanatory. The acquisition cost, operational cost, maintenance per year, and replacement per year are on a per unit basis. If you wish to enter the total replacement cost for the year, first take that value and divide it by the product of units with the number of platforms to obtain a per unit cost. Enter only per unit costs. Continue data entry until row 145.

- All grayed-out cells are computed values and should be left alone. If you wish to audit the calculations, first unlock/unprotect the worksheet and then select a cell to view its calculations.

- Area B147: D177 looks at nonrecurring costs to the acquisition process of this current system. All acquisition costs are summed and set as today's (Year 0) cost.

- Area B179:D187 looks at the nonrecurring end of life or disposition costs. These costs will be incurred at the end of the selected economic life (droplist circa cell

K2), and will be discounted appropriately based on the discount rate and term of life selected.

- Replicate the data entry above for up to five systems as required. If fewer than five systems are needed, simply ignore the unused worksheets but remember not to delete them unnecessarily. If more than five systems are required, create a copy of the file and apply these remaining systems as a separate file. Changing the structure of the file may invalidate some of the preset simulation models and assumptions.

	Nonrecurring Acquisition and End of Lifecycle Costs	Total	%
147	**Nonrecurring Acquisition and End of Lifecycle Costs**	**Total**	**%**
148	**Acquisition and Procurement**	**$29.00**	
149	Bid Specifications Development	$1.00	3.4%
150	Proposal Evaluation	$1.00	3.4%
151	Data Collection	$1.00	3.4%
152	Data Analysis	$1.00	3.4%
153	Contracts Development	$1.00	3.4%
154	Program Planning	$1.00	3.4%
155	Hardware Purchases	$1.00	3.4%
156	*Personal Computers*	$1.00	3.4%
157	*Peripherals*	$1.00	3.4%
158	*Storage*	$1.00	3.4%
159	*Networking*	$1.00	3.4%
160	*Related Equipment*	$1.00	3.4%
161	Other costs	$1.00	3.4%
162	Administrative Cost	$1.00	3.4%
163	Asset Management	$1.00	3.4%
164	Overseeing Contractor Services	$1.00	3.4%
165	In-House Training for Staff	$1.00	3.4%
166	Product Maintenance	$1.00	3.4%
167	Help Desk Support	$1.00	3.4%
168	IT Support for Database Management	$1.00	3.4%
169	Network Management Support	$1.00	3.4%
170	Software Upgrades	$1.00	3.4%

Analysis Notes

Analysis Assumptions

Figure 3.3 – Input Worksheet (Nonrecurring Acquisition Cost)

	A	B	C	D
179		**Nonrecurring End of Lifecycle Costs**	**Total**	**%**
180		**End of Lifecycle**	**$7.00**	
181		Administrative Cost	$1.00	14.3%
182		Asset Management	$1.00	14.3%
183		Vendor Contract Procurement	$1.00	14.3%
184		Staging, Sanitizing, Testing	$1.00	14.3%
185		Follow-Up Support	$1.00	14.3%
186		Recycling and Disposal Fees	$1.00	14.3%
187		Value of Sold Products and Materials	$1.00	14.3%

Figure 3.4 – Input Worksheet (Nonrecurring End of Life Cycle Cost)

Figure 3.5 illustrates the Monte Carlo simulations section. This section is preset and should not be modified unless the user is adequately trained in using Risk Simulator. This table summarizes the sections of the costs and created simulation variables (cells in green). Figure 3.6 shows how these simulated results will be used to generate the life cycle of the cost structure of the system, where the economic life of the system is accounted for, as well as any required discounting to generate the present value of the costs. If the user wishes to run a simulation using Risk Simulator, we recommend first coming to this section and then hitting **Run**. This way, the user can see the actual simulation executing and how the cells in green change (Figure 3.5), as well as how the subsequent calculations will simulate and change (Figure 3.6).

Note that, by default, 10,000 simulation trials have been set because triangular probability distributions were applied on each of the subtotaled cost items, and the process is modeled to run without any predetermined seed values.

Risk-Based Monte Carlo Simulation on Uncertainty Ranges

	Acquisition Cost (Low)	Acquisition Cost (Mid)	Acquisition Cost (High)	Simulation	Operations and Maintenance with Replacement Costs (Low) Per Year	Operations and Maintenance with Replacement Costs (Mid) Per Year	Operations and Maintenance with Replacement Costs (High) Per Year	Simulation
Narrow-Medium Field of View (NFOV) Sensors	$16.15	$17.00	$17.85	$17.00	$48.45	$51.00	$53.55	$51.00
Wide Field of View (WFOV) Sensors	$6.65	$7.00	$7.35	$7.00	$19.95	$21.00	$22.05	$21.00
EO/IR Sensor Manager (ESM)	$5.70	$6.00	$6.30	$6.00	$17.10	$18.00	$18.90	$18.00
Human Machine Interface (HMI)	$4.75	$5.00	$5.25	$5.00	$14.25	$15.00	$15.75	$15.00
Product Support Management	$8.55	$9.00	$9.45	$9.00	$25.65	$27.00	$28.35	$27.00
Design Interface	$10.45	$11.00	$11.55	$11.00	$31.35	$33.00	$34.65	$33.00
Supply Support	$11.40	$12.00	$12.60	$12.00	$34.20	$36.00	$37.80	$36.00
Support Equipment	$7.60	$8.00	$8.40	$8.00	$22.80	$24.00	$25.20	$24.00
Packaging, Handling, Storage and Transportation	$3.80	$4.00	$4.20	$4.00	$11.40	$12.00	$12.60	$12.00
Computer Resources	$5.70	$6.00	$6.30	$6.00	$17.10	$18.00	$18.90	$18.00
Manpower and Personnel	$5.70	$6.00	$6.30	$6.00	$17.10	$18.00	$18.90	$18.00
Maintenance Planning and Management	$14.25	$15.00	$15.75	$15.00	$42.75	$45.00	$47.25	$45.00
Training and Training Support	$7.60	$8.00	$8.40	$8.00	$22.80	$24.00	$25.20	$24.00
Facilities and Infrastructure	$3.80	$4.00	$4.20	$4.00	$11.40	$12.00	$12.60	$12.00
Technical Data Management	$6.65	$7.00	$7.35	$7.00	$19.95	$21.00	$22.05	$21.00
Acquisition Costs	$27.55	$29.00	$30.45	$29.00				
End of Life Disposition Costs	$6.65	$7.00	$7.35	$7.00				

Figure 3.5 – Monte Carlo Uncertainty Simulation

	Q	R	S	T	U	V	W	X	Y	Z	AA
25		**Year**	**Acquisition**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
26		**Cash Flow**	$154.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	
27		**Present Value of Cash Flow**	$154.00	$364.08	$358.78	$353.55	$348.40	$343.33	$338.33	$333.40	
28		**Year**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
29		**Cash Flow**	$416.19	$422.43	$428.77	$435.20	$441.73	$448.36	$455.08	$461.91	
30			$328.55	$323.76	$319.05	$314.40	$309.82	$305.31	$300.86	$296.48	
31		**Year**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	
32		**Cash Flow**	$468.84	$475.87	$483.01	$490.25	$497.61	$505.07	$512.65	$520.34	
33			$292.16	$287.91	$283.72	$279.58	$275.51	$271.50	$267.55	$263.65	
34		**Year**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**Disposition**	
35		**Cash Flow**	$528.14	$536.06	$544.10	$552.27	$560.55	$568.96	$577.49	$7.00	
36			$259.81	$256.03	$252.30	$248.62	$245.00	$241.44	$237.92	$7.00	
37		**Total Acquisition Cost for System A**	$154.00								
38			5 Years	10 Years	15 Years	20 Years	25 Years	30 Years			
39		**List of Total Lifetime Cost for System A**	$2,093.10	$4,174.52	$6,416.80	$8,832.38	$11,434.63	$14,238.01			
40		**List of Present Value Lifetime Cost for System A**	$1,928.17	$3,570.42	$5,096.58	$6,514.85	$7,832.85	$9,057.68			
41											
42		**Total Lifetime Cost for System A (20 Years)**	$8,832.38	20 Years							
43		**Total PV Lifetime Cost for System A (20 Years)**	$6,514.85								

Figure 3.6 – Lifecycle Cost Cash Flow Calculations

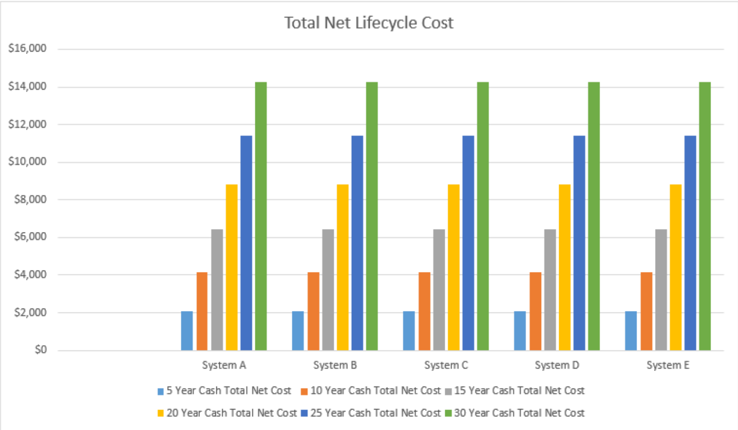
In the Summary worksheet, the total costs as well as present values of total costs for various economic and useful lives are tabulated (Figure 3.7). You can view the results as tables and charts. Here, a comparative cross-sectional **analysis of alternatives** assessment can be seen, and a growth of the costs can be seen in the charts. Note that these results and charts are single-point estimates and are calculated prior to any simulations.

If a simulation is run, the resulting charts in Figure 1.8 will be automatically generated. For more information, see Chapter 2 for instructions on setting up and running simulations and interpreting the basic results, as well as using some basic decision analytics tools. Note that this manual provides only the most basic information needed. If detailed understanding is required, please see Dr. Johnathan Mun's more than two dozen books (*Modeling Risk,* Third Edition, 2016, is particularly recommended).

The model has predetermined simulation settings created and as such, the user can simply click on the *Run Simulation* icon in Risk Simulator to execute the run. Running the simulation will make changes to the cells in Figures 1.5 and 1.6 as previously discussed. If the other worksheets have populated inputs, these worksheets will also be run, and the results will be presented as probability distributions (Figure 1.8). Each system's calculated Total Cost and the Present Value of Total Costs will be shown (for the selected economic and useful life) as probability distributions and simulation statistics. Users can also perform comparative analysis by using Overlay Charts (bottom of Figure 1.8), generate reports of the statistical results (Figure 1.9), and run detailed reports of the analysis (Figure 1.10), as well as other analytics such as scenario analysis and sensitivity analysis.

Analysis Period/Type	System A	System B	System C	System D	System E
5 Year Cash Total Net Cost	$2,093.10	$2,093.10	$2,093.10	$2,093.10	$2,093.10
10 Year Cash Total Net Cost	$4,174.52	$4,174.52	$4,174.52	$4,174.52	$4,174.52
15 Year Cash Total Net Cost	$6,416.80	$6,416.80	$6,416.80	$6,416.80	$6,416.80
20 Year Cash Total Net Cost	$8,832.38	$8,832.38	$8,832.38	$8,832.38	$8,832.38
25 Year Cash Total Net Cost	$11,434.63	$11,434.63	$11,434.63	$11,434.63	$11,434.63
30 Year Cash Total Net Cost	$14,238.01	$14,238.01	$14,238.01	$14,238.01	$14,238.01

Analysis Period/Type	System A	System B	System C	System D	System E
5 Year Cash Cost in Present Values	$1,928.17	$1,928.17	$1,928.17	$1,928.17	$1,928.17
10 Year Cash Cost in Present Values	$3,570.42	$3,570.42	$3,570.42	$3,570.42	$3,570.42
15 Year Cash Cost in Present Values	$5,096.58	$5,096.58	$5,096.58	$5,096.58	$5,096.58
20 Year Cash Cost in Present Values	$6,514.85	$6,514.85	$6,514.85	$6,514.85	$6,514.85
25 Year Cash Cost in Present Values	$7,832.85	$7,832.85	$7,832.85	$7,832.85	$7,832.85
30 Year Cash Cost in Present Values	$9,057.68	$9,057.68	$9,057.68	$9,057.68	$9,057.68



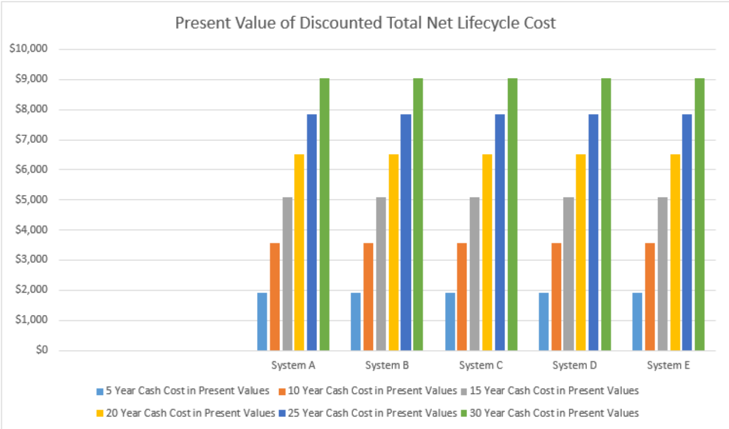


Figure 3.7 – Lifecycle Cost Cash Flow Results and Dashboard

If a simulation is run, the resulting charts in Figure 3.8 will be automatically generated. For more information, see Chapter 2 for instructions on setting up and running simulations and interpreting the basic results, as well as using some basic decision analytics tools. Note that this manual provides only the most basic information needed. If detailed understanding is required, please see Dr. Johnathan Mun's more than two dozen books (*Modeling Risk,* Third Edition, 2016, is particularly recommended).

The model has predetermined simulation settings created and as such, the user can simply click on the *Run Simulation* icon in Risk Simulator to execute the run. Running the simulation will make changes to the cells in Figures 3.5 and 3.6 as previously discussed. If the other worksheets have populated inputs, these worksheets will also be run, and the results will be presented as probability distributions (Figure 3.8). Each system's calculated Total Cost and the Present Value of Total Costs will be shown (for the selected economic and useful life) as probability distributions and simulation statistics. Users can also perform comparative analysis by using Overlay Charts (bottom of Figure 1.8), generate reports of the statistical results (Figure 3.9), and run detailed reports of the analysis (Figure 3.10), as well as other analytics such as scenario analysis and sensitivity analysis (see Chapter 2).

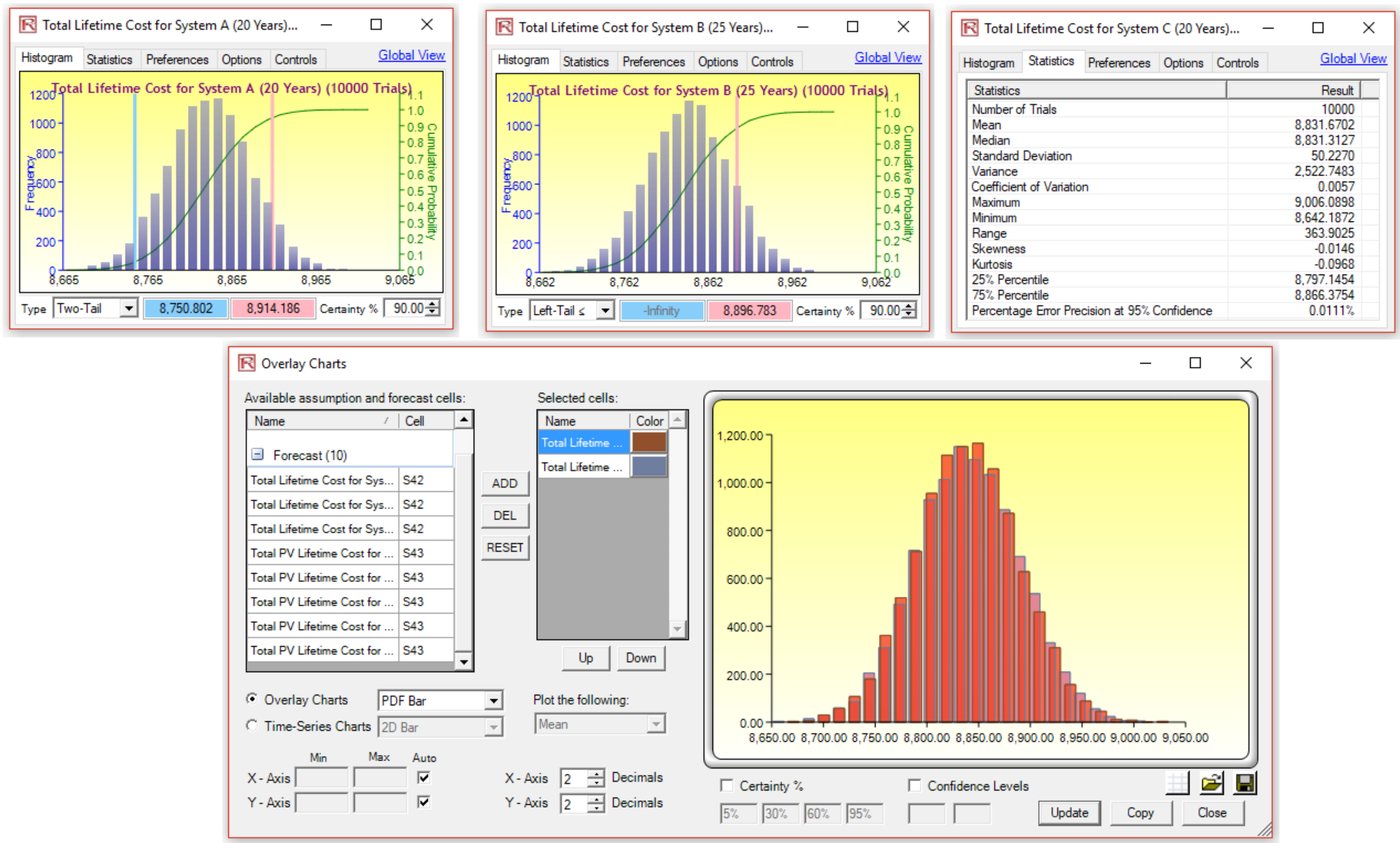


Figure 3.8 – Example Simulation Results

Forecast Statistics Table - TOC Model

Cell	Total Lifetime Cost for System A (20 Years)	Total Lifetime Cost for System B (25 Years)	Total Lifetime Cost for System C (20 Years)	Total Lifetime Cost for System D (10 Years)	Total Lifetime Cost for System E (15 Years)	Total PV Lifetime Cost for System A (20 Years)	Total PV Lifetime Cost for System B (25 Years)	Total PV Lifetime Cost for System C (20 Years)	Total PV Lifetime Cost for System D (10 Years)	Total PV Lifetime Cost for System E (15 Years)
Name	S42	S42	S42	S42	S42	S43	S43	S43	S43	S43
Number of Datapoints	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Mean	$8,831.96	$8,832.11	$8,831.67	$8,832.22	$8,833.20	$6,514.55	$6,514.66	$6,514.34	$6,514.74	$6,515.45
Median	$8,832.09	$8,832.36	$8,831.31	$8,832.68	$8,833.84	$6,514.71	$6,514.79	$6,514.06	$6,515.10	$6,515.92
Standard Deviation	$49.60	$49.78	$50.23	$49.66	$50.31	$36.37	$36.49	$36.83	$36.41	$36.89
Variance	2460.2390	2477.5659	2522.7483	2465.9911	2531.3819	1322.4143	1331.8844	1356.4244	1325.8729	1360.8216
Coefficient of Variation	0.56%	0.56%	0.57%	0.56%	0.57%	0.56%	0.56%	0.57%	0.56%	0.57%
Maximum	$9,027.86	$9,011.75	$9,006.09	$9,009.43	$9,003.96	$6,658.10	$6,646.07	$6,642.13	$6,644.26	$6,640.59
Minimum	$8,655.82	$8,652.68	$8,642.19	$8,660.92	$8,665.34	$6,385.77	$6,382.97	$6,375.27	$6,389.07	$6,392.70
Range	$372.04	$359.07	$363.90	$348.51	$338.63	$272.33	$263.11	$266.86	$255.19	$247.90
Skewness	0.0074	-0.0160	-0.0146	-0.0251	-0.0198	0.0077	-0.0158	-0.0150	-0.0256	-0.0202
Kurtosis	-0.0662	-0.0987	-0.0968	-0.0796	-0.0914	-0.0653	-0.0993	-0.0963	-0.0786	-0.0916
25% Percentile	$8,798.40	$8,798.34	$8,797.15	$8,799.02	$8,798.81	$6,489.99	$6,489.93	$6,488.95	$6,490.41	$6,490.24
75% Percentile	$8,865.49	$8,865.74	$8,866.38	$8,865.77	$8,866.89	$6,539.05	$6,539.33	$6,539.87	$6,539.27	$6,540.17
Error Precision at 95%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
5% Percentile	$8,750.80	$8,749.88	$8,748.87	$8,750.02	$8,750.08	$6,455.09	$6,454.33	$6,453.63	$6,454.58	$6,454.45
10% Percentile	$8,768.11	$8,768.33	$8,767.45	$8,767.78	$8,767.83	$6,467.70	$6,467.94	$6,467.36	$6,467.41	$6,467.44
20% Percentile	$8,790.18	$8,789.76	$8,788.77	$8,790.54	$8,790.56	$6,483.91	$6,483.59	$6,482.92	$6,484.17	$6,484.13
30% Percentile	$8,805.71	$8,805.99	$8,804.53	$8,806.06	$8,806.62	$6,495.32	$6,495.49	$6,494.57	$6,495.54	$6,496.10
40% Percentile	$8,818.82	$8,819.88	$8,818.79	$8,819.62	$8,820.54	$6,504.97	$6,505.68	$6,504.87	$6,505.48	$6,506.12
50% Percentile	$8,832.09	$8,832.36	$8,831.31	$8,832.68	$8,833.84	$6,514.71	$6,514.79	$6,514.06	$6,515.10	$6,515.92
60% Percentile	$8,844.69	$8,844.76	$8,844.26	$8,845.26	$8,846.54	$6,523.91	$6,523.96	$6,523.52	$6,524.33	$6,525.27
70% Percentile	$8,858.16	$8,857.91	$8,858.11	$8,858.30	$8,859.69	$6,533.76	$6,533.60	$6,533.74	$6,533.85	$6,534.87
80% Percentile	$8,873.26	$8,874.27	$8,874.71	$8,874.33	$8,875.39	$6,544.78	$6,545.59	$6,545.98	$6,545.52	$6,546.35
90% Percentile	$8,896.26	$8,896.78	$8,896.86	$8,895.78	$8,897.90	$6,561.77	$6,562.09	$6,562.10	$6,561.33	$6,562.91
95% Percentile	$8,914.19	$8,914.12	$8,913.73	$8,914.62	$8,916.08	$6,574.83	$6,574.91	$6,574.50	$6,575.13	$6,576.09
99% Percentile	$8,946.27	$8,945.13	$8,946.00	$8,946.14	$8,950.41	$6,598.43	$6,597.55	$6,598.03	$6,598.03	$6,601.18

Figure 3.9 – Example Simulation Statistics Tables (Only Sample Basic Results Shown)

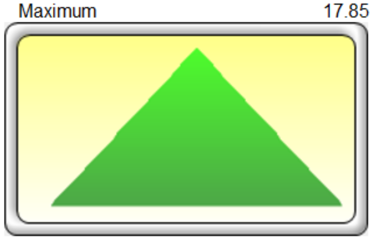
Simulation - TOC Model

General

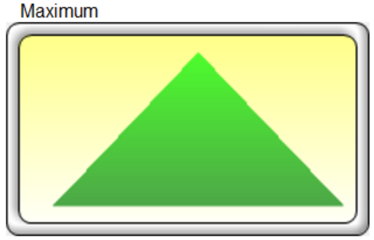
Number of Trials	10000
Stop Simulation on Error	No
Random Seed	Random
Enable Correlations	Yes

Assumptions

Name	**Field of View (NFOV) Sensors**
Enabled	Yes
Cell	V6
Dynamic Simulation	No
Range	
Minimum	-Infinity
Maximum	Infinity
Distribution	Triangular
Minimum	16.15
Most Likely	17
Maximum	17.85



Name	**Wide Field of View (WFOV) Sensors**
Enabled	Yes
Cell	V7
Dynamic Simulation	No
Range	
Minimum	-Infinity
Maximum	Infinity
Distribution	Triangular
Minimum	6.65
Most Likely	7
Maximum	7.35



Name	**O/IR Sensor Manager (ESM)**
Enabled	Yes
Cell	V8
Dynamic Simulation	No
Range	
Minimum	-Infinity
Maximum	Infinity
Distribution	Triangular
Minimum	5.7
Most Likely	6
Maximum	6.3

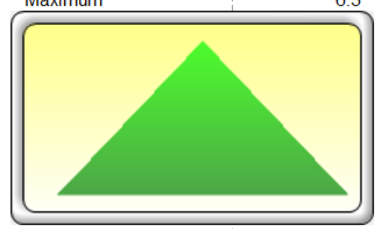


Figure 3.10 – Example Simulation Report

Finally, in the Summary worksheet, users have the option to make adjustments to the cost cash flow series by making ± $ adjustments in the empty cells with borders (Figure 3.11). This capability allows for any known factors such as technology insertion to be applied every few years, foreseen major structural modifications, or any other such adjustments. The cash flows will be adjusted accordingly in this worksheet. Note that as of the current version, simulations will not be applied to any such modifications, only single-point results.

If there are any requests for changes or modifications, enhancements, and updates, please feel free to contact the author at the Naval Postgraduate School (jcmun@nps.edu or johnathanmun@cs.com).

	C	D	E	F	G	H	I	J	K	L	M	N	O	P
37		Acquisition	Disposition	1	2	3	4	5	6	7	8	9	10	11
38	Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
39	Manual Adjustment													
40	Net Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
41	PV Cash Flows	$154.00		$364.08	$358.78	$353.55	$348.40	$343.33	$338.33	$333.40	$328.55	$323.76	$319.05	$314.40
42														
43														
44	System B	Discount Rate	3.00%											
45		Acquisition	Disposition	1	2	3	4	5	6	7	8	9	10	11
46	Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
47	Manual Adjustment													
48	Net Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
49	PV Cash Flows	$154.00		$364.08	$358.78	$353.55	$348.40	$343.33	$338.33	$333.40	$328.55	$323.76	$319.05	$314.40
50														
51														
52	System C	Discount Rate	3.00%											
53		Acquisition	Disposition	1	2	3	4	5	6	7	8	9	10	11
54	Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
55	Manual Adjustment													
56	Net Cash Flow	$154.00	$7.00	$375.00	$380.63	$386.33	$392.13	$398.01	$403.98	$410.04	$416.19	$422.43	$428.77	$435.20
57	PV Cash Flows	$154.00		$364.08	$358.78	$353.55	$348.40	$343.33	$338.33	$333.40	$328.55	$323.76	$319.05	$314.40

Figure 1.11 – Manual Adjustments to Lifecycle Cost Cash Flow

APPENDIX: MONTE CARLO RISK SIMULATION

Monte Carlo risk simulation, named for the famous gambling capital of Monaco, is a very potent methodology. For the practitioner, simulation opens the door for solving difficult and complex but practical problems with great ease. Monte Carlo simulation creates artificial futures by generating thousands and even millions of sample paths of outcomes and looks at their prevalent characteristics. For analysts in a company, taking graduate-level advanced math courses is just not logical or practical. A brilliant analyst would use all available tools at his or her disposal to obtain the same answer the easiest and most practical way possible. And in all cases, when modeled correctly, Monte Carlo simulation provides similar answers to the more mathematically elegant methods. So, what is Monte Carlo simulation and how does it work?

What Is Monte Carlo Simulation?

Monte Carlo simulation in its simplest form is a random number generator that is useful for forecasting, estimation, and risk analysis. A simulation calculates numerous scenarios of a model by repeatedly picking values from a user-predefined probability distribution for the uncertain variables and using those values for the model. As all those scenarios produce associated results in a model, each scenario can have a forecast.

Forecasts are events (usually with formulas or functions) that you define as important outputs of the model. These usually are events such as totals, net profit, or gross expenses.

Simplistically, think of the Monte Carlo simulation approach as repeatedly picking golf balls out of a large basket with replacement. The size and shape of the basket depend on the distributional input assumption (e.g., a normal distribution with a mean of 100 and a standard deviation of 10, versus a uniform distribution or a triangular distribution) where some baskets are deeper or more symmetrical than others, allowing certain balls to be pulled out more frequently than others. The number of balls pulled repeatedly depends on the number of trials simulated. For a large model with multiple related assumptions, imagine a very large basket wherein many smaller baskets reside. Each small basket has its own set of golf balls that are bouncing around. Sometimes these small baskets are linked with each other (if there is a correlation between the variables) and the golf balls are bouncing in tandem, while other times the balls are bouncing independently of one another. The balls that are picked each time from these interactions within the model (the large central basket) are tabulated and recorded, providing a forecast output result of the simulation.

Risk Simulator Software Installation Requirements and Procedures

The Risk Simulator software has the following modules:

- Monte Carlo Simulation (runs parametric and nonparametric simulation of 45 probability distributions with different simulation profiles, truncated and correlated simulations, customizable distributions, precision and error-controlled simulations, and many other algorithms)
- Forecasting (runs Box–Jenkins ARIMA, combinatorial fuzzy logic, cubic spline, GARCH, multiple regression, neural network, nonlinear extrapolation, stochastic processes, time-series analysis, and others)
- Optimization Under Uncertainty (runs optimizations using discrete integer and continuous variables for portfolio and project optimization with and without simulation)
- Modeling and Analytical Tools (runs tornado, spider, and sensitivity analysis, as well as bootstrap simulation, hypothesis testing, distributional fitting, probability distribution analysis and charts, etc.)
- ROV BizStats (over 130 business statistics and analytical models)
- ROV Decision Tree (decision tree models, Monte Carlo risk simulation on decision trees, sensitivity analysis, scenario analysis, Bayesian joint and posterior probability updating, expected value of information, MINIMAX, MAXIMIN, risk profiles)

To install the software, follow the on-screen instructions. The minimum requirements for this software are:

- Pentium IV processor or later (dual core recommended)
- Windows XP, Vista, Windows 7, Windows 8, Windows 10, or later
- Microsoft Excel 2010, 2013, 2016, or later
- Microsoft .NET Framework 2.0
- 800 MB free space
- 2GB RAM minimum (4GB recommended)
- Administrative rights to install software
- Please note that this software is *not* NMCI, which means the computer on which the software will be installed will need to be either a personal computer or one with a developer seat.

Most new computers come with Microsoft .NET Framework 2.0/3.0 already installed. However, if an error message pertaining to requiring .NET Framework occurs during the installation of Risk Simulator, exit the installation. Then, install the relevant .NET Framework software included on the ROV website. Complete the .NET installation, restart the computer, and then reinstall the Risk Simulator software.

Licensing

There is a default 15-day trial license file that comes with the software. Within this trial period, please e-mail your Hardware ID to ROV, Inc.as noted below so a permanent license file can be generated for you. The project comes with **two** permanent licenses. Follow the instructions below:

- Start Excel 2013/2016 and locate the Risk Simulator icon ribbon inside Excel. Click on the License icon or *Risk Simulator | License* and copy and e-mail your 11 to 20 digit and alphanumeric HARDWARE ID that starts with the prefix "RS2018-" (you can also select the Hardware ID and do a right-click copy or click on the e-mail Hardware ID link) to *admin@realoptionsvaluation.com*. Once we have obtained this ID, a newly generated permanent license will be e-mailed to you. When your license file arrives, simply save it to your hard drive (if it is a zipped file, first unzip its contents and save them to your hard drive). Start Excel, click *on Risk Simulator | License* or click on the License icon, then click on Install License and point to this new license file. Restart Excel and you are done. The entire process will take less than a minute and you will be fully licensed.
- Once installation is complete, start Microsoft Excel and if the installation was successful, you should see an additional "Risk Simulator" item on the menu bar in Excel 2013/2016, and a new icon bar on Excel as seen in Figure A.1. In addition, a splash screen will appear as seen in Figure A.2, indicating that the software is functioning and loaded into Excel. Figure A.3 also shows the Risk Simulator toolbar. If these items exist in Excel, you are now ready to start using the software.

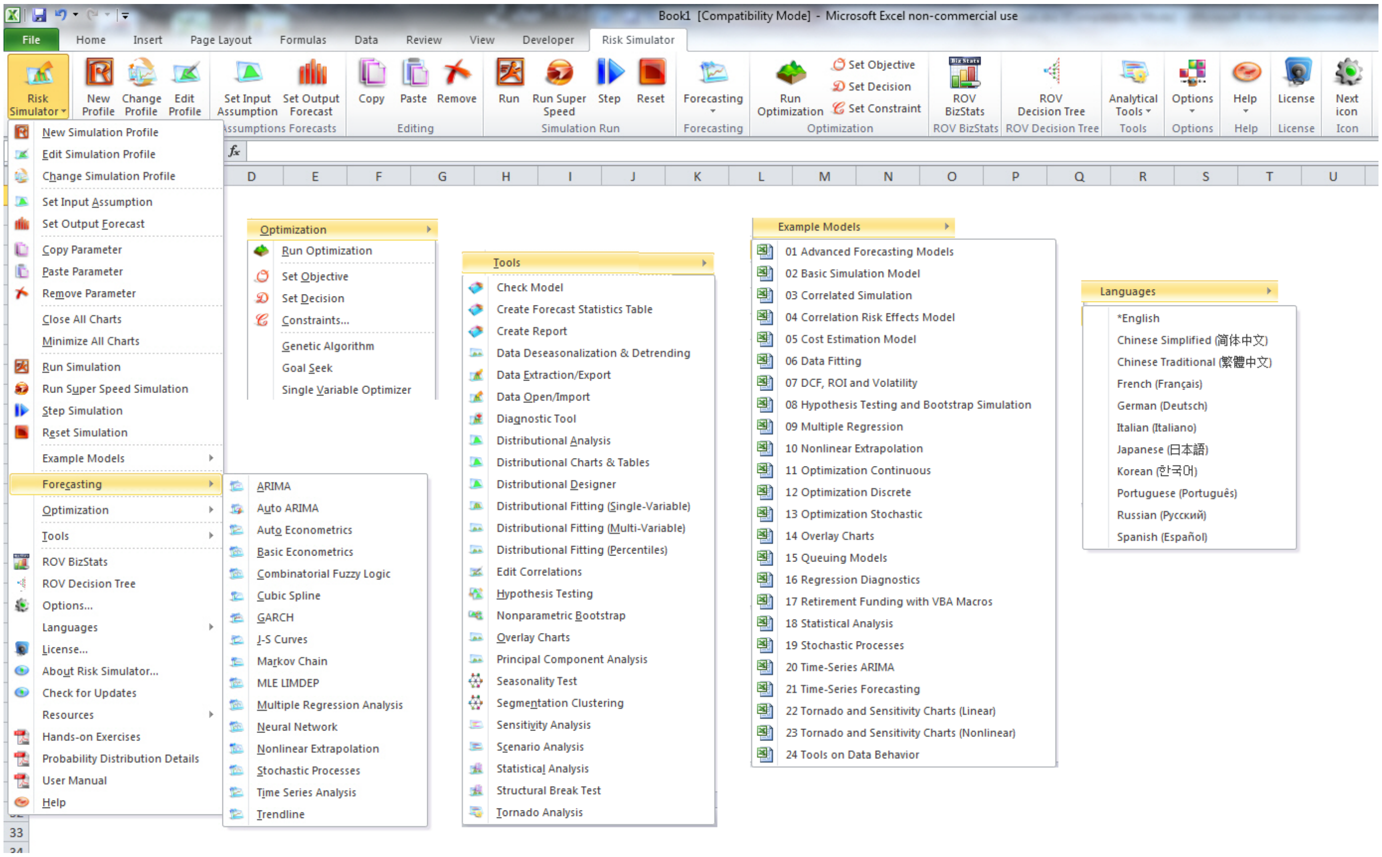


Figure A.1 – Risk Simulator Menu and Icon Bar in Excel 2013/2016

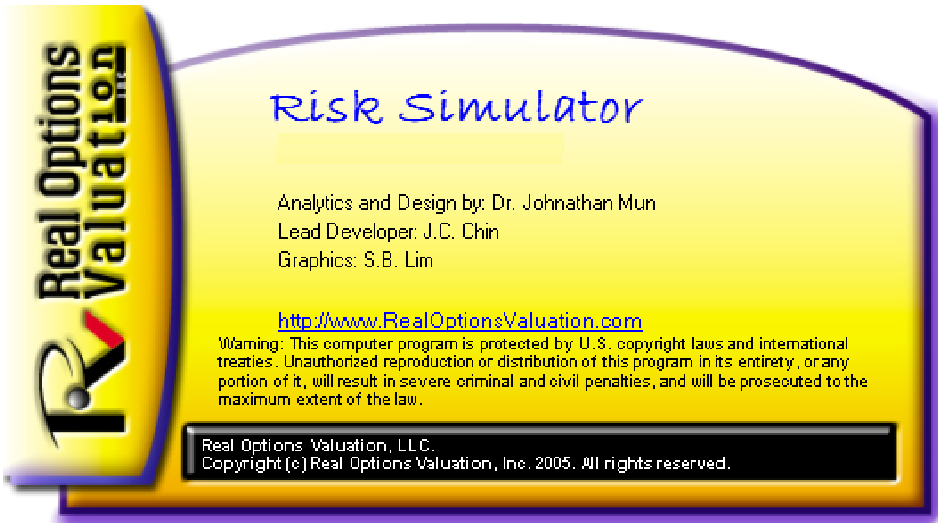


Figure A.2 – Risk Simulator Splash Screen

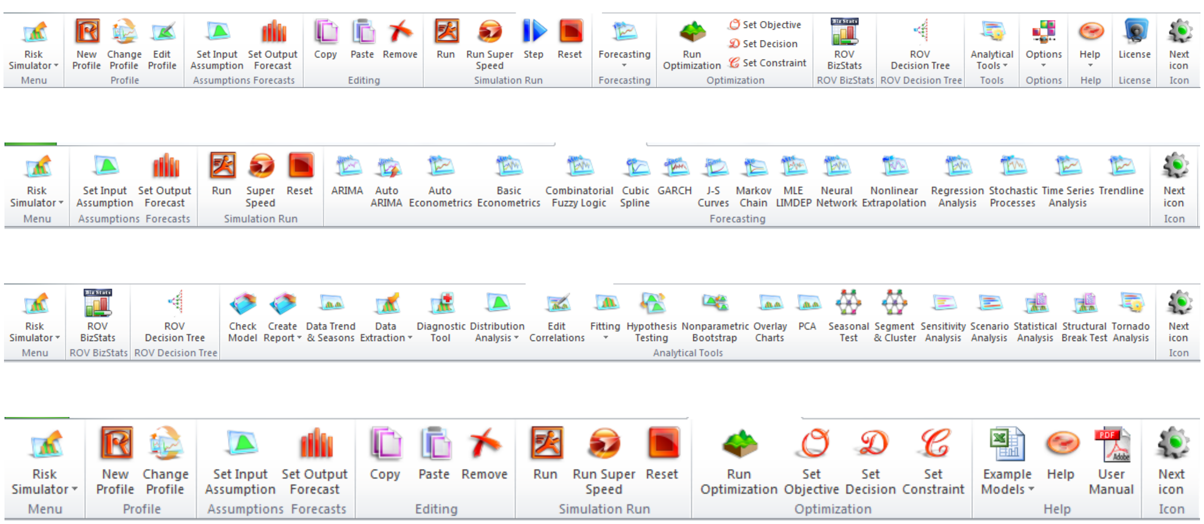


Figure A.3 – Risk Simulator Icon Toolbars in Excel 2013/2016

Getting Started with Risk Simulator

A High-Level Overview of the Software

The Risk Simulator software has several different applications including Monte Carlo simulation, forecasting, optimization, and risk analytics.

- The Simulation Module allows you to run simulations in your existing Excel-based models, generate and extract simulation forecasts (distributions of results), perform distributional fitting (automatically finding the best-fitting statistical distribution), compute correlations (maintain relationships among simulated random variables), identify sensitivities (creating tornado and sensitivity charts), test statistical hypotheses (finding statistical differences between pairs of forecasts), run bootstrap simulation (testing the robustness of result statistics), and run custom and nonparametric simulations (simulations using historical data without specifying any distributions or their parameters for forecasting without data or applying expert opinion forecasts).
- The Forecasting Module can be used to generate automatic time-series forecasts (with and without seasonality and trend), multivariate regressions (modeling relationships among variables), nonlinear extrapolations (curve fitting), stochastic processes (random walks, mean-reversions, jump-diffusion, and mixed processes), Box–Jenkins ARIMA (econometric forecasts), Auto ARIMA, basic econometrics and auto econometrics (modeling relationships and generating forecasts), exponential J curves, logistic S curves, GARCH models and their multiple variations (modeling and forecasting volatility), maximum likelihood models for limited dependent variables (Logit, Tobit, and Probit models), combinatorial fuzzy logic, neural networks, Markov chains, trendlines, spline curves, and others.

- The Optimization Module is used for optimizing multiple decision variables subject to constraints to maximize or minimize an objective, and can be run either as a static optimization, dynamic, and stochastic optimization under uncertainty together with Monte Carlo simulation, or as a stochastic optimization with super speed simulations. The software can handle linear and nonlinear optimizations with binary, integer, and continuous variables, as well as generate Markowitz efficient frontiers.
- The Analytical Tools Module allows you to run segmentation clustering, hypothesis testing, statistical tests of raw data, data diagnostics of technical forecasting assumptions (e.g., heteroskedasticity, multicollinearity, and the like), sensitivity and scenario analyses, overlay chart analysis, spider charts, tornado charts, and many other powerful tools.
- ROV BizStats (over 130 business statistics and analytical models).
- ROV Decision Tree (decision tree models, Monte Carlo risk simulation on decision trees, sensitivity analysis, scenario analysis, Bayesian joint and posterior probability updating, expected value of information, MINIMAX, MAXIMIN, risk profiles).
- The Real Options Super Lattice Solver is a software that complements Risk Simulator, used for solving simple to complex real options problems.

The following sections walk you through the basics of the Simulation Module in Risk Simulator, while future chapters provide more details about the applications of other modules. To follow along, make sure you have Risk Simulator installed on your computer to proceed.

In fact, it is highly recommended that you first watch the getting started videos on the web (www.realoptionsvaluation.com/risksimulator.html) or attempt the step-by-step exercises at the end of the user manual before coming back and reviewing the text in this chapter. This approach is recommended because the videos will get you started immediately, as will the exercises, whereas the text in this chapter focuses more on the theory and detailed explanations of the properties of simulation.

Running a Monte Carlo Simulation

Typically, to run a simulation in your existing Excel model, the following steps have to be performed:

1. Start a new simulation profile or open an existing profile.
2. Define input assumptions in the relevant cells.
3. Define output forecasts in the relevant cells.
4. Run simulation.
5. Interpret the results.

If desired, and for practice, open the example file called Basic Simulation Model and follow along with the examples below on creating a simulation. The example file can be found either by going to the installation folder (e.g., c:\Program Files (x86)\Real Options Valuation\Risk Simulator\Risk Simulator*) or accessed direc*tly through *Risk Simulator | Example Models*.

Starting a New Simulation Profile

To start a new simulation, you will first need to create a simulation profile. A simulation profile contains a complete set of instructions on how you would like to run a simulation, that is, all the assumptions, forecasts, run preferences, and so forth. Having profiles facilitates creating multiple scenarios of simulations. That is, using the same exact model, several profiles can be created, each with its own specific simulation properties and requirements. The same person can create different test scenarios using different distributional assumptions and inputs, or multiple persons can test their own assumptions and inputs on the same model.

- Start Excel and create a new model or open an existing one (you can use the Basic Simulation Model example to follow along).
- Click on *Risk Simulator | New Simulation Profile*.
- Specify a title for your simulation as well as all other pertinent information (Figure A.4).

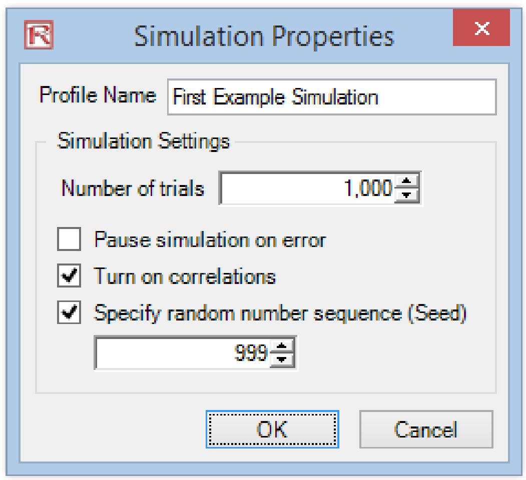


Figure A.4 – New Simulation Profile

- **Title:** Specifying a simulation title allows you to create multiple simulation profiles in a single Excel model. Thus you can now save different simulation scenario profiles within the same model without having to delete existing assumptions and changing them each time a new simulation scenario is required. You can always change the profile's name later (*Risk Simulator | Edit Profile*).
- **Number of trials:** This is where the number of simulation trials required is entered. That is, running 1,000 trials means that 1,000 different iterations of

outcomes based on the input assumptions will be generated. You can change this number as desired, but the input has to be positive integers. The default number of runs is 1,000 trials. You can use precision and error control described later in this chapter to automatically help determine how many simulation trials to run (see the section on precision and error control for details).

- **Pause simulation on error:** If checked, the simulation stops every time an error is encountered in the Excel model. That is, if your model encounters a computation error (e.g., some input values generated in a simulation trial may yield a divide by zero error in one of your spreadsheet cells), the simulation stops. This function is important to help audit your model to make sure there are no computational errors in your Excel model. However, if you are sure the model works, then there is no need for this preference to be checked.

- **Turn on correlations:** If checked, correlations between paired input assumptions will be computed. Otherwise, correlations will all be set to zero, and a simulation is run assuming no cross-correlations between input assumptions. As an example, applying correlations will yield more accurate results if, indeed, correlations exist, and will tend to yield a lower forecast confidence if negative correlations exist. After turning on correlations here, you can later set the relevant correlation coefficients on each assumption generated.

- **Specify random number sequence:** Simulation, by definition, will yield slightly different results every time a simulation is run. This characteristic results from the random number generation routine in Monte Carlo simulation and is a theoretical fact in all random number generators. However, when making presentations, sometimes you may require the same results (especially when the report being presented shows one set of results and during a live presentation you would like to show the same results being generated, or when you are sharing models with others and would like the same results to be obtained every time), so you would then check this preference and enter in an initial seed number. The seed number can be any positive integer. Using the same initial seed value, the same number of trials, and the same input assumptions, the simulation will always yield the same sequence of random numbers, guaranteeing the same final set of results.

Note that once a new simulation profile has been created, you can come back later and modify these selections. To do so, make sure that the current active profile is the profile you wish to modify, otherwise, click on *Risk Simulator | Change Simulation Profile*, select the profile you wish to change and click *OK* (Figure A.5 shows an example where there are multiple profiles and how to activate a selected profile). Then, click on *Risk Simulator | Edit Simulation Profile* and make the required changes. You can also duplicate or rename an existing profile. When creating multiple profiles in the same Excel model, make sure to provide each profile a unique name so you can tell them apart later. Also, these profiles are stored inside hidden sectors of the Excel *.xls file and you do not have to save any additional files. The profiles and their contents (assumptions, forecasts, etc.) are automatically saved when you save the Excel file. Finally, the last profile that is active when you exit and save the Excel file will be the one that is opened the next time the Excel file is accessed.

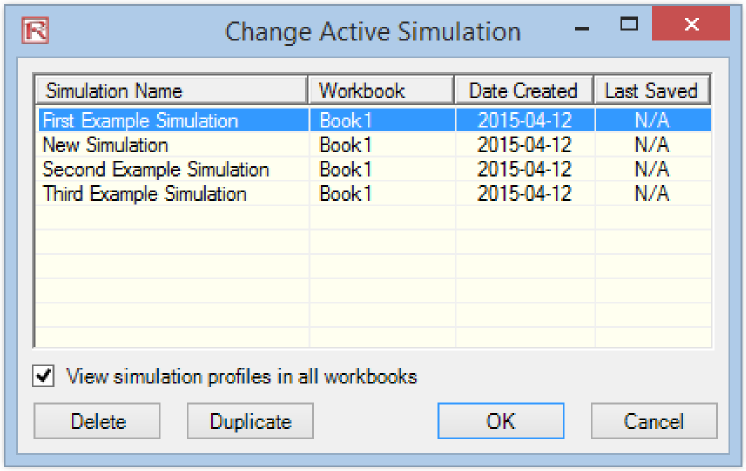


Figure A.5 – Change Active Simulation

Defining Input Assumptions

The next step is to set input assumptions in your model. Note that assumptions can only be assigned to cells without any equations or functions—typed-in numerical values that are inputs in a model—whereas output forecasts can only be assigned to cells with equations and functions—outputs of a model. Recall that assumptions and forecasts cannot be set unless a simulation profile already exists. Do the following to set new input assumptions in your model:

- Make sure a Simulation Profile exists; open an existing profile or start a new profile (*Risk Simulator | New Simulation Profile*).
- Select the cell you wish to set an assumption on (e.g., cell *G8* in the Basic Simulation Model example).
- Click on *Risk Simulator | Set Input Assumption* or click on the set input assumption icon in the Risk Simulator icon toolbar.

- *Select the relevant distribution* you want, *enter the relevant distribution parameters* (e.g., Triangular distribution with 1, 2, 2.5 as the minimum, most likely, and maximum values), and hit *OK* to insert the input assumption into your model (Figure A.6).

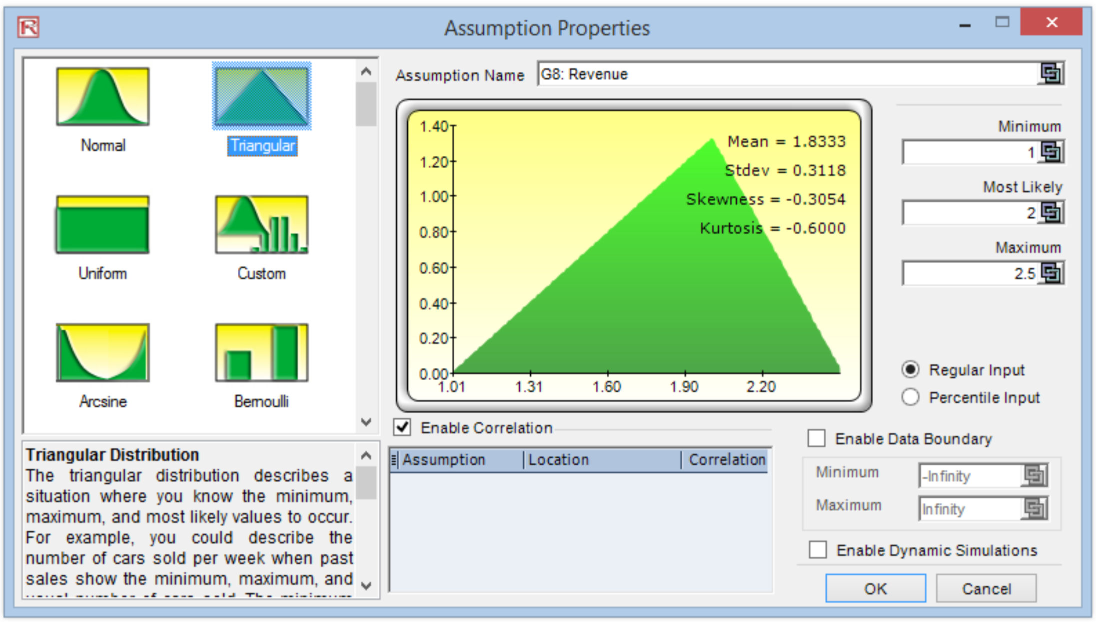


Figure A.6 – Setting an Input Assumption

Note that you can also set assumptions by selecting the cell you wish to set the assumption on and using the mouse right-click to access the shortcut Risk Simulator menu. In addition, for expert users, you can set input assumptions using the Risk Simulator RS Functions: select the cell of choice, click on Excel's Insert, Function, select the All Category, and scroll down to the RS functions list (we do not recommend using

RS functions unless you are an expert user). For the examples going forward, we suggest following the basic instructions for accessing menus and icons.

As shown in Figure A.7, there are several key areas in the Assumption Properties worthy of mention.

- **Assumption Name:** This is an optional area to allow you to enter in unique names for the assumptions to help track what each of the assumptions represents. Good modeling practice is to use short but precise assumption names.
- **Distribution Gallery:** This area to the left shows all of the different distributions available in the software. To change the views, right-click anywhere in the gallery and select large icons, small icons, or list. There are over two dozen distributions available.
- **Input Parameters:** Depending on the distribution selected, the required relevant parameters are shown. You may either enter the parameters directly or link them to specific cells in your worksheet. Hard coding or typing the parameters is useful when the assumption parameters are assumed not to change. Linking to worksheet cells is useful when the input parameters need to be visible or are allowed to be changed (click on the link icon to link an input parameter to a worksheet cell).
- **Enable Data Boundary:** These are typically not used by the average analyst but exist for truncating the distributional assumptions. For instance, if a normal distribution is selected, the theoretical boundaries are between negative infinity and positive infinity. However, in practice, the simulated variable exists only within some smaller range, and this range can then be entered to truncate the distribution appropriately.

- **Correlations:** Pairwise correlations can be assigned to input assumptions here. If correlations are required, remember to check the Turn on Correlations preference by clicking on *Risk Simulator | Edit Simulation Profile*. See the discussion on correlations in Dr. Mun's book for more details about assigning correlations and the effects correlations will have on a model. Notice that you can either truncate a distribution or correlate it to another assumption, but not both.

- **Short Descriptions:** These exist for each of the distributions in the gallery. The short descriptions explain when a certain distribution is used as well as the input parameter requirements. See the section Understanding Probability Distributions for Monte Carlo Simulation in Mun's book for details on each distribution type available in the software.

- **Regular Input and Percentile Input:** This option allows the user to perform a quick due diligence test of the input assumption. For instance, if setting a normal distribution with some mean and standard deviation inputs, you can click on the percentile input to see what the corresponding 10th and 90th percentiles are.

- **Enable Dynamic Simulation:** This option is unchecked by default, but if you wish to run a multidimensional simulation (i.e., if you link the input parameters of the assumption to another cell that is itself an assumption, you are simulating the inputs, or simulating the simulation), then remember to check this option. Dynamic simulation will not work unless the inputs are linked to other changing input assumptions.

Note: If you are following along with the example, continue by setting another assumption on cell *G9*. This time use the Uniform distribution with a minimum value of 0.9 and a maximum value of 1.1. Then, proceed to defining the output forecasts in the next step.

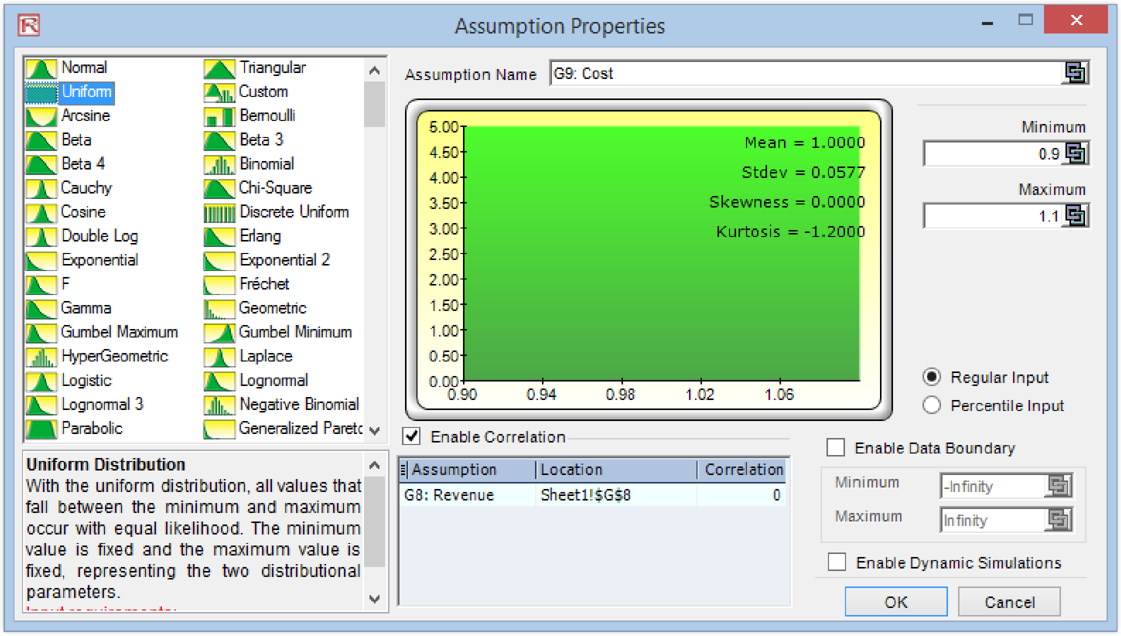


Figure A.7 – Assumption Properties

Defining Output Forecasts

The next step is to define output forecasts in the model. Forecasts can only be defined on output cells with equations or functions. The following describes the set forecast process:

- Select the cell you wish to set a forecast (e.g., cell *G10* in the Basic Simulation Model).
- Click on *Risk Simulator | Set Output Forecast* or click on the set output forecast icon on the Risk Simulator icon toolbar (Figure A.3).
- Enter the relevant information and click *OK*.

Note that you can also set output forecasts by selecting the cell you wish to set the forecast on and using the mouse right-click to access the shortcut Risk Simulator menu to set an output forecast. Figure A.8 illustrates the set forecast properties.

- **Forecast Name:** Specify the name of the forecast cell. This is important because when you have a large model with multiple forecast cells, naming the forecast cells individually allows you to access the right results quickly. Do not underestimate the importance of this simple step. Good modeling practice is to use short but precise forecast names.
- **Forecast Precision:** Instead of relying on a guesstimate of how many trials to run in your simulation, you can set up precision and error controls. When an error-precision combination has been achieved in the simulation, the simulation will pause and inform you of the precision achieved, making the required number of simulation trials an automated process rather than a guessing game. Review the section on error and precision control later in this chapter for more specific details.
- **Show Forecast Window:** Allows the user to show or not show a particular forecast window. The default is to always show a forecast chart.

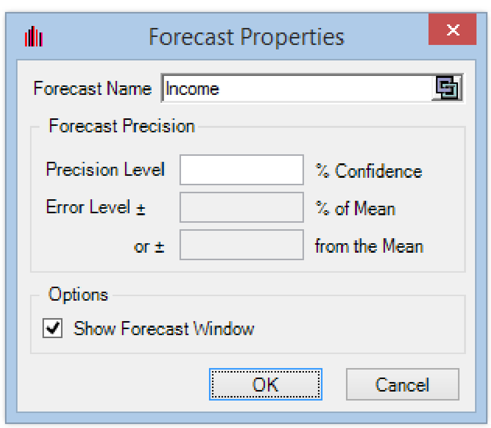


Figure A.8 – Set Output Forecast

Running the Simulation

If everything looks right, simply click on *Risk Simulator | Run Simulation* or click on the *Run icon* on the Risk Simulator toolbar and the simulation will proceed. You may also reset a simulation after it has run to rerun it (*Risk Simulator | Reset Simulation* or the reset simulation icon on the toolbar) or to pause it during a run. Also, the step function (*Risk Simulator | Step Simulation* or the *step simulation icon* on the toolbar) allows you to simulate a single trial, one at a time, useful for educating others on simulation (i.e., you can show that at each trial, all the values in the assumption cells are being replaced and the entire model is recalculated each time). You can also access the run simulation menu by right-clicking anywhere in the model and selecting Run Simulation.

Risk Simulator also allows you to run the simulation at extremely fast speed, called Super Speed. To do this, click on *Risk Simulator | Run Super Speed Simulation* or use the run super speed icon. Notice how much faster the super speed simulation runs. In fact, for practice, *Reset Simulation* and then *Edit Simulation Profile* and change the *Number of Trials* to 100,000, and Run Super Speed. It should only take a few seconds to run. However, please be aware that super speed simulation will not run if the model has errors, VBA (visual basic for applications), or links to external data sources or applications. In such situations, you will be notified and the regular speed simulation will be run instead. Regular speed simulations are always able to run even with errors, VBA, or external links.

Interpreting the Forecast Results

The final step in Monte Carlo simulation is to interpret the resulting forecast charts. Figures A.9 through A.16 show the forecast chart and the corresponding statistics generated after running the simulation. Typically, the following elements are important in interpreting the results of a simulation:

Forecast Chart The forecast chart shown in Figure A.9 is a probability histogram that shows the frequency counts of values occurring in the total number of trials simulated. The vertical bars show the frequency of a particular *x* value occurring out of the total number of trials, while the cumulative frequency (smooth line) shows the total probabilities of all values at and below *x* occurring in the forecast.

Forecast Statistics The forecast statistics shown in Figure A.10 summarize the distribution of the forecast values in terms of the four moments of a distribution. See the Understanding the Forecast Statistics section in Mun's book for more details on what some of these statistics mean. You can rotate between the histogram and statistics tabs by depressing the space bar.

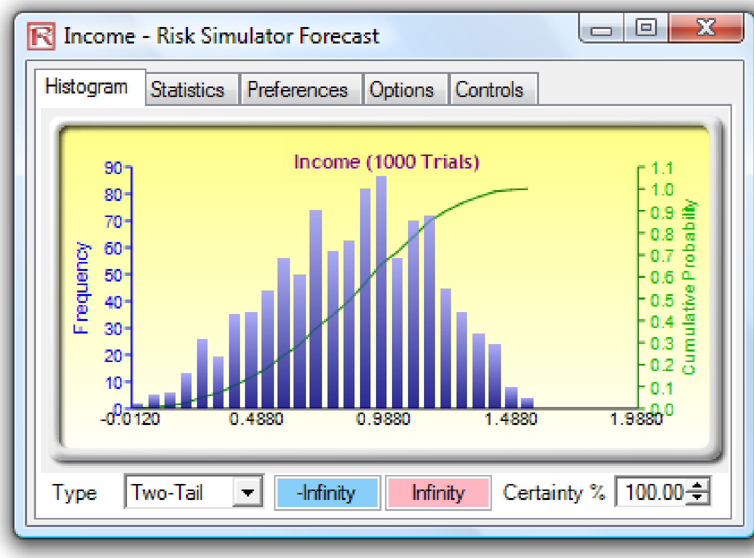
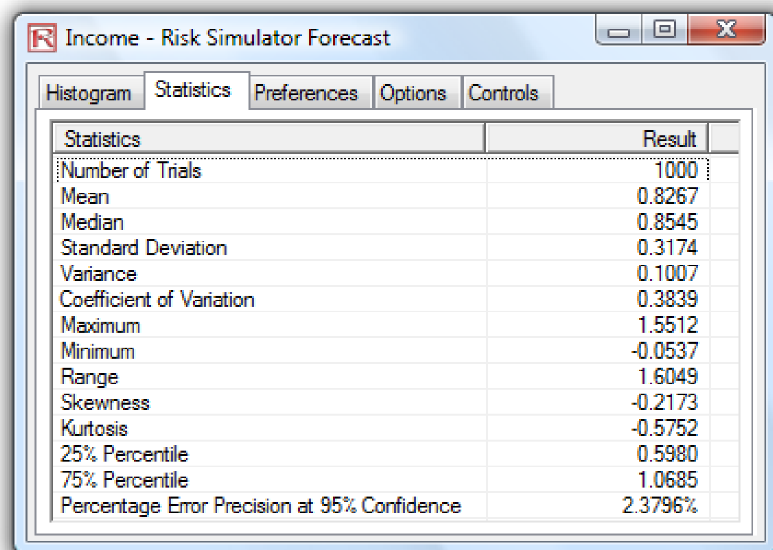


Figure A.9 – Forecast Chart



Statistics	Result
Number of Trials	1000
Mean	0.8267
Median	0.8545
Standard Deviation	0.3174
Variance	0.1007
Coefficient of Variation	0.3839
Maximum	1.5512
Minimum	-0.0537
Range	1.6049
Skewness	-0.2173
Kurtosis	-0.5752
25% Percentile	0.5980
75% Percentile	1.0685
Percentage Error Precision at 95% Confidence	2.3796%

Figure A.10 – Forecast Statistics

Forecast Chart Tabs

Preferences The preferences tab in the forecast chart (Figure A.11A) allows you to change the look and feel of the charts. For instance, if *Always On Top* is selected, the forecast charts will always be visible regardless of what other software are running on your computer. *Histogram Resolution* allows you to change the number of bins of the histogram, anywhere from 5 bins to 100 bins. Also, the *Data Update* feature allows you to control how fast the simulation runs versus how often the forecast chart is updated. For example, viewing the forecast chart updated at almost every trial will slow down the simulation as more memory is being allocated to updating the chart versus running the simulation. This is merely a user preference and in no way changes the results of the simulation, just the speed of completing the simulation. To further increase the speed of the simulation, you can minimize Excel while the simulation is running, thereby reducing the memory required to visibly update the Excel spreadsheet and freeing up the memory to run the simulation. The *Close All* and *Minimize All* controls all the open forecast charts.

Options As shown in Figure A.11B, this forecast chart feature allows you to show all the forecast data or to filter in/out values that fall within either some specified interval or some standard deviation you choose. Also, the precision level can be set here for this specific forecast to show the error levels in the statistics view. See the section on error and precision control later in this chapter for more details. Show the following statistic on histogram is a user preference for whether the mean, median, first quartile, and fourth quartile lines (25th and 75th percentiles) should be displayed on the forecast chart.

Controls As shown in Figure A.11C, this tab has all the functionalities in allowing you to change the type, color, size, zoom, tilt, 3D, and other things in the forecast chart, as well as to generate overlay charts (PDF, CDF) and run distributional fitting on your forecast data (see the Data Fitting sections in Mun's book for more details on this methodology).

Global View versus Normal View Figures A.11A, A.11B, and A.11C show the forecast chart's Normal View where the forecast chart user interface is divided into tabs, making it small and compact. In contrast, Figure A.12 shows the Global View where all elements are located in a single interface. The results are identical in both views and selecting which view is a matter of personal preference. You can switch between these two views by clicking on the link, located at the top right corner, called *Global View* and *Local View*.

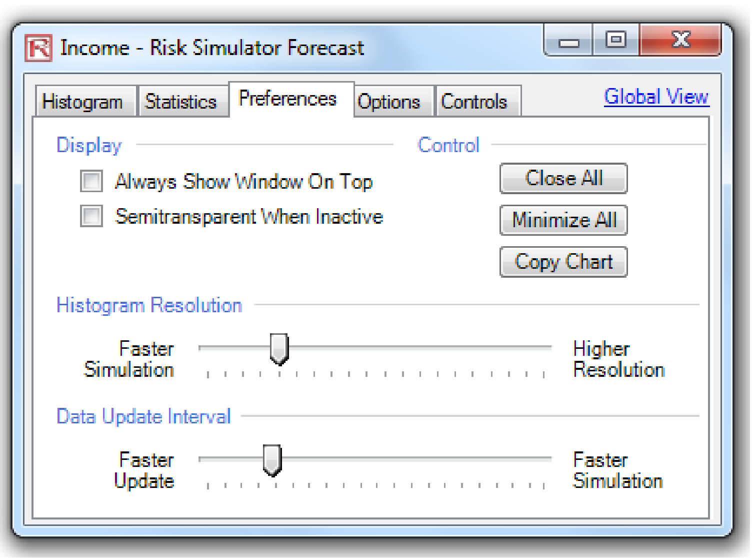


Figure A.11A – Forecast Chart Preferences

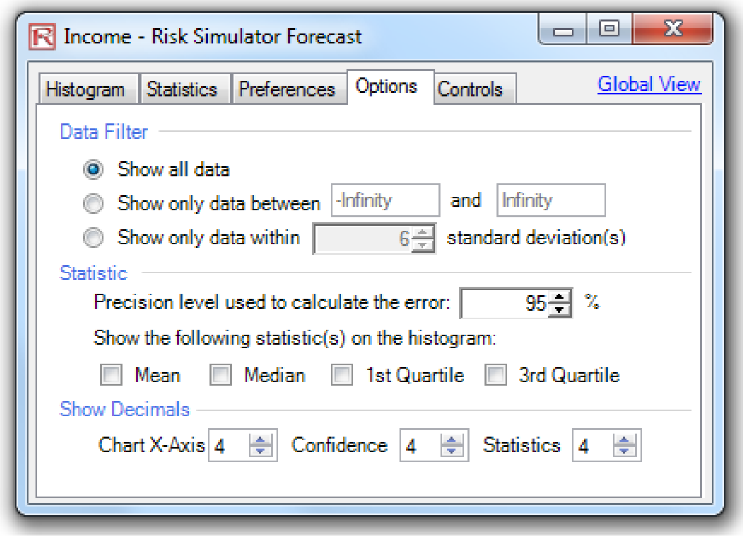


Figure A.11B – Forecast Chart Options

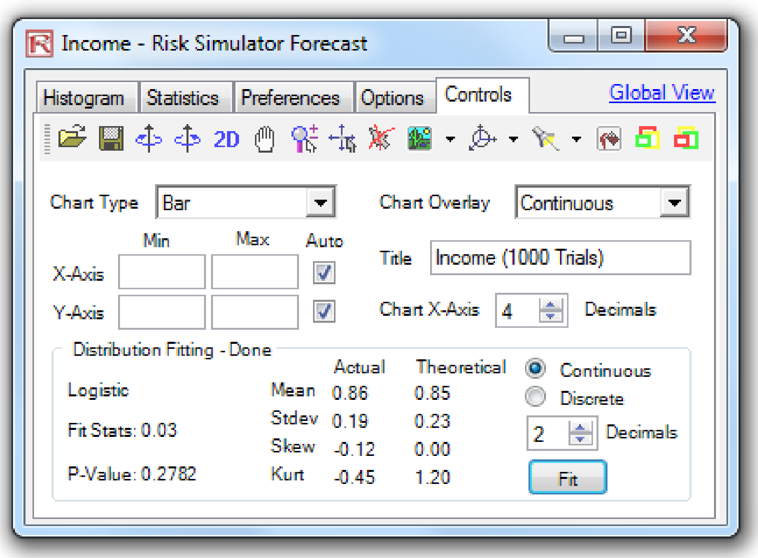


Figure A.11C – Forecast Chart Controls

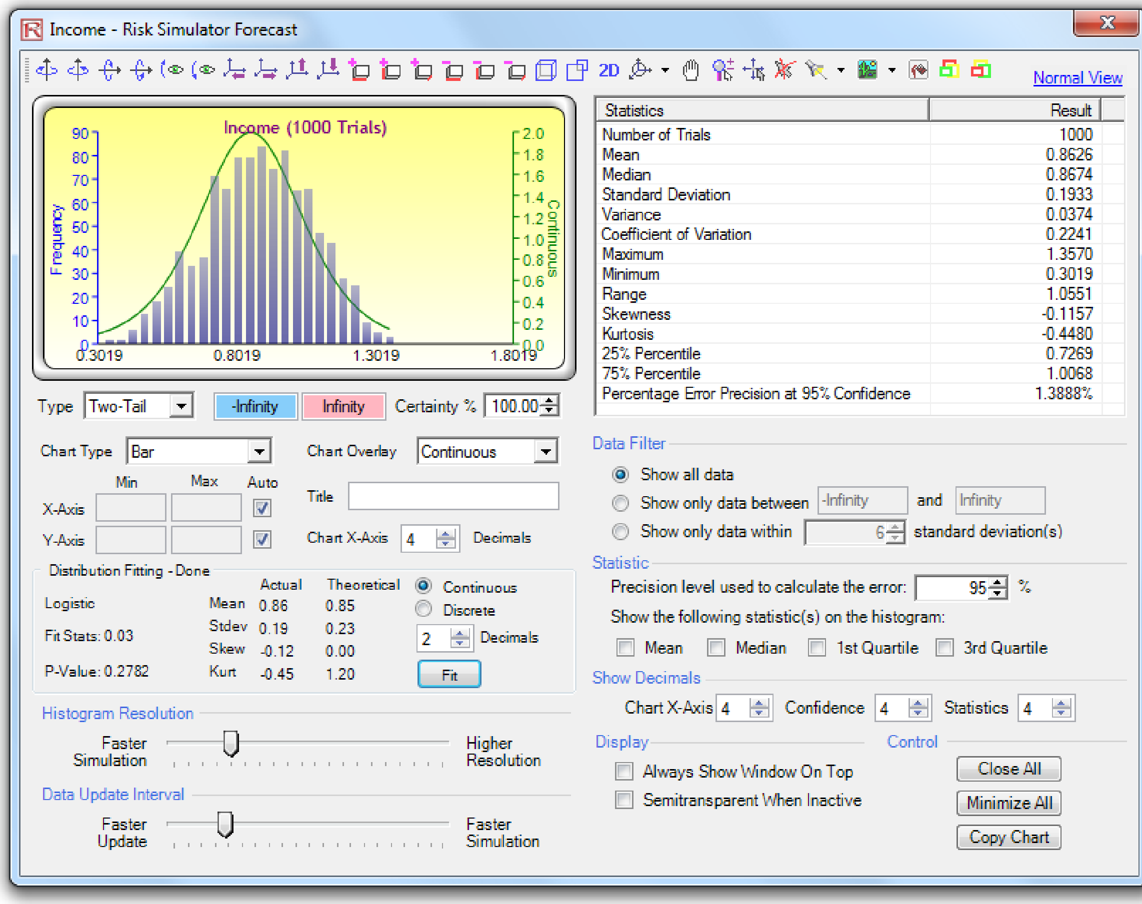


Figure A.12 – Forecast Chart Global View

Using Forecast Charts and Confidence Intervals

In forecast charts, you can determine the probability of occurrence called *confidence intervals*. That is, given two values, what are the chances that the outcome will fall between these two values? Figure A.13 illustrates that there is a 90% probability that the final outcome (in this case, the level of income) will be between $0.2653 and $1.3230. The two-tailed confidence interval can be obtained by first selecting *Two-Tail* as the type, entering the desired certainty value (e.g., *90*) and hitting TAB on the keyboard. The two computed values corresponding to the certainty value will then be displayed. In this example, there is a 5% probability that income will be below $0.2653 and another 5% probability that income will be above $1.3230. That is, the two-tailed confidence interval is a symmetrical interval centered on the median, or 50th percentile, value. Thus, both tails will have the same probability.

Alternatively, a one-tail probability can be computed. Figure A.14 shows a left-tail selection at 95% confidence (i.e., choose *Left-Tail ≤* as the type, enter *95* as the certainty level, and hit TAB on the keyboard). This means that there is a 95% probability that the income will be below $1.3230 or a 5% probability that income will be above $1.3230, corresponding perfectly with the results seen in Figure A.13.

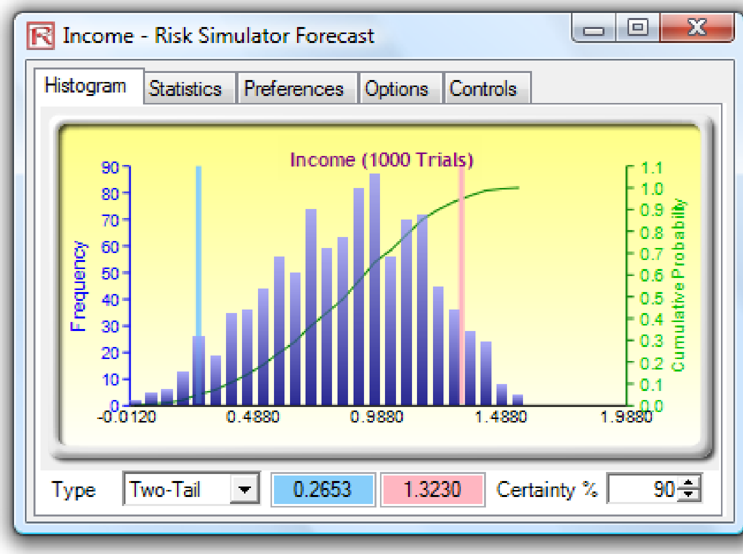


Figure A.13 – Forecast Chart Two-Tail Confidence Interval

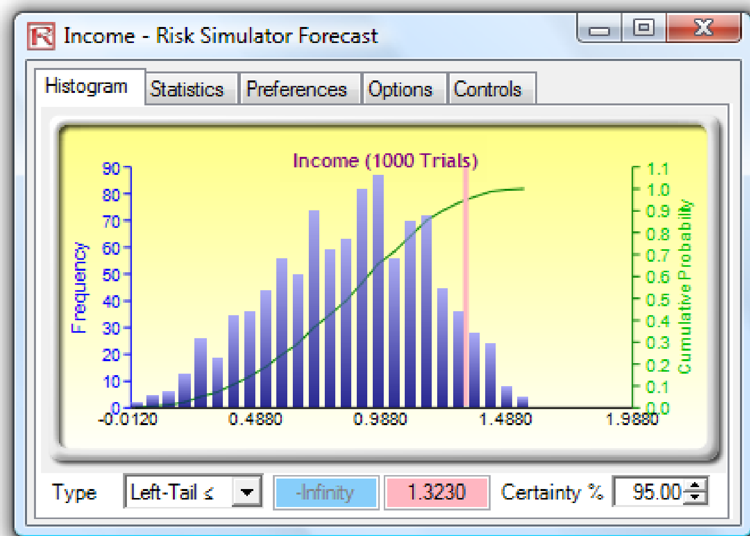


Figure A.14 – Forecast Chart One-Tail Confidence Interval

In addition to evaluating what the confidence interval is (i.e., given a probability level and finding the relevant income values), you can determine the probability of a given income value. For instance, what is the probability that income will be less than or equal to $1? To obtain the answer, select the *Left-Tail ≤* probability type, enter *1* into the value input box, and hit TAB. The corresponding certainty will then be computed (in this case, as shown in Figure A.15, there is a 67.70% probability income will be at or below $1).

For the sake of completeness, you can select the *Right-Tail >* probability type, and enter the value *1* in the value input box, and hit TAB. The resulting probability indicates the right-tail probability past the value 1, that is, the probability of income exceeding $1 (in this case, as shown in Figure A.16, we see that there is a 32.30% probability of income exceeding $1). The sum of 67.70% and 32.30% is, of course, 100%, the total probability under the curve.

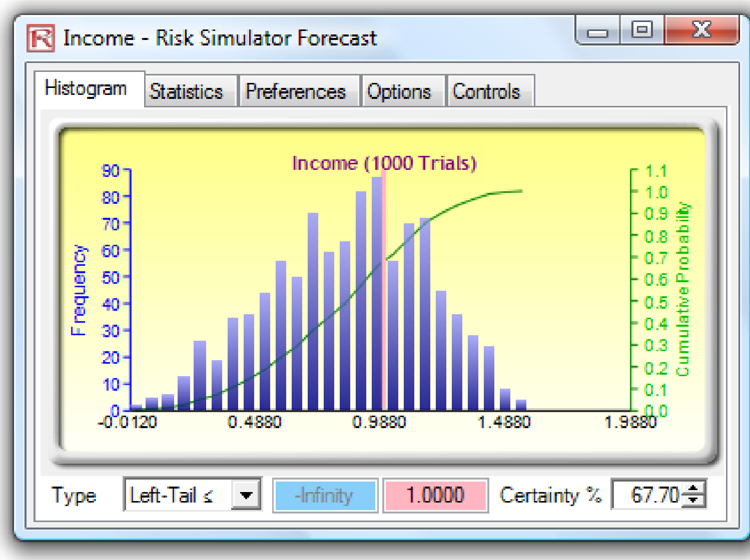


Figure A.15 – Forecast Chart Probability Evaluation

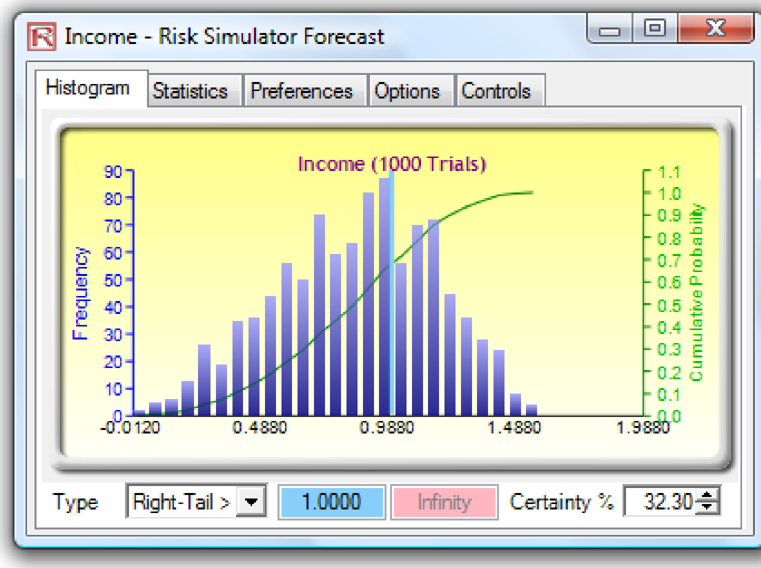


Figure A.16 – Forecast Chart Probability Evaluation

TIPS

- The forecast window is resizable by clicking on and dragging the bottom right corner of the forecast window.
- It is advisable that the current simulation be reset (*Risk Simulator | Reset Simulation*) before rerunning a simulation.
- Remember that you will need to hit TAB on the keyboard to update the chart and results when you type in the certainty values or right- and left-tail values.
- You can also hit the spacebar on the keyboard repeatedly to cycle among the histogram to statistics, preferences, options, and control tabs.
- In addition, if you click on *Risk Simulator | Options* you can access several different options for Risk Simulator, including allowing Risk Simulator to start each time Excel starts or to only start when you want it to by going to the installation folder (e.g., c:\Program Files (x86)\Real Options Valuation\Risk Simulator\Risk Simulator),

changing the cell colors of assumptions and forecasts, and turning cell comments on and off (cell comments will allow you to see which cells are input assumptions and which are output forecasts as well as their respective input parameters and names). Do spend some time playing around with the forecast chart outputs and various bells and whistles, especially the Controls tab.

Tornado and Sensitivity Tools in Simulation

Tornado analysis is a powerful simulation tool that captures the static impacts of each variable on the outcome of the model. That is, the tool automatically perturbs each variable in the model a preset amount, captures the fluctuation on the model's forecast or final result, and lists the resulting perturbations ranked from the most significant to the least. Figures A.17 through A.22 illustrate the application of a tornado analysis. For instance, Figure A.17 is a sample discounted cash flow model where the input assumptions in the model are shown. The question is: what are the critical success drivers that affect the model's output the most? That is, what really drives the net present value of $96.63 or which input variable impacts this value the most?

The tornado chart tool can be accessed through *Risk Simulator | Analytical Tools | Tornado Analysis*. To follow along with the first example, open the example located at *Risk Simulator | Example Models | 22 Tornado and Sensitivity Charts (Linear)*. Figure A.18 shows this sample model where cell *G6* containing the net present value is chosen as the target result to be analyzed. The target cell's precedents in the model are used in creating the tornado chart. Precedents are all the input and intermediate variables that affect the outcome of the model. For instance, if the model consists of A = B + C, and where C = D + E, then B, D, and E are the precedents for A (C is not a precedent as it is only an intermediate calculated value). Figure A.18 also shows the testing range of each precedent variable used to estimate the target result. If the precedent variables are simple inputs, then the testing range will be a simple perturbation based on the range chosen (e.g., the default is ±10%). Each precedent variable can be perturbed at different percentages if required. A wider range is important as it is better able to test extreme values rather than smaller perturbations around the expected values. In certain circumstances, extreme values may have a larger, smaller, or unbalanced impact (e.g., nonlinearities may occur where increasing or decreasing economies of scale and scope creep in for larger or smaller values of a variable) and only a wider range will capture this nonlinear impact.

Procedure

- Open the example model *Risk Simulator | Example Models | 22 Tornado and Sensitivity Charts (Linear)* and go to the DCF Model worksheet.
- Select the single output cell (i.e., a cell with a function or equation) in an Excel model (e.g., cell *G6* is selected in our example).
- Select *Risk Simulator | Analytical Tools | Tornado Analysis*.
- Review the precedents and rename them as needed (renaming the precedents to shorter names allows a more visually pleasing tornado and spider chart), and click *OK*.

Discounted Cash Flow Model

Base Year	*2005*	*Sum PV Net Benefits*	***$1,896.63***
Market Risk-Adjusted Discount Rate	*15.00%*	*Sum PV Investments*	***$1,800.00***
Private-Risk Discount Rate	*5.00%*	*Net Present Value*	***$96.63***
Annualized Sales Growth Rate	*2.00%*	*Internal Rate of Return*	*18.80%*
Price Erosion Rate	*5.00%*	*Return on Investment*	*5.37%*
Effective Tax Rate	*40.00%*		

	2005	*2006*	*2007*	*2008*	*2009*
Product A Avg Price/Unit	$10.00	$9.50	$9.03	$8.57	$8.15
Product B Avg Price/Unit	$12.25	$11.64	$11.06	$10.50	$9.98
Product C Avg Price/Unit	$15.15	$14.39	$13.67	$12.99	$12.34
Product A Sale Quantity ('000s)	50.00	51.00	52.02	53.06	54.12
Product B Sale Quantity ('000s)	35.00	35.70	36.41	37.14	37.89
Product C Sale Quantity ('000s)	20.00	20.40	20.81	21.22	21.65
Total Revenues	***$1,231.75***	***$1,193.57***	***$1,156.57***	***$1,120.71***	***$1,085.97***
Direct Cost of Goods Sold	$184.76	$179.03	$173.48	$168.11	$162.90
Gross Profit	***$1,046.99***	***$1,014.53***	***$983.08***	***$952.60***	***$923.07***
Operating Expenses	$157.50	$160.65	$163.86	$167.14	$170.48
Sales, General and Admin. Costs	$15.75	$16.07	$16.39	$16.71	$17.05
Operating Income (EBITDA)	***$873.74***	***$837.82***	***$802.83***	***$768.75***	***$735.54***
Depreciation	$10.00	$10.00	$10.00	$10.00	$10.00
Amortization	$3.00	$3.00	$3.00	$3.00	$3.00
EBIT	***$860.74***	***$824.82***	***$789.83***	***$755.75***	***$722.54***
Interest Payments	$2.00	$2.00	$2.00	$2.00	$2.00
EBT	***$858.74***	***$822.82***	***$787.83***	***$753.75***	***$720.54***
Taxes	$343.50	$329.13	$315.13	$301.50	$288.22
Net Income	***$515.24***	***$493.69***	***$472.70***	***$452.25***	***$432.33***
Noncash: Depreciation Amortization	$13.00	$13.00	$13.00	$13.00	$13.00
Noncash: Change in Net Working Capital	$0.00	$0.00	$0.00	$0.00	$0.00
Noncash: Capital Expenditures	$0.00	$0.00	$0.00	$0.00	$0.00
Free Cash Flow	***$528.24***	***$506.69***	***$485.70***	***$465.25***	***$445.33***
Investment Outlay	***$1,800.00***				

Financial Analysis					
Present Value of Free Cash Flow	***$528.24***	***$440.60***	***$367.26***	***$305.91***	***$254.62***
Present Value of Investment Outlay	***$1,800.00***	***$0.00***	***$0.00***	***$0.00***	***$0.00***
Net Cash Flows	($1,271.76)	$506.69	$485.70	$465.25	$445.33

Figure A.17 – Sample Model

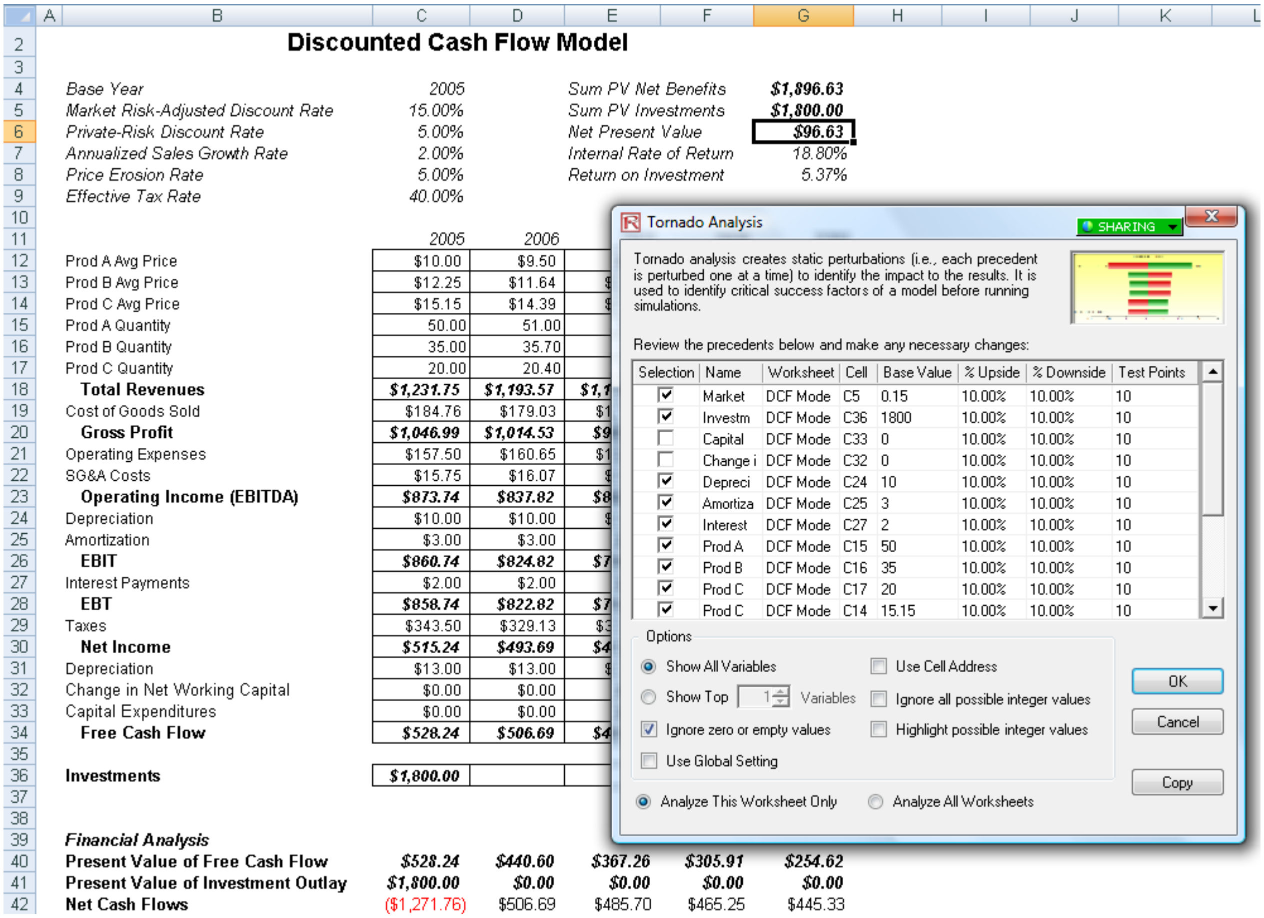


Figure A.18 – Running Tornado Analysis

Figure A.19 shows the resulting tornado analysis report, which indicates that capital investment has the largest impact on net present value, followed by tax rate, average sale price, quantity demanded of the product lines, and so forth. The report contains four distinct elements:

- A statistical summary listing the procedure performed.

- A sensitivity table (Figure A.20) showing the starting NPV base value of 96.63 and how each input is changed (e.g., Investment is changed from $1,800 to $1,980 on the upside with a +10% swing, and from $1,800 to $1,620 on the downside with a –10% swing; the resulting upside and downside values on NPV is –$83.37 and $276.63, with a total change of $360, making investment the variable with the highest impact on NPV). The precedent variables are ranked from the highest impact to the lowest impact.
- A spider chart (Figure A.21) illustrating the effects graphically. The y-axis is the NPV target value while the x-axis depicts the percentage change on each of the precedent values (the central point is the base case value at 96.63 at 0% change from the base value of each precedent). A positively sloped line indicates a positive relationship or effect, while negatively sloped lines indicate a negative relationship (e.g., Investment is negatively sloped, which means that the higher the investment level, the lower the NPV). The absolute value of the slope indicates the magnitude of the effect (a steep line indicates a higher impact on the NPV y-axis given a change in the precedent x-axis).
- A tornado chart illustrating the effects in another graphical manner, where the highest impacting precedent is listed first. The x-axis is the NPV value, with the center of the chart being the base case condition. Green bars in the chart indicate a positive effect, while red bars indicate a negative effect. Therefore, for

investments, the red bar on the right side indicates a negative effect of investment on higher NPV—in other words, capital investment and NPV are negatively correlated. The opposite is true for price and quantity of products A to C (their green bars are on the right side of the chart).

Tornado and Spider Charts

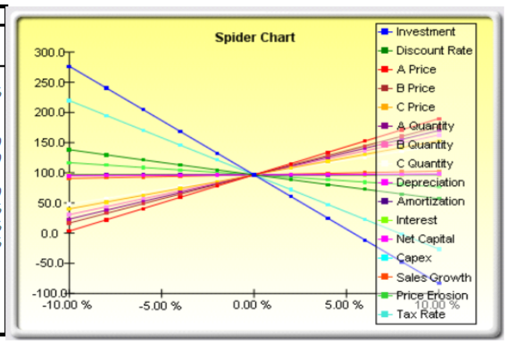
Statistical Summary

One of the powerful simulation tools is the tornado chart—it captures the static impacts of each variable on the outcome of the model. That is, the tool automatically perturbs each precedent variable in the model a user-specified preset amount, captures the fluctuation on the model's forecast or final result, and lists the resulting perturbations ranked from the most significant to the least. Precedents are all the input and intermediate variables that affect the outcome of the model. For instance, if the model consists of A = B + C, where C = D + E, then B, D, and E are the precedents for A (C is not a precedent as it is only an intermediate calculated value). The range and number of values perturbed is user-specified and can be set to test extreme values rather than smaller perturbations around the expected values. In certain circumstances, extreme values may have a larger, smaller, or unbalanced impact (e.g., nonlinearities may occur where increasing or decreasing economies of scale and scope creep occurs for larger or smaller values of a variable) and only a wider range will capture this nonlinear impact.

A tornado chart lists all the inputs that drive the model, starting from the input variable that has the most effect on the results. The chart is obtained by perturbing each precedent input at some consistent range (e.g., ±10% from the base case) one at a time, and comparing their results to the base case. A spider chart looks like a spider with a central body and its many legs protruding. The positively sloped lines indicate a positive relationship, while a negatively sloped line indicates a negative relationship. Further, spider charts can be used to visualize linear and nonlinear relationships. The tornado and spider charts help identify the critical success factors of an output cell in order to identify the inputs to simulate. The identified critical variables that are uncertain are the ones that should be simulated. Do not waste time simulating variables that are neither uncertain nor have little impact on the results.

Result

	Base Value: 96.6261638553219			Input Changes		
Precedent Cell	Output Downside	Output Upside	Effective Range	Input Downside	Input Upside	Base Case Value
Investment	$276.63	($83.37)	360.00	$1,620.00	$1,980.00	$1,800.00
Tax Rate	$219.73	($26.47)	246.20	36.00%	44.00%	40.00%
A Price	$3.43	$189.83	186.40	$9.00	$11.00	$10.00
B Price	$16.71	$176.55	159.84	$11.03	$13.48	$12.25
A Quantity	$23.18	$170.07	146.90	45.00	55.00	50.00
B Quantity	$30.53	$162.72	132.19	31.50	38.50	35.00
C Price	$40.15	$153.11	112.96	$13.64	$16.67	$15.15
C Quantity	$48.05	$145.20	97.16	18.00	22.00	20.00
Discount Rate	$138.24	$57.03	81.21	13.50%	16.50%	15.00%
Price Erosion	$116.80	$76.64	40.16	4.50%	5.50%	5.00%
Sales Growth	$90.59	$102.69	12.10	1.80%	2.20%	2.00%
Depreciation	$95.08	$98.17	3.08	$9.00	$11.00	$10.00
Interest	$97.09	$96.16	0.93	$1.80	$2.20	$2.00
Amortization	$96.16	$97.09	0.93	$2.70	$3.30	$3.00
Capex	$96.63	$96.63	0.00	$0.00	$0.00	$0.00
Net Capital	$96.63	$96.63	0.00	$0.00	$0.00	$0.00



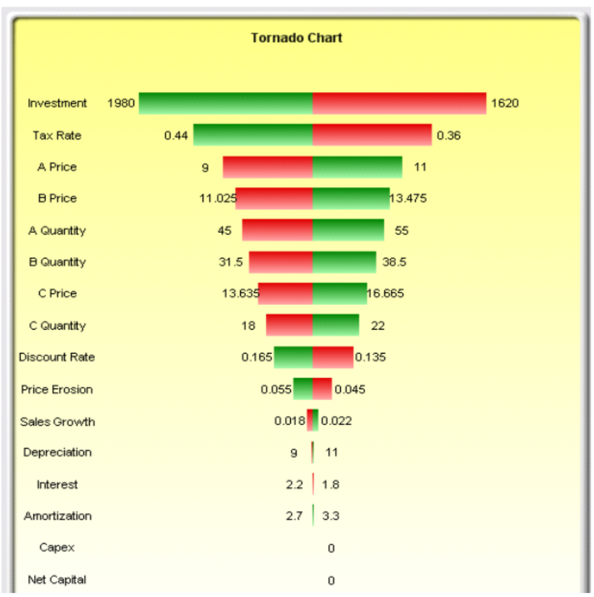


Figure A.19 – Tornado Analysis Report

Notes

Remember that tornado analysis is a static sensitivity analysis applied on each input variable in the model—that is, each variable is perturbed individually and the resulting effects are tabulated. This approach makes tornado analysis a key component to execute before running a simulation. One of the very first steps in risk analysis is capturing and identifying the most important impact drivers in the model. The next step is to identify which of these important impact drivers are uncertain. These uncertain impact drivers are the critical success drivers of a project, where the results of the model depend on these critical success drivers. These variables are the ones that should be simulated. Do not waste time simulating variables that are neither uncertain nor have little impact on the results. Tornado charts assist in identifying these critical success drivers quickly and easily. Following this example, it might be that price and quantity should be simulated, assuming that the required investment and effective tax rate are both known in advance and unchanging.

	Base Value: 96.6261638553219			Input Changes		
Precedent Cell	Output Downside	Output Upside	Effective Range	Input Downside	Input Upside	Base Case Value
Investment	$276.63	($83.37)	360.00	$1,620.00	$1,980.00	$1,800.00
Tax Rate	$219.73	($26.47)	246.20	36.00%	44.00%	40.00%
A Price	$3.43	$189.83	186.40	$9.00	$11.00	$10.00
B Price	$16.71	$176.55	159.84	$11.03	$13.48	$12.25
A Quantity	$23.18	$170.07	146.90	45.00	55.00	50.00
B Quantity	$30.53	$162.72	132.19	31.50	38.50	35.00
C Price	$40.15	$153.11	112.96	$13.64	$16.67	$15.15
C Quantity	$48.05	$145.20	97.16	18.00	22.00	20.00
Discount Rate	$138.24	$57.03	81.21	13.50%	16.50%	15.00%
Price Erosion	$116.80	$76.64	40.16	4.50%	5.50%	5.00%
Sales Growth	$90.59	$102.69	12.10	1.80%	2.20%	2.00%
Depreciation	$95.08	$98.17	3.08	$9.00	$11.00	$10.00
Interest	$97.09	$96.16	0.93	$1.80	$2.20	$2.00
Amortization	$96.16	$97.09	0.93	$2.70	$3.30	$3.00
Capex	$96.63	$96.63	0.00	$0.00	$0.00	$0.00
Net Capital	$96.63	$96.63	0.00	$0.00	$0.00	$0.00

Figure A.20 – Sensitivity Table

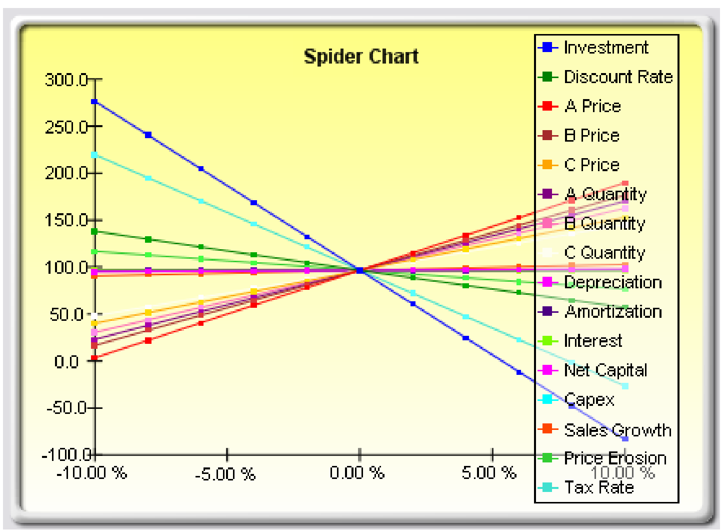


Figure A.21 – Spider Chart

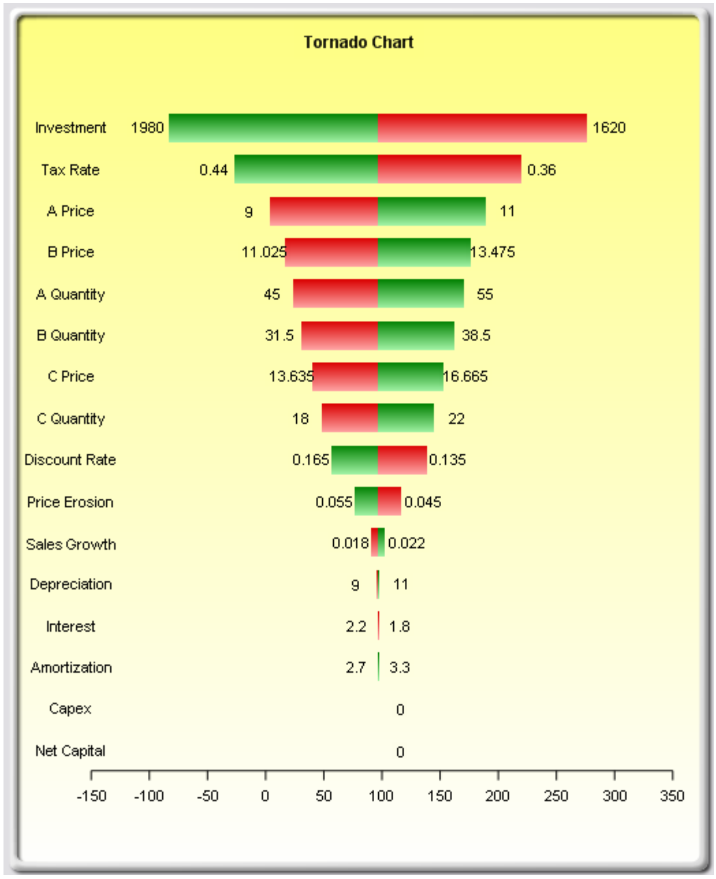


Figure A.22 – Tornado Chart

Although the tornado chart is easier to read, the spider chart is important for determining if there are any nonlinearities in the model. For instance, Figure A.23 shows another spider chart where nonlinearities are fairly evident (the lines on the graph are not straight but curved). The model used is located at *Risk Simulator | Example Models | 23 Tornado and Sensitivity Charts (Nonlinear)*, which uses the Black-Scholes option pricing model as an example. Such nonlinearities cannot be ascertained from a tornado chart and may be important information in the model or provide decision makers with important insight into the model's dynamics.

Figure A.18 shows the Tornado Analysis tool's user interface. Here are some tips on running tornado analysis and details on the new enhancements:

- Tornado analysis should never be run just once. It is meant as a model diagnostic tool, which means that it should ideally be run several times on the same model. For instance, in a large model, Tornado can be run the first time using all of the default settings and all precedents should be shown (select *Show All Variables*). The result may be a large report and long (and potentially unsightly) tornado charts. Nonetheless, this analysis provides a great starting point to determine how many of the precedents are considered critical success factors. For example, the tornado chart may show that the first 5 variables have high impact on the output, while the remaining 200 variables have little to no impact, in which case, a second tornado analysis is run showing fewer variables. For example, select the *Show Top 10 Variables* if the first 5 are critical, thereby creating a nice report and tornado chart that shows a contrast between the key factors and less critical factors. (You should never show a tornado chart with only the key variables. You need to show some less critical variables as a contrast to their effects on the output.) Finally, the default testing points can be increased from the ±10% of the parameter to some larger value to test for nonlinearities (the spider chart will show nonlinear lines and tornado charts will be skewed to one side if the precedent effects are nonlinear).
- *Selecting Use Cell Address* is always a good idea if your model is large, as it allows you to identify the location (worksheet name and cell address) of a precedent cell. If this option is not selected, the software will apply its own fuzzy logic in an attempt to

determine the name of each precedent variable (in a large model, the names might sometimes end up being confusing, with repeated variables or the names that are too long, possibly making the tornado chart unsightly).

- The *Analyze This Worksheet* and *Analyze All Worksheets* options allow you to control whether the precedents should only be part of the current worksheet or include all worksheets in the same workbook. This option comes in handy when you are only attempting to analyze an output based on values in the current sheet versus performing a global search of all linked precedents across multiple worksheets in the same workbook.
- Selecting *Use Global Setting* is useful when you have a large model and wish to test all the precedents at, say, ±50% instead of the default 10%. Instead of having to change each precedent's test values one at a time, you can select this option, change one setting, and click somewhere else in the user interface to change the entire list of the precedents. Deselecting this option will allow you the control to change test points one precedent at a time.
- *Ignore Zero or Empty Values* is an option turned on by default where precedent cells with zero or empty values will not be run in the tornado analysis. This is the typical setting.
- *Highlight Possible Integer Values* is an option that quickly identifies all possible precedent cells that currently have integer inputs. This function is sometimes important if your model uses switches (e.g., functions such as IF a cell is 1, then something happens, and IF a cell has a 0 value, something else happens, or integers such as 1, 2, 3, etc., which you do not wish to test). For instance, ±10% of a flag switch value of 1 will return a test value of 0.9 and 1.1, both of which are irrelevant and incorrect input values in the model, and Excel may interpret the function as an error. This option, when selected, will quickly highlight potential problem areas for

tornado analysis, and then you can determine which precedents to turn on or off manually, or you can use the *Ignore Possible Integer Values* function to turn all of them off simultaneously.

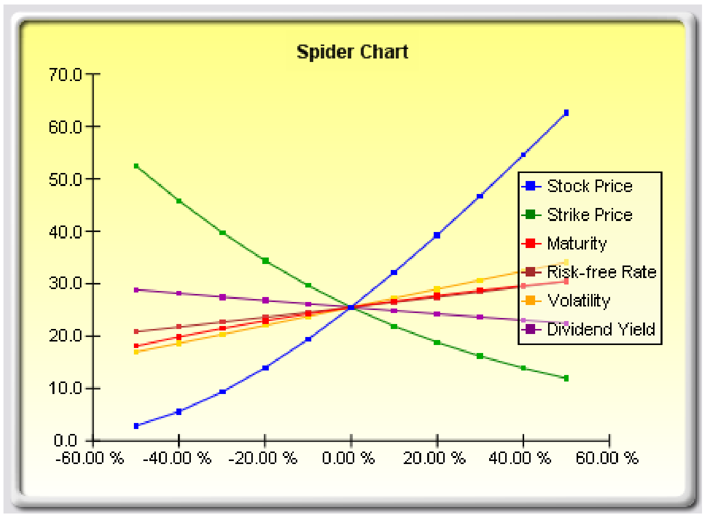


Figure A.23 – Nonlinear Spider Chart

Sensitivity Analysis

While tornado analysis (tornado charts and spider charts) applies static perturbations before a simulation run, sensitivity analysis applies dynamic perturbations created after the simulation run. Tornado and spider charts are the results of static perturbations, meaning that each precedent or assumption variable is perturbed a preset amount one at a time, and the fluctuations in the results are tabulated. In contrast, sensitivity charts are the results of dynamic perturbations in the sense that multiple assumptions are perturbed simultaneously and their interactions in the model and correlations among variables are captured in the fluctuations of the results. Tornado charts, therefore, identify which variables drive the results the most and, hence, are suitable for simulation, whereas sensitivity charts identify the impact to the results when multiple interacting variables are simulated together in the model. This effect is clearly illustrated in Figure A.24. Notice that the ranking of critical success drivers is similar to the tornado chart in the previous examples. However, if correlations are added between the assumptions, a very different picture results, as shown in Figure A.25. Notice, for instance, that price erosion had little impact on NPV, but when some of the input assumptions are correlated, the interaction that exists between these correlated variables makes price erosion have more impact.

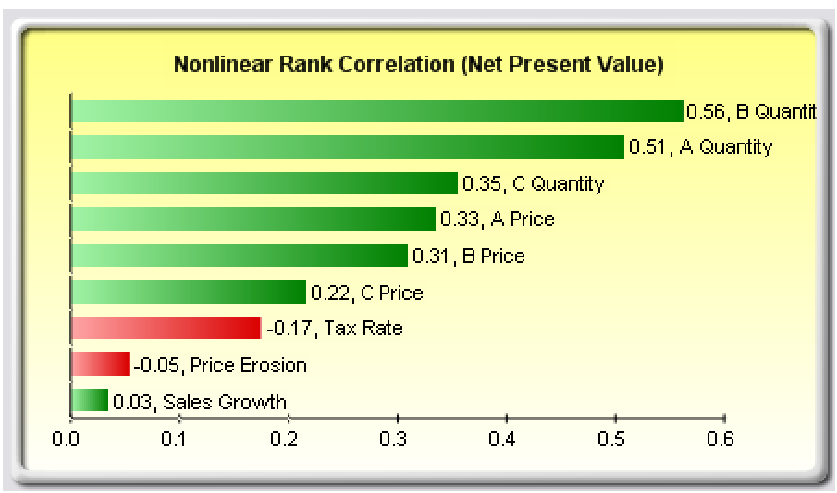


Figure A.24 – Sensitivity Chart Without Correlations

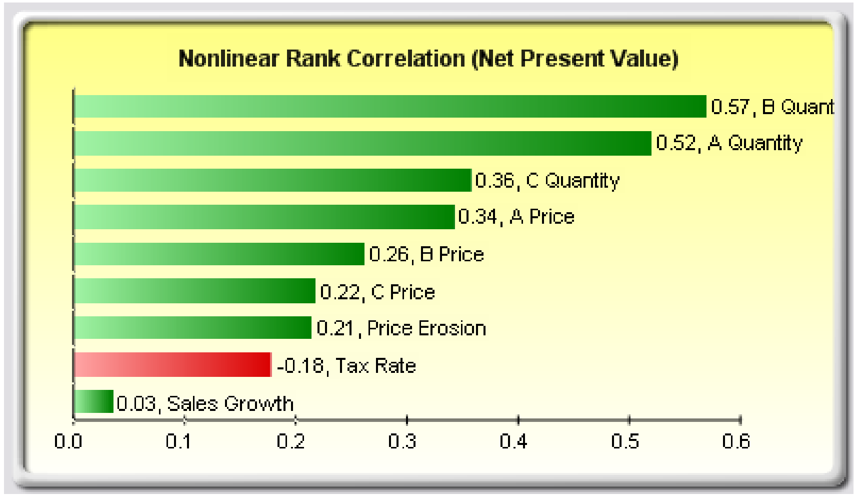


Figure A.25 – Sensitivity Chart with Correlations

Procedure

- Open or create a model, define assumptions and forecasts. If using the example model, open it from *Risk Simulator | Example Models | 22 Tornado and Sensitivity Charts (Linear)* and go to the *DCF Model* worksheet.
- Risk Simulator | R*un Simulation*.
- Select *Risk Simulator | Analytical Tools | Sensitivity Analysis*.
- Select the forecast of choice to analyze and click *OK* (Figure A.24).

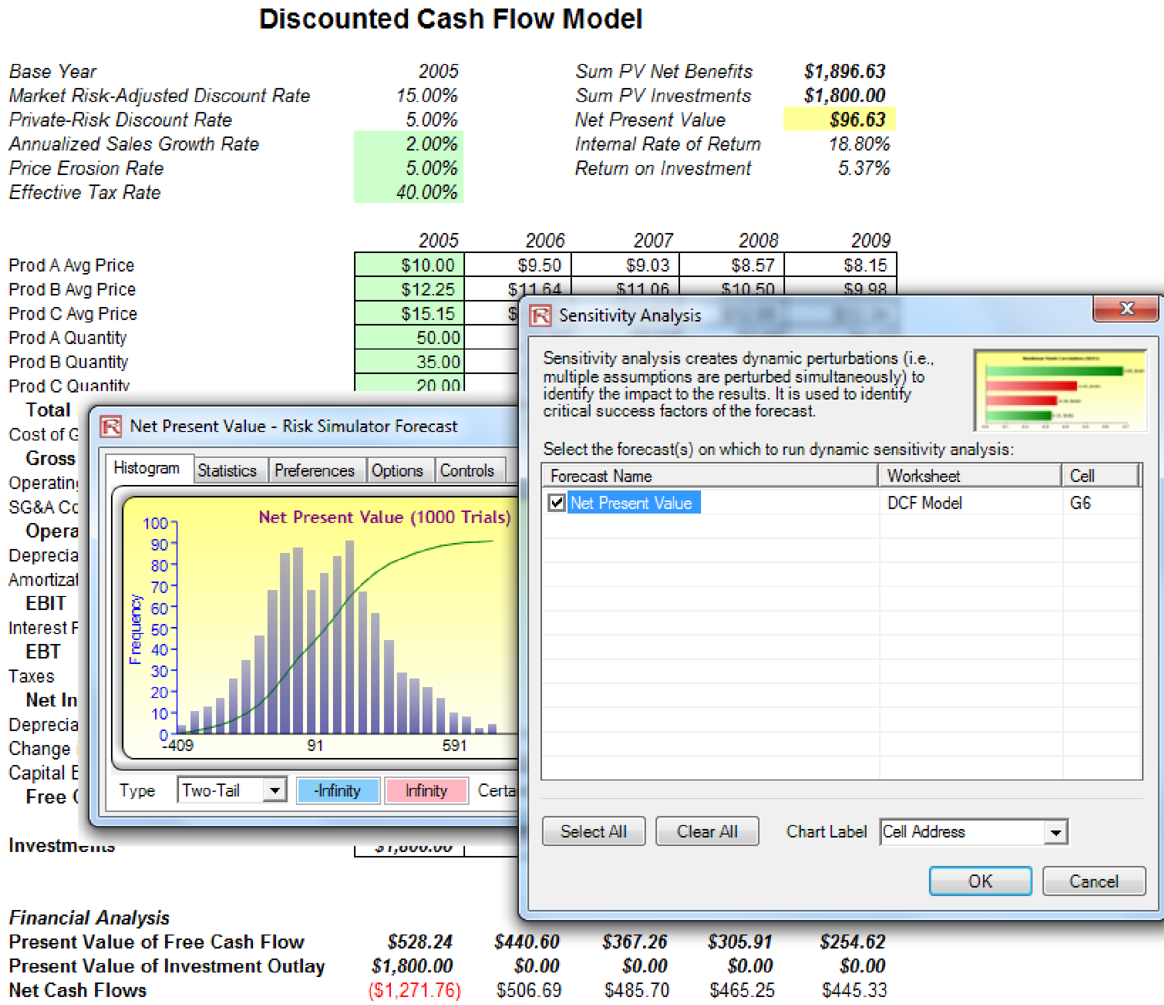


Figure A.24 – Running Sensitivity Analysis

The results of the sensitivity analysis comprise a report and two key charts. The first is a nonlinear rank correlation chart (Figure A.25) that ranks from highest to lowest the assumption-forecast correlation pairs. These correlations are nonlinear and nonparametric, making them free of any distributional requirements (i.e., an assumption with a Weibull distribution can be compared to another with a beta distribution). The results from this chart are fairly similar to that of the tornado analysis seen previously (of course, without the capital investment value, which we decided was a known value and, hence, was not simulated), with one special exception: Tax rate was relegated to a much lower position in the sensitivity analysis chart (Figure A.26) as compared to the tornado chart in the previous section. This is because by itself, tax rate will have a significant impact, but once the other variables are interacting in the model, it appears that tax rate has less of a dominant effect (because tax rate has a smaller distribution as historical tax rates tend not to fluctuate too much, and also because tax rate is a straight percentage value of the income before taxes, where other precedent variables have a larger effect on). This example proves that performing sensitivity analysis after a simulation run is important to ascertain if there are any interactions in the model and if the effects of certain variables still hold. The second chart (Figure A.26) illustrates the percent variation explained. That is, of the fluctuations in the forecast, how much of the variation can be explained by each of the assumptions after accounting for all the interactions among variables? Notice that the sum of all variations explained is usually close to 100% (there are sometimes other elements that impact the model but that cannot be captured here directly), and if correlations exist, the sum may sometimes exceed 100% (due to the interaction effects that are cumulative).

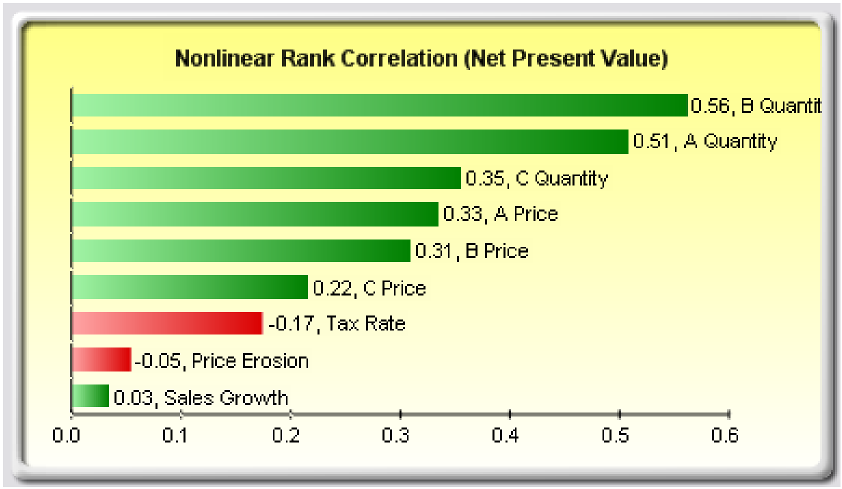


Figure A.25 – Rank Correlation Chart

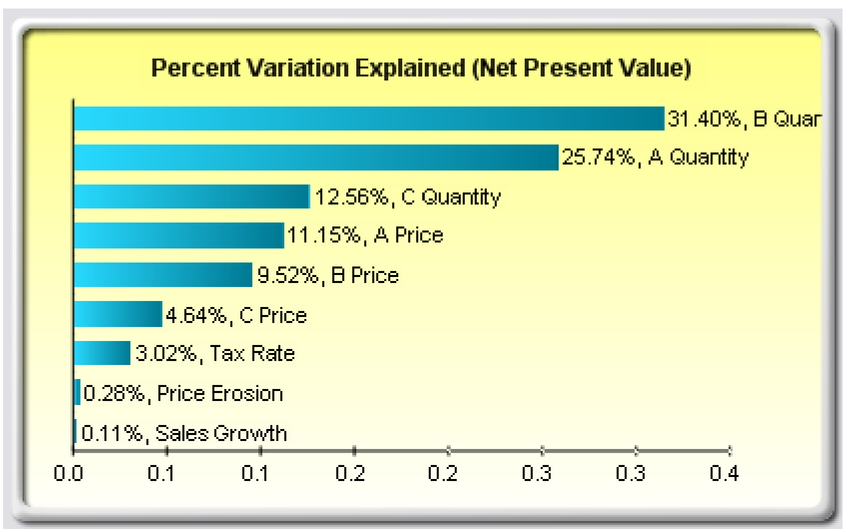


Figure A.26 – Contribution to Variance Chart

Data Extraction and Saving Simulation Results

A simulation's raw data can be very easily extracted using Risk Simulator's Data Extraction routine. Both assumptions and forecasts can be extracted, but a simulation must first be run. The extracted data can then be used for a variety of other analyses.

Procedure

- Open or create a model, define assumptions and forecasts or open the example model *Risk Simulator | Example Models | 07 DCF, ROI and Volatility* and go to the *Model* worksheet.
- *Risk Simulator | Run Simulation*.
- Select *Risk Simulator | Analytical Tools | Data Extraction*.
- Select the *assumptions* and/or *forecasts* you wish to extract the data from and click *OK*.

The data can be extracted to various formats:

- Raw data in a new worksheet where the simulated values (both assumptions and forecasts) can then be saved or further analyzed as required
- Flat text file where the data can be exported into other data analysis software
- Risk Simulator file where the results (both assumptions and forecasts) can be retrieved later by selecting *Risk Simulator | Analytical Tools | Data Open/Import*

The third option is the most popular selection, that is, to save the simulated results as a *.risksim file where the results can be retrieved later and a simulation does not have to be rerun each time. Figure A.27 shows the dialog box for extracting or exporting and saving the simulation results.

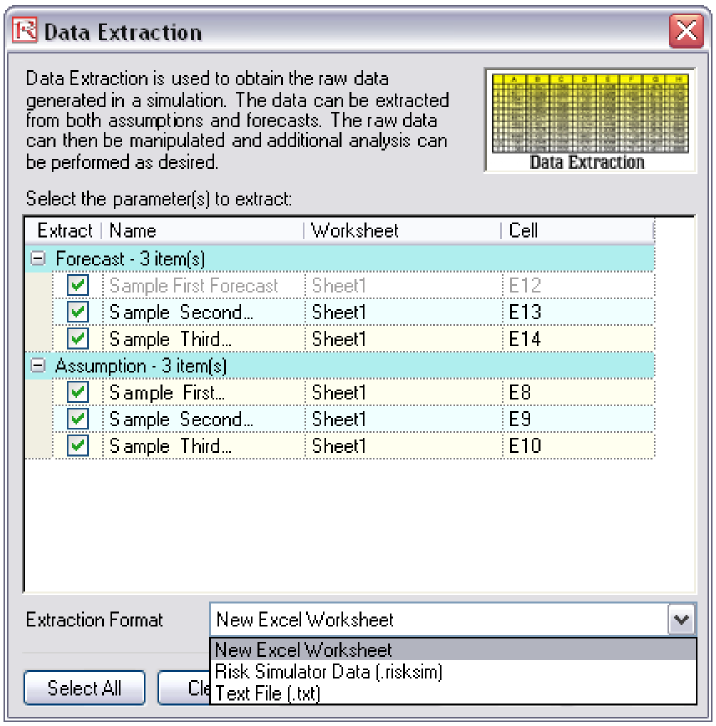


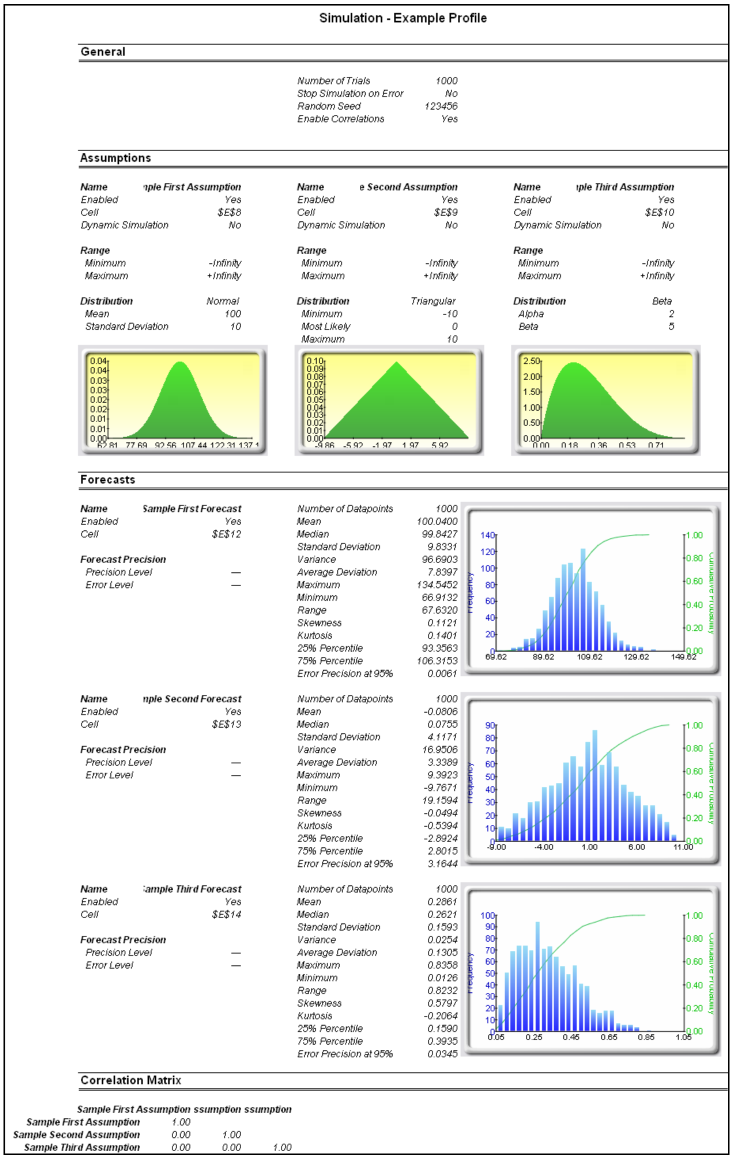
Figure A.27 – Sample Simulation Report

Create Report

After a simulation is run, you can generate a report of the assumptions and forecasts used in the simulation run, as well as the results obtained during the simulation run.

Procedure

- Open or create a model, define assumptions and forecasts or open the example model *Risk Simulator | Example Models | 07 DCF, ROI and Volatility* and go to the *Model* worksheet. Then, click on *Risk Simulator | Run Simulation*.
- Select *Risk Simulator | Create Report* (Figure A.28).



Simulation - Example Profile

General

Number of Trials	1000
Stop Simulation on Error	No
Random Seed	123456
Enable Correlations	Yes

Assumptions

Name	nple First Assumption	Name	e Second Assumption	Name	nple Third Assumption
Enabled	Yes	Enabled	Yes	Enabled	Yes
Cell	E8	Cell	E9	Cell	E10
Dynamic Simulation	No	Dynamic Simulation	No	Dynamic Simulation	No
Range		Range		Range	
Minimum	-Infinity	Minimum	-Infinity	Minimum	-Infinity
Maximum	+Infinity	Maximum	+Infinity	Maximum	+Infinity
Distribution	Normal	Distribution	Triangular	Distribution	Beta
Mean	100	Minimum	-10	Alpha	2
Standard Deviation	10	Most Likely	0	Beta	5
		Maximum	10		

Forecasts

Name	Sample First Forecast	Number of Datapoints	1000
Enabled	Yes	Mean	100.0400
Cell	E12	Median	99.8427
		Standard Deviation	9.8331
Forecast Precision		Variance	96.6903
Precision Level	—	Average Deviation	7.8397
Error Level	—	Maximum	134.5452
		Minimum	66.9132
		Range	67.6320
		Skewness	0.1121
		Kurtosis	0.1401
		25% Percentile	93.3563
		75% Percentile	106.3153
		Error Precision at 95%	0.0061

Name	nple Second Forecast	Number of Datapoints	1000
Enabled	Yes	Mean	-0.0806
Cell	E13	Median	0.0755
		Standard Deviation	4.1171
Forecast Precision		Variance	16.9506
Precision Level	—	Average Deviation	3.3389
Error Level	—	Maximum	9.3923
		Minimum	-9.7671
		Range	19.1594
		Skewness	-0.0494
		Kurtosis	-0.5394
		25% Percentile	-2.8924
		75% Percentile	2.8015
		Error Precision at 95%	3.1644

Name	ample Third Forecast	Number of Datapoints	1000
Enabled	Yes	Mean	0.2861
Cell	E14	Median	0.2621
		Standard Deviation	0.1593
Forecast Precision		Variance	0.0254
Precision Level	—	Average Deviation	0.1305
Error Level	—	Maximum	0.8358
		Minimum	0.0126
		Range	0.8232
		Skewness	0.5797
		Kurtosis	-0.2064
		25% Percentile	0.1590
		75% Percentile	0.3935
		Error Precision at 95%	0.0345

Correlation Matrix

	Sample First Assumption	ssumption	ssumption
Sample First Assumption	1.00		
Sample Second Assumption	0.00	1.00	
Sample Third Assumption	0.00	0.00	1.00

Figure A.28 – Sample Simulation Report

Scenario Analysis Tool

The Scenario Analysis tool in Risk Simulator allows you to run multiple scenarios quickly and effortlessly by changing one or two input parameters to determine the output of a variable. Figure A.29 illustrates how this tool works on the discounted cash flow sample model (Model 7 in Risk Simulator's Example Models folder). In this example, cell G6 (net present value) is selected as the output of interest, whereas cells C9 (effective tax rate) and C12 (product price) are selected as inputs to perturb. You can set the starting and ending values to test, as well as the step size, or the number of steps, to run between these starting and ending values. The result is a scenario analysis table (Figure A.30), where the row and column headers are the two input variables and the body of the table shows the net present values.

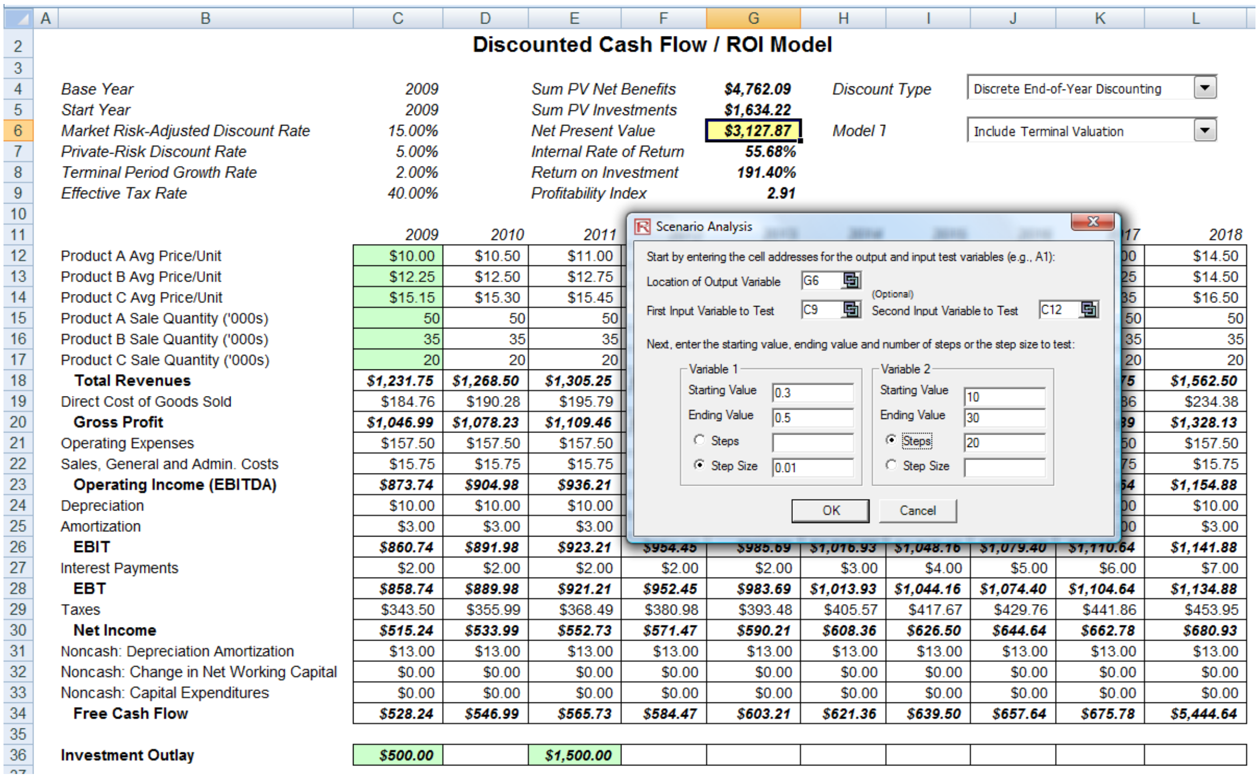


Figure A.29 – Scenario Analysis Tool

SCENARIO ANALYSIS TABLE

Output Variable:	G6	**Initial Base Case Value:**	$3,127.87					
Column Variable:	C12	**Min:** 10	**Max:** 30	**Steps:** 20	**Stepsize:** ---		**Initial Base Case Value:**	$10.00
Row Variable:	C9	**Min:** 0.3	**Max:** 0.5	**Steps:** ---	**Stepsize:**	0.01	**Initial Base Case Value:**	40.00%

	$10.00	**$11.00**	**$12.00**	**$13.00**	**$14.00**	**$15.00**	**$16.00**	**$17.00**	**$18.00**	**$19.00**	**$20.00**
30.00%	$3,904.83	$4,134.43	$4,364.04	$4,593.64	$4,823.24	$5,052.84	$5,282.44	$5,512.04	$5,741.64	$5,971.24	$6,200.85
31.00%	$3,827.14	$4,053.46	$4,279.78	$4,506.10	$4,732.42	$4,958.74	$5,185.06	$5,411.39	$5,637.71	$5,864.03	$6,090.35
32.00%	$3,749.44	$3,972.48	$4,195.52	$4,418.56	$4,641.61	$4,864.65	$5,087.69	$5,310.73	$5,533.77	$5,756.81	$5,979.85
33.00%	$3,671.75	$3,891.51	$4,111.27	$4,331.03	$4,550.79	$4,770.55	$4,990.31	$5,210.07	$5,429.83	$5,649.60	$5,869.36
34.00%	$3,594.05	$3,810.53	$4,027.01	$4,243.49	$4,459.97	$4,676.45	$4,892.94	$5,109.42	$5,325.90	$5,542.38	$5,758.86
35.00%	$3,516.35	$3,729.55	$3,942.76	$4,155.96	$4,369.16	$4,582.36	$4,795.56	$5,008.76	$5,221.96	$5,435.16	$5,648.36
36.00%	$3,438.66	$3,648.58	$3,858.50	$4,068.42	$4,278.34	$4,488.26	$4,698.18	$4,908.10	$5,118.03	$5,327.95	$5,537.87
37.00%	$3,360.96	$3,567.60	$3,774.24	$3,980.88	$4,187.53	$4,394.17	$4,600.81	$4,807.45	$5,014.09	$5,220.73	$5,427.37
38.00%	$3,283.27	$3,486.63	$3,689.99	$3,893.35	$4,096.71	$4,300.07	$4,503.43	$4,706.79	$4,910.15	$5,113.51	$5,316.88
39.00%	$3,205.57	$3,405.65	$3,605.73	$3,805.81	$4,005.89	$4,205.97	$4,406.06	$4,606.14	$4,806.22	$5,006.30	$5,206.38
40.00%	$3,127.87	$3,324.67	$3,521.48	$3,718.28	$3,915.08	$4,111.88	$4,308.68	$4,505.48	$4,702.28	$4,899.08	$5,095.88
41.00%	$3,050.18	$3,243.70	$3,437.22	$3,630.74	$3,824.26	$4,017.78	$4,211.30	$4,404.82	$4,598.35	$4,791.87	$4,985.39
42.00%	$2,972.48	$3,162.72	$3,352.96	$3,543.20	$3,733.45	$3,923.69	$4,113.93	$4,304.17	$4,494.41	$4,684.65	$4,874.89
43.00%	$2,894.79	$3,081.75	$3,268.71	$3,455.67	$3,642.63	$3,829.59	$4,016.55	$4,203.51	$4,390.47	$4,577.43	$4,764.40
44.00%	$2,817.09	$3,000.77	$3,184.45	$3,368.13	$3,551.81	$3,735.49	$3,919.18	$4,102.86	$4,286.54	$4,470.22	$4,653.90
45.00%	$2,739.39	$2,919.79	$3,100.20	$3,280.60	$3,461.00	$3,641.40	$3,821.80	$4,002.20	$4,182.60	$4,363.00	$4,543.40
46.00%	$2,661.70	$2,838.82	$3,015.94	$3,193.06	$3,370.18	$3,547.30	$3,724.42	$3,901.54	$4,078.66	$4,255.79	$4,432.91
47.00%	$2,584.00	$2,757.84	$2,931.68	$3,105.52	$3,279.37	$3,453.21	$3,627.05	$3,800.89	$3,974.73	$4,148.57	$4,322.41
48.00%	$2,506.31	$2,676.87	$2,847.43	$3,017.99	$3,188.55	$3,359.11	$3,529.67	$3,700.23	$3,870.79	$4,041.35	$4,211.91
49.00%	$2,428.61	$2,595.89	$2,763.17	$2,930.45	$3,097.73	$3,265.01	$3,432.29	$3,599.58	$3,766.86	$3,934.14	$4,101.42
50.00%	$2,350.91	$2,514.91	$2,678.92	$2,842.92	$3,006.92	$3,170.92	$3,334.92	$3,498.92	$3,662.92	$3,826.92	$3,990.92

	$21.00	**$22.00**	**$23.00**	**$24.00**	**$25.00**	**$26.00**	**$27.00**	**$28.00**	**$29.00**	**$30.00**
30.00%	$6,430.45	$6,660.05	$6,889.65	$7,119.25	$7,348.85	$7,578.45	$7,808.05	$8,037.65	$8,267.26	$8,496.86
31.00%	$6,316.67	$6,542.99	$6,769.31	$6,995.63	$7,221.96	$7,448.28	$7,674.60	$7,900.92	$8,127.24	$8,353.56
32.00%	$6,202.89	$6,425.94	$6,648.98	$6,872.02	$7,095.06	$7,318.10	$7,541.14	$7,764.18	$7,987.22	$8,210.26
33.00%	$6,089.12	$6,308.88	$6,528.64	$6,748.40	$6,968.16	$7,187.92	$7,407.68	$7,627.45	$7,847.21	$8,066.97
34.00%	$5,975.34	$6,191.82	$6,408.30	$6,624.79	$6,841.27	$7,057.75	$7,274.23	$7,490.71	$7,707.19	$7,923.67
35.00%	$5,861.57	$6,074.77	$6,287.97	$6,501.17	$6,714.37	$6,927.57	$7,140.77	$7,353.97	$7,567.17	$7,780.38
36.00%	$5,747.79	$5,957.71	$6,167.63	$6,377.55	$6,587.47	$6,797.39	$7,007.32	$7,217.24	$7,427.16	$7,637.08
37.00%	$5,634.01	$5,840.65	$6,047.30	$6,253.94	$6,460.58	$6,667.22	$6,873.86	$7,080.50	$7,287.14	$7,493.78
38.00%	$5,520.24	$5,723.60	$5,926.96	$6,130.32	$6,333.68	$6,537.04	$6,740.40	$6,943.76	$7,147.13	$7,350.49
39.00%	$5,406.46	$5,606.54	$5,806.62	$6,006.70	$6,206.79	$6,406.87	$6,606.95	$6,807.03	$7,007.11	$7,207.19
40.00%	$5,292.68	$5,489.49	$5,686.29	$5,883.09	$6,079.89	$6,276.69	$6,473.49	$6,670.29	$6,867.09	$7,063.89
41.00%	$5,178.91	$5,372.43	$5,565.95	$5,759.47	$5,952.99	$6,146.51	$6,340.03	$6,533.56	$6,727.08	$6,920.60
42.00%	$5,065.13	$5,255.37	$5,445.61	$5,635.86	$5,826.10	$6,016.34	$6,206.58	$6,396.82	$6,587.06	$6,777.30
43.00%	$4,951.36	$5,138.32	$5,325.28	$5,512.24	$5,699.20	$5,886.16	$6,073.12	$6,260.08	$6,447.04	$6,634.01
44.00%	$4,837.58	$5,021.26	$5,204.94	$5,388.62	$5,572.30	$5,755.98	$5,939.67	$6,123.35	$6,307.03	$6,490.71
45.00%	$4,723.80	$4,904.20	$5,084.61	$5,265.01	$5,445.41	$5,625.81	$5,806.21	$5,986.61	$6,167.01	$6,347.41
46.00%	$4,610.03	$4,787.15	$4,964.27	$5,141.39	$5,318.51	$5,495.63	$5,672.75	$5,849.87	$6,027.00	$6,204.12
47.00%	$4,496.25	$4,670.09	$4,843.93	$5,017.77	$5,191.62	$5,365.46	$5,539.30	$5,713.14	$5,886.98	$6,060.82
48.00%	$4,382.48	$4,553.04	$4,723.60	$4,894.16	$5,064.72	$5,235.28	$5,405.84	$5,576.40	$5,746.96	$5,917.52
49.00%	$4,268.70	$4,435.98	$4,603.26	$4,770.54	$4,937.82	$5,105.10	$5,272.38	$5,439.67	$5,606.95	$5,774.23
50.00%	$4,154.92	$4,318.92	$4,482.92	$4,646.93	$4,810.93	$4,974.93	$5,138.93	$5,302.93	$5,466.93	$5,630.93

Figure A.30 – Scenario Analysis Table

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