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NAVAL SURFACE WARFARE CENTER
Dahlgren, Virginia 22448-5100

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WHAT DOES (SHOULD) AN ANALYST DO?

A BRIEF INTRODUCTION FOR NEW ANALYSTS

BY DAVID A. CLAWSON

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David A. Clawson

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This document describes the tasks an analyst performs, outlines the methodology and practices of a good analyst, and underscores the analyst’s increasing responsibility and role in Navy decision-making. The report attempts to provide a broad overview of the kinds of tasks an analyst needs to be able to perform. It is not an exhaustive treatise on how to conduct analyses. The goal is to improve the quality of analysis by:

1. Moving away from a “turn-the-crank” analysis mentality by providing new analysts with a better understanding of what it takes to conduct an excellent analysis and by reinforcing the point that the goal of analysis is to provide insight, not numbers!
2. Helping new analysts (and their supervisors) identify training needs by highlighting the skills vital to a good analyst.

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FOREWORD

This report is intended to serve as a basic guide for the analyst in preparing for and functioning in that crucial role for Navy decision-making. While this document does not provide exhaustive detail on how to conduct analyses, it seeks to improve the quality of analysis by moving away from a mechanistic approach toward a better understanding of the principles that, put into practice, produce high-quality analysis—analysis that provides needed insight as opposed to numerical data alone. This report also provides guidance to both new analysts and their supervisors in identifying training that will build vital skills.

The author thanks Mses. Amanda Matthews, Elizabeth White, Sarah Healy, and Heather Murray for providing feedback from a new analyst's perspective, and Messrs. Mark Earnesty and George Durling for providing feedback from the not-so-new analyst's perspective. The author also acknowledges Mr. John B. Shipp III (Chief Scientist, Warfare Systems Department) for his thoughtful comments on the early draft of this paper. This document was reviewed by Anne M. Maliwauki, Head, Capability Definition & Analysis Branch.

Approved by:

DAVID S. RICHARDSON, Head
Warfare Systems Engineering &
Analysis Division

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

TABLES

GLOSSARY

AAW	Anti-Air Warfare
CIWS	Close-In Weapon System
MOEs	Measures of Effectiveness
Pk	Probability of Kill
PRA	Probability of Raid Annihilation
SUW	Surface Warfare

AXIOMS OF GOOD ANALYSIS

The following axioms are discussed in the text and are listed here for the convenience and guidance of the reader.

1. A good analyst takes the time to PEE (plan, execute, and explain). (See page 3.)
2. A good analyst works with the sponsor to ensure that the study will answer the right questions. (See page 4.)
3. A good analyst will provide the sponsor with the whole story. (See page 6.)
4. A good analyst will take time to write an analysis plan. (See page 7.)
5. A good analyst designs a simulation experiment to maximize the amount of information obtained from a limited set of runs and to provide a desired level of confidence in the results. (See page 10.)
6. A good analyst will have a plan for efficiently managing and organizing the flow of data associated with the study. (See page 14.)
7. A good analyst will assess input data for reasonableness, intuitiveness, and consistency. (See page 15.)
8. A good analyst asks “Why?” (See page 17.)
9. A good analyst effectively conveys findings and insights to others. (See page 23.)
10. A good analyst never stops learning. (See page 25.)

INTRODUCTION

What does an analyst do? A common misperception among nonanalysts (including some managers and sponsors) is that the analyst's job consists of three tasks: enter data into a computer, run a computer model, and provide tables or plots to summarize the numbers that the model spits out (see Figure 1). Unfortunately, the source of this misperception is all too often the "analysts" themselves. So perhaps a better question to ask is: What should an analyst do? This paper provides a fairly top-level discussion of the various tasks that a good analyst will undertake during the course of an analysis project. The intent here is NOT to provide an exhaustive treatise on how to conduct analyses, but to provide a broad overview of the kinds of tasks an analyst needs to be able to perform and to identify fundamental practices (referred to as axioms) that characterize a good analyst. The goal is to improve the quality of analysis by accomplishing two things:

1. Moving away from a "turn-the-crank" analysis mentality by providing new analysts with a better understanding of what it takes to conduct an excellent analysis and by reinforcing the point that *the goal of analysis is to provide insight, not numbers!*

2. Helping new analysts (and their supervisors) identify training needs by highlighting the skills vital to a good analyst.

Throughout my 30-year career, I have had the opportunity to work with many analysts from multiple laboratories and observe the practices that differentiate a good analyst from a not-so-good analyst. The material contained in this paper is based on those observations and on my experience as a senior analyst within the Warfare Systems Department.

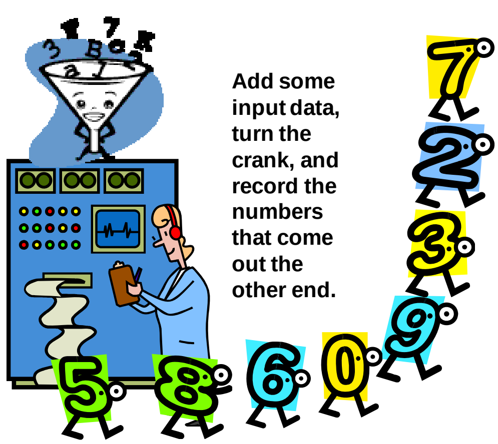

FIGURE 1. HOW SOME PERCEIVE THE ANALYST'S JOB

SO WHAT SHOULD AN ANALYST DO?

Contrary to what some believe, there is more to the analyst's job than just "turning the crank" – a whole lot more. Figure 2 lists some of the tasks that an analyst may perform during the course of an analysis project. You should take away at least four important pieces of information from this figure.

1. There are three phases of analysis identified: a planning phase, an execution phase, and an "explanation"[1] phase. Each is an equally important part of the total analysis.
2. Each phase consists of multiple tasks. Note that "turn the crank" is indeed part of the job, but not the only part.
3. In general, the three phases are performed serially, so it will be necessary to complete all the tasks in one phase before proceeding to the next phase.
4. The analysis process is typically an iterative one. Work done in one of the phases may raise issues or questions that must be addressed and cause the analyst to revisit work performed either in a previous phase or earlier in the current phase.

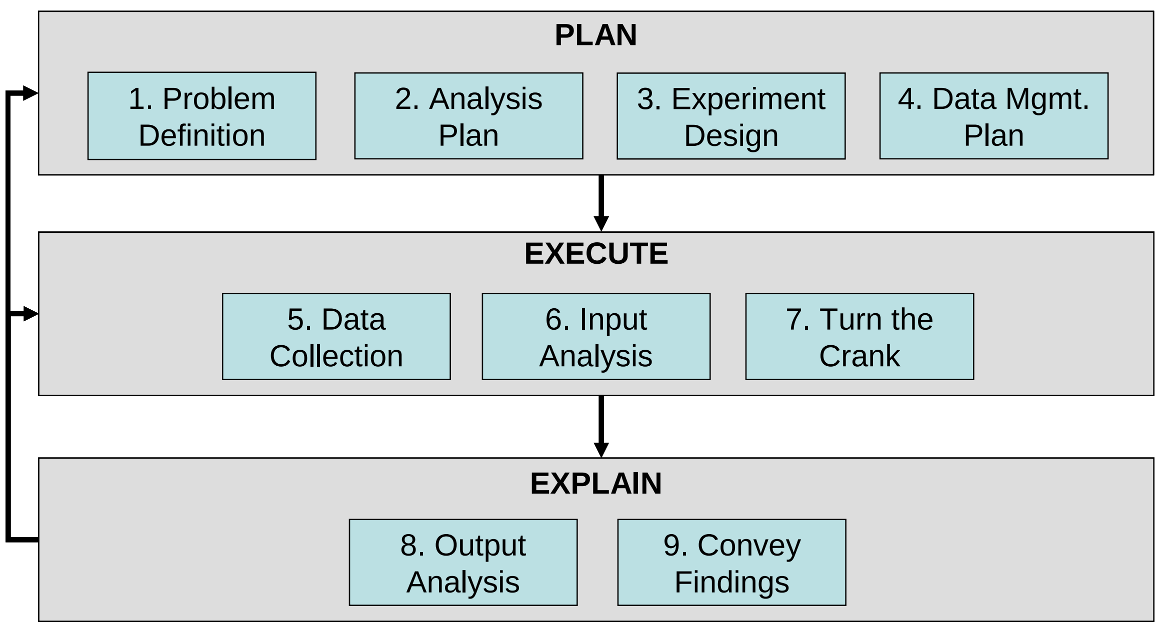

FIGURE 2. ANALYSIS PHASES AND TASKS

[1] The term "explanation" is used in place of the more common "documentation" to place emphasis on the need to explain what the data means vice what too often is simply the documentation of what was done and the regurgitation of output data. This will be further discussed later in the paper.

If this looks like a lot of work, you're right! Good analysis, though, requires it. The good news is that as you gain experience with each of these tasks, you will become more efficient and be able to complete them more quickly. The key is to take the time to **P**lan, **E**xecute, and **E**xplain, which leads to our first Axiom of Good Analysis:

Axiom 1

A good analyst takes
the time to PEE.

In the remaining sections of this paper, we'll take a look at each analysis phase in slightly more detail.

PLAN

The planning phase lays the foundation for the analysis. It is often tempting to skip this phase or to give the tasks only cursory consideration, but experience teaches that you short-change the planning phase at your own risk!

During the planning phase of an analysis, at least four tasks need to be completed: define the problem, write the analysis plan, design the experiment, and formulate a data management plan.

TASK 1: DEFINE THE PROBLEM

Axiom 2

A good analyst works with the sponsor to ensure that the study will answer the right questions.

The first task is extremely important, yet surprisingly, it is often omitted by new analysts. The purpose of this task is to ascertain the question(s) to be answered, and to define the scope of the study.

Ascertaining the questions to be answered is an extremely important first step in any analysis. No sponsor will be happy with an analysis, regardless of how thorough it is or how expertly it was conducted and documented, if it fails to answer the questions of interest.

To ascertain the questions to be answered, the analyst must determine what the sponsor is after and how the results will be used. Let’s illustrate this process with a simple example.

Suppose your sponsor asks you to simulate two different combat system configurations for a particular class of ships: one including the Close-In Weapon System (CIWS) and one without the CIWS. Do you run off to make the requested runs, or are there some questions that you would like answered prior to proceeding?

> Exercise 1: Before reading further, write down several questions you would ask the sponsor.

Depending on your experience and how much you know about CIWS, you may have thought of several good questions to ask the sponsor, but three important questions are:

1. For the "without CIWS" case, do you want both the radar and the gun removed, or just the gun?
2. Do you want all CIWS systems removed or just one? Which one?
3. For what do you intend to use the results?

The third question listed above is perhaps the most important question the analyst can ask the sponsor, and the answer must be obtained before formal planning can begin. Why? Because analysis designed for one purpose may not be valid or sufficient for another.

> Exercise 2: Below are two possible responses to the third question. How might an analysis designed to address the first response differ from one designed to address the second response?
>
> *Response 1: I need to know if the ship can meet its Anti-Air Warfare (AAW) self-defense requirement if CIWS goes down.*
>
> *Response 2: I need to know if I can remove CIWS from the ship without a significant impact to the ship's self-defense capability.*

> *"Analysis designed for one purpose may not be valid or sufficient for another."*

It may appear that both responses say the same thing and that an analysis designed to address one will also address the other, but, in reality, there may be significant differences. An analysis that addresses the first response would compare how well the ship can defend itself against AAW threats when CIWS is functioning properly and when it is down. In contrast, when the sponsor is considering removing a system from a ship, the analyst must consider ALL possible impacts of losing that system. In this case, not only should the analyst assess the impact on AAW, but she also needs to assess the impact on Surface Warfare (SUW).[2] If the sponsor were to pull CIWS off the ship based on an AAW-only analysis, he may regret that decision upon discovering that SUW capability is significantly degraded.

It's important to understand that the sponsor may have framed Response 1 or 2 only in terms of AAW, but it is the analyst's responsibility to make the sponsor aware of ALL *significant* effectiveness impacts when considering the removal of a system. Discussions with subject matter experts will help the analyst identify these impacts.

This last point can be generalized: The analyst is duty-bound to provide the sponsor with the whole story. So, for example, the analyst should inform the sponsor of a system's "Achilles' heel" (e.g., radar XYZ may perform very well in an open-ocean environment, but is nearly useless near land) even if the limitation is not brought out in the main portion of the study. Sometimes studies are narrowly focused. If an inference can be drawn from the study that is not broadly applicable beyond the study's scope, then you need to caveat the results appropriately and inform the sponsor, and any relevant information you have, regardless of whether it is derived from the study, should be provided to the sponsor. This is such an important point that it qualifies as an axiom of good analysis.

Axiom 3

A good analyst will
provide the sponsor with
the whole story.

Once the questions to be answered have been clearly defined, the analyst needs to determine the appropriate scope of the analysis. Questions that need to be asked include: Which threats should be considered? Which ship classes and combat systems will be examined? Is a single-ship analysis appropriate or should a multiship battle group be considered? What year will the battle be set in? Which environments and geographic locations will be used? It may be necessary to negotiate the scope of the analysis with the sponsor – especially if the sponsor would like to see a much broader scope than can reasonably be accommodated in the time allotted to the study.

[2] CIWS can be used against surface threats as well as air threats.

TASK 2: WRITE THE ANALYSIS PLAN

Axiom 4

A good analyst will take time to write an analysis plan.

The previous task identified the question(s) to be answered. In this task, you determine how you will go about answering the question(s), and you will put your plan on paper. Writing an analysis plan can be quite time consuming and tends to be one of the least favorite tasks the analyst needs to perform (another is writing the final report). In fact, it is not unusual to find that no formal analysis plan exists. So, why should you take the time to write an analysis plan? Because it will help you to:

1. *Think through the problem*. Figure 3 contains some sample topics for a general analysis plan. In the course of developing your plan, you will need to answer many questions, such as: How will you approach the problem? Do you already have data that can be used to answer the question? Will a simple graph answer the question? Will you need to run a model? Which model(s) will you use? What assumptions will need to be made? Do you need to generate any input data? How will the data be generated? Who will do it? Does the data have to be approved? By whom? What are the appropriate measures of effectiveness? How will you display the results? How long will the analysis take? How much will it cost? Who will be working on the study? Are they available when needed? By answering these and other questions, you will greatly increase your understanding of the problem at hand.

2. *Obtain feedback and buy-in from your sponsor and your analysis team.* It is never a good idea to plan and execute an analysis in a vacuum. If you do, you may be unpleasantly surprised at your briefout when your sponsor tells you that your approach is flawed, or that your major assumption is incorrect, or that you failed to consider a factor that he thinks is very important. You may be further embarrassed when one of your team members announces that a small change in one of the radar parameters would have changed the study results considerably. It is very important that you keep your sponsor and team informed throughout the analysis process, and it is just as important that you receive feedback from them. Obtaining buy-in and keeping everyone informed will greatly increase the likelihood of producing a high-quality analysis and having a satisfied sponsor at

the end of the study. The discussions you have during the development of the analysis plan will start you off on the right track.

3. *Identify issues EARLY in the process.* As with any other process, the earlier you identify issues, the easier (and, often, the less expensive) it is to address them. The process of writing the analysis plan will help you identify issues and thereby allow you time to speak with others on the matter and come up with a solution or a backup plan.

Sample Topics

- **Purpose of the analysis**
  - **What's the question?**
  - **Who's asking and why?**
- **Study Scope & Key Assumptions**
  - **Timeframes, Locations, Single vs. Multi Ship, etc**
  - **Systems included or excluded from the study**
  - **Red & Blue capabilities assumed (e.g., perfect ID, etc.)**
- **Measures of Effectiveness (MOEs)**
- **Products/Deliverables**
- **Top-level approach**
  - **The process used to answer the question**
- **Models to be used**
  - **What will each model generate and what does it feed?**
- **Data needs & data collection plan**
  - **What data do you need, and where will you get it?**
  - **Does any data need to be generated? By who?**
  - **Does data need to be approved/blessed/released? By who?**
- **Potential issues and solutions**
  - **Backup plan if unable to obtain data in time to meet schedule**
  - **Resource issues**
- **Schedule**
- **Cost**

FIGURE 3. SAMPLE TOPICS FOR AN ANALYSIS PLAN

The best way to learn how to develop an effective analysis plan is to practice. As a new analyst, you should take time to write one for every study/project you are assigned. Even if the project is relatively simple and the plan is a page long, it will still be worth doing. Here are a few points to keep in mind as you plan:

1. The scope and approach should be commensurate with schedule and funding. If you are given 1 week and $10,000, then give your sponsor a $10,000 answer. If you are given 1 year and $10,000,000, give your sponsor a $10,000,000 answer. In all cases, make sure that your sponsor knows what he is getting for his money and what he is not.

2. Begin by thinking about what the answer to the question might look like rather than thinking about how to use your favorite model. Will a simple Pk curve answer the question? A simple timeline? Or is something more complex

needed? What are the major measures of effectiveness? What are the major independent variables?

3. Once you better understand what the output needs to be, you can think about the best way of generating it. You should try to use the simplest approach/model available to you that is adequate for the job at hand. Can existing data or results from previous work be used? If not, will simple "back-of-the-envelope" calculations be sufficient? Will you need to build a spreadsheet model, or perhaps create a simple timeline based on constant-speed weapons and threats? If the simpler approaches cannot capture important features of the problem, or the problem is too complex, you may need to run a simulation. In some cases, one or more high-fidelity simulations may also need to be run (e.g., a high-fidelity radar or missile model).

4. If you determine that a simulation needs to be run, spend some time thinking about which simulation to run. Some factors to consider: the required fidelity, the availability of the model and of personnel trained to run it, and the credibility of the model. Do not limit your thinking to tools located only within your own branch. You may find that the best tool for the job is located in another branch, division, or department. In many case, it will be appropriate (even necessary) to use tools that reside in different labs.

5. Try to keep the plan UNCLASSIFIED and top-level. You want to be able to discuss the plan via e-mail or over the phone, and it needs to be easily understood by your sponsor who may not be trained as an analyst.

6. If you are working with a team, get them involved in the process. Solicit their feedback on the overall plan and ask them to contribute to sections related to the areas in which they will be working. They will be your best source of information for cost and schedule estimates.

REALITY CHECK

Don't be surprised when your study doesn't run according to plan. You cannot be expected to foresee and plan for EVERY possible contingency, but going through the process of preparing an analysis plan may help you identify and plan for some of them. The reality, though, is that it is not unusual for a study schedule to change or an approach to be modified after the study begins. Try to remain flexible, and make sure you keep your sponsor informed of MAJOR changes.

TASK 3: DESIGN THE EXPERIMENT

Axiom 5

A good analyst designs a simulation experiment to maximize the amount of information obtained from a limited set of runs and to provide a desired level of confidence in the results.

If you use a simulation to generate data for analysis, you are essentially running a computer-based statistical sampling experiment, and as observed in the preeminent text on modeling and simulation, "if the results of a simulation study are to have any meaning, appropriate statistical techniques must be used to design and analyze the simulation experiments."[3] The design of experiments is one of the most powerful but least utilized tools in the analyst's toolbox. What is experimental design? Simply put, it is the application of probability and statistics to:

1. Determine, before runs are made, which set of runs to make in order to obtain the desired information with the least amount of simulating.

2. Ensure that a desired level of confidence in the results is achieved.

Most analysts understand the benefit of reducing the number of runs, but the benefits of achieving a specified confidence in the results are not as well understood, and reporting of confidence levels is rarely included in study documentation. In fact, it would not be surprising to find that the lead analyst has no idea of the confidence level associated with his or her findings. So, is experimental design really useful or important? Let's consider an example for each of the two design goals listed above.

Example 1: Reducing the number of runs

Suppose your task is to assess the impact of ten different factors on the performance of the combat system and that each factor can be assigned one of two values (e.g., a current and improved detection range, weapon selection policy A or B, auto vice semi-auto operating mode, etc.). An inexperienced analyst might approach this problem by running the simulation once with all ten

[3] Law and Kelton, *Simulation Modeling and Analysis*, Third Edition, McGraw Hill, 2000, p.496.

factors set to their lowest value or “level” and then running ten more cases – setting one factor at a time to its highest level while holding the remaining factors at their lowest level. To estimate the impact of one of the factors, the analyst would then compare the result when all factors are set to their lowest level to the result when that particular factor is set to its highest level.

This would not be a bad approach except for one important detail: the one-at-a-time approach is not valid when there are important interactions between the factors (and there usually are). Table 1 illustrates how two factors, operating mode and detection range, might interact. Note how, in this example, the effect of an improved detection range is much greater when the system is operated in a semi-automatic mode. A “one-at-a-time” approach in which operating mode is fixed at “fully automatic” might conclude there is no benefit to improving detection range when, in fact, the longer detection range allows the ship to operate in the safer semi-automatic mode while maintaining an excellent self-defense capability.

When factors interact, the factor levels must be varied simultaneously to capture the interaction effects – not one at a time. For a small number of factors and factor levels, this may not be a problem, but for the 10-factor example considered here, we would have to run 2^{10} = 1024 cases to examine all possible factor combinations. Fortunately, experimental design techniques show us how to obtain good estimates of the10 main effects (i.e., the individual factors) and the 45 two-way interactions (such as the interaction between detection range and operating mode) in just 128 runs. As you might suspect, not just any 128 runs will do. Instead, a specific set of 128 runs, which the design techniques will identify for you, must be used.

TABLE 1. EXAMPLE OF A TWO-WAY INTERACTION

Operating Mode	Detection Range	Probability of Raid Annihilation
Fully Automatic	Current	0.93
	Improved	0.95
Semi Automatic	Current	0.70
	Improved	0.95

Example 2: Achieving a desired confidence

Assume you've been asked to determine whether a particular ship meets its Probability of Raid Annihilation (PRA) requirement of 0.90 against a specific threat. You have decided to estimate PRA by replicating the battle 100 times via simulation and computing the proportion of replications in which the raid is annihilated. So, for example, if the raid is annihilated in 80 of the 100 replications, then PRA is estimated to be 0.80. You also decide to accept the proposition that the ship meets its PRA requirement if the estimated value of PRA is at least 0.90; you will reject the proposition if estimated PRA is less than 0.90. This seems to be a reasonable approach and is not atypical of studies we have seen, but now let's assume that the true, but unknown, value of PRA is exactly 0.90. What is the probability that you will make the right decision and accept the proposition in this case? You may be surprised to learn that a simple calculation shows the probability of making the correct decision using the approach outlined above is 0.58 – a little better than just flipping a coin. [4]

Let's consider a second approach. After a brief discussion with your sponsor, you learn that she would like to be at least 95% confident that the correct decision is made. In addition, in exchange for a significant savings in run time, she is willing to accept the possibility that the ship will be accepted as having met the 0.90 requirement even though actual PRA is as low as 0.85, but if PRA is less than 0.85 it MUST be rejected. With this information in hand, you apply some basic probability theory to determine your approach.[5] Your calculations tell you to estimate PRA by replicating the battle 474 times and, if the estimate is at least 416/474 ~ 0.878, you will accept the proposition that the ship meets the requirement. Based on this approach, you and your sponsor can be at least 95% confident that the correct decision (accept or reject) will be made if actual PRA is at least 0.90 or is less than 0.85. What happens if actual PRA is between 0.85 and 0.90? In that case the probability of incorrectly accepting the proposition that the ship meets the requirement may be quite high, but at least you and your sponsor are aware of the risk and have already discussed whether it is acceptable.

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[4] This result is obtained by calculating the probability of obtaining at least 90 "successes" in 100 independent trials when the probability of "success" on any one trial is 0.90:

$\sum_{i=90}^{100} \frac{100!}{i!(100-i)!} \cdot 0.9^{i} \cdot 0.1^{100-i}$. Software with a built-in Binomial Distribution function makes this an easy calculation.

[5] Alternatively, you can look up the data you need in *Controlling the Probability of Misclassification in Simulation-Based Assessments of the Probability of Raid Annihilation (PRA)*, by David A. Clawson, NSWCDD/TR-05/13, February 2005, Naval Surface Warfare Center, Dahlgren Division, Dahlgren, Va.

The last example provides an excellent illustration of why it's not necessarily a good idea to use a "tried and true" approach without questioning its suitability for your particular problem. Why are you running 100 replications or considering just those two particular environments? Is it because "that's what we've always done"? Even if it turns out that 100 replications and two environments are adequate for your task (and that's a big "if"), is that the answer you want to give your sponsor? Far better to be able to say "I ran 325 replications because there is less than a 5% chance that running more replications will change the result significantly, and I chose these two environments because they will bound the results for this system." Do not blindly adopt the parameter values from previous studies. They may not be valid or sufficient for your study.

WARNING: Do not confuse a simulation with the real world.

The discussion above talks about estimating the "actual" value of PRA via simulation. However, it is extremely important that the analyst and sponsor bear in mind that a simulation is just a representation of the real world. The degree to which results from a simulation reflect real-world performance depends on many factors, including:

1. ***Whether the simulation models all factors (and their interactions) that will have a significant impact on real-world performance***
2. ***How accurately the simulation represents all the real-world environments and systems it models***
3. ***Whether all the data are entered correctly into the simulation***
4. ***Whether the simulation has been properly coded***

A failing in any one of these areas could produce results that are significantly different from what would happen in the real world. The statistical techniques discussed above will not protect you from these kinds of errors. So when we say, for example, that we are at least 95% confident that the correct decision will be made, we mean that that there is less than a 5% chance that the decision will change if additional replications were to be run. It does NOT imply that actual, real-world, performance has been estimated with 95% confidence. Similarly, "actual PRA" refers to PRA in the <u>simulated</u> world, which may be significantly different from PRA in the real world. Making assertions about real-world system performance requires a model that is verified and validated for the given scenario.

TASK 4: DEVELOP A DATA MANAGEMENT PLAN

Axiom 6

A good analyst will have a plan for efficiently managing and organizing the flow of data associated with the study.

During the course of your study, you will generate and receive data, including input and output data, e-mails, the statement of work, the analysis plan, notes from telephone conversations, meeting notes, briefing material, schedules, and interim reports. The amount of data you have to deal with can be overwhelming, and you should consider how to organize it. Your goal is to be organized in such a way as to minimize the time spent looking for a piece of information and reducing the rework caused by accidentally using an “old” piece of data.

Some questions to consider include: How will you handle classified data? Do you need to establish a file-naming convention? What file structure will help you quickly locate the data you need? What kind of configuration control process will be used to manage draft reports, draft presentations, changing versions of software, updates to input/output and system data, etc.? How will you distribute updated/corrected data to the rest of the team? How can you be confident that everyone is using the same (most current) data?

Not everyone is a natural organizer. If you have difficulty in this area, you may need to get some help, so don’t be afraid to ask.

EXECUTE

The execution phase of the analysis contains the tasks most people associate with an analysis job: collecting data and turning the crank on a simulation. But this phase also includes a necessary task that must occur between these two: input analysis.

TASK 5: DATA COLLECTION

If you've followed the recommendations, you already have a data collection plan. Now is the time to put the plan into action. During the planning phase, you've determined what data you need, who will supply it, and when you will receive it. It is hoped that you also had discussions with the people responsible for generating the data, and they have agreed to the tasking and schedule. If the schedule starts to slip, you may even have a backup plan in your back pocket. The time you have spent in upfront planning should now pay dividends by reducing the number of surprises you will confront.

TASK 6: INPUT ANALYSIS

Axiom 7

A good analyst will assess input data for reasonableness, intuitiveness, and consistency.

There are two types of data an analyst must examine: input data and output data. Many new analysts fail to consider the input data as part of the analysis process. Yet an understanding of and a familiarity with the input data are vital prerequisites to output analysis. To understand the output, you must first understand the input.

"To understand the output, you must first understand the input."

When you receive a set of input data, you should review it carefully. Some questions to ask include:

1. *Is the data reasonable?* Even if you are not an expert in a particular area, you should still be able to determine if the data are extreme or even incorrect. Probabilities should be between zero and one. Detection range is not likely going to be measured in the thousands of miles.

2. *Is there anything in the data that appears to be counterintuitive?* For example, does the probability of kill data indicate worse performance for a slow, nonmaneuvering target than for a fast maneuvering target? Counterintuitive data isn't necessarily incorrect, but you should question it. If the data turns out to be correct, you will at least have learned the cause of the aberrant behavior.

3. *Is the data consistent with other data you've seen?* If you've seen data for the same or a similar system in the past, does the new data seem to fit in, or is it significantly different? Again, inconsistency does not necessarily imply the data is wrong. For example, it could be that our knowledge of the system or threat has changed, so the new data better represents our latest understanding. The key is to question inconsistent data and determine whether or not it is correct.

4. *What does the data tell you about the system?* What inferences can you reasonably make? Understanding the capabilities and limitations of the system elements is key to explaining overall combat system performance. For example, knowing that the input data shows the primary sensor has a problem in environment X will help you explain why the combat system performed poorly in that environment.

5. *Is the data in the appropriate format?* Your data collection plan should have specified the units to be used and the file format. Confirm that what was delivered meets the specification.

TASK 7: TURN THE CRANK

At this point in the process, the model has been modified as necessary, and you've received and assessed the input data (and resolved any inconsistencies). It's now time to "turn the crank" on the model and generate the output data. Remember to run the simulation experiment according to your design to achieve the desired confidence in the estimates.

EXPLAIN

This phase of the analysis is more typically referred to as the Documentation or Reporting stage. These terms, however, do not convey the most important aspect of analysis. It is not unusual to see study reports that do a good job of summarizing the study approach, major assumptions, and simulation output but make no attempt to explain the results. If you take away only one point from this paper, this is the one it should be: The goal of analysis is to provide insight, not numbers! The tasks that make up this phase, "Output Analysis" and "Relate Findings," will help you do just that.

> *"...the goal of analysis is to provide insight, not numbers!"*

TASK 8: OUTPUT ANALYSIS

Axiom 8

A good analyst asks "Why?"

It is during the Output Analysis task that you begin to put enough data together to be able to answer your sponsor's questions. By organizing and looking at your output data in different ways, you should be able to formulate the answers. Does the data support the argument that System B is better than System A? Sometimes the answer will be clear. For example, if the probability of raid annihilation is 0.20 with System A and is 0.95 with System B, then System B appears to be the clear winner. In other cases, the answer may be more complex. For example, System B may be better against some threats, but System A is better against other threats. Just be sure to lay out all the facts for your sponsor. She is the one who will have to make the final decision. It is your job to provide her with the insights she needs to make an informed decision. This is why it is so important that you go beyond providing simple answers to questions or a table of numbers. You must also examine the output to discover what it can tell you about the fundamental processes that drive the answer to your sponsor's question.

To uncover the insights in your data, you must be willing to ask “Why?” Without a doubt, this is the most important question an analyst can ask: Why does my data look this way? Why did the results turn out as they did? Why was there such a big improvement? Why was there no improvement? Why did things get WORSE when we expected them to get better? Your sponsor may have asked you to determine whether System B is better than System A, but a simple yes/no answer is not sufficient. She also needs to know why System B is better than System A, or why System B can defeat Target X but is ineffective against Target Y.

The skill of uncovering insights that are important to your sponsor is one that separates really good analysts from mediocre analysts, and like any other skill, it is one you can develop through practice and study. To give you a sense of how an analyst might go about answering the all-important question “Why?” let’s consider the following example that is based on an actual analysis.

Analysis Example

The Bigger-Is-Better manufacturing company has proposed a new radar, the Eye of God (EoG), for use on Armageddon class of ships. The Office of the Chief of Naval Operations (OPNAV) is interested in the radar but wants to know if it really provides added value.

Your analysis plan called for running a baseline case with the current Armageddon sensor suite and a second case in which the new sensor replaces the existing sensor. You have selected 90% Firm-Track Range (FTR) and Probability of Raid Annihilation (PRA) as the primary Measures of Effectiveness (MOEs). The results are given in the Table 2 below.

TABLE 2. SIMULATION RESULTS

MOE	With Current Radar	With EoG
90% FTR (Nautical Miles)	11	50
PRA	0.90	0.65

As you review the simulation results, you see that the EoG almost quintuples the range at which the target enters track. This is definitely a significant improvement over the current radar. Your enthusiasm is dampened, however, when you note that not only is there no improvement in the probability of raid annihilation, but PRA actually decreased significantly! Because you are an excellent analyst, you ask yourself an extremely important question: Why did PRA drop significantly even though firm-track range increased?

How do you go about answering this question? There is no simple “one-size-fits-all” answer. You learn by doing. However, there is a general framework that applies to many cases you are likely to face. Figure 4 illustrates the framework.

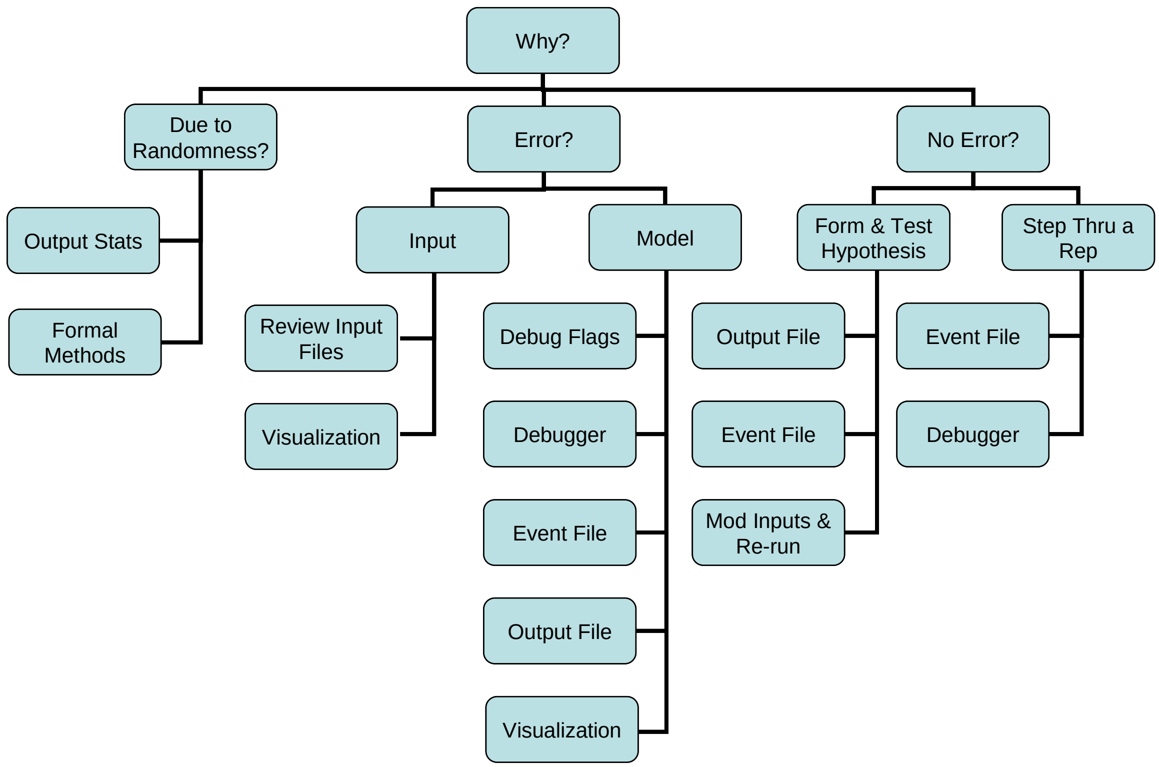

FIGURE 4. ANSWERING THE QUESTION “WHY?”

Is the difference “real”?

Applying this framework to our example, you would first want to determine if the drop in PRA is real or if it is due to statistical randomness of the outputs. For example, suppose you flip a fair coin 10 times to estimate the probability of “heads.” Because you are tossing a fair coin, the probability of “heads” is 0.50, and on average, you would expect 5 “heads” and 5 “tails” in 10 tosses. However, because the process of tossing the coin is random in nature, it’s possible to have other outcomes, say 3 “Heads” and 7 “Tails,” which yields an estimate for the probability of “Heads” = 3/10 = 0.30. A good analyst will recognize that it is not unusual to observe 3 or fewer “heads” in just 10 tosses of a fair coin (probability ~ 0.17) and will not immediately conclude that the coin has been tampered with. Instead, the analyst will conclude that there is insufficient evidence to infer that the coin is not fair, so additional tosses will be needed.[6] The same logic may be applied to our example. If the observed drop in PRA is due to randomness, then we would expect our estimate to increase as additional replications of the simulation are run.

Clearly, you don't want to spend a lot of your time trying to explain a difference that isn't "real." So, how do you know if the observed drop is due to randomness or is a "real" difference between the two systems? As the framework indicates, you may choose to:

1. Make additional replications to see if there is a significant change in the estimated value. You will need to do this for both systems. (Rather than the estimate for the new system being too low, maybe the estimate for the baseline is too high.) In addition, you will want to make sure that you run enough additional replications to see the change. It is not unusual to double or even quadruple the number of replications when taking this approach, but depending on the circumstances, there is still no guarantee that even this is sufficient. The application of probability theory will help determine a good guess at the number of additional replications required.

2. Examine the output statistics to get a feel for the variability of the MOE. If the variability is quite small relative to the estimated values, it lends support to the idea that the difference is real. However, this is no guarantee either, since the difference between the two outputs may (and generally will) have a greater variance than the individual estimates.[7]

3. Use a formal statistical approach to determine whether there is enough evidence to reject the "no difference" hypothesis. If the hypothesis is rejected, then you can reasonably assume that the difference you see is real and not due to randomness.[8]

Is the difference due to an error?

For our example, let's assume that we determine the observed difference is "real." We now need to determine why. The next step is to determine whether the observed difference is due to an error either in the simulation's input or in the model itself. If it is, then the error must be corrected and the case (or cases) rerun.

[6] If the coin is fair, the estimated value of the probability of "Heads" will approach 0.50 as more tosses are included in the calculation of the estimate.

[7] The use of common random numbers will reduce the variance of the difference. This technique is taught in introductory modeling and simulation (M&S) classes.

[8] If common random numbers are used for each run, you must be sure to use a formal method that makes no assumption about the independence of the two outputs.

It's usually easier to look for an input error, so you may want to start there first. Review the input files carefully – especially those sections that should be different between the two systems. A text "differencing" tool may be available that will quickly compare the input files and identify all the differences for you. A visualization tool, if available, will make it easier to find errors. Given that a typical input file may contain thousands of pieces of data, you should not be surprised to learn that input errors are quite common. Fortunately, they are also easily correctable once discovered.

If the input files are correct, it is possible that there is an error within the model itself. Tracking down a model error, however, can be very difficult and requires a significant understanding of the model. For this reason, it is often better to leave this possibility and return to it only if no other reasonable explanation for the difference can be found.

Is there a system explanation for the difference?

If the observed difference does not appear to be due to randomness or to an error, then we need to explain what about the system causes the difference. For our example, you might begin by identifying system factors that impact PRA. Some possibilities include Firm-Track range, Reaction Time, and Probability of Kill (Pk).

A low firm-track range and/or a long reaction time can result in low PRA. However, you know that the EoG delivers a very long firm-track range compared to the current sensor, and in the previous steps, you've confirmed the input file is correct. You decide to examine output statistics or data from individual replications and are able to confirm that, when the model runs, firm-track range is as far out as expected. You also confirmed earlier that reaction time was input correctly and that the same value is used for the baseline and improved systems, so it can't be responsible for the observed difference between the two systems. You next turn your attention to missile Pk. You pull the appropriate data from the input file and plot it. The resulting chart is given in Figure 5.

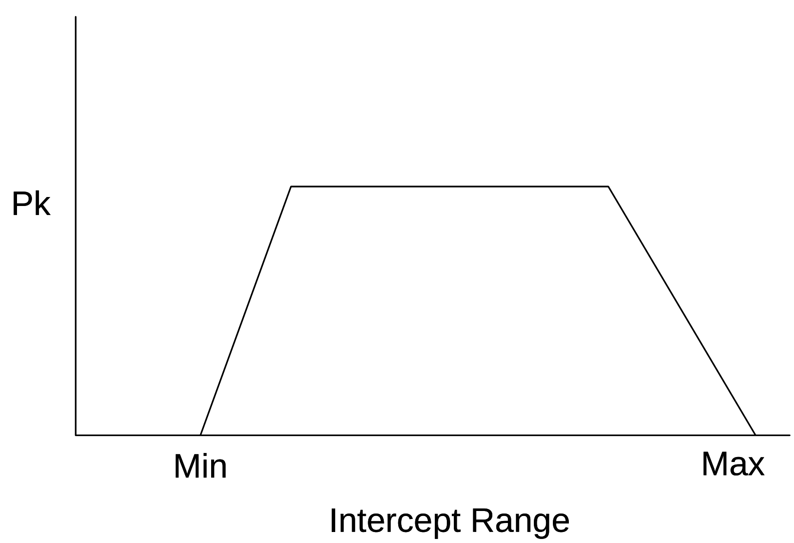

FIGURE 5. PROBABILITY OF KILL VS. INTERCEPT RANGE

Before reading further, look at Figure 5 and see if you can come up with a possible explanation for why PRA decreased even though firm-track range increased.

Notice how missile performance falls off at the longer intercept ranges against this particular threat. If the target is intercepted near the missile's maximum range, Pk will be close to zero, but Pk rises as intercept range moves in towards the ship, hits a plateau, and then falls off again as the intercept range nears the minimum range of the missile. In other words, intercepts that occur near maximum range will have worse performance than those that occur near mid-range. Since the longer detection range afforded by the EoG could result in earlier (longer range) intercepts, this may be the explanation. To confirm your hypothesis, you pull actual intercept ranges from the appropriate simulation output files and overlay the intercepts on the Pk curve. The result is shown in Figure 6.

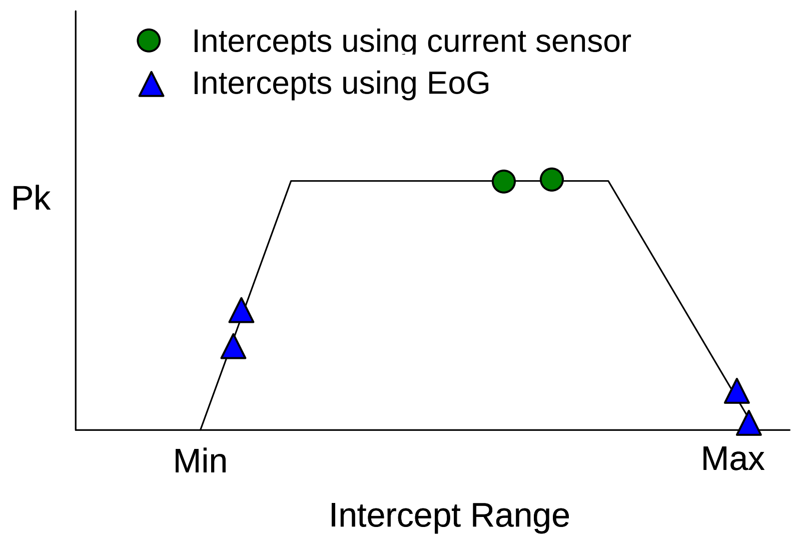

FIGURE 6. PK CURVE WITH INTERCEPTS OVERLAYED

Your analysis has confirmed your suspicion. The longer detection range produced a lower PRA, because the initial intercepts occur much earlier, in a region of low Pk near the missile's maximum range. Even though there is time to reengage the threat with two more rounds, these intercepts occur in a region of reduced Pk near the missile's minimum range. On the other hand, the current system detects the threat later, so the target is engaged later, and the intercepts occur closer to the ship – in the best part of the Pk curve. The net result is that, even though the EoG improved firm-track range, more rounds were shot against the threat and PRA was degraded.

Your analysis has put you in the position of being able to provide your sponsor with more than a table of numbers. You can now offer additional and valuable insights. Your sponsor will learn that improvements to one part of a system don't guarantee improved system performance – in fact, performance can be degraded! Having an understanding of what went wrong in this case, your sponsor is in a much better position to make an informed decision. It may be, for example, that he will purchase the EoG and invest in improving missile performance at longer ranges, or in a smarter system that will delay launch to avoid intercepts in bad parts of the Pk curve.

TASK 9: CONVEY FINDINGS TO OTHERS

Axiom 9

A good analyst effectively conveys findings and insights to others.

Finally, we come to the last task of the analysis process: conveying what you've learned to others. Earlier, I mentioned that writing the analysis plan and writing the final report are among the least favorite tasks in the analysis process. Yet, if you don't effectively convey your findings to others, all your work has been a waste of time! So, in a sense, this may be the most important task of all.

"...if you don't effectively convey your findings to others, all your work has been a waste of time!"

There are at least three audiences you need to consider when preparing your documentation: your sponsor, your management, and your colleagues. The approach you take with each of these audiences may be quite different.

1. Your sponsor, of course, needs to know the answer to his question, but he also needs to know about the insights you've uncovered during the analysis. In addition, you should make sure he is aware of major assumptions that impact the results and any caveats concerning the use or interpretation of the results.

2. In addition to the material you briefed to the sponsor, your management, not surprisingly, will be interested in management issues: Is the sponsor happy with your work? Who are you briefing? Was the work completed on time and within budget? Are there any personnel or "political" issues they need to be aware of? Your management needs to be kept informed of issues as the analysis proceeds and should be briefed BEFORE you go to your sponsor.

3. In addition to the material you briefed to the sponsor, your colleagues will want to know more about how you got from Point A to Point B. You will probably go into a lot more detail on the assumptions and all the intermediate steps taken to get to the results. How did you model System X ? Did you identify any modeling issues they need to be aware of? Were there any nonintuitive results and, if so, how did you determine what was really going on? Were any new tools used? Did you come up with a good way of summarizing/presenting the data? Keep your colleagues informed from the beginning as well. You can discuss ideas and issues with them, and they may be able to provide you with a lead to some relevant information or to a person who will prove invaluable to you. Sharing our analysis experiences with each other is a great way to learn to "do analysis"!

One important aspect you need to consider when preparing your documentation is how to best display the results and explain your insights. Considering the sponsor's question(s), what is the most clear and effective way to present the results of the analysis with respect to those questions? When making this decision, consider the sponsor's familiarity with the subject matter at issue and with the type of display you plan to use. Often a table or curve is appropriate. Sometimes, though, you may need to be more creative -- especially if what you are trying to explain is complex. You may need to break your explanation into smaller, easily understandable blocks that you build upon. A good visual can often display a lot of data in a way that is informative. For example, a graphic that shows the relative location of the ships, the direction from which the threat attacks, and uses color to indicate individual ship survivability may prove very helpful in summarizing results and explaining why certain ships were less likely to survive.

Crafting a good final report or summary presentation is more art than science, and, like many other parts of the analysis process, is learned by doing and by observing what others have done. There are a few points, though, that you ought to keep in mind:

1. Make sure you include at least one paragraph/chart for each major insight you want to discuss.

2. Try to get your message across in as few words/slides as possible.

3. Avoid complex figures/charts that are hard to follow.

4. In a presentation, each chart should have a reason for being shown. Ask yourself what the purpose of each chart is. If you can't answer the question, consider removing the chart or placing it in backup.

5. Do NOT display data to an accuracy that is unwarranted. On occasion, I have seen analysts display the probability of raid annihilation to 10+ digits (usually in a spreadsheet). I can't imagine they believed their data was really that accurate. Even if it were, that many digits can be very difficult to read and forces the

audience to round it. Make life a little easier for your audience and round the number for them.[9]

6. Avoid 3D graphs. It's hard to visually pull off a data point from one with any accuracy.

A Presentation is No Substitute for a Formal Report!

Because the above discussion applies to both a formal report and a summary presentation, you may mistakenly think that a presentation alone is sufficient for documenting your work. For all but the simplest of analyses, however, a formal report will be required. Although a summary presentation is useful for status meetings and briefouts, the formal report offers distinct advantages:

1) It is a true stand-alone document. Copies of a presentation do not, in general, stand by themselves. A briefer who is intimately familiar with the material is needed to explain the charts and provide details that have been omitted. Because text on a chart tends to be quite terse, material in a presentation may be misunderstood or taken out of context unless the briefer is present. A well-written report, on the other hand, can stand alone.

2) It is a detailed record of what you did, why you did it, how you did it, and what it all means! If two years after completing an analysis you are asked to respond to a technical question about your work, or you need to recall a fairly low-level detail, a formal report will be much more useful to you than a handful of summary plots and text charts.

The formal report is the best way to transfer technical knowledge, so you should ensure that sufficient time and funds are allotted during the planning phase to formally document your work.

[9] For additional information on the concepts of precision and accuracy, see the "IEEE Standard Glossary of Software Engineering Terminology" (IEEE Std 610.12-1990). A good reference on determining which digits in a calculation are significant is located at http://www.physics.uoguelph.ca/tutorials/sig_fig/SIG_dig.htm

GET THE TRAINING YOU NEED

Axiom 10

A good analyst never stops learning.

No matter what level of experience you have as an analyst, you need training. The topics and level of presentation may change as you become more experienced, but your need for training never diminishes.

Both you and your supervisor bear some responsibility for making sure you get the training you need. You must be proactive and discuss your needs with your supervisor, and you need to take advantage of training opportunities. Your supervisor should make you aware of training opportunities and actively help you reach your training objectives.

Your next step should be to discuss your training requirements with your supervisor. To help you think about this, below is a "starter" list of training areas and topics for you to consider. Look the list over and identify the areas in which you need additional training, then make an appointment with your supervisor and ask her to help you develop a training plan that meets your needs and fits in with the group's priorities. Remember, you don't have to be an expert in all these areas, but you do need a basic understanding. Ask your supervisor, senior analysts, and colleagues to help you identify the subject matter experts in each of these areas and get to know them. Also, consider attending a symposium sponsored by the Military Operations Research Society (MORS). You'll be exposed to a number of briefs on a variety of topics and have the opportunity to sign up for tutorials, many of which are led by nationally recognized experts in their field. Refer to the MORS website for details: www.mors.org.

SUGGESTED AREAS OF STUDY

Modeling and Simulation

Consider taking a short course, or preferably, a semester-long introductory course on Modeling and Simulation. Currently, Old Dominion University (ODU) provides an excellent course that is available at Dahlgren. You want a course that, at a minimum, covers the following topics:

1. Discrete-event simulations
2. Random-number generation
3. Use of common random numbers and other variance reduction techniques
4. Statistical analysis of simulation output

Your Primary Analysis Tool

You need to know something about the tools you will be using. Obviously, you will need to know how to set up input files and run the tool, but it would be very helpful for you to have some additional knowledge as well – especially information that will help you judge whether the model is at the right level of fidelity for your analysis task. Obtain any documentation that is available and read it. Ask if there is a tutorial available. Try to get answers to the following questions:

1. What are the model's capabilities and limitations?
2. How are the systems you are evaluating characterized within the model?
3. What are the primary events modeled?
4. Is there a brief, top-level summary of what the model does for each type of event?
5. What random processes are modeled?
6. How are various inputs used within the model?
7. Which inputs are required?
8. Are there default values for any of the inputs?
9. Do any inputs interact with each other? (You may be surprised to learn that one input may overwrite another, or that to make a change in some relatively simple aspect of a system's characterization requires multiple input fields to be modified.)
10. What outputs are available? And how are they defined/calculated?
11. Has the model or simulation been validated or accredited? By whom and for what purpose?

Weapon Systems

You should become familiar with the various components of modern naval weapon systems:

1. Radars and Illuminators
2. Electronic Sensing Systems
3. Missiles
4. Guns
5. Decoys and Jamming Systems
6. Control Systems

Doctrine and Tactics

You also need to know something about how the Navy fights. In particular, try to get a basic understanding of the following:

1. Weapon Selection Policies
2. Distributed Weapons Control (Ship-to-Ship Engagement Coordination)
3. Combat Identification and Rules of Engagement
4. Firing Policies

Threats

It's important that you can at least characterize the major air-launched, surface-launched, and subsurface-launched threats. At a minimum, you'll want to know speed (subsonic or supersonic), launch platform(s), approximate minimum and maximum launch range, approximate altitude profile, approximate maneuver profile, guidance type, level of proliferation, and who has it. Ask if there is a threat presentation available. The Scientific and Technical Intelligence Liaison Office (STILO) is an excellent source of threat information.

Probability and Statistics

Because the output you will be analyzing comes from a random process, you really need to have some knowledge of probability and statistics. Take an introductory probability or stats course. If you want to go a little further, look for an introductory course on the design of experiments (especially one that covers factorial, fractional factorial, and Latin Hypercube designs). Other topics to consider:

1. Multiple Comparison Procedures are statistical techniques for comparing MOEs across multiple cases of interest.

2. Ranking and Selecting Procedures deal with statistical techniques to choose the "best" system, identify the subset of systems that satisfy some criteria, or rank the systems from best to worst.

Technical Writing

Improve your ability to write a clear, effective technical report. Short courses on technical writing are offered relatively frequently at Dahlgren.

Graph Design (Data Visualization)

Anyone can make a graph, but not all graphs are effective. Some can even be misleading. Invest in a good text on graph design. One text that I've found helpful is *Elements of Graph Design* by Stephen M. Kosslyn, but there are quite a few from which to choose, including the classic set of texts by Edward Tufte. Try browsing at an online bookstore or the library.

Making and Giving a Presentation

Take a short course or find a text on how to design an effective presentation. Look into short courses that help improve your presentation skills.

THE ANALYST'S BOOKSHELF

Several texts that you may find helpful are listed below.

Box, George E. P.; Hunter, William G.; and Hunter, J. Stuart, *Statistics for Experimenters: an Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, Inc., New York, NY, 1978. (This is an excellent introduction to statistics – especially the design of experiments. The material is presented clearly and is designed for nonstatisticians.)

Frieden, David R., Ed., *Principles of Naval Weapons Systems*, Naval Institute Press, Annapolis, MD, 1988. (This is a primer on radar, weapons and control systems.)

Gilman, E. Ward, Ed., *Merriam-Webster's Pocket Guide to English Usage*, Merriam-Webster, Inc., Springfield, MA, 1998. (This is an abridgment of *Merriam-Webster's Dictionary of English Usage*. I find this little book to be indispensable when writing a report. If you aren't sure whether to use the word "affect" or "effect," this book will help you decide by providing a clear explanation of the difference in usage as well as sample sentences using each word. Over 1000 entries clarify confusable words and other issues.)

Kosslyn, Stephen M., *Elements of Graph Design*, W. H. Freeman and Company, New York, NY, 1994. (This is a good book on how to create effective graphs.)

Law, Averill M.; and Kelton, W. David, *Simulation Modeling and Analysis*, Third Edition, McGraw Hill Book Co., Inc., New York, NY, 2000. (This is the preeminent text on all aspects of modeling and simulation.)

Tufte, Edward Rolf, *The Visual Display of Quantitative Information,* Second Edition, Graphics Press, Cheshire, CT, 2001. (This text, along with three others by Tufte -- *Envisioning Information, Visual Explanations,* and *Beautiful Evidence* – are considered by many to be classics. My personal preference, though, leans towards a more direct presentation such as Kosslyn's text listed above. I have included Tufte's texts in this listing because they are held in such high regard.)

Wagner, Daniel H.; Mylander, W. Charles; and Sanders, Thomas J., *Naval Operations Analysis*, Third Edition, Naval institute Press, Annapolis, MD, 1999. (This text is used at the Naval Academy and at the Naval Postgraduate School. This book describes nonsimulation approaches to solving problems that are important to the Navy. Many topics are covered, including radar detection, search and patrol, barrier patrols, mine warfare, fleet air warfare, and reliability.)

Walpole, Ronald E.; and Myers, Raymond H., *Probability and Statistics for Engineers and Scientists*, Fifth Edition, MacMillan Publishing company, New York, NY, 1993. (This is a more traditional Probability and Statistics text. This text has been used in statistics courses offered at Dahlgren.)

Weiss, Edmond H., *The Writing System for Engineers and Scientists*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1982. (This is one of the best texts about writing technical reports that I have found. Unfortunately, it is now out of print, but you can still find used copies at online bookstores.)

FINAL WORDS

I hope this paper has made you more aware of the kinds of tasks you will be performing as an analyst and what it takes to be a good analyst. The trend for the foreseeable future is that the Navy will come to depend even more on analytical results to guide decisions that will have far-reaching impacts for decades to come. As analysts, we have the responsibility to be honest brokers for the Navy – to provide impartial and insightful results that enable well-informed decisions. I encourage you to become the best possible analyst you can be, not only because of the benefit it will bring to your career, but because of the benefit it will bring to our nation as well.

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