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Cost vs. Risk in Defense Portfolios

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Recent announcements by the Pentagon indicate that budgetary constraints coupled with an uncertain threat environment will unavoidably lead to tradeoffs between cost and preparedness. Analogous tradeoffs have been optimized in portfolios of financial assets for decades, and recent technologies have the potential to generalize this approach to cover defense portfolios as well.

Background

It is common to think of managing a portfolio of military assets in terms of ranking the things you want in order of preference, then starting at the top and working your way down until you run out of money. But this misses what are known as *portfolio effects*. For example, take a couple of seconds to rank your own top 10 personal purchase preferences. For purposes of argument, let's assume that a house is on your list. Did fire insurance make the list as well? Probably not, yet portfolio effects dictate that you will need insurance if you buy a house. This shows that preference ranking alone is insufficient for managing portfolios in the face of uncertainty.

Portfolio effects also abound among military assets. If you have only land forces, your adversary will mass all its assets at choke points to block your advance. If you have only an air force, your adversary will disperse its assets throughout the civilian population, rendering air attack too costly and prohibitive in terms of collateral damage. With both ground and air forces, you can apply the former when the adversary disperses and the latter when the adversary masses in a few locations. Again, you should choose assets based on their mutual ability to reduce risk in the face of uncertain contingencies rather than rank preferences alone.

Efficient Frontiers

Modern finance introduced the concept of the efficient frontier to describe the optimal tradeoffs between risk and return in financial portfolios (Markowitz 1952, 1997). Every investment portfolio has an average return and also a risk. A portfolio is efficient if it minimizes the risk for its given level of return. The set of such portfolios for various levels of return form what is known as an efficient frontier, as Figure 1 shows. Where you choose to invest on the efficient frontier depends on your personal risk attitude, but you should never invest off the frontier.

As the defense industry moves into a budget-constrained environment in an increasingly uncertain world, it faces similar tradeoffs, but instead of financial risk versus financial return, in general, it faces the risk of a preparedness shortfall versus the cost of the defense portfolio. Although in reality there are multiple dimensions of risk, we have represented this conceptually as a single dimension in Figure 2.

Efficient frontiers cannot be determined without an explicit representation of the interrelated uncertainties involved. This is not possible using single average numbers, which leads to the *Flaw of Averages* (Savage 2009). On average, your house doesn't burn down and there isn't a war. Risk matrices at least recognize the existence of risks, but because they do not reflect full probability distributions of outcomes, they mask portfolio effects and cannot be used to determine efficient frontiers.

Probability Management

The emerging field of Probability Management promises to facilitate the analysis and communication of risk/cost tradeoffs by quantifying uncertainties as sharable data elements, known as distribution strings or DISTs. The DISTs in turn link analytics of various sorts, such as forecasts, stochastic optimization, surrogate models, design of experiments, and interactive simulation into system-wide models. Because DISTs contain compressed vectors of thousands of simulated future scenarios, they may be added together to capture portfolio effects, and communicate them effectively to decision-makers (Brown and Savage 2009).

We describe a proof of concept model below in which a portfolio of air mobility assets must be chosen in the face of uncertain military lift requirements.

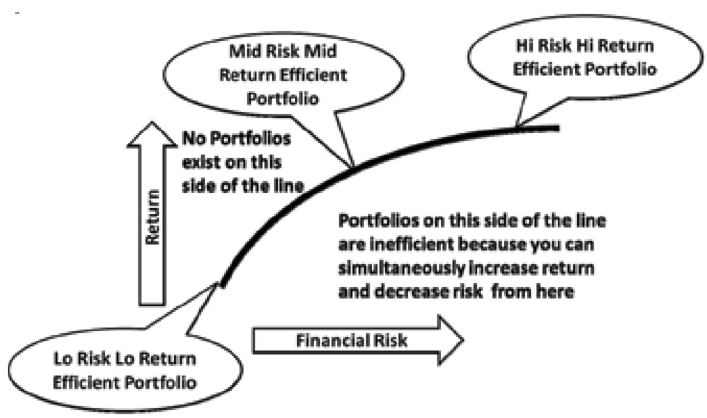

Figure 1. An efficient frontier for financial portfolios.

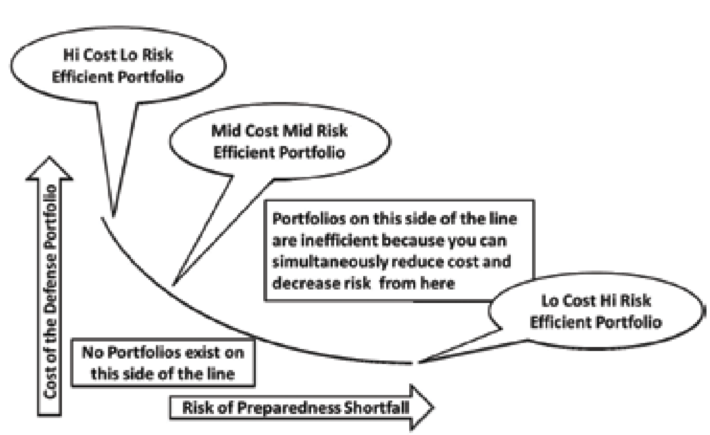

Figure 2. An efficient frontier for defense portfolios.

The Problem

As the head of Air Force acquisitions, you need to determine how many additional cargo aircraft to purchase to be prepared to project military force into to six regions. The lift requirements in tons per day of materiel for each region are uncertain, and you have a constrained budget. The Ash Carter memo, dated November 3, 2010, directs that you evaluate your decision "across all products in the relevant portfolio" (Carter 2010). In our example, the choices include small aircraft, medium aircraft, and large aircraft with maximum additional totals for each aircraft type shown in Figure 3.

The Requirement Forecast

We will assume that the current fleet is fully assigned, and that the new aircraft will be devoted to meeting new requirements, which are uncertain. We will need a separate forecast of airlift requirement for each of the six regions in tons of materiel per day. Although it is common for such forecasts to be summarized by a single number, this leads straight back to the Flaw of Averages. Instead, the uncertainty will be captured in five coherent scenarios, with a distribution of five potential lift requirements for each region, based upon which scenario actually occurs. That is, under scenario 1, region A would require 20 tons per day, whereas region B would require none, C would require 4, and so on, whereas under scenario 3, region A would require 10 tons per day, region B, 10 tons, and so on, as shown in Figure 4.

Although in this example, we have limited ourselves to five discrete scenarios, all with equal likelihoods of occurring, from a practical standpoint, we could have assumed unequal likelihoods, or developed a full multivariate distribution through a Monte Carlo or discrete event simulation. In any case, the results are stored compactly in DIST format, so all components of the portfolio will be exposed to the same requirements under the same scenario. This may seem to be a subtle point at first, but it is vital in aggregating simulation results into a system wide model.

Figure 3. Potential products in the relevant portfolio.

Potential Tons/Day

Region	A	B	C	D	E	F
Scenario 1	20	0	4	3	14	20
Scenario 2	20	0	5	2	14	8
Scenario 3	10	10	3	4	16	11
Scenario 4	0	20	4	2	14	13
Scenario 5	0	20	4	4	17	18

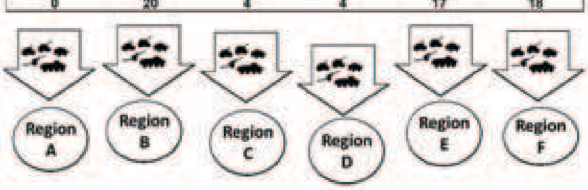

Figure 4. Uncertain airlift requirements.

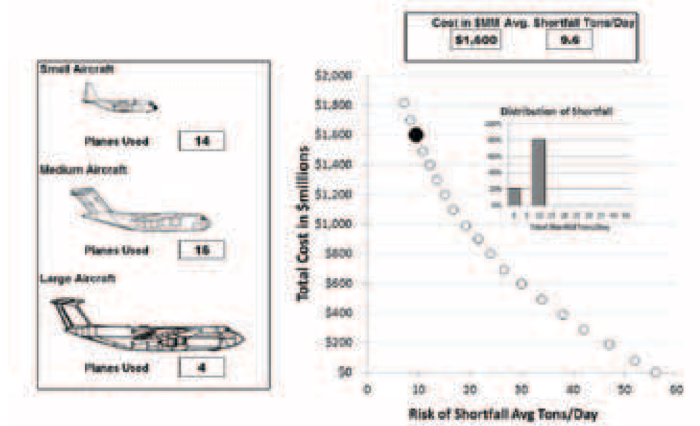

Figure 5. Efficient frontier for airlift capacity, highlighted for budget = $1.6 billion.

Stochastic Optimization

In the past, it was common to apply mathematical optimization to military logistics problems based on the average requirements. In fact, George Dantzig invented the powerful technique of linear programming (LP) in 1947, while solving such problems for the Air Force.

Today, LP has been generalized to encompass stochastic optimization, which can look at both cost and risk in the same model (Birge 1997, Infanger 2010). In this case, stochastic optimization has been applied repeatedly to minimize the risk (measured in average tons of shortfall per day), while constraining cost to a particular budget level. For the proof of concept model, the cost is defined as acquisition, plus operation and sustainment in a given mode of deployment over the lifetime of the aircraft. The result is an efficient frontier, as Figure 5 shows.

The highlighted point on the frontier shows a portfolio of 14 small, 15 medium, and four large aircraft, for a total cost of $1.6 billion. The average shortfall is 9.6 tons per day, and the histogram above the frontier shows a 20% chance of no shortfall at all, given the uncertain requirements.

Interactive Simulation

The authors have found that these concepts are easy to explain. The hard part is getting people to understand them. Toward this end, interactive simulation may be applied to such models to let decision-makers explore the tradeoffs on their own. The idea is that through interaction, procedures such as riding bicycles or skiing that are in fact governed by complicated underlying mathematical equations, can nonetheless be understood by a large audience. This model is available with documentation by contacting the authors (see also Savage 2003). It requires Excel 2007 or later, with macros enabled. When a point on the frontier is selected, the associated portfolio of planes and other statistics appear instantly. Figure 6 shows the result for a budget of $600M. Note that no small planes are called for, and there is no chance of avoiding a shortfall. By trying your own portfolios of planes and deployment options on the detail page of the model, you may gain insight into the tradeoffs. It is instructive to see if you can get to the efficient frontier by hand.

Ash Carter's memo goes on to direct decision-makers to "provide a quantitative analysis of the program's portfolio or mission

see ***Defense Portfolios*** on the following page

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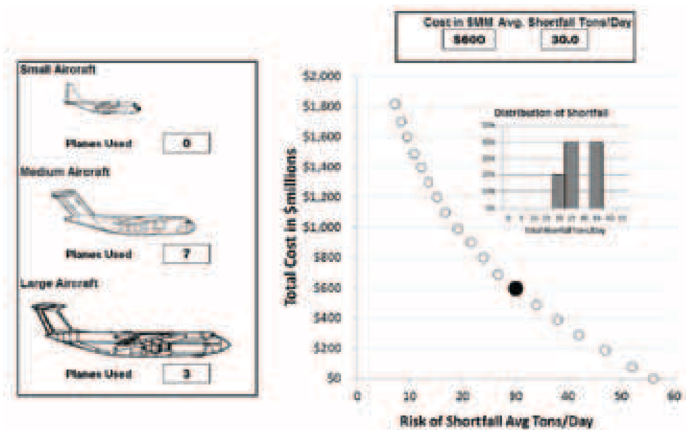

Figure 6. Efficient frontier for airlift capacity, highlighted for budget = $0.6 billion

area across the life cycle of all products in the portfolio or mission area, including … operating and support budget suitability ….” We believe this is best accomplished through interactive decision support applications, which allow the user to quickly switch between multiple potential alternative solutions. This builds intuition and helps the decision-maker arrive at a conclusion based on his or her own level of risk tolerance.

Expanding and Generalizing the Model

The model accompanying this paper is focused on the best mix of assets within a portfolio of cargo lift platforms based on simple assumptions, which nonetheless model uncertainty explicitly. Many more details could be added to such a model, for example, the redeployment of the current fleet, the modeling of multiple time periods, and uncertainties in the cost of fuel, manpower, etc. It is also possible to simulate the benefits of enhanced aircraft capabilities within the context of the current portfolio. A more detailed model would push the solution beyond the limits of the spreadsheet, but the DIST data type allows results of large stochastic computer models to be returned to desktop tools such as Excel and JMP to create intuitive interactive dashboards for management.

More importantly, similar models could be built around ground, naval, and air strike assets. Although constructed and analyzed individually, through the use of coherent libraries of threat scenarios, fuel costs, manpower rates, inflation rates, etc., the results of such models could be added together like numbers. This would create a portfolio of portfolios leading to an overall efficient hyper-frontier that balances multiple metrics of total force readiness against multiple constrained resources. We are not saying this will be effortless, but the recent ability to form networks of today’s most powerful analytics suggests that it should now be within reach.

References

Birge, J. R., and Louveaux, F. V., 1997, *Introduction to Stochastic Programming*, Springer Verlag, New York.

Brown, A., and Savage, S., 2009, “The March Toward a Consolidated Risk Statement”, *Risk Professional* (December).

Carter, A., 2010, *Memorandum for Secretaries of the Military Departments* (November).

Infanger, G., 2010, *Stochastic Programming: The State of the Art in Honor of George B. Dantzig*, Springer.

Markowitz, H. M., 1952, “Portfolio Selection,” *Journal of Finance*, Vol. 7, No. 1 (March), 77-91.

Markowitz, H. M., 1997, *Portfolio Selection: Efficient Diversification of Investments*, 2nd edition, Blackwell Publishers, Malden, MA.

Savage, S., 2003, *Decision Making with Insight*, 2nd edition, Chapter 8, Cengage Learning.

Savage, S., 2009, *The Flaw of Averages*, John Wiley & Sons, New Jersey.

About the Authors

Dr. Sam L. Savage *is the author of* The Flaw of Averages, Why we Underestimate Risk in the Face of Uncertainty *(John Wiley & Sons 2009). In 2008, Dr. Savage invented a new data type, the Distribution String, which, according to Nobel Laureate Harry Markowitz, “represents a major breakthrough in the communication of risk and uncertainty. It significantly widens the practical applicability of sound theory in these areas.” In 2010, Dr. Savage cofounded Vector Economics, Inc., which provides probability management solutions by integrating the latest simulation, data, and cloud computing technologies. Dr. Savage received a PhD in computational complexity from Yale University, and holds the positions of Consulting Professor of Management Science and Engineering at Stanford University, and Fellow at Cambridge University’s Judge Business School. He has consulted and lectured extensively to industry and has been called the “Edward Tufte of Risk.”*

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