RESOURCE ALLOCATION MODEL FOR OPTIMAL EXPENDITURE OF ARMY MISSILE RESEARCH AND DEVELOPMENT FUNDING

MGMT 224
Executive Decision Making
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Abstract
As staff analysts in the Office of the Assistant Secretary of the Army for Research, Development, and Acquisition, we are responsible for evaluating new and existing Army research and development programs. Specifically, our team analyzes missile related research and development (R&D) programs. Our goal is to optimally allocate limited funding resources across multiple project proposals in order to meet the Army's varied missile needs.

Introduction

As a member of the Army headquarters staff, we are tasked with developing, testing, procuring, and maintaining all of the Army's missile systems. This includes missiles ranging in size from the now familiar Patriot anti-missile defense system, which requires a dedicated vehicle to transport it, to the latter-day Bazooka, carried by the infantryman into battle.

The Problem

The Department of Defense is currently facing unique circumstances with regard to the development and acquisition of weapon systems. The Cold War has ended, and with it the fear of war that prompted astronomical defense expenditures. At the same time, technology is progressing at the most rapid pace in history. Perhaps the most affected by these circumstances are those in the business of developing the weapons that will accompany our Armed Forces into the conflicts of the future. Keeping up with the technological Joneses is becoming increasingly expensive; to complicate matters, the options to choose from (all with their proponents, many in Congress), most of them dead-ends, are multiplying at a logarithmic rate.

The Goal

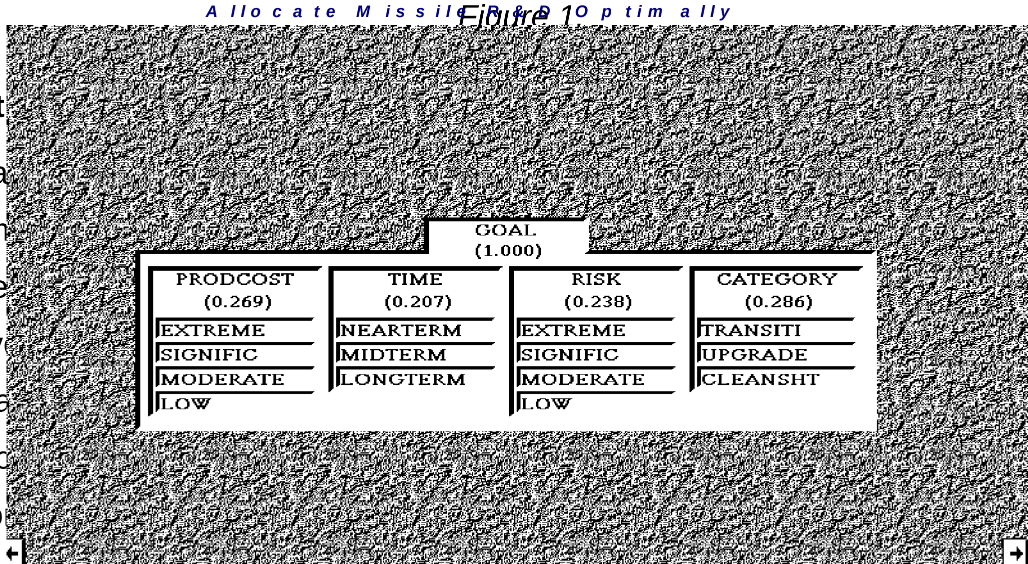
The overarching goal of the Office of the Assistant Secretary of the Army for Research, Development, and Acquisition is to optimally allocate the research and development funding appropriated for Army programs. Our task is to optimally allocate funds for missile research and development to the projects that are most likely to be of value in the future. In this particular situation, we are allocating R&D funds between the following Army missile system R&D projects: the Guided Multiple Launch Rocket

System (MLRS), Rapid Force Projection Initiative (RFPI) Demonstration, Counter Active Protection System (CAPS), Enhanced Fiber Optic Guided Missile (EFOGM), Hypervelocity Missile, Stinger Block II, Hellfire III Seeker, and Low Cost Precision Kill (LCPK).

The Objectives

Before structuring our decision process, we determined which objectives should be pursued to most effectively fulfill our goal of optimally allocating the R&D funding. Figure 1 illustrates the model developed using these objectives.

Figure 1



Abbreviation	Definition
CATEGORY	
CLEANSHT	

Transit [illegible]

A prima [illegible] ssfully field a n [illegible] anned anywhe [illegible] still in the dev [illegible] eir eventua [illegible] failure to do so [illegible] no effect o [illegible] e system, and other R&D programs whose funds will subsequently be reprogrammed to alleviate the problem.

Upgrades to Existing Systems

Another primary objective of R&D funding is to fund the R&D necessary to upgrade current, fielded systems to meet the latest threat. Oftentimes, upgrades are necessary as a result of technology's relentless march forward. A common predicament today relates to computer systems. Many of the weapon systems in the field today rely on military-unique computers incompatible with today's desk- and laptop models. The effort to re-write the computer programs to work on the newer models is considered R&D, and while it's not the glamorous sort of R&D - it's necessary nonetheless. Additionally, there are systems in the field that, perhaps as a result of a situation similar to the one described above, require additional R&D just to function as they were intended (i.e. they don't work).

"Clean Sheet" Programs

Here's where we find the projects that are, initially at least, more dream than reality, the projects that made Popular Science, well, popular (yeah, we've all got subscriptions…). In light of the priorities afforded the two prior objectives, it would seem unlikely that the Clean Sheet programs would receive enough funding to survive. But you must recall that we *are* rocket scientists and we *are* in charge here. Realistically speaking, these are the types of projects that have the potential to raise the technology bar; possibly resulting in returns to the military and modern civilization many times the investment.

Although these first three objectives were developed independently, it turns out that projects that support one or the other are almost certainly mutually exclusive. For this reason, we decided to combine the three into an objective we decided to call "Category" (see Figure 2)

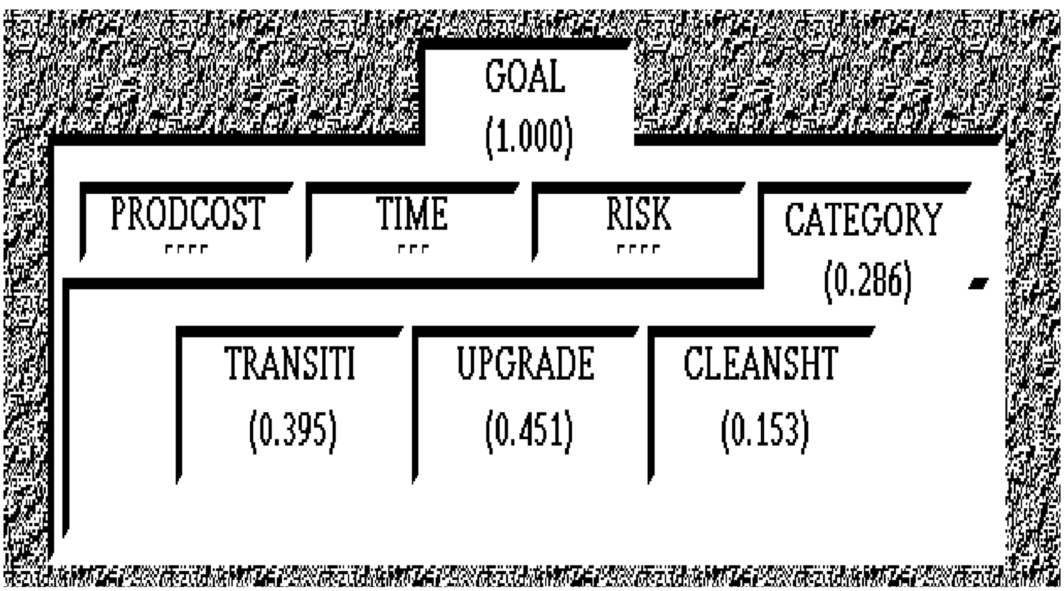


Figure 2.

Production Cost

This objective relates to the expected production cost of a weapon system expected to result from the products of the R&D. It is included because it makes little sense to spend millions of dollars on R&D only to find that the system isn't pragmatic due to extremely high production costs. We want to use our R&D funding to research technologies that will result in relatively low-cost weapons, i.e. more bang for the buck. This also applies to systems already in the field. R&D that can result in lower recurring costs is beneficial in the long run. (Most DoD expenditures go toward repairing and maintaining equipment. The actual costs to develop and acquire them are often minimal in comparison.) We rated the alternative projects with respect to the Production Cost objective as extreme, significant, moderate, or low - lower production costs being preferred.

Technological Risk

This objective relates to the risk associated with the technology being developed. In other words, what's the chance that the R&D will ever bear fruit? While technologically feasible, many projects have little chance of ever succeeding. Although difficult to evaluate, an independent determination of a project's chance of success is critical in making the resource allocation decision. We rated the alternative projects with respect to this objective in the same way we rated them for the production cost objective: extreme, significant, moderate, or low - again, low risk is preferred.

Time to Completion

The time necessary to complete an R&D project is also taken into consideration when evaluating competing projects. As the time to complete a project lengthens, the greater is the likelihood that funding will be cut. Additionally, as projects stretch over fiscal years, the amount of funding necessary to complete them tends to grow as a result of fixed overhead costs. Finally, projects that will translate more rapidly into systems deployed in the field are more defendable and contribute to the confidence level in the manager making the recommendation. We rated the alternative projects with respect to this objective as near-term (1-5 years), mid-term (5-10 years), or long-term (10+ years).

Alternatives

The following alternative projects were evaluated with respect to the aforementioned objectives. They run the gamut from the clean sheet category to upgrades to current systems to projects aimed at defending against the latest threat.

1. Guided MLRS
2. RFPI Demonstration ($20M)
3. RFPI Demonstration ($28M)
4. RFPI Demonstration ($32M)
5. CAPS
6. EFOGM ($25M)
7. EFOGM ($30M)
8. EFOGM ($37M)
9. Hyper-Velocity Missile
10. Stinger Block II
11. Hellfire III Seeker

Guided MLRS

The objective of the Guided MLRS Advanced Technology Demonstration (ATD) is to demonstrate the feasibility of building a guided version of the MLRS rocket at an affordable cost and with minimal or no impact to the current launcher or to current maintenance, handling, or training procedures.

Improving the delivery accuracy of the MLRS rocket through the addition of Global Positioning System/Inertial Navigation System (GPS/INS) guidance will significantly reduce the number of rockets required to defeat the target. This reduction (as much as six-fold for bomblet warheads at extended ranges) leads to several categories of cost savings:

a. The cost of the ammunition expended in a mission is reduced.
b. The cost of transporting the rockets from the factory to the launch point is reduced because the tonnage is significantly reduced.

c. The overall cost of the extended range MLRS rocket production can be reduced while still maintaining the same level of destructive potential.

d. A reduced number of launchers and personnel could be used to achieve mission success. Other advantages of the Guided MLRS include reduced mission time/earlier attrition of targets leading to a higher survivability of friendly forces and the flexibility to engage targets in close proximity to neutral or friendly forces and avoid collateral damage and fratricide.

RFPI Demonstration

In the post Cold War Era it is essential that the Army evaluate technology to address the special needs of force projection. The RFPI Advanced Concept Technology Demonstration (ACTD) will demonstrate a highly lethal and survivable enhancement to the early entry task force in an airlift-constrained environment with no loss of deployability. This demonstration will be accomplished through a large scale live demonstration to be conducted as a part of the RFPI Advanced Warfighting Experiment (AWE) which will begin in FY98. System of systems issues associated with a hunter standoff killer concept to make air deployable forces more survivable against a heavily armored threat will be addressed in this ACTD. TRADOC has evaluated the Science and Technology Objective for RFPI as the number one priority out of two hundred. The ACTD will determine what enhancements are needed to make our early entry capability more robust and inform future procurement decisions.

CAPS

The objective of the CAPS program is to develop and demonstrate techniques and technologies which will allow anti-tank guided weapons (ATGW) to defeat threat tanks equipped with Active Protection Systems (APS). Technology components of the Counter Active Protection System Suite include Radar Countermeasures, advanced Long Standoff Warheads, and Missile Armoring Techniques. These techniques will work together or separately to defeat threat APS by preventing the detection, tracking, or destruction of an ATGW before it can successfully defeat the target. RF Countermeasures must limit probability of detection to 10% at the minimum response range of the APS munition system.

Long Standoff Warheads must perforate target armor at the maximum range of the APS munition for 90% of possible engagements.

EFOGM

EFOGM is the primary "killer" within the Office of the Secretary Defense (OSD) approved Rapid Force Projection Initiative (RFPI) ACTD. The EFOGM system is a multi-purpose, precision kill weapon system. The primary mission of the EFOGM is to engage and defeat threat armored combat vehicles, other high value ground targets, and hovering or moving rotary wing aircraft that may be masked from line-of-sight direct fire weapon systems. EFOGM is a day/night, adverse weather capable system that allows the maneuver commander to extend the battle space beyond line-of-sight to ranges up to 15 kilometers, thus reducing the exposure of the gunner and allowing targets to be taken out of the battle early. The system consists of a gunner's station, a tactical missile, and a fiber optic data link plus command vehicles. The missile can navigate to the target area automatically, and the gunner can intervene at any time to lock on and engage any detected targets. This gunner in the loop capability enhances the target acquisition process and minimizes fratricide and collateral damage. The gunner views the flight path and target via a seeker on the missile linked to the gunner's video console. The missile incorporates an IR imaging seeker and a variety of advanced targeting functionalities.

Hypervelocity Missile

This project will demonstrate concepts and components for small, lightweight hypervelocity guided missiles. Focus areas include missile kinetic energy penetrators capable of achieving lethal energy at short ranges; insensitive propulsion; and miniaturized guidance and control actuator technology. In addition, this project will demonstrate an insensitive, lightweight, miniature hypervelocity kinetic energy missile which is compatible with the Line-of-Sight Anti-Tank (LOSAT) fire control system, for close combat and air defense missions. This effort will demonstrate technologies suitable for upgrading current kinetic energy systems (LOSAT) to be capable of launching from lightweight platforms such as the Heavy HMMWV while maintaining overwhelming lethality.

Stinger Block II

The objective of this project is to demonstrate the technology for a comprehensive upgrade to the STINGER missile system through the incorporation of an advanced imaging infrared (IR) seeker to enable the engagement of hostile helicopters in clutter at extended ranges (2-3x). This project will demonstrate the ability to package the previously developed commercial breadboard signal processing electronics in a 2.75 inch diameter seeker. In addition, signal processing algorithms for target detection, tracking, and IR counter-countermeasures (IRCCM) will be developed and demonstrated via hardware in the loop simulations, ground tests, and captive carry tests. This seeker will maintain compatibility with existing STINGER launchers and retain STINGER's excellent capability against fixed-wing aircraft.

Hellfire III Seeker

The Hellfire III Seeker project will conduct a Best Technical Approach study of seeker alternatives for the Army's planned Hellfire Block III upgrade program. Specifically, this project will investigate technical, cost, and performance tradeoffs for dual-mode seeker candidates. The dual seeker candidates currently under consideration are a millimeter wave active radar in conjunction with an imaging infrared; an imaging infrared with an infrared laser detector; or a dual-band infrared approach. Each seeker candidate will be self-contained onboard the missile.

LCPK

This project will demonstrate two alternative guidance package retrofit kits for the Army's 2.75 inch Hydra-70 rocket currently in production. One approach will utilize a unique sensor technology to a laser designator pointed at the target by an independent operator. This concept exploits phenomena known as backscatter and has the inherent advantage of no moving parts; however, this technology is high risk and has never been demonstrated previously. The other competing approach will be to use a gimbaled laser seeker that detects the laser spot created by a designator pointed towards the target much like a flashlight. This approach uses mature technology but is more costly due to a significant number of moving parts. The LCPK project will demonstrate prototypes of each of the two candidates and recommend the best seeker technology prior to the Army beginning Engineering and Manufacturing Development of this system in the near future.

Decision Process

Evaluation of Objectives

In order to decide on the optimal allocation of funding, we first weighted the objectives with respect to each other. To reiterate, the objectives were production cost, time to completion, technological risk, and the category of the R&D program. After our evaluation using pairwise comparisons, it turned out that there wasn't a great deal of difference between the most and least important objectives. The most important objective was approximately 1.4 times more important than the least important objective.

We determined that the category of the R&D program was the most important objective to meet. This is because the first thing we consider when funding a program is how synergistic it will be with respect to planned or existing programs or whether it is required in order to meet a newly identified threat (i.e. a clean sheet program). The next highest priority objective was determined to be the expected production cost of the system. Unless the results of the R&D program are affordable, there is little chance that production of the system developed will ever be funded. The technological risk of the program was considered the next most important objective. Even taking into account that we are talking about research and development, we don't want to fund R&D programs that are so far-fetched as to be unexecutable. Lastly, we determined that the time to completion for the program was the least important objective. The time estimated for an R&D program is really just a best guess, so basing too much on this figure could be misleading. However, the time is important because, while our current goal is to optimally allocate this year's funding, we will have to continue to fund projects in future years, so the longer a program will take to complete, the greater the chance that funding will be reduced. Figure 1 illustrates the model structure and indicates the relative weights of the objectives.

Evaluation of Alternatives With Respect To Objectives

In rating the alternative projects, we weighed our understanding of each project against the objectives we selected for our model. The following rationales were used for each alternative project.

Guided MLRS

The estimated unit production cost of the guidance package is supposed to be less than or equal to that of the unguided rocket (approx. $18,000 per copy), so we rated production cost as low for this project. The project will last approximately three years and then the Engineering and Manufacturing Development phase will begin. Thus, this project is classified as a near-term effort. Also, this project only exhibits moderate risk because most of the components, internal to the guidance package, are off-the-shelf. The only reason we classified this as moderate risk versus low risk was because inertial guidance packages can sometimes be difficult to assemble and we felt that past experience warrants a higher risk rating. Guided MLRS fell into the upgrade category because, in production, the guidance package is simply a new nose cone that can be fitted onto the current missile in place of the empty nose cone that is fitted to the unguided missile.

RFPI Demonstration

We decided to consider three funding levels (roughly translating to activity levels) for RFPI because of the magnitude of this effort. Large demonstration programs are often scaleable and we felt that RFPI could be scaled if sufficient funding was not available for the proposed effort. The lower funding options are intended to represent slower-paced options. By this we mean that instead of completing the demonstration effort in

5 years at the full funding level, it might add an additional six months at $28M or an additional year if the project could only be funded at $20M. RFPI is a very large program impacting many functional areas within the Army if fielded. Therefore, we rated production cost as moderate to extreme depending on which funding option will be chosen, our rationale being that the lowest funded option will have the highest production cost because so much time will pass between the start and finish of the program that inflation will become a factor in unit pricing. RFPI was rated as a mid- to long-term effort because of the unique and revolutionary nature of this project. Totally new concepts often produce unexpected outcomes, which, either good or bad, cause the schedule to slip. We rated risk as significant for the obvious reason that this is a totally new and potentially revolutionary concept, which is a real gamble.

CAPS

CAPS is categorized as an upgrade because the technologies being explored, if proven successful, will be added to existing missiles as a retrofit and implemented into existing production lines. We rated production cost as moderate because CAPS is exploring multiple technologies. If the Army determines, based on threat assessments and results of the CAPS demonstration, that more than one of these technologies will be required to meet the need, then this will be a more costly solution than it would be it only one technology is needed. For example, if a jammer and new warhead are needed to defeat the active protection system threat, this will be more expensive than just using a new warhead. Unfortunately, the cost of this upgrade will not be known until the threat is better quantified. CAPS is expected to be complete in the mid-term timeframe because the proposed demonstration is expected to take approximately five years to complete. Risk is moderate because little is known about the threat and a technical solution could prove to be challenging if the threat does indeed turn out to be formidable.

EFOGM

We decided to consider three funding levels (roughly translating to activity levels) for EFOGM, similar to RFPI above, because of the magnitude of this effort. The lower funding levels of $30M and $25M represent a combination of fewer missiles being produced and flown in demonstration testing and a longer timeframe to complete the entire project. EFOGM is categorized as a transition because a full-scale production program would have to be initiated if the Army decided to pursue this technology beyond the R&D phase. Production cost is considered to be moderate to significant (depending on the quantity of missiles being procured) because of the relative complexity of the system. We rated this as a near- to mid-term effort because a significant amount of effort is still required to develop an operational concept for this type of revolutionary weapon. The Army does not currently have any missiles capable of engaging targets beyond the line-of-sight and being remotely operated while in flight. The risk for this effort is moderate to significant because of open issues of how to integrate this type of weapon into the Army's Command and Control architecture.

Hypervelocity Missile

We rated this project as having a high production cost because of the unique components inside this type of missile. For example, a small lightweight kinetic energy missile requires a motor propellant with a very high thrust level (previously unachievable) to offset the reduction in weight from current kinetic energy missiles. The objective missile will weigh 75% of the current LOSAT missile and be approximately half as long (5 feet versus 9 ½ feet for LOSAT). This project is inherently long-term and high risk because the technologies being investigated are only in their infancy at this point.

Stinger Block II

Stinger Block II is categorized as an upgrade because the seeker being demonstrated in this project will replace the current Stinger missile seeker. Production cost is significant in comparison to the current Stinger seeker because the Block II seeker will employ imaging infrared technology whereas the existing seeker is simply an infrared "hot spot" tracker. This is a mid-term effort because the technology demonstration will be completed within 3 years and the prototype technology handed over to a production program. The technical risk is significant because this project is attempting to demonstrate the smallest 3-axis stabilized imaging infrared seeker ever built (2.75 inches in diameter).

Hellfire III Seeker

This project is categorized as a transition because the Hellfire missile bus currently in production will have to be completely redesigned in order to accommodate this type of seeker. This means an entirely new development program has been funded by the Army even though the name would indicate that this is simply a block upgrade to an existing weapon system. Production cost will be extremely high for this seeker because it will incorporate sensors capable of detecting in two different regions of the electromagnetic spectrum. From an engineering standpoint this represents a very big challenge which led us to rate the Hellfire III seeker project as high risk. Additionally, the customer has requested that this technology be available in the mid-term. Hence, our mid-term rating and further justification for a high risk rating.

LCPK

This project is categorized as a transition because the Army intends to make multiple design changes to the existing Hydra-70 rocket, outside of adding a guidance package. Consequently, the guided weapon will bear little resemblance to the current system (unlike Guided MLRS described earlier). The guidance package is expected to have a low production cost because both seeker candidates are relatively simple with few moving parts. Thus, even if the gimbaled version is selected the total guidance package will have a relatively low unit production cost. This is a near-term effort which will transition to production within 3 years and, as stated earlier, is low risk because two candidates are being evaluated.

Allocation of Funding

Our R&D budget for the current year is $60 million. We have eight alternative R&D programs that we must allocate this funding amongst. Two of the programs, the RFPI Demonstration and the EFOGM, if fully funded, would be over ten times more costly than the least costly programs (see Figure 3). As a practical matter, the smaller programs are truly go/no go decisions; a decrease in the funding level would make pursuit of them unrealistic. For this reason, they are not considered at different activity levels. However, for the two large programs, different activity levels can be analyzed separately. These figures are representative of the actual funding levels considered; however actual government funding levels are not currently releasable.

Alternatives	PRIORITY	Cost	DV's	F. Benefit	F. Cost	
Guided MLRS	0.895	$ 6,800	1	0.895	$ 6,800	
RFPI Demonstration ($20M)	0.314	$ 20,000	0	0	$ -	
RFPI Demonstration ($28M)	0.402	$ 28,000	0	0	$ -	
RFPI Demonstration ($32M)	0.471	$ 32,000	0	0	$ -	
CAPS	0.705	$ 2,400	1	0.705	$ 2,400	
EFOGM ($25M)	0.555	$ 25,000	0	0	$ -	
EFOGM ($30M)	0.673	$ 30,000	1	0.673	$ 30,000	
EFOGM ($37M)	0.742	$ 37,000	0	0	$ -	
Hyper-Velocity Missile	0.366	3400	1	0.366	$ 3,400	
Stinger Block II	0.591	2,900	1	0.591	$ 2,900	
Hellfire III Seeker	0.469	6,500	1	0.469	$ 6,500	
LCPK	0.964	3,950	1	0.964	$ 3,950	
Total				**4.663**	**$ 55,950**	**$ 60,000**
						Available Funds

Figure 3.

After evaluating each of the alternatives with respect to the objectives, we determined that the LCPK program had the highest priority, closely followed by the Guided MLRS. The lowest activity level of the RFPI Demonstration received the lowest priority. When judging the alternatives using the cost/benefit ratio, the CAPS program provided the most benefit for the dollar, closely followed by the LCPK program. The middle activity level for the RFPI Demonstration program had the lowest cost/benefit ratio.

In order to allocate the funding optimally, we used the results discussed above, which we determined using Expert Choice, and moved them into an Excel environment. Using Excel's solver tool, we maximized the total benefit (based on the priorities) while limiting our total expenditures to our $60 million budget. This resulted in a decision to fund all of the less expensive programs and to fund the EFOGM program at the middle level ($30M). The RFPI Demonstration was not funded at all. By adjusting this decision model to allow non-integer decision variables (an option we considered versus different activity levels), the results were similar, but the EFOGM program was funded at a level that expended the entire budget. We decided against this approach primarily because it didn't accurately reflect the lower priority given to a project because of the reduction in funding. The priority reduction implied by using a decision variable less than one was based on a linear relationship that we didn't feel reflected reality.

Conclusion

Without using Excel to maximize the total benefits provided by our selection of R&D programs, we would have intuitively chosen those with the highest priorities. This would have changed our decision somewhat; we would have fully funded the EFOGM program and would not have funded the Hyper-Velocity Missile program. This decision would have expended $59.550 million and resulted in a total benefit of 4.366, six percent less than the total benefit gained using the Excel solver. In other words, our use of this decision methodology allowed us to increase our utility (at a lower cost, no less).

One aspect of the decision process that our model may not adequately take into account is the political one. The issue here is not really at the Congressional level, those decisions have already been incorporated into our budgets, but really is with respect to the engineers and managers making the decision, and the field activities that will be performing the R&D. Each one of them has their own areas of expertise and their own pet projects. We considered including this factor in the model, but felt that our knowledge of the different variables present would not be sufficient to accurately prioritize the alternatives. Additionally, and more importantly, while using an objective relating the alternatives to political power might be useful for predicting the outcome of this resource allocation decision, it would not be useful for allocating the resources optimally – our goal.

Therefore, we have attempted to bring a structured look to what has previously been a chaotic and somewhat random process in the hope that precious taxpayer resources will be used in the most effective manner possible. In the long-term, analysis of this type may even have a tempering effect on the influence exerted by powerful individuals and organizations over the decision making process. In discussions with decision-makers, the model we created was greeted with some respect; however, each of them noted that an objective analysis of the facts was not the way that decisions are currently made. Facts and figures are considered in the initial evaluation phases, but, notwithstanding them, decisions are often made in the face of overwhelming evidence in direct contradiction of them. The military landscape is littered with their remains.