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Achieving Cost Effective Conservation: ORES801 Case Studies of Optimization Application to the Department of Defense's Readiness and Environmental Protection Initiative.

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Case Studies
by
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ABSTRACT

The following case studies were developed as research projects of the ORES801 course entitled “Optimization: Models and Methods” taught by Dr. Kent Messer at the University of Delaware in the Fall of 2010.

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Readiness and Environmental Protection Initiative Case Study: Applying Optimization to the Project Selection Process

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1. Introduction

In the lead up to World War II, the military established many training and testing ranges on large tracts of remote rural land. As military suppliers and families moved to the areas surrounding these installations, urban and suburban communities developed and continue to grow along the installation boundaries. Simultaneously, the military's land and resource requirements are growing with the evolution of technology and training activities, creating conflicts with the civilian population. Military operations have been challenged with safety concerns, endangered species restrictions, light pollution, and electromagnetic frequency spectrum usage, while the civilian communities are affected by the noise, dust, and smoke emanating from military training activities.

To address this encroachment problem, the Department of Defense (DoD) established the Sustainable Ranges Initiative (SRI) in December 2001. One of the key components of SRI is the Readiness and Environmental Protection Initiative (REPI) Program, which is administered by the Office of the Secretary of Defense (OSD). The 2010 REPI Program Guide defines the objective of the program as follows:

> "The overarching goal of REPI conservation and compatible land use partnering is to create a dynamic equilibrium, or adaptive steady state, where the warfighter has continued access to the land, airspace, sea space and frequency spectrum necessary for testing and training needed to maintain readiness. The Program's objective is to meet this goal through strong Service partnerships with entities that share an interest in preserving and protecting land. In particular, Program funding will support Service partnering agreements that, as authorized in section 2684a, seek to: (1) limit any development or use of real property that would be incompatible with the mission of the installation; or (2) preserve off-base habitat to

relieve current or avoid future environmental restrictions on military operations." (page 3)

Because of the extensive funding requirements of conservation and compatible land projects and the limitations of the REPI budget, the REPI Program must be selective in its allocation of funds. In this paper, we will assess the current rank-based method that REPI uses for project selection and consider how implementing binary linear program in the selection process would affect the program's results.

2. Problem Formulation

2.1 Data and General Assumptions

The OSD provided us with information on forty-four actual projects, categorized by Service, which are being considered for REPI Funding. Included in the data set are project benefit scores, acquisition costs, and sizes of projects in terms of acreage affected.

The benefit scores for the projects are grouped into three main categories: Encroachment Threat, Incompatible Development/Habitat Preservation, and Viability of Agreement. Each branch (Air Force, Army, Navy, and Marines) scores the projects submitted by the other services. The OSD also scores the projects, taking into account the project assessment of the submitting service. The average score of these four is then used as the final project score in the selection process; this is the score referred to in the remainder of the paper.

The acquisition costs are also divided into four categories based on the source of funding. The Partner Contribution is the amount of money pledged by outside agencies, such as conservation organizations, local, regional, and state governments, and other federal agencies. The other categories are Service Contribution, REPI Funding Request, and Other. The REPI Funding Request is the actual amount of money that the Project hopes to be granted by the REPI Program. Note that it represents a potential benefit to the project in terms of fulfilled funding requirements, but a potential cost for the REPI program in terms of funding allocated.

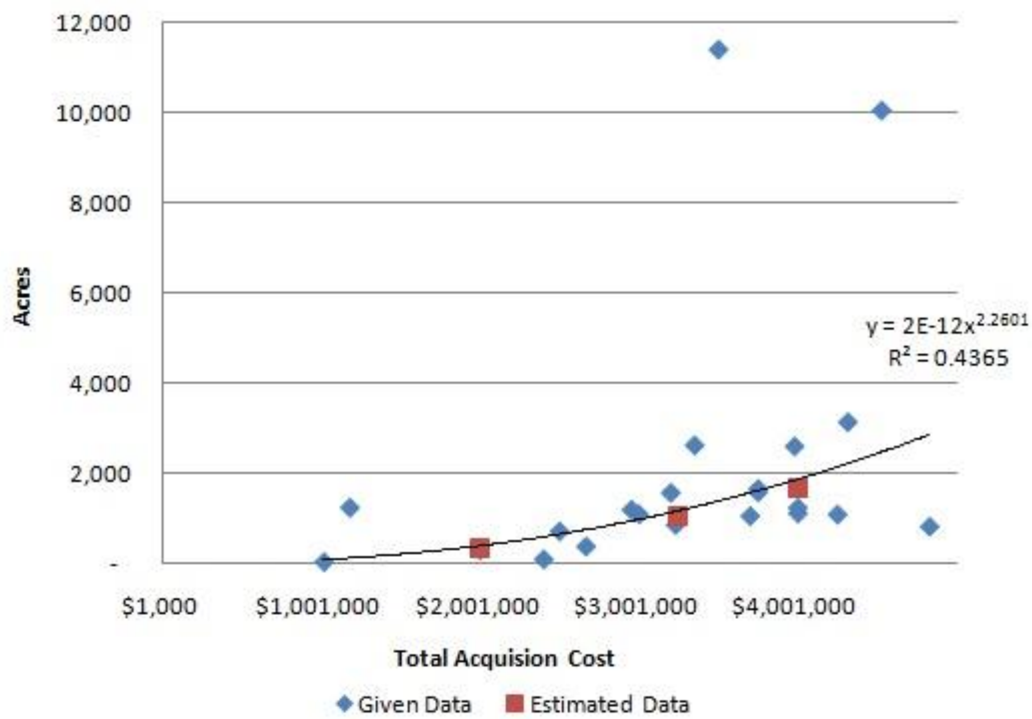


Figure 1: Estimating Acreage from Total Acquisition Cost

Also included in the data is the size of the project in terms of the amount of land, measured in acres, that would be affected by the project. The acreage for three projects, AF-7, N-11, and N-12, is unknown and thus had to be estimated. We assumed that the total acquisition cost is directly related to acreage. Since the total acquisition costs range from $0.9 million to $46 million, while the total acquisition costs for the projects with unknown acreage are $3.25 million, $4 million, and $2 million respectively, we restricted our consideration to projects with total acquisition costs between $1 million and $5 million. From these 22 projects, we obtain our best r2 value, r2 = 0.4365, using power regression; other methods considered were linear regression and exponential regression. From the resulting power regression function Acreage = (2 · 10-12)(TotalAcqCost)2.2601, we estimate the size of the unknown projects to be approximately 1,044, 1,669, and 348 acres respectively.

The projects are ranked by decreasing total score, and in the event that two projects have the

	Air Force	Army	Navy	Total
Number of Projects	9	23	12	44
Encroachment Score	363.00	859.50	439.00	1662
Incompatible Development /Habitat Preservation Score	117.25	346.50	149.75	614
Viability of Agreement Score	163.00	636.00	204.00	1003
Total Score	643.25	1842.00	792.75	3278
Average Total Score	71.47	80.09	66.06	74.50
Average Score Standard Deviation	9.20	11.09	12.76	12.60
REPI Funding Request	$19,857,000	$78,264,217	$27,864,880	$125,986,097
Average REPI Funding Request	$2,206,333	$3,402,792	$2,322,073	$2,863,320
REPI Funding Request Standard Deviation	$1,219,306	$2,313,497	$969,060	$1,915,153
Total Anticipated Acquisition Cost	$31,187,250	$211,692,048	$50,646,427	$293,525,725
REPI Share of Cost	63.67%	36.97%	55.02%	42.92%
Estimated Size (acres)	21,920.01	90,478.00	12,761.09	125,159.10
Estimated Average Size	2,435.56	3,933.83	1,063.42	2,844.53
Size Standard Deviation	3,468.67	5,052.78	1,007.65	4,137.07
Average Rank	26	17	30	

Table 1: Data Summary

same score, we subsequently rank them by increasing REPI Funding Request. We note in Table 1 that the Army has the highest average rank, 17, while the Navy has the lowest average rank, 30. All of the top five projects are from the Army and three of the subsequent five projects are from the Army, with the Air Force having one project ranked 6th and the Navy having one project ranked 8th. Additional statistics summarizing the projects such as benefit scores, costs, and estimated size are included in Table 1.

We assume that REPI has a budget of $54 million; the REPI budget for the 2010 Fiscal Year was $54.7 million, a decrease from the $56 million budget in 2009. In order to allocate funds to as many projects as possible, there is also a $3 million dollar cap on funding for any one project.

2.2 Project Selection Methods

The REPI program currently uses a rank-based method to allocate funds. After ranking the projects by highest total score and subsequently lowest REPI Funding Request, a tier system is used to determine the amount of the REPI allocation for each project. The top five ranked projects are allocated the minimum of 100% of their requested amount or the cap amount of $3 million. Projects ranked 6th through 10th are allocated the minimum of 75% of their requested amount or the cap amount of $3 million. After selecting and funding the top ten projects, REPI then works through the rest of the list, allocating the minimum of 50% of their requested amount or the cap amount of $3 million to subsequent projects, until the budget is depleted. All of the projects on the list are considered; if the remaining REPI budget cannot cover the necessary allocation for a project, the project is skipped and the remaining projects are considered for funding.

We will consider the results of the actual production rank-based method which includes the tier and cap system as well as the results of the rank-based method without tiers and caps. In the second method, all projects are funded 100% of their actual request, not the minimum of the request and the cap, in rank-based order.

We will alternatively consider Binary Linear Programming (BLP) as a project selection method for REPI. The BLP method selects projects such that the total benefit obtained is maximal with respect to given constraints. For our set of projects, we assign each project a unique index number from 1 to 44. This index can be the same as the project's rank used in the rank-based method, but the actual value is irrelevant as it is only used to identify the project and has no impact on the results. We define the binary decision variable xi for i = 1, 2,..., 44 such that

$$x_i = \begin{cases} 1 & \text{if project i is selected for funding} \\ 0 & \text{otherwise} \end{cases}$$

For i = 1, 2,..., 44, let bi be the total benefit score of project i, and let ci be the REPI Funding Request of project i. Note that ci can also be identified as the cost to REPI if project i is selected. As we will consider the BLP method with tiers and caps and without tiers and caps, we also define ci as the minimum of the tier adjusted (100%, 75%, or 50%) REPI Funding Request and the $3 million dollar cap for project i, where the tier adjustment is determined by the projects benefit score rank.

The BLP problem without tiers and caps is formulated as

$$\text{Max:} \quad z = \sum_{i=1}^{44} b_i x_i$$

$$\text{s.t} \quad \sum_{i=1}^{44} b_i x_i \le 54{,}000{,}000$$

$$x_i \in \{0,1\}, \quad i = 1,2,\dots,44$$

where z is the total benefit score of all selected projects. As we seek to maximize total benefit, the first equation is our objective function. The inequality is the budget constraint which restricts the total allocated REPI funding to be within the assumed budget of $54 million. The last constraint forces the decision variables to assume only 0 or 1 values, ensuring that xi is a binary variable for all indices 1 ≤ i ≤ 44.

The BLP method with tiers and caps is the same as the BLP method without tiers and caps except for REPI Funding Requests. When including tiers and caps, the BLP method assumes that the REPI Funding Request for project i is $\overline{ci}$ instead of ci. Therefore, the formulation of the BLP method with tiers and caps has the same objective function as the previous model, budget constraint

$$\sum_{i=1}^{44} \overline{c_i} x_i \le 54{,}000{,}000,$$

and the same binary constraint as the previous model.

In addition to the rank-based method and the BLP method, we consider two intermediate methods which we will call "Hybrid-5" and "Hybrid-10". Both methods start by following the rank-based method, where Hybrid-5 will select the top five ranked projects and Hybrid-10 will select the top ten ranked projects. They then use the BLP method to select the remaining projects. These methods can be formulated as the original BLP model with the additional constraint

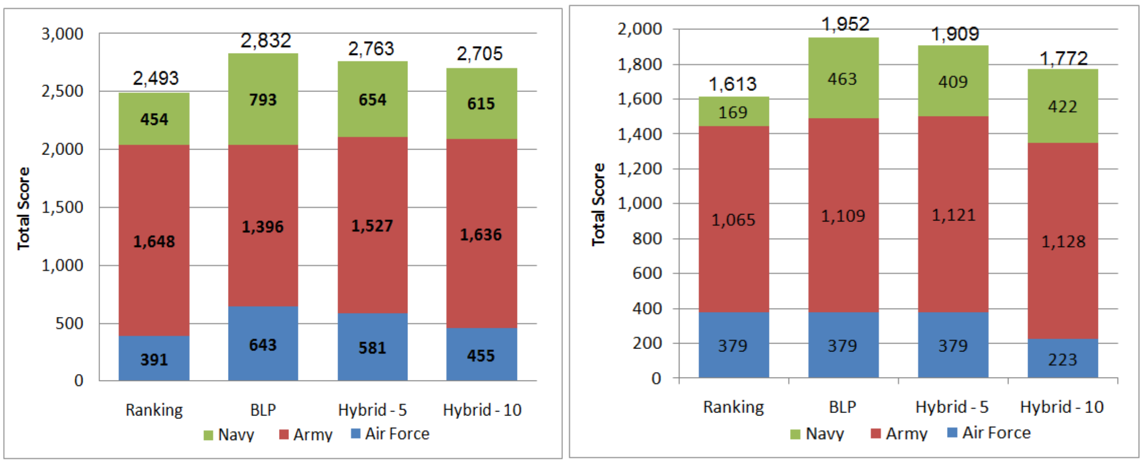
$$x_j = 1, \qquad j \in \{k\text{:rank of project } k \le n\}$$

where n = 5 for Hybrid-5 and n = 10 for Hybrid 10. These definitions of the hybrid models do not include the tiers and caps, but we can easily revise the models to include tiers and caps by changing the budget constraint.

Results

3.1 Benefit Scores

As the REPI program currently uses the rank-based method with the tiers and cap, we obtain a baseline total benefit score of 2,493. In comparison with the BLP method and the hybrid methods, we observe in Figure 2(a) that all three alternative methods obtain higher benefit scores than the rank



(a) With Tiers and Cap (b) Without Tiers and Cap

Figure 2: Total Benefit Score

based method. The BLP method obtains the highest total benefit score of 2,832, a 13.6% increase over the baseline. The Hybrid-5 method obtains the second highest benefit score of 2,763. This score is lower than that of the BLP method because the BLP method does not select the third, fourth, and fifth ranked projects. Hence, when the hybrid method is forced to include these projects, it must forgo the selection of other benefit increasing projects. Similarly, the Hybrid-10 method score is lower than that of the Hybrid-5 method and the BLP method as these methods do not select the tenth ranked project. Although the hybrid methods do not obtain the maximal possible score of the BLP methods, they still show 10.8% and 8.5% respective improvements over the rank-based method.

The total benefit score results of the four models without the tiers and cap are shown in Figure 2(b). We again observe the same relationship between the methods as in the models with the tiers and cap; the BLP method obtains the highest total benefit score of 1,952, the rank-based method obtains the lowest total benefit score of 1,613, and the Hybrid-5 and Hybrid-10 methods fall in between with respective total benefit scores of 1,909 and 1,772. Note that the BLP method does not select the fifth and tenth ranked projects, which accounts for the differences of the hybrid models. Considering the rank-based total benefit score to be the baseline, we observe a 21% increase in the BLP model and 18.4% and 9.9% increases respectively in the Hybrid-5 and Hybrid-10 models.

We note that the total benefit score values for the models without the tiers and cap are much lower than their tiers and cap counterparts. Because we are funding the entire REPI request of the projects instead of a percentage of it as in the tiers and cap models, the per project costs to REPI are higher, and hence the budget is depleted faster. When developing the alternative method models, there was concern that a project might not be completed if it receives only a portion of its requested REPI amount; if a project requests $3 million but receives only 50%, the concerned Service must obtain another $1.5 million by alternative means to complete the project. As we are assuming that a project which receives funding is completed and hence contributes its whole potential benefit, the existence of uncompleted partially funded projects would overstate our results, reducing their validity. To relieve this concern, the models without the tiers and caps where developed so that we could have higher confidence in the completion of projects and the validity of our results. For the remainder of this paper, we will only discuss the models without the tiers and cap. However, we do note that the models with the tiers and cap were also studied, and although the exact values differ from the models without the tiers and cap, the general patterns and relationships remain the same. Likewise, we will focus our attention on the Hybrid-5 method, but we note that the corresponding Hybrid-10 results are always slightly below that of Hybrid-5 and significantly higher than that of the rank-based method. The results of all models are summarized in the appendix.

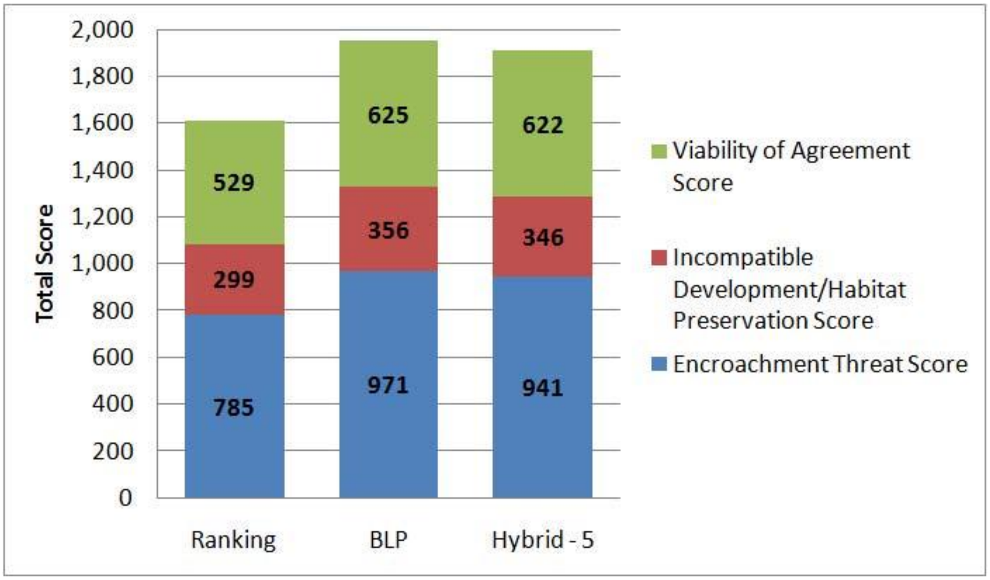


Figure 3: Distribution of Total Benefit Score by Category (w/o Tiers and Cap)

The total benefit score is divided into three categories which are distinguished in Figure 3 for the models without the tiers and cap. Each of the three benefit score categories follow the same pattern as the total benefit score; the rank-based method obtains the lowest values, and the BLP method obtains the highest values. The most dramatic changes are observed for the Encroachment Threat score, the category that also happens to account for the largest share of the total benefit scores. The Hybrid-5 method obtains an Encroachment Threat score of 941 which is 20% higher than that of ranked-based method, and the BLP method obtains an Encroachment Threat score of 971 which is 23.7% higher than that of the rank-based method. The lowest percentage change when using the ranked-based method as the base line is an increase of 7.6% for the Hybrid-5 Viability of Agreement score. Correspondingly, the lowest percentage change observed for the BLP method, 18.1%, is also for the Viability of Agreement score.

3.2 Additional Measures and Cost Effectiveness

The relationships observed between the benefit scores of the different models also emerge in other measures of project selection. The number of acres protected by the selected projects, which can be thought of the cumulative size of the project selection, is shown in Figure 4. The rank-based method

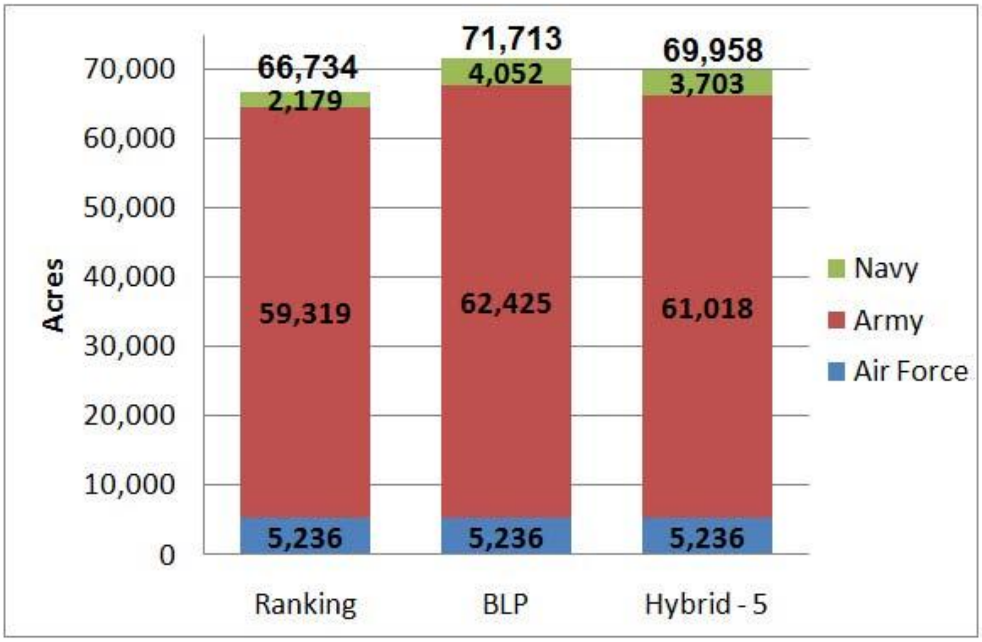


Figure 4: Estimated Acreage Protected (w/o Tiers and Cap)

protects the smallest number of acres, 66,734, and the BLP method protects the largest number of acres, 71,713, with the Hybrid-5 method falling slightly below with 69,958 protected acres. The BLP method protects 7.5% more acres then the rank-based method, the total of which accounts for 57.3% of the total possible acreage; the rank-based method protects 53.3% of the total possible acreage. Looking at the acres protected by Service, the same pattern arises within each, with the exception of the Air Force whose acreage protected remains constant; all three methods select the same Air Force projects. Note that the acreage is an estimate as we interpolated acreage values for three of the projects, although only one of these projects, N-12, is selected by the BLP method and is the only estimated acreage project included in the chart. (This is not generally true of all models, as the BLP model with the tiers and cap selects all three projects with estimated acreage.) However, even if we exclude the 348 estimated acres of N-12, the BLP method still protects 71,365 acres, exceeding the acreage protected by the rank-based method by 6.9%.

The number of projects selected by each method is displayed in Figure 5. Once again, the rank-based method selects the fewest projects, 19, the BLP method selects the most projects, 25, and the Hybrid-5 method selects 24 projects, slightly below the BLP method.

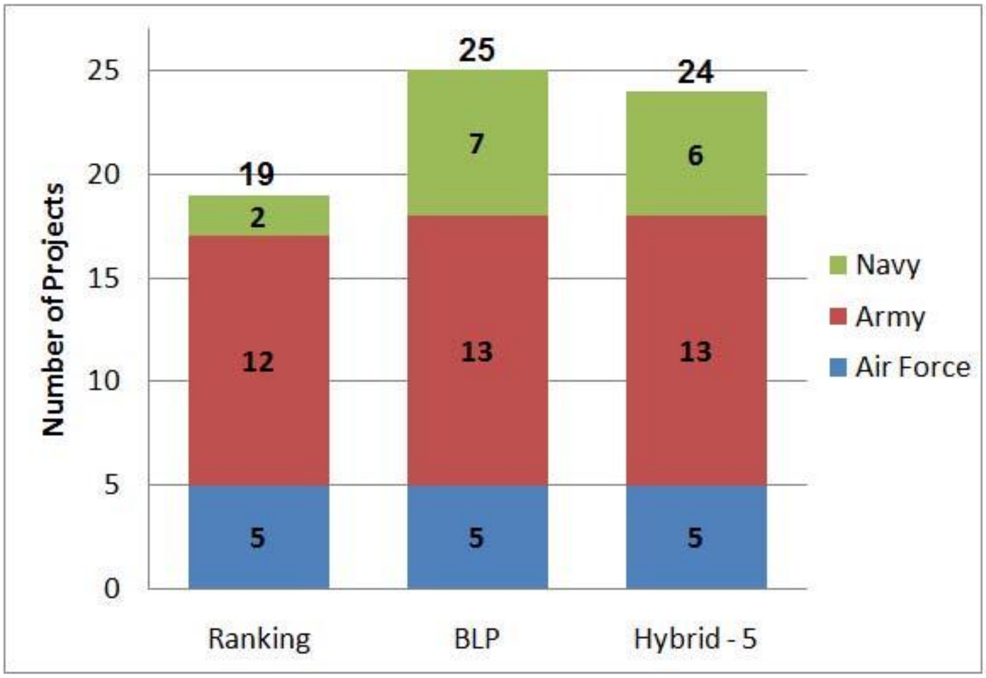


Figure 5: Number of Selected Projects (w/o Tiers and Cap)

Looking at the project selections, we note that the Air Force consistently has 5 projects selected, as the same projects are picked by all three methods, and the Army has one additional project selected by the BLP and Hybrid-5 methods over the 12 projects selected by the rank-based method. The majority of variability is seen in the Navy; 2 Navy projects are selected by the rank-based method, 7 Navy projects are selected by the BLP method, and 6 Navy projects are selected by the Hybrid5 method. Referencing back to Table 1, we recall that the Navy had the lowest average rank of the three Services, and consequently, it is not surprising that few Navy projects are selected by the rank-based method. While the benefit scores of the Navy projects are low, the corresponding costs of the projects are also relatively low. Therefore, it is possible to fund several low-ranking Navy projects with the same amount of money as a single high-ranking project while achieving a cumulatively higher benefit score. As the BLP method recognizes this cost savings, which is ignored by the rank-based method as it only looks at projects individually and not as a group, the BLP model selects the several smaller cost projects over the single large cost project.

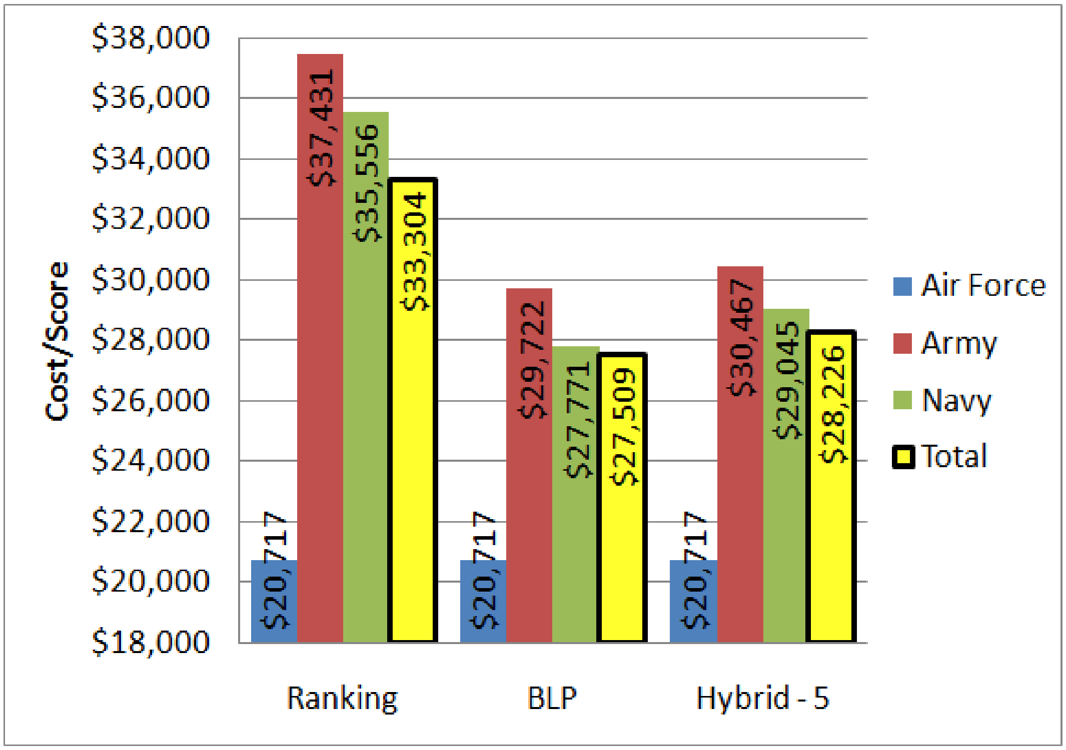


Figure 6: Cost per Score Point (w/o Tiers and Cap)

The cost effectiveness concept of the BLP method selecting low cost but relatively high benefit projects over high benefit but relatively high cost projects can be measured by considering the ratio of cost to benefit score. Figure 6 charts the cost per benefit score point for each of the three methods. The rank-based method pays $29,293 for each score point while the BLP method pays $27,509 for each score point; one additional score point for the BLP method costs approximately 11.7% less than for the rank-based method. The Hybrid-5 method also pays approximately 10% less than the rank-based method for each score point. The BLP method seeks out the most efficient purchases and, in a way, selects projects with the highest benefit to cost ratio instead of the projects with just the highest benefit. Therefore, although the average benefit score for projects selected by the BLP method is 8.7% lower than that of the rank-based method, it selects 6 more projects than the rank-based method to achieve a cumulative total benefit score that is 21% higher than the total benefit score of the rank-based method. In order for the rank-based method to achieve the same total benefit score as the BLP method, the budget must increase by approximately 37.2% to $20.1 million.

4. Recommendations

Regardless of the status of the tiers and caps, the results of this study strongly suggest that the REPI Program should adopt some configuration of the BLP method for project selection. In all cases, the REPI Program's current rank-based project selection method performed worse than the BLP and hybrid methods. The BLP method increases the efficiency of REPI allocations, and thus for the same cost, the BLP method with the tiers and cap achieves a 13.6% higher benefit score then its rank-based counterpart while the BLP method without the tiers and cap achieves a 21% higher benefit score then its rank-based counterpart. As another measurement of the BLP model's efficiency, we note that with the tiers and cap, an additional $4.3 million dollars must be spent for the ranking method to achieve the same score as the BLP method, and without the tiers and caps, an additional $20.1 million dollars must be spent for the ranking method to achieve the same score as the BLP method. Hence, using the BLP method achieves an 8% cost savings with the tiers and cap and a 37.2% cost savings without the tiers and cap.

While the purely binary linear programming method achieves the best results, we recognize that it may not be optimal with respect to the political environment. The BLP method, as demonstrated in this study, is not guaranteed to select any project with a given rank; although it was not observed with this data set, it is possible that the BLP method will not select the highest ranked project and so forth. Such actions may invoke confusion, opposition, and anger by the concerned parties. In such a case, we recommend using a hybrid method, such as the Hybrid-5 and Hybrid-10 methods, to select a given number of top ranked projects and then use binary linear programming to select the remaining projects. While these methods do not achieve the best results, they still perform significantly better than the rank-based method, and they present a strategic benefit that may be worth the small trade-off in benefit score.

We also recommend eliminating the tiers and cap. The BLP method as defined in this study relies on the assumption that any allocation of funds to a project ensures its completion and contribution of full benefit. In practice, incomplete funded projects would result in the REPI program achieving a much smaller benefit then projected; better, though not optimal, results would be achieved if the funding was reallocated to projects that could actually be completed. If the tiers and cap are to be retained in the selection process, the BLP model should be amended to consider incomplete projects. In this case, we recommend developing a process that scales the benefit scores with respect to the probability of a project’s completion and then utilizing the scaled benefit scores in the BLP model.

A Appendix

			With Tiers and Cap				Without Tiers and Cap					
Project	Rank	Average Score	Rank-Based	BLP	Hybrid-5	Hybrid-10	Rank-Based	BLP	Hybrid-5	Hybrid-10	FY11 REPI Funding Request	Size (acres)
AF-1	39	62.75		1	1						$3,000,000	11,414
AF-2	36	63.75		1	1						$3,000,000	2,615
AF-3	6	88.5	1	1	1	1	1	1	1	1	$1,200,000	81
AF-4	35	64		1	1	1	1	1	1	1	$485,000	1,725
AF-5	20	75.5	1	1	1	1					$3,000,000	1,611
AF-6	16	78.25	1	1	1	1	1	1	1		$3,000,000	1,850
AF-7	41	62		1							$3,000,000	1,044
AF-8	17	78	1	1	1	1	1	1	1		$3,000,000	1,560
AF-9	26	70.5	1	1	1	1	1	1	1	1	$172,000	20
A-1	14	80.75	1	1	1	1	1	1	1		$3,000,000	16,000
A-2	3	98.5	1		1	1	1	1	1	1	$3,000,000	2,745
A-3	24	72.5	1	1	1	1					$3,000,000	3,259
A-4	40	62		1							$3,000,000	1,647
A-5	7	87.75	1	1	1	1	1	1	1	1	$3,000,000	1,348
A-6	30	68.5	1	1	1	1					$3,000,000	1,572
A-7	23	72.75	1	1	1	1					$2,898,750	1,045
A-8	10	87	1			1	1			1	$8,467,000	6,776
A-9	1	99.25	1	1	1	1	1	1	1	1	$2,948,500	1,110
A-10	19	76	1	1	1	1		1	1	1	$2,000,000	702
A-11	15	79	1								$12,000,000	7,175
A-12	33	65.25		1	1						$2,952,500	1,181
A-13	32	66.75		1	1	1					$3,000,000	1,082
A-14	28	70.25	1	1	1	1					$2,984,467	2,593
A-15	11	86	1	1	1	1	1	1	1	1	$630,000	1,230
A-16	9	87	1	1		1	1	1	1	1	$3,000,000	2,700
A-17	29	69.75	1	1	1	1		1	1	1	$1,798,000	10,061
A-18	18	76.75	1	1	1	1	1	1			$2,800,000	3,130
A-19	22	74.75	1	1	1	1		1	1	1	$1,785,000	842
A-20	2	98.75	1	1	1	1	1	1	1	1	$3,000,000	2,121
A-21	12	81.5	1	1	1	1	1	1	1	1	$3,000,000	19,968
A-22	4	92.25	1		1	1	1	1	1	1	$3,000,000	468
A-23	5	89	1		1	1	1		1	1	$4,000,000	1,723
N-1	31	68.5	1	1	1	1					$3,000,000	3,639
N-2	27	70.5	1	1	1	1					$3,000,000	1,100
N-3	21	75.5	1	1	1	1					$3,000,000	1,077
N-4	8	87.25	1	1		1	1	1	1	1	$3,000,000	230
N-5	43	51.25		1							$3,000,000	1,225
N-6	13	81.5	1	1	1	1	1	1	1	1	$3,000,000	1,949
N-7	38	63		1	1			1	1	1	$2,000,000	365
N-8	44	41.5		1	1	1		1	1		$450,000	71
N-9	34	64.5		1	1	1		1	1	1	$1,000,000	280
N-10	25	70.75	1	1	1	1		1	1	1	$2,414,880	808
N-11	37	63.75		1	1						$3,000,000	1,669
N-12	42	54.75		1	1	1		1		1	$1,000,000	348
Total			31	39	37	35	19	25	24	22		

Table 2: Project Selection by Method The acreage values in red are estimated as discussed in Section 2.1

	With Cap and Tiers				Without Cap and Tiers			
	Ranking	BLP	Hybrid - 5	Hybrid - 10	Ranking	BLP	Hybrid - 5	Hybrid - 10
Number of Selected Projects								
Air Force	5	9	8	6	5	5	5	3
Army	20	18	19	20	12	13	13	13
Navy	6	12	10	9	2	7	6	6
Total	31	39	37	35	19	25	24	22
Total REPI Fund Alllocation (Cost)								
Air Force	$5,486,000	$10,228,500	$8,728,500	$5,728,500	$7,857,000	$7,857,000	$7,857,000	$1,857,000
Army	$38,896,609	$28,372,859	$33,622,859	$37,396,609	$39,845,500	$32,961,500	$34,161,500	$39,628,500
Navy	$9,457,440	$14,682,440	$10,932,440	$10,682,440	$6,000,000	$12,864,880	$11,864,880	$12,414,880
Total	$53,840,049	$53,283,799	$53,283,799	$53,807,549	$53,702,500	$53,683,380	$53,883,380	$53,900,380
Encroachment Threat Score								
Air Force	212	363	327	252	207	207	207	122
Army	760	651	707	754	481	513	508	520
Navy	258	439	363	336	97	251	226	236
Total	1,230	1,453	1,397	1,342	785	971	941	877
Incompatible Development/Habitat Preservation Score								
Air Force	69	117	107	79	64	64	64	42
Army	315	261	289	311	207	210	211	211
Navy	82	150	124	114	28	82	71	74
Total	466	528	520	504	299	356	346	326
Viability of Agreement Score								
Air Force	110	163	148	124	108	108	108	60
Army	573	484	531	571	377	387	402	397
Navy	114	204	167	165	44	130	112	112
Total	797	851	846	860	529	625	622	569
Total Score	2,493	2,832	2,763	2,705	1,613	1,952	1,909	1,772
% Change from Ranking		13.6%	10.8%	8.5%		21.0%	18.4%	9.9%
Average Score per Project	80.41	72.62	74.66	77.29	84.87	78.06	79.54	80.56
% Change from Ranking		-9.7%	-7.1%	-3.9%		-8.0%	-6.3%	-5.1%
Average Cost per Project	$1,736,776	$1,366,251	$1,440,103	$1,537,359	$2,826,447	$2,147,335	$2,245,141	$2,450,017
% Change from Ranking		-21.3%	-17.1%	-11.5%		-24.0%	-20.6%	-13.3%
Average Cost per Score Point	$21,599	$18,813	$19,288	$19,890	$33,304	$27,509	$28,226	$30,414
% Change from Ranking		-12.9%	-10.7%	-7.9%		-17.4%	-15.2%	-8.7%
Total Acreage*	100,493	106,272	104,362	96,825	66,734	71,713	69,958	57,601
% Change from Ranking		5.8%	3.9%	-3.7%		7.5%	4.8%	-19.7%
Average Acres per Project*	3,242	2,725	2,821	2,766	3,512	2,869	2,915	2,618
Budget increase to Achieve BLP Score	$4,300,000				$20,100,000			

Table 3: Summary of Results by Method

Applying Goal Programming to the REPI Project Selection Process

Thomas Bounds

Introduction

Since 2004, the United States Department of Defense (DoD) has sponsored a service-wide land easement program – the Readiness and Environmental Protection Initiative (REPI) – to protect acreage on military bases that is particularly important for environmental conservation. The United States Congress appropriates funding annually to the program, and its current purchasing budget is 54 million dollars. As both the REPI program's demand for and the service branches' supply of purchasable land far outpaces the program's budget, a method is needed to allocate funding for land purchase in an optimal fashion. In the past, the REPI program has relied upon a rank-based method of land purchase [see section I], wherein the most desirable parcels are purchased without respect to cost until all of the funds have been spent. [1]

Ms. Nancy Netoli, director of the REPI program, has expressed interest in using more dynamic, cost-effective techniques to allocate the program's budget. In particular, she has requested analysis of the purchasing program using an Operations Research technique termed 'goal programming.' Under this methodology, purchasing decisions are made based on the comparison of various characteristics of the parcels. This enables the purchasing agent to select parcels in an optimal fashion based on one characteristic, or in a more dynamic fashion based on the relative weights of multiple characteristics. [2]

The goal programming technique is used to determine parcel selection based on the relative weighting of two benefit categories for which the parcels were scored: benefits to military operations and benefits to the environment. [See sections 2 and 3 for more information]. A third category, the viability of agreement between buyer and seller, is also weighed against the two aforementioned criteria, enabling performance of a second three-goal analysis [See section 3.b]. In this paper, I will discuss the benefits of goal programming as it relates to the purchase of military land parcels, and will compare these results to those found in the more basic rank-based approach to military land easement.

Section I: The Rank-based REPI approach

Under the rank-based REPI purchasing program, all parcels under easement consideration are scored based on multiple criteria – encroachment threat, incompatible development or habitat preservation (collectively, environmental protection), and viability of agreement – by the Office of the Secretary of Defense and by the Army, Navy, Marine Corps, and Air Force, excluding the branch that is presenting the parcel for purchase. The four presented scores are then averaged to generate an overall score.

The REPI program ranks the parcels on this score, then proceeds to allocate funding from the highest scoring parcel to the lowest scoring parcel until the $54 million budget has been spent.

The results of the rank-based purchasing program are shown on the following page:

Installation	Overall Average Score	Military Readiness	Environmental Protection	Viability of Agreement	FY11 REPI Funding Request ($)	Acquisition Cost ($)	Size (acres)
A-9	99.25	46.5	19	34	2,948,500	5,508,500	1,110
A-20	98.75	48.0	17	34	3,000,000	6,416,658	2,121
A-2	98.5	43.0	18	38	3,000,000	19,000,000	2,745
A-22	92.25	45.0	17	30	3,000,000	7,000,000	468
A-23	89	31.5	18	40	4,000,000	25,000,000	1,723
AF-3	88.5	47.0	22	20	1,200,000	2,400,000	81
A-5	87.75	36.5	19	32	3,000,000	11,000,000	1,348
N-4	87.25	48.0	15	24	3,000,000	8,000,000	230
A-16	87	48.5	19	20	8,467,000	10,667,000	6,776
A-8	87	35.0	14	38	3,000,000	6,700,000	2,700
A-15	86	44.5	19	23	630,000	1,180,000	1,230
A-21	81.5	30.0	14	38	3,000,000	19,000,000	19,968
N-6	81.5	48.5	13	20	3,000,000	6,000,000	1,949
A-1	80.75	36.5	19	25	3,000,000	46,000,000	16,000
AF-6	78.25	39.5	13	26	3,000,000	7,500,000	1,850
AF-8	78	46.0	10	22	3,000,000	3,200,000	1,560
A-18	76.75	36.0	16	25	2,800,000	4,315,000	3,130
AF-9	70.5	34.5	10	26	172,000	1,017,000	20
AF-4	64	40.0	10	14	485,000	970,000	1,725

REPI Rank-based Purchase Approach (No tier or monetary cap) [Fig. 1.1]

Total							
19	1612.5	784.5	299	529	53,702,500	190,874,158	66,734
Average							
12A;2N;5AF	84.9	41.3	16	28	2,826,447	10,046,008	3,512

Summary of REPI Rank-based Purchase Approach (No tier or monetary cap) [Fig. 1.2]

As is shown on the previous page, the REPI program's purchasing decisions focus entirely on the overall score of the parcels. Perhaps a more dynamic approach to purchasing can be used to produce results favoring more than this single criteria. To this end, this paper will consider the goal programming methodology as it applies to this land easement problem.

Section 2: Goal Programming

The goal programming technique enables the REPI program to make purchase decisions with a view to maximizing a particular set of objectives: here, military readiness and environmental protection. When the maximum values for the two objectives have been determined independently, it is possible to consider purchase decisions resulting from a relative weighting of the goals. In this instance, an intermediate value of lambda, $\lambda = .50$, is used to determine the purchase decision when the military readiness and environmental protection goals are weighed equally.

The results of this analysis are presented on the following page:

Installation	Overall Score	Military Readiness	Environmental Protection	Viability of Agreement	FY11 REPI Funding Request ($)	Acquisition Cost (S)	Size (acres)
AF-3	88.5	47	22	20	1,200,000	2,400,000	81
AF-4	64	40	10	14	485,000	970,000	1,725
AF-5	75.5	45	15	16	3,000,000	6,000,000	1,611
AF-9	70.5	35	10	26	172,000	1,017,000	20
A-1	80.75	37	19	25	3,000,000	46,000,000	16,000
A-2	98.5	43	18	38	3,000,000	19,000,000	2,745
A-5	87.75	37	19	32	3,000,000	11,000,000	1,348
A-7	72.75	34	17	22	2,898,750	3,700,000	1,045
A-9	99.25	47	19	34	2,948,500	5,508,500	1,110
A-10	76	42	14	20	2,000,000	2,500,000	702
A-15	86	45	19	23	630,000	1,180,000	1,230
A-17	69.75	35	14	21	1,798,000	4,527,100	10,061
A-18	76.75	36	16	25	2,800,000	4,315,000	3,130
A-19	74.75	35	11	29	1,785,000	3,230,000	842
A-20	98.75	48	17	34	3,000,000	6,416,658	2,121
A-22	92.25	45	17	30	3,000,000	7,000,000	468
N-2	70.5	44	14	13	3,000,000	4,000,000	1,100
N-3	75.5	44	15	17	3,000,000	4,250,000	1,077
N-4	87.25	48	15	24	3,000,000	8,000,000	230
N-6	81.5	49	13	20	3,000,000	6,000,000	1,949
N-7	63	37	12	15	2,000,000	2,666,667	365
N-8	41.5	16	8	18	450,000	900,000	71
N-9	64.5	38	12	15	1,000,000	2,000,000	280
N-10	70.75	40	11	20	2,414,880	4,829,760	808
N-12	54.75	25	12	18	1,000,000	2,000,000	935

Goal Programming – Equal Objective Weighting [Fig. 2.1]

Totals							
25	1921	986	367	569	53,582,130	159,410,685	51055
Average							
12A;9N;4AF	77	39	15	23	2,143,285	6,376,427	2,042

Summary of Goal Programming – Equal Objective Weighting [Fig. 2.2]

As can be seen from the equally-weighted data, the goal programming methodology produces quantifiably better results than the rank-based method. While the results of these two methodologies will be compared at a later point [see Section 4], it is now appropriate to apply sensitivity analysis to the goal programming problem in order to study the dynamics of this technique more closely.

Section 3: Sensitivity Analysis – Military Operations vs. Environmental Protection

Since it is not possible to make purchase decisions based on a maximized military operations score and a maximized environmental protection score at the same time, it is necessary to model purchase decisions that weigh the two objectives relative to one another. To do so, a lambda function is established that determines an optimal purchasing structure favoring military operations exclusively ($\lambda = 0$), environmental protection exclusively ($\lambda = 1$), or some balance of the two (in which case λ represents a fractional value between the two extremes).

In order to study the effects of choosing between the two parameters, a sensitivity analysis report is generated, which details the purchase decisions and overall military operation and environmental readiness scores for the whole spectrum of lambda values at intervals of .05.

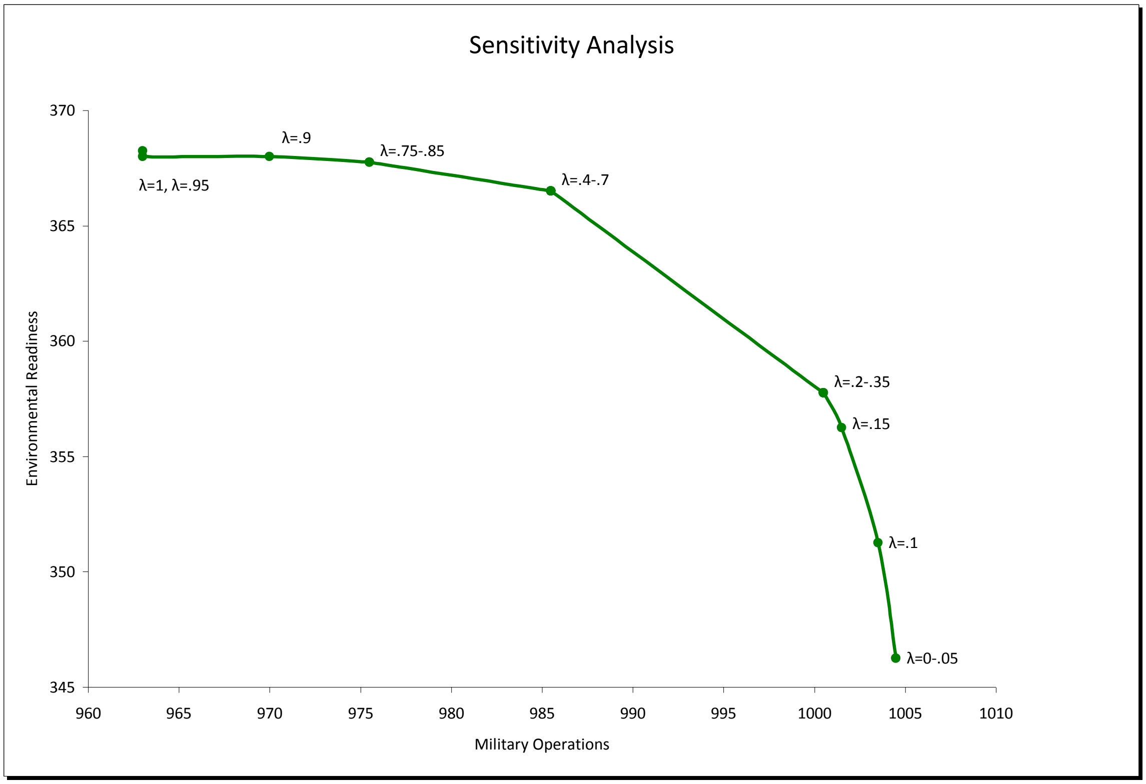
The results, and a corresponding graph, are presented on the following pages:

lambda	Overall Score	Military Operations	Environmental Protection	Viability of Agreement	FY11 REPI Funding Request ($)	Acquisition Cost ($)	Size (acres)
0	1886	1005	346	535	53,883,380	112,595,935	45,453
0.05	1886	1005	346	535	53,883,380	112,595,935	45,453
0.1	1904	1004	351	549	53,883,380	155,095,685	50,039
0.15	1928	1002	356	570	53,883,380	162,095,685	50,290
0.2	1913	1001	358	555	53,883,380	158,595,685	49,537
0.25	1913	1001	358	555	53,883,380	158,595,685	49,537
0.3	1913	1001	358	555	53,883,380	158,595,685	49,537
0.35	1913	1001	358	555	53,883,380	158,595,685	49,537
0.4	1921	986	367	569	53,582,130	159,410,685	51,055
0.45	1921	986	367	569	53,582,130	159,410,685	51,055
0.5	1921	986	367	569	53,582,130	159,410,685	51,055
0.55	1921	986	367	569	53,582,130	159,410,685	51,055
0.6	1921	986	367	569	53,582,130	159,410,685	51,055
0.65	1921	986	367	569	53,582,130	159,410,685	51,055
0.7	1921	986	367	569	53,582,130	159,410,685	51,055
0.75	1903	976	368	560	53,582,130	157,410,685	50,203
0.8	1903	976	368	560	53,582,130	157,410,685	50,203
0.845	1903	976	368	560	53,582,130	157,410,685	50,203
0.9	1896	970	368	558	53,582,130		
0.95	1901	963	368	570	53,582,130		
1	1901	963	368	570	53,582,130	157,160,685	50,675

Sensitivity Report – Military Ops v. Environmental Protection – λ =.05*x [Fig. 3.1]

Totals							
	20,737	7,604	11,770	40,111	1,020,470,470	2,922,033,515	948,044
Average							
	1910	987.9	362.3	560.5	53,696,892	153,791,238	49,897.5

Summary of Sensitivity Report [Fig. 3.2]



Military Operations v. Environmental Protection Graph [Fig. 3.3]

Based on the report generated above and the corresponding graph, several conclusions can be made. For small lambda values (λ = 0 - .35), which favor military operations at the expense of environmental readiness, shifts towards the environmental and away from the military parameters have large benefits for the environment with limited repercussions for the military. The change at the mid-level lambda (λ=.4) represents a dramatic shift away from military operations and in favor of the environmental readiness. For all greater lambda values (λ=.45 – 1), small shifts in favor of environmental readiness have large negative repercussions for military operations.

The graph of the sensitivity analysis between environmental readiness and military operations, much like a production possibility frontier curve in economics, enables the evaluation of trade-offs between the two competing goals. All values on the line represent the best possible values of environmental readiness and military operations scores given a variety of weightings between the two objectives.

It is now appropriate to consider the results of a more robust analysis that considers the viability of agreement score in addition to the military readiness and environmental protection scores.

Section 3b: Three-Way Sensitivity Analysis – Military Operations, Environmental Protection, and Viability of Agreement

Like the two variable sensitivity analysis performed above, a three-way analysis model uses a weighting function to favor specific objectives over others. However, where the two-criteria analysis required only one variable, lambda, to designate relative weighting, the three-criteria analysis requires two: lambda one ($\lambda 1$), which favors military operations over the other two criteria, and lambda two ($\lambda 2$), which shifts favor from viability of agreement ($\lambda 2=0$) to environmental readiness ($\lambda 2=1$) . In the three-way analysis, $\lambda 1$ is valued between 0 and 1, at intervals of 0.1, and, for each of these lambda one values, a purchasing decision is made for values of lambda two between 0 and $1-\lambda 1$, at intervals of 0.1. The result is a series of purchasing decisions for a complex of 59 lambda one-lambda two levels favoring, at various weightings between 0 and 1, the goals of maximizing military operations, environmental protection, and viability of agreement scores. [4]

Because the analysis generates values for three criteria, it is not possible to plot the results on a Cartesian plane. Furthermore, the formulae used to generate the maximizing functions make difficult an explanation of the actual weightings between criteria for each lambda one-lambda two level. In an attempt to remedy this problem, this group has developed an analysis that compares the score for each of the three criteria with its the maximum possible score. In the table that follows, each of the scoring combinations generated in the analysis is presented, along with the percentage of each criterion's score relative to the maximum possible score given the budget constraints. A ranking of the possible decisions is then determined by weighing each of the three percentages equally, thereby producing an aggregate percentage. The results are presented on the following page:

Mil Ops Score	% of Max	Envi Readiness Score	% of Max	Viability of Agreement	% of Max	Total Score	Overall % (*)	# of occurences
958	95.37	363.25	98.64	625	96.90	1946	96.97	2
962	95.77	365.5	99.25	616	95.50	1944	96.84	1
953	94.87	365.25	99.19	622	96.43	1940	96.83	1
953	94.87	356	96.67	637	98.76	1946	96.77	2
938	93.38	360.25	97.83	639	99.07	1937	96.76	9
970.5	96.62	356	96.67	625	96.90	1952	96.73	1
940.5	93.63	364.75	99.05	628	97.36	1933	96.68	1
958.5	95.42	367	99.66	612	94.88	1938	96.65	3
944.5	94.03	367	99.66	619	95.97	1931	96.55	4
950.5	94.62	353	95.86	639	99.07	1943	96.52	4
929.5	92.53	362	98.30	636	98.60	1928	96.48	2
979.5	97.51	354.75	96.33	616	95.50	1950	96.45	1
963	95.87	350.25	95.11	634	98.29	1947	96.43	5
983	97.86	362	98.30	598	92.71	1938	96.29	1
977	97.26	366.5	99.52	594	92.09	1943	96.29	3
993	98.86	356.25	96.74	595	92.25	1944	95.95	2
986.5	98.21	350.5	95.18	608	94.26	1945	95.88	1
985.5	98.11	366.5	99.52	569	88.22	1921	95.28	5
1000	99.55	351	95.32	583	90.39	1893	95.09	2
893	88.90	355.5	96.54	644	99.84	1934	95.09	1
998	99.35	359.25	97.56	569	88.22	1926	95.04	1
1001.5	99.70	356.25	96.74	570	88.37	1928	94.94	2
890.5	88.65	352.75	95.79	645	100.0	1888	94.81	1
975.5	97.11	367.75	99.86	560	86.82	1903	94.60	1
1000.5	99.60	357.75	97.15	555	86.05	1913	94.27	2
1003.5	99.90	351.25	95.38	549	85.12	1904	93.47	1

Sensitivity Report – Military Operations, Environmental Protection, & Viability of Agreement [Fig. 3.4]

* Overall Percentage = [(Mil Ops % + Envi Readiness % + Via Agreement %)/ 3]

Totals								
25,088		9,338		15,787		50,213		59
Average								
965	96.06	359	97.53	607	94.1	1,931	95.91%	2.27

Summary of Sensitivity Report [Fig. 3.5]

Considering the results above, and comparing them to those from the two-way analysis, several conclusions can be made. First, the three-way analysis is very effective at closing in on the maximum scores for each of the three criteria. Comparing the current results with earlier analysis that determined the maximum score possible for each of the three categories independently, one sees that this new methodology produces purchasing decisions capable of meeting, on average, over 95% of the maximum possible scores for the three criteria. Further, this three-way analysis averages an overall score 21 points higher than that generated by the two-way analysis. As such, while this more complex form of goal programming analysis lacks some of the specificity of the two-goal analysis, it is able to achieve demonstrably better results within the same budget limitations.

It is now appropriate to compare the results of the rank-based method to those found with goal programming.

Section 4: Rank-based v. Goal Programming

The first step in comparing rank-based and goal programming methods for REPI land purchase is a comparison of the results generated by both methods. Using the totaled results from Sections 1 for the rank-based method, and considering an equally weighted balance between military operations and environmental readiness (λ=.5) for the goal programming method, the following comparison chart can be generated:

	Rank-based Method	Goal Programming Method (λ=.5)	Change in Quantity	Percent Change (%)	
No. of Parcels	19	25	6	31.6	↑
Overall Score	1613	1921	308	19.1	↑
Military Ops. Score	785	986	201	25.6	↑
Envi. Protection Score	299	367	68	22.7	↑
Viability Score	529	569	40	7.6	↑
Total REPI Cost ($)	53,702,500	53,582,130	120,370	0.2	↓
Total Acquisition Cost ($)	190,874,158	159,410,685	31,463,473	16.5	↓
Total Acreage	66,734	51,055	15,679	23.5	↓

Comparison of Rank-based v. Goal programming methods [Fig. 4.1] [3]

As can be seen from the comparison chart above, the equally-weighted goal programming method provides a better REPI purchasing portfolio in seven out of eight quantifiable categories. Using less REPI money, the purchasing fund can provide easement for more parcels with a better overall score, as well as better military, environmental, and viability scoring components. The only downside is the total number of acres protected: the rank-based method beats the goal programming method by over 15,000 acres, or 23.5%.

Based on these analysis numbers, it appears that the goal programming method is a better tool for the REPI program's purchasing objectives. However, in order to provide as comprehensive a comparison as possible, it is helpful to consider the costs necessary for the rank-based method to obtain similar results to those obtained by the goal programming method. The targets for the rank-based model will be the overall score generated by the goal programming method, as well as the military operations and environmental protection scores from the same analysis. The results of this work are posted below:

	REPI Budget ($)		Cost Increase ($)	Percent Increase (%)
	Goal Programming	Rank Based		
Overall Score	53,582,130	77,729,250	24,147,120	45.1
Military Readiness	53,582,130	83,144,130	29,562,000	55.2
Environmental Protection	53,582,130	80,729,250	27,147,120	50.7

Rank-based cost increase to match Goal Programming [Fig. 4.2] [3]

As can be seen from the chart above, a cost increase of approximately 50 percent is necessary for the rank-based method of land easement to match that of the goal programming method. This further confirms the initial analysis: the goal programming method is a much better means of meeting the REPI program's purchasing objectives than the rank-based method.

Conclusion

The analysis in this presentation serves to demonstrate that the goal programming method provides a better means of allocating the REPI program's resources than the rank-based method. Using the standard goal programming procedures with equal weighting between the military and environmental objectives, it is possible to obtain a purchasing portfolio that is significantly better than that obtained by the rank-based method in nearly all categories.

It is recommended that the REPI program implement the goal programming methodology, particularly if the primary goals involve military readiness and environmental protection, or a pair or set of similarly quantifiable goals.

References

[1] Office of the Deputy Under Secretary of Defense for Installations & Environment. 2010. “Readiness and Environmental Protection Initiative (REPI) Program Guide: Department of Defense Conservation and Compatible Land Use Partnering.”

[2] Allen, W., and K. Messer. 2009. “Optimizing Project Selection for the US Army Compatible Use Buffer Program.” White Paper.

[3] Liu, Z. 2010. “Readiness and Environmental Protection Initiative (REPI). Case Study II – Appling Goal Programming to the Project Selection Process.” Presented at the University of Delaware, Newark, DE. (Note: While the conception of figures 4.1 and 4.2 is derived from Zhou Liu’s report, the analysis was performed and the results were generated by the author of this paper.)

[4] Jacob Fooks, Manager of the Experimental Economics Laboratory for Policy and Behavioral Research and Research Assistant in the Agricultural & Resource Economics Department at the University of Delaware, developed the methodology necessary to perform the three-way goal programming analysis, and ran modeling software to generate results for the same.