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Abstract

In the effort to provide electrical power service and the sustaining fuel required to run generators at forward-deployed bases in Afghanistan and Iraq over more than 10 years, the US military spent billions of dollars and a paid a heavy toll in terms of human casualties. The green energy linear program for optimizing deployments (GELPOD) proof-of-concept model showed that a linear program could be used to optimize combat deployment of energy generation systems to minimize cost and casualties. Results indicated that reduction in both cost and casualties for renewable energy sources was highly dependent on fuel cost and deployment length. Neglected in the decision making process, however, were factors that impact the operational success of the mission. When deploying combat units, commanders must not only consider potential costs and casualties, they must also contend with battlefield mobility requirements, maintenance capability (or lack thereof), weather, and anticipated hostile action that could affect operational performance. This paper leverages the simple multi-attribute rating technique (SMART), pioneered by Edwards, to attempt to address this deficiency. The resulting simple multi-attribute rating technique for renewable energy deployment decisions (SMART REDD) model allows commanders to take mission attributes into consideration when making decisions on which energy source is most appropriate for the mission as well as providing information on operations costs, expected transportation requirements, and expected casualties.

Keywords: renewable energy, combat deployment, logistics, mobility, optimization, linear program, simple multi-attribute rating technique (SMART), multi-attribute utility measurement, decision making

1. Introduction

As the US military experienced in Afghanistan and Iraq, nation-stabilizing missions often involve deploying troops from 'forward operating locations' to perform their combat duties. As the equipment carried by modern armies has increased in sophistication, the need for power, especially electrical power, has increased. In addition to computers and other specialized equipment, more 'quality of life needs', such as refrigeration and air conditioning, are essential to support combat operations.

When indigenous utility services are not available, an extensive logistics network is needed to support troops in the field. These logistics 'lines of communication' could involve a variety of transportation modes, including air, overland, and sea. Recent combat experience in Afghanistan showed that US troops consumed, on average, 8000 gallons of fuel each, per year, just to meet energy demands.[1] The cost of transporting that fuel to remote bases can vary from $20 to $1,000 per gallon, depending on the transportation method used.[2] As operations from these outposts stretch from months to years, the total spent can

easily reach billions when carried on over the course of 10 years of combat operations.[3]

Along with the financial costs, the human toll required to provide this logistic network is considerable. Convoys, one of the most economical methods to deliver materiel, require truck drivers and security personnel, exposing them to significant risk from enemy attack. After analyzing casualty statistics from operations in Iraq during fiscal year 2007, the Army Environmental Policy Institute calculated that there was one casualty in every 38.5 fuel convoys.[4]

With the human and financial costs of providing energy an ever-growing challenge, organizations across the Department of Defense were encouraged to reduce energy demand and investigate use of renewable energy to decrease costs and lower the need to expose troops to hostile action in resupply actions. The US Marine Corps, wrote in their *Initial capabilities document for expeditionary energy, water, and waste* that their goal was ''self-sufficient operational nodes'' with the capability to ''harvest all available energy (solar, thermal, kinetic, etc.) to power energy-efficient C4ISR and life support equipment''.[5] In the same way, the US Army sought the goals of ''reduced energy consumption'' and ''increased use of renewable/ alternative energy'' in the *2009 Army energy security implementation strategy*.[6]

2. Problem statement

Despite the clear goals of the military to increase energy independence and efficiency, a standard 'green energy' solution will likely lead to an inefficient deployment of resources. As an example, a solar power system with ample capability to replace electricity from diesel generators when deployed to an African desert would suffer severe shortfalls when the same system is deployed to northern latitudes in the winter months.

Investments in renewable energy technologies have put these capabilities in the arsenal of front-line combat forces. Unfortunately, many of the planning tools that would allow efficient integration of these capabilities are lacking. While some research papers have proposed methods for optimization of hybrid generation systems that include more than one renewable energy source,[7–9] they neglect important attributes of the military mission, such as location (and solar insolence) mobility requirements, resupply rate, and maintainability.

In attempt to address some of the logistics planning shortfalls, researchers at the University of Nebraska developed the green energy linear program for optimizing deployments (GELPOD).[10] This model took into account the electrical demand of a battalion-sized unit of 1000 troops to optimize the deployment of diesel generators or solar panel systems needed to satisfy the demand. Using the output from 24 diesel-powered generators that provide 60 kW of electrical power as the baseline,[11] a linear program was developed to minimize the financial costs or casualties associated with deploying these systems over a range of time frames from 3 months to 5 years. As an example, Figure 1 shows that when GELPOD used a high cost of delivering fuel to remote outposts ($20 per gallon), the point at which solar panel systems provide the lowest cost and casualty rate is only 240 days into the mission.

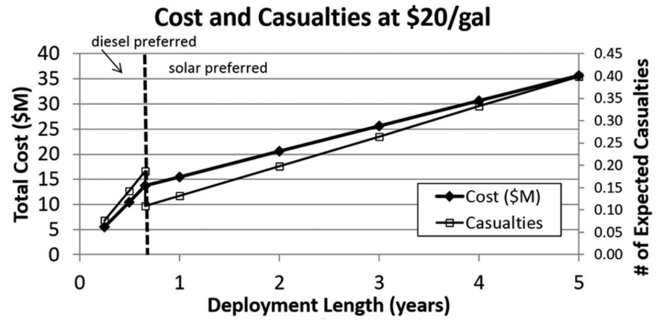

Figure 1. GELPOD cost and casualty results using fuel rate of $20 per gallon, showing minimal cost break-even point for solar at 240 days.

While the GELPOD concept supported optimization studies using diesel generator-provided power and solar panel-provided power to minimize cost or casualties, the mission constraints and deployed environment were arbitrarily set. To understand the problems that could arise with these generic conditions, consider a situation where GELPOD analysis showed that the solar panel system was optimal for a 3-year mission and a fuel cost of $20 per gallon. Despite the data in Figure 1 showing that the solar panel system is clearly optimal, this result would be especially problematic if the solar panel system takes a month to set up, but the commander expects a rapid mobility pace of moving the unit's operating location every 3 weeks to be a key factor in mission success. It is clear that factoring in the attributes of the mission is critical to a decision maker who must determine the right mix of capabilities to deploy to the battlefield.

3. Methodology

3.1. SMART REDD model development

One method of incorporating solution attribute values into the final decision is to use multi-attribute utility measurement.[12] Edwards' work in this area led to the development of the simple multi-attribute rating technique (SMART). This method leverages input from the decision maker to ascertain the relative importance of various attributes of proposed solutions. The SMART model has the advantage of adding emphasis to the more important attributes while diminishing the value of lesser attributes when assessing the overall utility of the solution. Taking

this concept a step further, the simple multi-attribute rating technique for renewable energy deployment decisions (SMART REDD) model allows commanders to take mission-related attributes of energy systems into consideration while at the same time, factoring in mission constraints. In addition to selecting the energy source that is most appropriate for the mission, SMART REDD provides the decision maker with important information on expected operations costs, transportation requirements, and casualties.

3.2. SMART REDD implementation

Decision maker input is critical to an effective attribute rating process. For the SMART REDD concept, the decision maker is the unit commander with responsibility for deciding what type of equipment gets deployed with the combat unit.

3.2.1. Establish mission parameters. For this concept exploration, it is assumed that the commander must decide between deploying diesel generator systems or solar panel systems with the combat unit. To begin the process, the commander must assess the projected mission parameters, including expected mission duration, expected fuel price per gallon, average daily solar insolation at the deployed location. As an example, assume that the commander has a mission to support training operations at a fixed site in Kuwait for 36 months where fuel is readily available at a price of $4.00 per gallon and the average daily solar insolation is 5.5 kWh per day per square meter. Further, assume that at least 25% of the electrical power must be provided by diesel generators and a minimum of 10% of the electrical power must come from renewable sources, as directed by higher headquarters policy makers.

3.2.2. Rate power system attributes. Once the mission parameters are set, the commander must rate the power system attributes in terms of their importance to accomplishing the mission. To maintain a common frame of reference, the following system attributes were used:[13,14]

> Reliability: mission requires a power system that performs to the rated probability of failure (MTBF) over the specified mission duration.
>
> Availability: mission requires a power system that is mission capable for the rated % of time available.
> Maintainability: mission requires a power system with restoration capability following failure, preventive maintenance, using on-hand equipment and personnel.
>
> Mobility: mission requires a power system capable of rapid intermodal transportation to support ongoing military operations across the battle space.
>
> Sustainability: mission requires a power system that operates without resupply for at least 5 days.
> Flexibility: mission requires a power system that can operate in a variety of environmental conditions.
>
> Survivability: mission requires a power system that provides improved protection against small arms, improvised explosive devices (IED), mine, rocket-propelled grenade (RPG), and overhead burst.

In rating the system attributes, the commander begins by assigning the least important attribute with a value of 10. For this example, mobility might be the least important attribute since the unit will be deployed to a fixed site. Next, additional attributes are scored by considering their importance to mission accomplishment relative to the least important attribute, mobility. Continuing the example, the commander assigns the values below to the system attributes for this mission:

Reliability: 60	Availability: 80
Maintainability: 20	Mobility: 10
Sustainability: 30	Flexibility: 20
Survivability: 30	

While there is no limit to how high an attribute might be rated, when attributes are orders of magnitude greater than peers, they tend to dominate the outcome.

3.2.3. Establish attribute scoring criterion. Next, an attribute utility scale must be developed to gauge how well each power system solution performs when considering each attribute. For effective comparisons, a team of subject matter experts in each area (not necessarily the commander) should develop the scale (see Table 1) using as much objective criterion as possible to include technical specifications and performance data. The scale does not need to be linear, but should provide sufficient differentiation between the scale categories.

3.2.4. Determine utility of each solution. Following agreement of the attribute scoring criterion, subject matter experts should evaluate each power solution to determine the utility that it provides relative to the criterion. Once the utility scores are established, the weighted score is found by multiplying the utility score for each category by the normalized attribute value. The normalized attribute value is found by dividing an individual attribute's score by the sum of all attribute scores. Finally, the sum of the weighted attribute scores determines the overall utility for each power solution:

$$U_i = \sum_j w_j u_{ij} \tag{1}$$

Table 1. Attribute scoring criterion table used to set system utility values.

	Unacceptable	Acceptable	Good	Ideal
Reliability (MTBF)	<200 hours	200–750 hours	750–1500 hours	>1500 hours
utility score	0.00	0.25	0.50	1.00
Availability	<90%	90%–95%	95%–99%	>99%
utility score	0.00	0.50	0.75	1.00
Maintainability	Depot	Base	Field	None
utility score	0.00	0.33	0.67	1.00
Mobility	>1 mo setup	1–4 wk setup	1–7 day setup	<1 day setup
utility score	0.00	0.50	0.75	1.00
Sustainability	Resupply <5 d	Resupply 5–10 d	Resupply 10–20 d	Resupply >20 d
utility score	0.00	0.40	0.60	1.00
Flexibility	None	Limited	Some restrictions	No restrictions
utility score	0.00	0.25	0.75	1.00
Survivability	COTS	Some ruggedizing	Full ruggedizing	Armored
utility score	0.00	0.50	0.75	1.00

Table 2. Weighted utility scores and overall utility values for diesel and solar panel solutions.

	Diesel	Weighted score	Solar panel	Weighted score
Reliability (MTBF)	700 hours		>1500 hours	
	0.25	0.06	1.00	0.24
Availability	95%–99%		>99%	
	0.75	0.24	1.00	0.32
Maintainability	Field		Base	
	0.67	0.05	033	0.03
Mobility	<1 day setup		1–4 wk setup	
	1.00	0.04	0.50	0.02
Sustainability	Resupply 5–10 d		Resupply >20 d	
	0.40	0.05	1.00	0.12
Flexibility	No restrictions		Limited	
	1.00	0.08	0.25	0.02
Survivability	Full ruggedizing		Some ruggedizing	
	0.75	0.09	0.50	0.06
	Total utility	0.61	Total utility	0.81

where w_j is the weighted importance of the jth attribute and u_{ij} is the utility score of the ith solution against the jth attribute.

4. Results

In this analysis, SMART REDD recommends that the commander add a solar panel solution since it provides more utility for the given mission parameters and prioritization of power system attributes than the diesel-powered solution. As shown in Table 2, the overall utility scores for both the diesel and solar panel power solutions clearly give the advantage to the solar panel solution.

In addition to recommending a preferred power solution, SMART REDD also calculates other data that is useful in deployment planning. The system will calculate the number of power systems required to satisfy the desired daily energy demand. This includes the ability to make adjustments to the deployment plan to account for policy constraints that may require a minimum percentage of diesel generators or power systems that utilize renewable energy sources. When these factors are evaluated, the output gives details on the number of power systems required (consistent with constraints specified in the model), procurement and operations costs, transportation requirements, and expected casualties, as shown in Tables 3 and 4.

The advantage of the SMART REDD model is that it sets up a process for the decision maker to analyze the attributes of support equipment (in this case, power generation) that will contribute to mission success. This model allows a wide range of 'what-if' studies to be easily conducted to give the decision maker an estimate of the consequences of choosing various courses of action. The SMART REDD model can also be customized to evaluate a range of systems, including those that are still under development by the acquisition community.

Table 3. SMART REDD output showing information on solar power system requirements, costs, and casualties.

1000 m^2 arrays required to supply solar panel load	36
Total number of transport containers required	116
Procurement cost to supply solar panel load	$12,882,713
Operations and maintenance cost	$966,203
Expected total cost	$13,848,917
Expected casualties	0.19

Table 4. SMART REDD output showing information on diesel generator system requirements, costs, and casualties.

Diesel generators required to supply electrical load	6
Total number of transport containers required	126
Procurement cost to supply diesel electric load	$108,000
Operations and maintenance cost	$14,929,920
Expected total cost	$15,037,920
Expected casualties	0.20

5. Conclusions and future work

Previous work on the GELPOD concept showed that diesel fuel demand over time dominated the cost and casualty rates, pushing recommendations to solar panel systems the longer a conflict continued. While this result is satisfying on the surface, it fails to address many of the complications associated with providing electrical power to deployed locations. Commanders responsible for these services often have a limited range of choices for satisfying the power demand of troops in the field. Those choices may not include acres of solar panels that have been ruggedized to survive in a combat environment. In addition, the dynamic nature of combat may favor particular attributes of one power delivery system over another to ensure that the mission is accomplished.

The SMART REDD model could be a useful tool for planners and commanders who need to consider power production solutions and select the one that gives the most utility for the given operational environment and mission constraints. While this concept requires some pre-planning to establish the weights and scoring criterion, this concept could be implemented in training environments to refine the process and evaluate effectiveness under field conditions. Additional refinements could include a database to capture environmental conditions, such as solar insolation, precipitation, cloud cover, temperature extremes, and average wind speed for proposed deployed locations. Panels of power production subject matter experts could be enlisted to craft attribute scoring criterion tables and complete scoring of power production equipment that already exists in the inventory. These SMART REDD 'modules' could be evaluated against recent performance data to 'calibrate' the scoring criterion before comparison with new power production concepts begins.

Through careful examination of the mission and the attributes of available support equipment, commanders can ensure that they are bringing the right mix of equipment to the fight. This process can save transportation costs, reduce risks to troops in the logistics train, and make increasingly scarce resources available for other missions.

References

1. Harrison T. Estimating funding for Afghanistan. http://www.csbaonline.org/publications/2009/12/ (2009, accessed 29 August 2012).
2. Lopez CT. Saving energy saves lives in theater. http://www.defense.gov/news/newsarticle.aspx?id=61274 (2010, accessed 30 August 2012).
3. Miles D. Military looks to synthetics, conservation to cut fuel bills. http://www.defense.gov/news/newsarticle.aspx?id=50131 (2008, accessed 30 August 2012).
4. Eady DS, et al. Sustain the mission project: casualty factors for fuel and water resupply convoys. Army Environmental Policy Institute. http://www.aepi.army.mil/docs/whatsnew/SMP_Casualty_Cost_Factors_Final1-09.pdf (2009)
5. United States Marine Corps. Initial capabilities document for United States Marine Corps expeditionary energy, water and waste. *Report, US Marine Corps*, August 2011.
6. Army Senior Energy Council and Office of the Deputy Assistant Secretary of the Army for Energy and Partnerships. Army energy security implementation strategy. *Report, Washington, DC*, January 2009.
7. Khodr HM, et al. Optimal methodology for renewable energy dispatching in islanded operation. In: *2010 IEEE PES transmission and distribution conference and exposition*, 19–22 April 2010, pp.1–7.
8. Bansal M, Saini RP, Khatod DK. An off-grid hybrid system scheduling for a remote area. In: *2012 IEEE Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, 1–2 March 2012, pp.1–4.
9. Chedid R, Karaki S, Rifai, A. A multi-objective design methodology for hybrid renewable energy systems. In: *2005 IEEE Russia Power Tech*, 27–30 June 2005, pp.1–6.
10. Taylor J and Love B. Proof-of-concept for a green energy linear program for optimizing deployments. In the Proceedings of Defense and Military Modeling and Simulation Symposium (DMMS), 2012 Autumn Simulation Multiconference, San Diego, CA, October 28–31, 2012
11. Erwin S. Prolonged wars tax military capacity to deploy electricity. http://www.nationaldefensemagazine.org/archive/2009/May/Pages/ProlongedWarsTaxMilitaryCapacitytoDeployElectricity.aspx (2009, accessed 30 August 2012).

12. Edwards W. How to use multi-attribute utility measurement for social decision-making, *IEEE Trans Syst Man Cybern* 1977; 7: 326–340.

13. Mitre. Systems engineering guide: reliability, availability, and maintainability. http://www.mitre.org/work/systems_engineering/guide/acquisition_systems_engineering/integrated_logistics_support/reliability_maintainability.html (2012, accessed 15 February 2013).

14. Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Defense science board task force on mobility. Report, September 2005

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James M. Taylor, Jr., currently works as the Research Coordinator for the University of Nebraska's Peter Kiewit Institute. He served for 20 years as an officer in the United States Air Force in the developmental engineering career field. During this time, he worked in a variety of disciplines including space nuclear power, airborne laser flight testing, low observable technology, air defense modeling and simulation, information warfare, aircraft survivability, air mobility research, and support of strategic nuclear operations. James received his Bachelor of Electrical Engineering degree from the Georgia Institute of Technology in 1991 and his Master's Degree in Electrical Engineering from the Air Force Institute of Technology in 1996. Currently, he is studying for a doctorate in computer engineering from the University of Nebraska–Lincoln. His research interest areas include wireless physical layer security, modeling and simulation, and electromagnetics.

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