CORE
Metadata, citation and similar papers at core.ac.uk
Provided by The University of Nebraska, Omaha

University of Nebraska at Omaha
DigitalCommons@UNO

Mathematics Faculty Proceedings & Presentations
Department of Mathematics

2012

Proof-of-concept for a green energy linear program for optimizing deployments

James M. Taylor
Peter Kiewit Institute - Omaha, jmtaylor@unomaha.edu

Betty Love
University of Nebraska at Omaha, blove@unomaha.edu

Follow this and additional works at: https://digitalcommons.unomaha.edu/mathfacproc

Part of the Mathematics Commons

Recommended Citation
Taylor, James M. and Love, Betty, "Proof-of-concept for a green energy linear program for optimizing deployments" (2012). *Mathematics Faculty Proceedings & Presentations*. 1.
https://digitalcommons.unomaha.edu/mathfacproc/1

This Conference Proceeding is brought to you for free and open access by the Department of Mathematics at DigitalCommons@UNO. It has been accepted for inclusion in Mathematics Faculty Proceedings & Presentations by an authorized administrator of DigitalCommons@UNO. For more information, please contact unodigitalcommons@unomaha.edu.

Proof-of-Concept for a Green Energy Linear Program for Optimizing Deployments

James M. Taylor, Jr.
jtaylor@nebraska.edu
Peter Kiewit Institute, University of Nebraska
1110 S. 67th Street
Omaha, NE 68182-0694

Betty N. Love
blove@unomaha.edu
Mathematics Department
University of Nebraska – Omaha
Omaha, NE 68182

Keywords: Renewable energy, combat deployment, logistics, optimization, linear program

Abstract:

The US military has spent billions of dollars and sacrificed many lives in the effort to bring electrical power services and the fuel that drives the generators to forward-deployed bases in Afghanistan and Iraq over the past 10 years. In an effort to reduce some of these tremendous costs, the US military has considered using alternative energy sources to generate electricity and reduce costs and exposure of fuel truck convoys. While some research [10] has used detailed software packages to model the electrical demand and renewable energy production tradeoffs in this environment, the impact of operational constraints is not readily apparent. The Green Energy Linear Program for Optimizing Deployments (GELPOD) is a proof-of-concept model that uses a linear program to optimize the combat deployment of energy generation systems while taking into account operational constraints of the mission. Results show a reduction in both cost and casualties for renewable energy sources that is highly dependent on fuel cost and deployment length. In the near term, energy demand reduction has potential for payoffs in both cost and casualty reduction.

1. INTRODUCTION

In many war-torn locations, such as Afghanistan and Iraq, the US military has deployed troops to perform their missions from bases known as "Forward Operating Locations." Modern armed forces require an ever-increasing amount of reliable electrical power to supply computers and other specialized equipment necessary for the vast array of high-tech equipment that deploys with troops in combat. Additionally, more pedestrian needs, such as refrigeration and air conditioning are also needed to support operations.

Often, as a result of conflict or general lack of infrastructure, these locations lack basic utility services, such as water, energy, and waste disposal. In these circumstances, these bases must be supplied with utility services to sustain the 24-hour operations tempo of the forces stationed there. Currently, these utility services are provided via a logistics network that could involve a variety of transportation modes including air, overland, and sea: all at significant cost and subject to enemy attack. According to a report from the independent, non-profit Center for Strategic and Budgetary Assessments, troops in Iraq and Afghanistan consumed, on average, 8,000 gallons of fuel per troop each year to meet energy needs alone [1]. With the fully-burdened rate of transporting that fuel to outposts ranging from $20 to $1,000 [2], costs can reach a staggering amount. Depending on how long it takes for local utility services to be restored, this is a tremendous expenditure as evidenced by the billions spent in Iraq and Afghanistan in fuel supplies over 10 years of combat operations [3].

In addition to the financial burdens of providing utility services to deployed troops, other costs are incurred that are more personal. Additional troops are needed to transport the fuel and provide security for the large number of convoys required. While this is the most cost-effective method of transporting fuel, it also exposes troops to significant risk from enemy attack. The Army Environmental Policy Institute analyzed convoy and casualty statistics for fiscal year 2007 and determined that in the Iraqi theater of operations, there was one casualty for every 38.5 fuel convoys [4].

In light of the costs associated with providing energy, the Department of Defense has mounted a campaign to encourage energy demand reduction and increased use of renewable energy to lower costs and reduce risks to troops. As an example, the Marines, in their Initial Capabilities Document for Expeditionary Energy, Water, and Waste have identified a target of deploying "self-sufficient operational nodes [to] harvest all available energy (solar, thermal, kinetic, etc.) to power energy-efficient C4ISR and life support equipment" [5]. Similarly, the US Army cited both "reduced energy consumption" and "increased use of renewable/alternative energy" as goals in their 2009 Army Energy Security Implementation Strategy [6].

2. PROBLEM STATEMENT

While goals to enhance the energy efficiency of military forces are laudable, it is clear that a one-size-fits-all solution will likely engender similar cost and casualty inefficiencies that have plagued current solutions. Even though solar power is a promising candidate to replace the electricity supplied by diesel generators, deploying a solar panel-based electrical generation system to a northern latitude location during the winter months or to a location with consistently overcast skies would not likely achieve the desired electrical energy production. Similarly, commanders deploying wind turbines to a location with low average wind speed would face difficulty meeting electricity demands compared to more optimal locations.

As renewable energy technologies become operational in front-line combat forces, operational planners and commanders need tools to assist them with integrating and optimizing their deployment and account for the potential costs and savings they provide. Although several papers discuss the optimal control of multi-modal (photo voltaic, wind, solar thermal, and fuel cells) "hybrid" generation systems [7] [8] [9], they fail to capture restrictions unique to a military installation, such as deployment location (and subsequent environmental factors). Research that has focused on renewable energy production at forward operating bases has been conducted using very detailed electrical load simulation modeling [10] and clearly shows the benefits in terms of lowered costs and reduced casualties over long time scales (2-8 years). However, the cost-focused model does not facilitate adding constraints to the optimization process. These constraints could include mobility requirements for equipment (including maximum size, weight, and volume for compatibility with transportation mode), distance from logistics centers, minimum on-demand power requirements to meet operational tempo, and limited area available for energy collection.

3. METHODOLOGY

3.1. Concept Development

To address this shortfall and simplify logistics planning, researchers at the University of Nebraska have developed a proof-of-concept linear programming model to optimize deployment of fossil fuel-based and renewable energy-based power generation systems. The Green Energy Linear Program for Optimizing Deployments (GELPOD) explores the tradeoffs between diesel generator-provided power and solar panel-provided power given an arbitrary deployed environment. To perform the optimization, an integer linear program (LP) model was developed that could be modified to evaluate both the financial and casualty costs associated with various energy generation deployment scenarios while remaining in compliance with various constraints required by mission scenarios.

3.2. Linear Program Development

Two separate LPs were developed to allow an analyst to determine the optimal mix of solar panel systems and diesel generators to be deployed. The first LP minimized the cost of operations over time, while the second LP was configured to minimize casualties throughout the duration of the deployment.

3.2.1. Baseline Configuration

For each LP, the electrical needs of a battalion-sized unit (~1,000 soldiers) was used to set the demand for the electrical generation systems. When deployed, a battalion's daily electrical demands are satisfied by 24 diesel generators, each with an output of 60 kW [11]. Specifications from commercially-available generators were used to provide the input to model parameters such as weight, volume, fuel consumption, and cost. The duty cycle of these generators was arbitrarily set at 100% for this analysis.

A renewable energy alternative was configured to allow a mix of solar panels, batteries, and inverters to augment or replace electrical power provided from diesel generators. As in the case of the diesel generators, commercially-available solar panels, batteries, and inverters were used to populate important model parameters including weight, volume, cost, power production, energy storage, and power conditioning capability.

Finally, a key cost component for this analysis, transportation, had to be included. The model factored the cost to transport the generators and other materiel to the deployed location using a benchmark price of $1.50 per pound. During optimization runs with Microsoft Excel Solver, the deployment duration was fixed for each iteration so that linearity requirements of the model could be met.

3.2.2. Minimal Operations Cost Configuration

In setting up the GELPOD to minimize costs, the decision variables were the number of diesel generators, solar panels, batteries, and inverters used to generate power during the deployment. Costs associated with each configuration were determined by multiplying the number of items by the respective cost per item. Additional costs were incurred by the diesel generators since they required fuel to operate. The fuel cost was calculated by determining the number of gallons required for operation during the deployment multiplied by the cost per gallon (varied from the $3.75 per gallon “bulk rate” to the $20.00 per gallon “fully burdened” rate. In the case of equipment transportation, the items would be packed in a standard 8’x8’x20’ shipping container that fits on one flatbed truck chassis.

The objective function for this linear program is simply the sum of all of the costs associated with procuring, deploying, and operating the electrical power generation systems.

To constrain the problem, the decision variables were subject to the following limits:

- Energy produced by all systems ≥ daily consumption by battalion
- Battery capacity ≥ solar energy produced for night operations
- Inverters capacity ≥ solar energy produced for day / night operations
- Diesel-produced energy ≥ 25% of daily consumption by battalion

Additionally, the decision variables were restricted to integer values, since purchasing half of a diesel generator or battery is not a viable option in this scenario.

3.2.3. Minimal Casualty Configuration

To examine the configuration of an electrical power generation system focused on minimizing casualties, GELPOD was again reconfigured. In this case, decision variables were the number of shipping containers required to transport each type of equipment and fuel throughout the duration of the deployment. The objective function was simply the sum of all containers needed to satisfy the various constraints. Minimizing this function would limit the number of trucks on the road, which is directly proportional to the casualty rate.

3.2.4. Demand Reduction Excursion

Development of new deployable renewable energy generation systems may not be affordable in the near-term. As a cost and casualty reduction measure, planners and commanders may look to energy demand reduction as a means of achieving this effect. To model the impact of demand reduction, the model was reconfigured with the energy demand reduced by an arbitrary 25% to gauge the effect on both casualty rate and cost of operations.

4. RESULTS

4.1. Minimal Operations Cost

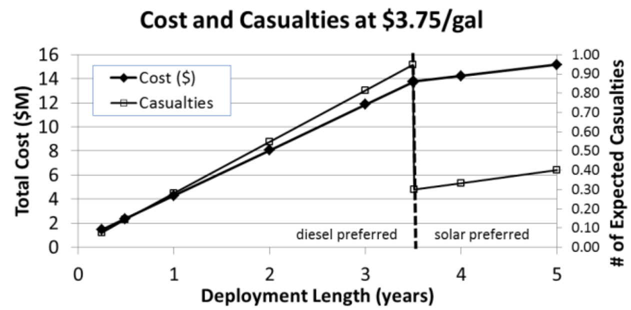

Figure 1. Cost and casualty results for diesel at $3.75 per gallon showing the break-even point for solar at ~3.5 years when optimizing for minimum cost

When the LP was run for a diesel-only configuration, the costs associated with electrical power generation were tabulated over a five year period. The linearity of this problem was evident and showed that fuel costs and the necessary deliveries are the primary drivers that affect both cost and casualty rates.

After the baseline diesel-only scenario was run, the simulation was modified to allow the introduction of a solar system to provide electrical power, subject to the constraints specified previously. Figure 1 shows the impact of allowing a renewable energy source into the GELPOD model. The solar system, while initially a more expensive investment, eventually becomes a more affordable alternative in the long run. For relatively “cheap” fuel that you might have access to ($3.75), the break-even point for solar comes at the ~3.5 year point.

The more interesting observation is the more than 50% drop in casualties when GELPOD recommends solar over the all-diesel solution. This is due to the direct relationship between the number of truck convoys used for fuel deliveries and the casualty rate. When solar is the preferred solution, a significant number of fuel trucks are eliminated, reducing exposure to the troops.

Since inexpensive fuel is not always available in a combat zone, it is interesting to examine the “fully-burdened” fuel rate. This is an assessment of not only the price of the fuel, but the cost of the weapon systems and personnel required to transport and protect the fuel as it transits to the user. This rate can vary, depending on the mode of transportation used (air-based transport being the most expensive). For ground-based delivery of fuel ~$20 per gallon is a reasonable assumption. Figure 2 shows how the break-even point has been moved dramatically to less than one year. With this high fuel cost, it makes even more fiscal sense to invest in renewable energy, even early in the deployment.

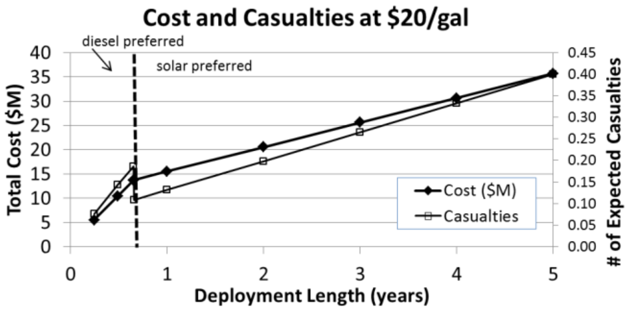

Figure 2. Cost and casualty results for fully-burdened rate of $20 per gallon showing the break-even point for solar at 240 days when optimizing for minimum cost

4.2. Minimal Casualties

To examine the configuration of an electrical power generation system focused on minimizing casualties, GELPOD was reconfigured to minimize the number of containers shipped by truck. This kept the focus on limiting the number of trucks on the road, without regard to cost so that casualties would be minimized. As the graph in Figure 3 shows, the up-front costs are higher, but the payoff is a significantly reduced casualty rate.

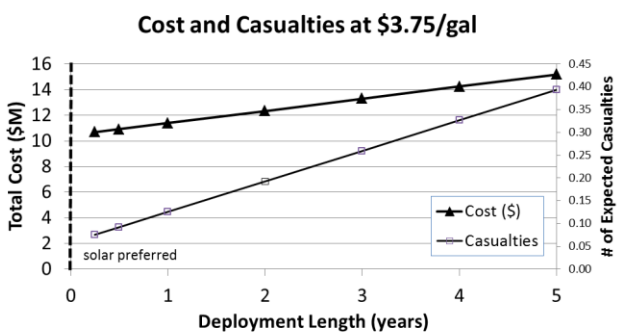

Figure 3. Cost and casualty results for fuel cost of $3.75 per gallon showing solar is preferred for all deployment lengths when optimizing for minimum casualties

4.3. Demand Reduction

Since the procurement and installation costs for a solar panel generation system may be prohibitive, except for very long-term installations, electrical power demand reduction was examined as a way to lower operations costs and casualties. To evaluate this effect, the demand was lowered by 25%. This could be accomplished through a variety of energy saving techniques, such as improved insulation in air-conditioned spaces, selecting more energy efficient mission equipment, and elimination of non-mission-essential electrical equipment. If this level of energy savings was achieved, the cost savings would also be significant as shown in Figure 4.

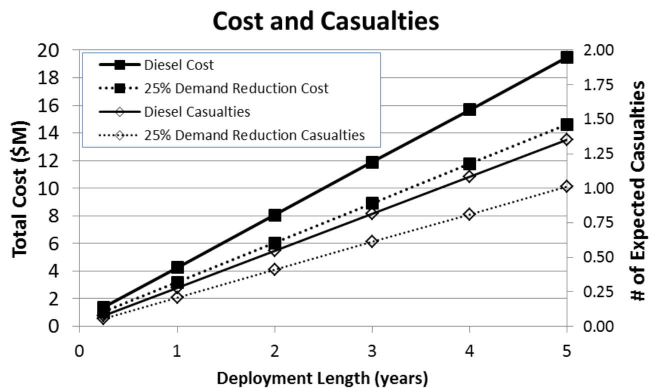

Figure 4. Impact of demand reduction on both cost and casualties for a diesel-only system.

5. CONCLUSIONS AND FUTURE WORK

The analysis associated with this Linear Program showed that fuel demand was the dominant factor in determining overall costs and casualty rates when supplying power to austere deployed locations. While solar power has high up-front costs, it provides significant casualty reductions and long-term savings. Additional costs that were not included in this analysis, but would have to be considered in a real-world implementation include installation time (15,000 solar panels were needed at maximum capacity) and real estate required (these panels needed an area equivalent to 4.6 football fields). In the near-term, demand reduction may be the most cost-effective way to reduce power generation costs and lower casualties, especially for short-term deployments.

The GELPOD concept could be a useful tool for planners and commands when making decisions about which type of energy production to deploy to the field, given the operational constraints of the mission. Additional modifications could include a database for various locations around the globe that would be used to factor in environmental factors affecting renewable energy production, such as average wind speed, solar irradiance, and average daily cloud cover. In addition, as renewable energy systems are developed, GELPOD "modules" could be developed that contain the performance specifications and characteristics that are necessary for inclusion in the model.

References

[1] T. Harrison, "Estimating Funding for Afghanistan." Internet: http://www.csbaonline.org/publications/2009/12/, Dec. 1, 2009 [Aug. 29, 2012].

[2] C. T. Lopez, "Saving Energy Saves Lives in Theater." Internet: http://www.defense.gov/news/newsarticle.aspx?id=61274, Oct. 14, 2010 [Aug. 30, 2012].

[3] D. Miles, "Military Looks to Synthetics, Conservation to Cut Fuel Bills." Internet: http://www.defense.gov/news/newsarticle.aspx?id=50131, Jun. 6, 2008 [Aug. 30, 2012].

[4] D. S. Eady, et al. (Sept. 2009), "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

[5] United States Marine Corps, (Aug. 1, 2011), "Initial Capabilities Document for United States Marine Corps Expeditionary Energy, Water and Waste."

[6] Army Senior Energy Council and Office of the Deputy Assistant Secretary of the Army for Energy and Partnerships, (Jan. 13, 2009), "Army Energy Security Implementation Strategy," Washington, D.C.

[7] H.M Khodr, et al, "Optimal methodology for renewable energy dispatching in islanded operation," *Transmission and Distribution Conference and Exposition, 2010 IEEE PES*, pp.1-7, 19-22 April 2010.

[8] M. Bansal, et al, "An off-grid hybrid system scheduling for a remote area," *Electrical, Electronics and Computer Science (SCEECS), 2012 IEEE Students' Conference on*, pp.1-4, 1-2 March 2012.

[9] R. Chedid, et al, "A multi-objective design methodology for hybrid renewable energy systems," *Power Tech, 2005 IEEE Russia*, pp.1-6, 27-30 June 2005.

[10] N. McCaskey, "Renewable Energy Systems For Forward Operating Bases: A Simulations-Based Optimization Approach," Master's thesis, Department of Electrical and Computer Engineering, Colorado State University, Aug. 2010.

[11] S. Erwin, "Prolonged Wars Tax Military Capacity to Deploy Electricity", Internet: http://www.nationaldefensemagazine.org/archive/2009/May/Pages/ProlongedWarsTaxMilitaryCapacitytoDeployElectricity.aspx, May 2009, [Aug. 30, 2012].

Biography

James Taylor 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.

Betty Love is an associate professor in the Department of Mathematics at the University of Nebraska at Omaha. She has taught courses in operations research, mathematics, and computer science there for the past 22 years. Betty received her Ph.D. in Operations Research from Southern Methodist University in 1991. Her research interests include optimization algorithms, data science, and mathematics pedagogy.