# Soldier Power Operational Benefit Analysis

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**Author Note:** Coree Aten, Andrew Michalowski, Maurice Williams, and Cody Stamm are second lieutenants in the United States Army and conducted this work during their senior capstone project in the Department of Systems Engineering at the United States Military Academy. Paul Evangelista is a lieutenant colonel in the U.S. Army and currently serving as an Academy Professor in the Department of Systems Engineering and the Director of the Operations Research Center at USMA.

**Abstract:** An operational benefit analysis of military small unit power (SUP) equipment is presented in detail. SUP equipment is designed to improve power generation, conservation, and overall power management strategies for dismounted military units. The operational benefit analysis examines four tactical scenarios and considers a naïve power management strategy and a SUP enabled power management strategy. The major findings and conclusions discussed in this paper include: specific conservation and generation strategies for select dismounted tactical scenarios; the importance of proper solar blanket employment; identification of a capability gap between 100W and 1000W in the power generation spectrum; the benefits of using conformal batteries; and the impact of inefficient PRC 154 battery swaps in the naïve case.

*Keywords:* Soldier power, operational benefit analysis, tactical batteries

## 1. Introduction and Related Work

Today's Soldiers have been inundated with communications and electronics technology that provide tremendous capabilities. However, these capabilities come with a number of costs, and one of the most significant costs is a growing requirement for electric power. Based on increasing electrical power consumption that supports numerous recent technological requirements, the U.S. Army fielded Small Unit Power (SUP) equipment across primarily light infantry formations in order to improve soldier power efficiency on the battlefield. The SUP equipment includes technology designed to improve power awareness and management. An example of this is the squad power manager (SPM) kit which provides several functions to small units: real time awareness of battery and charging levels through the SPM interface, cables and adaptors that provide flexibility to harvest power from multiple sources, and a 60 watt solar blanket. Additionally, each platoon is equipped with one 1kW generator, one 120 W solar blanket, and a modular universal battery charger (MUBC). The client for this problem is Program Manager Soldier Warrior (PM SWAR), one of the four PMs within Program Executive Office (PEO) Soldier. PM SWAR requested analysis that explains the operational impact of the SUP equipment and a decision support tool that helps commanders employ effective dismounted tactical power management strategies. PM SWAR requested that the analysis focuses on the equipment prescribed by the "Dismounted Baseline for the Soldier System", a document written to standardize Soldier system analysis (U.S. Army, 2014). Initial analysis of small unit power consuming equipment within the baseline showed that over 90% of power consumption involved the PRC 154 Rifleman Radio and the end user device (EUD), a Samsung Galaxy Note II configured with the Nett Warrior Android OS. For this reason, analysis focused on the power consumed by these two devices. It is important to understand that the Rifleman Radio and EUD both receive power from the Rifleman Radio battery; the radio receives direct power, and the EUD receives a constant trickle charge. The first part of this project focused on power consumption across four 72 hour mission scenarios: *Movement to Contact*, *Cordon and Search*, *Secure and Hold an Area Air Assault*, and *Establish a Combat Outpost*. For each scenario, two cases were examined, a naïve case and an enabled case. The naïve case did not employ SUP equipment; power management solely involved PRC 154 battery swaps. Based upon stakeholder analysis and user input, the enabled case employs SUP equipment strategies tailored to each scenario. For example, a movement to contact mission scenario requires 2,546 Wh per squad; the enabled case strategy for this mission decreases the energy requirement by 350 Wh through conservation. The major findings and conclusions include: specific conservation and generation strategies for each scenario; the importance of proper solar blanket employment; the benefits of using conformal batteries; and the impact of inefficient

PRC 154 battery swaps in the naïve case. Ultimately, this work will support the development of a decision support tool that will enable decisions for small unit power management strategies.

**Key Characteristics of Equipment**

SPM: Manages and provides awareness of power and battery recharging from solar, AC and DC sources.

Solar Blanket: Power generation from solar panels capable of producing 60W.

MUBC: Provides a lightweight universal charging solution for Soldier System batteries and radios.

Tactical Generator: Power generation source capable of producing 1,000 watts.

Conformal Battery: Thin and flexible battery that fits inside pouch and provides 150Wh.

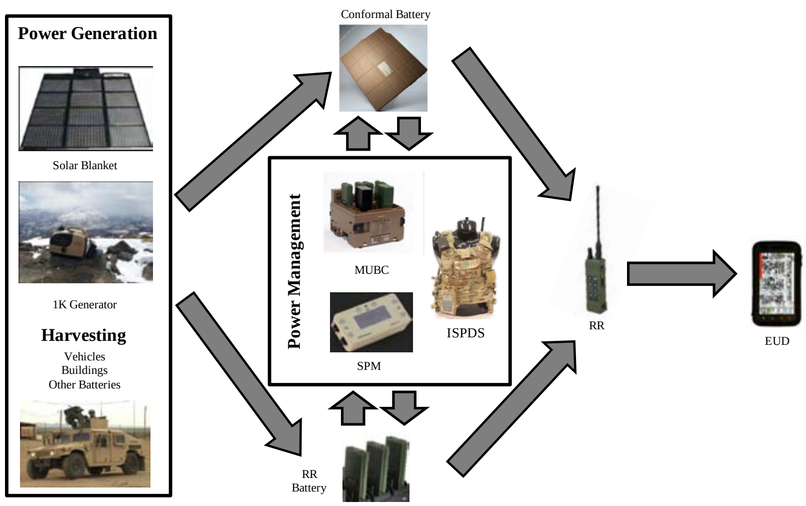


Figure 1. The operational view of system also depicts the system boundary.

The results of this study indicate that there is a need for today's Soldiers to improve their "power literacy". During the course of stakeholder analysis it became apparent that many Soldiers do not understand the capabilities of recently fielded power management equipment, and it also became apparent that Soldiers commonly lack basic knowledge with regard to power, electrical circuits, and batteries. This lack of knowledge should not be a surprise. Soldiers have never been required to learn or possess this knowledge, with the exception of some maintenance or communications occupational specialties. Unless a Soldier has taken college level physics, electrical engineering, or has experience in an electronics related career, knowledge of measures such as watts, amperes, volts, and watt-hours is commonly minimal. The intangible nature of electrical power exacerbates this problem further. Electrical power is invisible, odorless, and soundless. Batteries weigh the same amount whether fully charged or depleted. Monitoring power consumption and available power has never been a fundamental small unit task. However, future Soldiers will need to maintain awareness of power as a resource in the same manner that Soldiers monitor food, water, and ammunition. This requirement places increased emphasis on instrumentation and gauges, either integrated or peripheral, which will provide this power awareness. And Soldiers will need the education and training to understand the power monitoring measurements. As the Army moves towards increased electrical power requirements and expects Soldiers to manage power resources, the need for Soldiers to understand and monitor basic power measurements will grow.

Work related to this project includes a large body of technical reports and briefings written by U.S. Government research, development, and acquisition entities. The primary proponents of small unit power equipment include the Natick Soldier Research, Development, and Engineering Center (NSRDEC); the Communications and Electronics Research, Development, and Engineering Center (CERDEC); and the Program Executive Office (PEO) Soldier. All of these organizations have documented and conducted numerous studies and experiments examining the effects of this equipment. Tactical photovoltaic cells (solar blankets) are a significant component of this research and consistent theme across small unit power initiatives. Warner (2014) and Fredrickson (2014) both reinforce the well known fact that proper solar blanket employment is critical when generating solar power. The tilt and orientation play a vital role in the power output that the blanket generates. Solar blanket experimentation conducted during this research highlighted the need for real time awareness of charging gained through the SPM. Shafran (2014) describes the characteristics and capabilities of the squad power manager. The SPM enables battery recharging capability from several different power sources and allows Soldiers to manage power for up to six different power sources or sinks at one time. The SPM provides real time awareness for soldiers in terms of power generation and battery life, while providing information on rate of charge, voltage output, amps, and percent charge. Batteries were an additional area of research. Jha (2012) explores potential future battery technology that could help soldiers in dismounted scenarios.

## 2. Methodology

The operational benefit analysis portion of this research consisted of four key steps: stakeholder analysis, detailed study of small unit power equipment, estimation of equipment usage and power consumption from the Draper Laboratory scenarios[1], and modeling and analysis. Stakeholder analysis initiated during a trip to Fort Belvoir for the first client meeting with PEO Soldier. This meeting resulted in the following problem statement: *analyze the operational impact of small unit power equipment and develop a decision support tool that helps commanders employ effective dismounted tactical power management strategies*. Additional stakeholder analysis included interviews with soldiers from the 10th Mountain Division, 101st Airborne (Air Assault) Division, and Tactical Officers at the United States Military Academy.

Table 1. Findings, Conclusions, and Recommendations (FCR) Matrix from Stakeholder Analysis

| Major Topics | Findings | Conclusions | Recommendations |
|---|---|---|---|
| **New Equipment Training (NET)** | - NET consists of one session on the basic employment of SUP equipment.<br>- Soldiers indicated that hands on exploration with equipment was more beneficial than NET.<br>- Soldiers showed patterns of not using equipment because they do not see the purpose when they could just carry extra batteries. | - NET given to Soldiers is not as beneficial as intended. Hands on learning and exploration was the primary means of learning.<br>- Soldiers do not understand operational benefit of SUP equipment. | - Illustrate the benefits of using the SUP equipment to soldiers in an easy to understand method.<br>- Give the soldier more support associated with teaching the equipment to ensure proper usage and understanding by soldiers. |
| **SOPs** | - Standard Operating Procedures (SOPs) depended on the mission, and the number of batteries carried depended on length of mission.<br>- Soldiers are constantly charging, recharging, and swapping to deal with demands of mission. | - Documented SOPs for SUP equipment did not exist. The primary power related planning factor involved bringing additional batteries. | - Develop possible SOPs for different mission types.<br>- Create tool to help commanders with SOP decisions during their mission. |
| **Scenarios** | - With missions requiring significant movement, there were minimal ways to conserve power since radios are always on, and soldiers expressed the need to be light and mobile. | - Movement to contact requires the least amount of weight but radios must be on at all times. This has created a gap because soldiers require more capability with less equipment. | - Minimize weight of soldier load for a movement to contact while keeping radio capability. Find best options for dealing with this capability gap. |

The key findings of the stakeholder analysis revealed that today's soldiers are not "power literate" and do not understand the capabilities of recently fielded power management equipment. In order for the authors to understand this problem more deeply, a detailed study of SUP equipment occurred concurrently with stakeholder analysis. Members from PEO Soldier visited USMA and provided a detailed overview of SUP equipment and issued several pieces of equipment to the project team to include squad power managers (SPM), solar blankets, conformal batteries, and the 1kW tactical generator. The operational view diagram in Figure 1 illustrates most of this equipment.

Operational benefit analysis followed stakeholder analysis. As previously mentioned, four mission scenarios from Draper Laboratory provided estimation of equipment usage and power consumption. Modeling and analysis included an in-depth study of battery charging, solar blanket power generation, and recommended power management strategies for all four mission scenarios. The operational benefit analysis provided throughout this document was recently presented to PEO Soldier. Future work consists of developing a decision support tool to support small unit power management strategies.

## 3. Mission Scenario Power Management Strategies

SUP equipment was evaluated across four mission scenarios. Stakeholder analysis and Soldier insights assisted in the development of recommended conservation and generation strategies for each scenario. These recommended conservation and generation strategies resulted from analysis of mission scenarios, stakeholder recommendations on SUP equipment employment based upon each scenario, and ultimately a calculation of the power generated or conserved based

[1] Natick Soldier Research, Development, and Engineering Center (NSRDEC) and Draper Laboratory provided four tactical mission scenarios that included energy consuming equipment usage estimates and power generation estimates.

upon power consumption and generation specifications. Figure 1 displays the recommended power management strategies. Paragraphs below summarize the concept of each scenario as well as the recommended power management strategies.

*Movement to Contact*: The concept of operation for this scenario involves a 72 hour mission that limits the ability to apply conservation and generation strategies due to frequent movements and the high possibility of enemy contact. The conservation strategies for this scenario include turning off two rifleman radios for 20 hours conserving 339 Wh and turning off two EUDs for 32 hours conserving 96 Wh.

*Cordon and Search*: The concept of operation for this scenario involves a 72 hour mission that allows for the implementation of generation strategies due to the extended period of time the security element is stationary. The conservation strategies for this scenario include turning off two rifleman radios for 9 hours conserving 152 Wh and turning off two EUDs for 32 hours conserving 96 Wh. The generation strategy that exists for this scenario is the employment of the solar blanket in the outer cordon for 16 hours generating 480 Wh.

*Establish and Occupy COP*: The concept of operation for this scenario involves a 72 hour mission that provides ample time for both the solar blanket and the generator while stationary in the COP. The conservation strategies for this scenario include turning off two rifleman radios for 49 hours conserving 831 Wh and turning off two EUDs for 52 hours conserving 156 Wh. This scenario allows for the utilization of two generation strategies. The first generation strategy involves employing a solar blanket for 16 hours generating 480 Wh. The second generation strategy involves employing the generator for 36 hours generating 9,000.

*Secure and Hold an Area Air Assault*: The concept of operation for this scenario involves a 72 hour mission scenario with easy transportation of equipment due to the insertion method. The conservation strategies for this scenario include turning off two rifleman radios for 49 hours conserving 831 Wh and turning off two EUDs for 52 hours conserving 156 Wh. Due to the extended time spent stationary in the area, this scenario allows for both the solar blanket and generator. The solar blanket can be employed for 28 hours generating 840 Wh and the generator can be employed for 42hours generating 10,500 Wh.

For the purposes of analysis, two power management strategies or cases were examined - a naïve case that uses nothing more than PRC 154 battery swaps to manage needed power, and an enabled case that employs the recommended conservation and generation strategies described in the scenario summary paragraphs above. After analyzing the results of the recommended strategies for each mission scenario, there are several common key findings. First, the enabled case for each scenario allows the squad leader to remain connected as the charge from his conformal battery does not require him to conduct Rifleman Radio battery swaps. Additionally, the enabled case for each scenario benefits from 100% charged Rifleman Radio batteries due to constant conformal battery trickle charge, ultimately providing six to eight hours of reserve battery charge. Lastly, inefficient battery swaps for the naïve case could cost anywhere between five to ten pounds. An acknowledged limitation of our enabled case is the lack of communications redundancy during conservation periods.

When analyzing the recommended strategies there are several findings which are specific to each scenario. Table 2 below shows the calculations for each scenario. In regards to the *Movement to Contact* scenario, we estimated that the enabled case saves 350 Wh of energy or roughly 6 pounds. The next scenario, *Cordon and Search,* is where generation begins to be implemented into the recommended strategies. The enabled case for the *Cordon and Search* saves 248 Wh with conservation and 480 Wh by implementing the solar blanket, saving 12.6 pounds. The energy produced by the solar blanket is based off of the assumption that the blanket generates 30 W on average, meaning that there is potential for the strategy to generate more energy if higher power is provided by the solar blanket. The scenario *Establish and Occupy a Combat Outpost* utilizes the same previous strategies with the addition of the 1kW generator. The enabled case for this scenario conserves 965 Wh and generates 9,480 Wh. This case saves 30.6 pounds in batteries as it makes the squad self-sufficient meaning that squad leaders and team leaders are only required to bring 3 Rifleman Radio batteries and 6 conformal batteries. The final scenario, *Secure and Hold an Area Assault*, is extremely similar to the previous scenario in that this scenario also has the capability of utilizing the generator. The enabled case conserves 987 Wh and generates 11,340 Wh, which again makes the squad self-sufficient. The time allotted for each type of conservation and generation strategy was decided based on thorough analysis of the scenarios as well as stakeholder input. The data described above can be seen in comparison in Table 2 below.

Proper employment of the solar blanket was also a major consideration and area of research within our operational benefit analysis. It is well known that photovoltaic power generation depends directly on the tilt and orientation of the solar cells. However, this has never been discussed or translated when considering the employment of tactical solar blankets. Solar cells generate optimal power when the solar cells are placed at a 90 degree angle with the sun's rays. Soldiers typically employ solar blankets by laying them flat on a horizontal surface – typically the ground. Experimentation and theoretical analysis shows that laying the blanket flat on the ground significantly decreases blanket efficiency. There was a 50% decrease on the day of our testing. Stakeholder analysis and additional experiments also indicated that proper solar blanket employment cannot be accomplished without real-time awareness of the power generated by the solar blanket, and the easiest way for Soldiers to do this is use the squad power manager (SPM). The SPM provides immediate awareness of power generation. With consistent monitoring, Soldiers would be empowered to position the blanket to optimize power generation.

Table 2. Naïve vs Enabled Case Analysis across Four Mission Scenarios

| | Energy Req. (Wh) | Energy Conserved (Wh) | Energy Gen. (Wh) | Net Energy Req. (Wh) | RR batteries required | Conformal batteries required | Battery Weight (lbs) | Equipment Employed |
|---|---|---|---|---|---|---|---|---|
| ***Movement to Contact*** | | | | | | | | |
| Naïve w/ 70% swap | 2546 | 0 | 0 | **2,546** | 57 | 0 | 46.19 | N/A |
| Enabled | 2546 | 350 | 0 | **2,195** | 3 | 15 | 41.4 | N/A |
| ***Cordon and Search*** | | | | | | | | |
| Naïve w/ 70% swap | 2,607 | 0 | 0 | **2,607** | 60 | 0 | 48 | N/A |
| Enabled | 2,607 | 248 | 480 | **1,879** | 3 | 12 | 33.6 | Solar Blanket |
| ***Establish and Occupy a Combat Outpost*** | | | | | | | | |
| Naïve w/ 70% swap | 2,476 | 0 | 0 | **2,478** | 57 | 0 | 45.6 | N/A |
| Enabled | 2,476 | 965 | 9,480 | **-7,969** | 3 | 6 | 18 | Solar Blanket, Generator |
| ***Secure and Hold an Area Assault*** | | | | | | | | |
| Naïve w/ 70% swap | 2801 | 0 | 0 | **2801** | 64 | 0 | 51.2 | N/A |
| Enabled | 2801 | 988 | 11340 | **-9527** | 3 | 6 | 20.6 | Solar Blanket, Generator |

## 4. Analysis and Major Findings

The major findings include: specific conservation and generation strategies for select dismounted tactical scenarios; the importance of proper solar blanket employment; identification of a capability gap between 100W and 1000W in the power generation spectrum; the benefits of using conformal batteries; and the impact of inefficient PRC 154 battery swaps in the naïve case.

Stakeholder analysis suggests there is a capability gap in the power generation spectrum, essentially between 100W and 1000W. Lightweight solutions exist that produce less than 100W, tactical generators produce up to 1000W, but the power generation that soldiers really need is somewhere in the middle. The mission scenario analysis in section 2 displays the benefits of the generator, but also shows how much power is not even being used. It would be beneficial to soldiers to have a smaller, more practical device that soldiers could bring that generated less than 1000W, but was easier and lighter to carry.

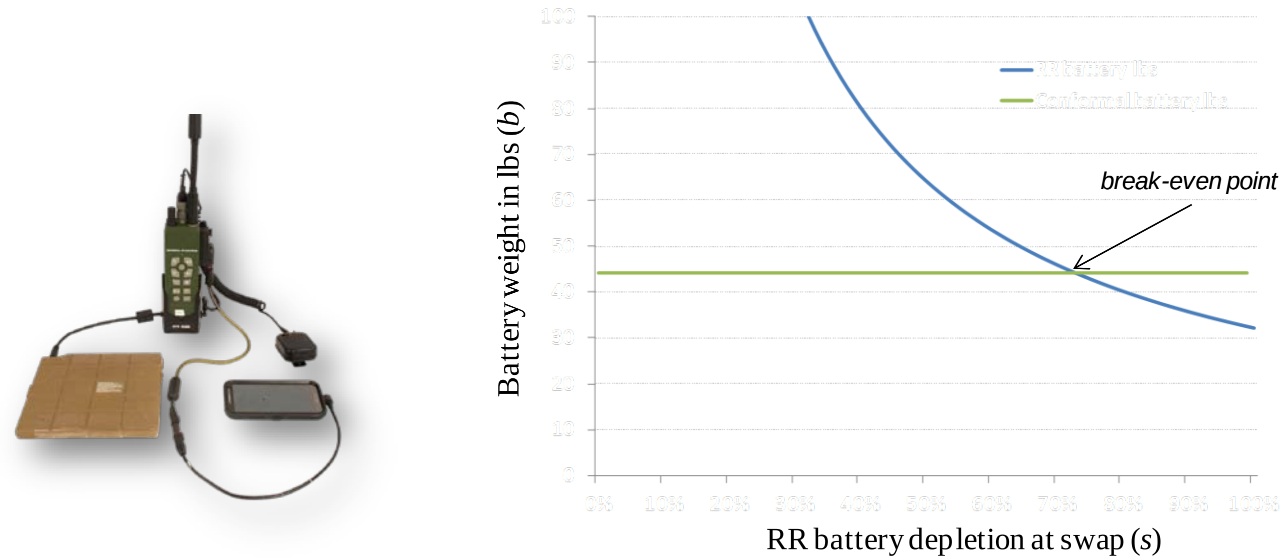


Figure 2. The conformal battery, Rifleman Radio, and Nett Warrior end user device (EUD) are shown from left to right. The plot shows the trade-off analysis between two battery replenishment strategies: swapping Rifleman Radio batteries or using the conformal battery as a constant trickle charge.

Another finding involved Rifleman Radio battery swaps. Rifleman radio battery swaps are inherently inefficient because users will typically swap batteries at some point less than complete depletion, primarily based upon tactical requirements. Batteries need to be swapped at a point in time during the mission that creates minimal risk. Swapping a Rifleman Radio battery takes the radio out of the network for approximately five minutes, constraining battery swaps to windows of time when radio communication is not required. Furthermore, Soldiers prefer fully charged batteries during critical or uncertain points during the mission to mitigate the risk of losing power to a radio. For these reasons, it is common for Soldiers to swap partially depleted batteries with a fully charged battery. This behavior implies that all Rifleman Radio battery swaps are inefficient, inherently wasting power that remains in partially depleted batteries. If Soldiers use the conformal battery to provide a trickle charge, the Rifleman Radio remains nearly fully charged at all times. The conformal battery can be fully depleted and swapped at nearly any time during the mission, preventing power waste and maintaining radio communications at all times. The arithmetic below supports these statements and the analytical excursion shown in figure 2. Based upon current power to weight ratios of the conformal and Rifleman Radio batteries, swapping Rifleman Radio batteries at a depletion of 72% would result in a break-even or equivalent cost in terms of weight.

Let $w_r$ = weight of Rifleman Radio batteries in pounds

Let $w_c$ = weight of conformal batteries in pounds

Let $s$ = average % Rifleman Radio battery energy depleted when swapped

Let $b_r$ = number of Rifleman Radio batteries required

Let $b_c$ = number of conformal batteries required

Let $R$ = power required in Wh

RR battery calculation:

$$b_r = R / (s \times 64 \text{ Wh}) \quad (1)$$

$$w_r = b_r(0.8 \text{ lbs}) = (R / (s \times 64 \text{ Wh}))(0.8 \text{ lbs}) \quad (2)$$

Conformal battery calculation:

$$b_c = R / 150\text{Wh} \quad (3)$$

$$w_c = (R / 150\text{Wh})\ (2.6 \text{ lbs}) \quad (4)$$

Set $w_c$ equal to $w_r$ in order to find the breakeven point:

$$(R / (s \times 64 \text{ Wh}))(0.8 \text{ lbs}) = (R / 150\text{Wh})\ (2.6 \text{ lbs}) \quad (5)$$

$$\Rightarrow s = 0.72 \quad (6)$$

The breakeven point of 72% is specific for the Rifleman Radio battery and conformal batteries based upon their current power to weight ratios. The plot shown in figure 2 is based upon $R$ = 2546 Wh which is the power requirement for the *Movement to Contact* mission. This equation can be further simplified:

Let $p_r$ = energy of the Rifleman Radio battery in watt-hours divided by the weight of the battery in pounds (power to weight ratio)

Let $p_c$ = energy of the conformal battery in watt-hours divided by the weight of the battery in pounds (power to weight ratio)

Substituting power to weight ratios for the actual weights and energy capacities of the batteries yields the following equation:

$$s = p_c / p_r \quad (7)$$

Equation 7 shows a fundamental relationship between the rifleman radio battery and the conformal battery. The breakeven point for weight can be calculated simply by dividing the power to weight ratio of the conformal battery by the power to weight ratio of the Rifleman Radio battery. Current technology places $s$ at 72%. Anecdotal evidence from tactical units indicates that most units try to change batteries at 80% depletion. If this is true, then from strictly a weight stand-point, it is slightly more efficient to swap Rifleman Radio batteries. However, if 80% is the goal, then it is likely that many Soldiers swap batteries before 80%, especially if the entire unit swaps at the same time or units insist on fully charged batteries during critical points of a mission. This also does not consider the additional costs of frequently powering down radios and managing a large number of these smaller Rifleman Radio batteries. If units attempt to push higher than an 80% depletion rate, they run the risk of radios shutting down and losing communication. Furthermore, since the EUD charges from the radio, if the EUD loses charge based upon a fully depleted Rifleman Radio battery, this creates complications beyond the scope of discussion for this paper. Stated simply, an EUD that fully discharges is likely to be inoperable for the duration of the mission.

The point of this battery swap analysis is two-fold: first, this analysis demonstrates the importance of closely monitoring battery levels; secondly, this analysis shows the value of using the conformal battery to continually replenish the Rifleman Radio and EUD. There is a useful gas station analogy that may help to reinforce these points. Suppose that when cars arrived at a gas station, rather than filling the tank, drivers simply swapped their partially empty tank for a full tank. Assume that the physical cost of this swap is negligible, perhaps nothing harder than exchanging a propane tank. From an economic standpoint, drivers would attempt to use as much fuel as possible before swapping tanks, realizing that any fuel remaining in the old tank would be wasted. This would create interesting problems for drivers who would quickly realize that replacing a half or three-quarters full tank makes no economic sense. This would create practical problems where drivers would strategize fuel tank exchange stops. Thankfully this has never been the solution for fueling a vehicle. However, Soldiers practice a similarly wasteful policy any time a partially charged battery is exchanged for a fully charged battery. The conformal battery technology moves a step in the right direction to eliminate this waste, and improving the conformal battery power to weight ratio will further illuminate the benefits of using conformal batteries as a power reservoir that charges Soldier systems that require electrical power.

The project team is working on developing the final part of the project, the decision support tool. The decision support tool will seek to educate users on basic power principles, inform users on the characteristics of their equipment, and recommend scenario based power management strategies. Currently, the team is rapidly employing the Systems Decision Process (SDP), which is a collaborative, iterative, and value-based decision process that can be applied in any system life cycle stage (Parnell, 2011). The authors created a value hierarchy and generated alternatives based on different interfaces capable of achieving function objectives. After feasibility screening, value scoring, and calculating total system value, the highest scoring solution is a smartphone interface capable of building your own scenario with a graphical training aid that helps improve power literacy across squads by providing information on basic power principles and equipment.

## 5. Conclusion

After thorough analysis on stakeholders, battery charging, solar blanket power generation, scenario based strategies, and a detailed study of small unit power equipment, tactical batteries, and power consuming equipment there are several findings. First, conservation and generation strategies for all four mission scenarios can result in a 10% to 30% reduced load for a dismounted unit. Second, the solar blanket power generation is most effectively measured and managed using the SPM and is significantly affected by proper tilt and orientation. Third, conformal batteries act as a power reservoir ensuring that users remain connected to the network as a trickle charge is constantly keeping the Rifleman Radio from running out of power. Analysis shows that disciplined use of conformal batteries reduces the total load and improves the operational effectiveness. Fourth, the project team has identified what we believe is a capability gap in the power generation spectrum, essentially between 100W and 1,000W. Lightweight solutions exist that produce less than 100W, tactical generators produce up to 1,000W, but the power generation that soldiers really need is somewhere in the middle. Lastly, our stakeholder analysis shows that units do not employ effective power management strategies and do not have an understanding of basic power management principles or equipment. The decision support tool seeks to address and improve power literacy across units, which will help commanders optimize power on the battlefield.

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