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Operational Energy Analysis for Dismounted Soldiers

V. Mittal

Department of Systems Engineering,
United States Military Academy West Point,
West Point, NY, USA

Corresponding author's Email: Vikram.Mittal@westpoint.edu

Author Note: Dr. Vikram Mittal currently serves as an Assistant Professor of Systems Engineering at the United States Military Academy at West Point. Prior to coming to West Point, he worked as a Senior Mechanical Engineer at Draper Laboratories, where he worked on numerous programs related to operational energy. Additionally, Dr. Mittal is a Captain in the Army National Guard and deployed in 2011 in support of Operation Enduring Freedom.

Abstract: Soldiers are reliant on cutting-edge equipment to have a technical advantage over adversaries in combat. This equipment is designed to maximize new capabilities while minimizing certain key system attributes, namely size, weight, and power (SWAP). However, these attributes do not reflect the equipment's actual usage in the field. Characterizing these attributes relative to a standard use case provides additional insight allowing for better design decisions. One such parameter is operational energy which derives from the power attribute. A case study is presented on performing an operational energy analysis. The process begins by identifying the power users, mission sets, and equipment loads. These parameters are fused together to generate a power usage profile and operational energy requirement which provide insight into the system design. The process serves as a guide for characterizing other time-based operational requirements, including physical and cognitive burden.

Keywords: Operational Energy, Dismounted Soldiers, Batteries

1. Introduction

Soldiers have always been issued equipment to provide them a tactical advantage over adversaries in combat (Marshall, 1980). This equipment ranges from bronze swords replacing stone weaponry all the way to the fielding of network radios to dismounted Soldiers in modern day combat operations. Existing engineering development processes strive to maximize the new capabilities provided by the equipment while reducing the burden on the Soldier. The burden on a Soldier is typically characterized in engineering design processes through the size, weight, and power (SWAP) attributes

SWAP attributes are readily measurable and useful parameters for design. However, they fail to capture the full impact of new equipment because they do not reflect the usage of the equipment over time. In particular, the power required for a piece of equipment becomes a significant issue for long-duration dismounted missions. As the duration increases, the energy required and the associated batteries increase as well, based on the activities that the Soldier is performing.

An operational energy analysis captures this shortcoming by mapping the power usage to a use case to determine the energy requirements and the associated battery weight. This information allows for better design analysis and decision making. For example, this paper will show that the battery weight required for a PRC-154 Rifleman Radio for 72 hours is 5 times more than the weight of the radio itself. Hence, the analysis allows an engineer manager to better analyze trade-offs, such as a 20% reduction in power draw would be result in a larger weight saving than a 20% reduction in the radio weight.

Though the case study focuses on operational energy, the process can be expanded to characterize any time-based attribute for a system. For example, the process can readily be translated to analyze physical and cognitive loading.

2. Overview of Operational Energy Analysis

The Army has identified that Soldiers are becoming more burdened as they are required to carry more pieces of electronics onto the battlefield. These electronics require batteries which often weigh significantly more than the equipment they are powering. The number and weight of batteries is related to the actual equipment usage over the course of a mission. An operational energy analysis captures these characteristics of the system.

The Army has conducted several surveys on Soldier load and operational energy. These surveys found that individual Soldiers could carry between 5 and 25 lb of batteries during dismounted operations (Harper, 2015; NSRDEC, 2012; USACAC, 2009; Task Force Devil, 2003). However, these surveys are not necessarily useful when attempting to predict the impact of a new piece of equipment. Therefore, the process outlined in this paper allows engineers to quantify the operational energy burden associated with fielding a new piece of equipment. This equipment includes both powered electronics and sources of energy, such as solar panels and energy harvesting that can be used to replenish some of the energy stores.

A process diagram for an operational energy analysis is shown in Figure 1. The operational energy analysis takes the users, their equipment, and their mission as an input. The mission is decomposed into select activities, which are mapped to equipment usage. This information provides the energy consumption for each piece of equipment, which can be used to calculate out the battery weight. Each of these processes are discussed in detail in the subsequent sections.

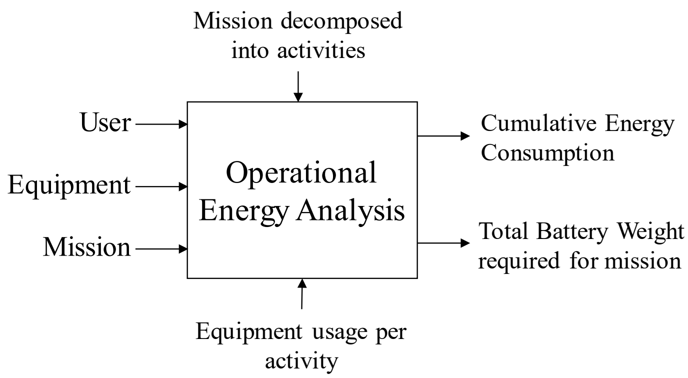

Figure 1. Process for performing an operational energy analysis

3. Dismounted Operational Energy Analysis Inputs

3.1. User

The first step in the operational energy analysis is to identify the users. This information is critical because it informs the equipment loads and the missions that the users will be performing. Though individual Soldiers can be used in an operational energy analysis, it is often more useful to perform the analysis for a group of Soldiers. Dismounted military missions are performed by Squads, Platoons, Companies, Battalions, and Brigades. Typically, the user for the operational energy analysis is the Squad. The results can then be aggregated for larger units.

This operational energy analysis is to be conducted on a Rifle Squad. The Rifle Squad consists of a Squad Leader (SL) and two Fire Teams. Each Fire Team consists of a Team Leader (TL), a Rifleman (RM), a Grenadier (GD), and an Automatic Rifleman (AR).

The SL is the most senior member of the Squad and is responsible for making the tactical decisions for the Squad. He is typically assigned additional communication and navigation equipment. The TL leads a Fire Team and is also issued additional communication equipment. The three junior members of each Fire Team are the AR, GD, and RM. As their names indicate, their position is based on what weapon they are carrying. The electronics carried by these positions are typically tied to their weapon systems.

3.2. Defining Mission

After identifying the user, the next step is to determine the mission that the Soldiers will be performing. A doctrinal 72-hour movement to contact was selected for the example operational energy analysis. This use case is based on a movement-to-contact mission spread out over 72 hours (US Army, 2007). Doctrine lists out the steps for the mission; however, the actual times associated with each step are determined from Soldier interviews. The overall mission duration is tied to the size of the unit. A 72-hour mission duration was selected because a squad is required to operate without resupply for this duration of time.

This mission is depicted in Figure 2 with the following narrative: *The Squad leaves the Assembly Area and marches towards an Objective. En route, the Squad establishes Patrol Base 1 to allow the Squad time to rest and prepare for mission. The Squad then moves from Patrol Base 1 towards the Objective Rally Point (ORP) from which they will launch their assault on the Objective. They secure the ORP and prepare for actions on the Objective. The Squad performs actions on the Objective and reconsolidates at the ORP. The Squad then moves back to Patrol Base 1. En route back to Patrol Base 1, the Squad must react to an enemy attack. The Squad returns to Patrol Base 1 and then moves back to the Assembly Area.*

Each phase of a mission can be readily decomposed into a number of Soldier activities. The following activity categories capture the range of actions that are being performed by the Squad:

- Resting: the Soldier is resting.
- Stationary Security Position: the Soldier is stationary and in a defensive posture.
- Surveillance: the Soldier is stationary and observing an enemy.
- Movement (Low Threat): the Soldier is walking as part of a Squad formation.
- Movement (High Threat): movement in a high threat environment could also be referred to as patrolling or scouting where Soldiers move slower and have higher equipment usage.
- Engaging with Enemy: the Soldiers are either moving to contact or reacting to contact.
- Miscellaneous high power activities: this catch-all category is used for the different activities that Soldiers perform that require a significant amount of power from their electronics. These activities include medical evacuations, coordinating with adjacent units, insertion by helicopter, extraction by helicopter, and sensitive site exploitation.

Figure 2 also displays the percentage of time that the Squad spends performing different activities in a given phase of the operation. To account for the variation across the Squad in activities performed (e.g. half the Squad is resting while half the Squad is pulling security), it is easiest to assign a percentage of time spent during each phase that the Squad is performing that activity.

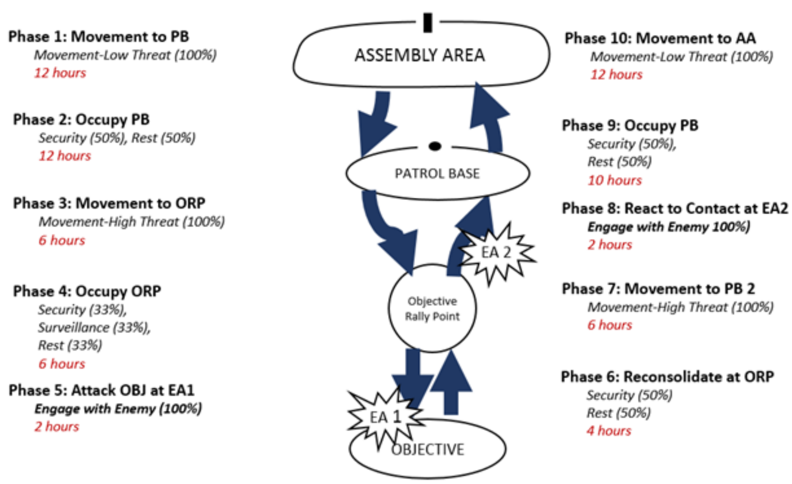

Figure 2. Use Case for energy calculations, based on a 72-hour doctrinal mission

3.3. Defining Equipment

The equipment load is defined next and is dependent on the users and the mission. Army equipment is broken up into two categories: baseline and mission-specific. The first category is the baseline set of equipment, which consists of equipment that is carried on every mission. Baseline equipment includes items such as radios, night vision, and weapon scopes. The second category of equipment is the mission-specific equipment, which consists of those pieces of equipment that are only required for specific missions, enemies, or terrain/weather. Mission-specific equipment includes additional radios, intelligence-gathering equipment, navigation equipment, and energy scavenging/harvesting equipment.

The full set of equipment included in this analysis is displayed in Figure 3. The baseline equipment that is carried for the Squad is as follows:

- Nett Warrior System which includes a smartphone and a PRC-154A Rifleman Radio, for the SL and TLs.
- Integrated Soldier Power and Data System (ISPDS) which is a hub that powers the Nett Warrior System from a centralized battery for the SL and TLs. Additional ports are available for mission-specific equipment.
- PSQ-20 Enhanced Night Vision Goggles for SL and TLs.
- PVS-14 Night Vision Goggles for the rest of Squad.
- PEQ-15 aiming lasers for all members of the Squad.
- M150 Rifle Combat Optics for the SL and TLs.
- M145 Machine Gun Optics for the AR.
- M68 Closed Combat Optics for the rest of Squad.
- M320 Day Night Sight (DNS) and Laser Range Finder (LRF) for the GD.
- Rifle Mounted Flashlights for all members of the Squad except for the AR.
- PAS-13 Heavy Thermal Weapon Sight (HTWS) for the SL.
- PAS-13 Medium Thermal Weapon Sight (MTWS) for the AR.
- PAS-13 Light Thermal Weapon Sight (LTWS) for the RM.
- Tactical Communications and Protection System (TCAPS) for all members of the Squad
- IR Beacons for all members of the Squad.

Additionally, the mission dictates that there is a large movement being performed by the Squad, and hence they need additional equipment to be able to perform their mission:

- PRC-148 Multiband Inter/Intra Team Radio (MBITR) to provide reachback communication for the SL.
- Defense Advanced GPS Receiver (DAGR) to provide secure navigation for the SL and TLs.
- 60W Solar Blanket for recharging the Squad batteries when they are in stationary positions during daylight hours.

Several pieces of equipment are interconnected to each other through the ISPDS system which is issued to SL and TLs. In this power architecture, up to 4 devices can receive power from a large conformal battery. For the SL, these devices are Nett Warrior, PRC-148 MBITR, and the DAGR. For the TLs, these devices include Nett Warrior and the DAGR.

Figure 3. Equipment set for Rifle Squad in operational energy analysis. Number in red indicate the number of each piece carried by the Squad.

3.4. Determine Equipment Usage by Activity

After identifying the user, mission, and equipment, the next step is to determine the usage profiles for each piece of equipment. The usage profile is defined for each piece of equipment by two sets of numbers:

- The average power consumption for each operating mode
- The percentage of time spent operating in a given mode for a given activity.

The majority of the equipment only has two operating modes: on and off. Therefore, for a given activity, the usage profile is defined as the percentage of time that the piece of equipment is turned on. However, some of the items have multiple operational modes; for example, the radios can be on standby, receive, transmit, or off.

Additionally, many pieces of equipment have significant variation between day and night. For example, night vision and flashlights are used primarily at night time. Therefore, it is necessary, to derive separate usage profiles for the activities at day and night. The usage profiles are derived from Soldier interviews in regards to equipment usage. For example, the radios are always on so that the Squad can receive information. However, they are transmitting significantly more when the Squad is engaging an enemy than when they are sleeping. Certain low-power equipment was similarly found to always be on, such as the M68 CCO. Other devices are used only in the event of an emergency, such as the IR Beacon. However, even emergency equipment must be included in the analysis since a battery will be taken on the mission in the event of an emergency that requires the use of that equipment. Table 1 shows the average power draw for each piece of equipment for each activity.

The average power consumed while performing a given activity is then determined by multiplying the power draw for a given activity by the percentage of time spent in the activity, and summing these values for all the modes. This process is done for each piece of equipment individually. Table 1 provides these values.

Table 1. Average power consumption for each piece of equipment as rifle squad is performing a given activity

Equipment	Engaging with Enemy		Miscellaneous High Power Activities		Movement (High Threat)		Surveillance		Movement (Low Threat)		Stationary Security Position		Sleeping	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
PRC-154 Rifleman Radio	8.5 W	8.5 W	8.5 W	8.5 W	8.1 W	8.1 W	8.1 W	8.1 W	8.0 W	8.0 W	8.0 W	8.0 W	7.9 W	7.9 W
Nett Warrior EUD	2.3 W	2.3 W	2.3 W	2.3 W	1.6 W	1.6 W	1.6 W	1.6 W	1.6 W	1.6 W	0.8 W	0.8 W	0.3 W	0.3 W
PRC-148 MBITR	6.0 W	6.0 W	6.0 W	6.0 W	4.0 W	4.0 W	4.0 W	4.0 W	3.4 W	3.4 W	3.4 W	3.4 W	3.0 W	3.0 W
DAGR	0.9 W	0.9 W	0.9 W	0.9 W	0.9 W	0.9 W	0.5 W	0.5 W	0.9 W	0.9 W	0.0 W	0.0 W	0.0 W	0.0 W
PSQ-20 ENVG	2.4 W	2.4 W	2.4 W	2.4 W	0.0 W	2.4 W	0.2 W	2.4 W	0.0 W	1.2 W	0.0 W	1.8 W	0.0 W	0.0 W
PVS-14 MNVD	0.6 W	0.6 W	0.6 W	0.6 W	0.0 W	0.6 W	0.1 W	0.6 W	0.0 W	0.3 W	0.0 W	0.5 W	0.0 W	0.0 W
M150 ACOG	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW	0.0 mW
M68 CCO	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW
M145 MGO	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW	1.8 mW
M320 Grenadier Optic	0.6 W	0.6 W	0.6 W	0.6 W	0.0 W	0.3 W	0.0 W	0.1 W	0.0 W	0.1 W	0.1 W	0.1 W	0.0 W	0.0 W
M320 LRF	2.0 W	2.0 W	2.0 W	2.0 W	1.0 W	1.0 W	1.0 W	1.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W
PEQ-15	0.5 W	0.5 W	0.5 W	0.5 W	0.0 W	0.5 W	0.1 W	0.5 W	0.0 W	0.4 W	0.0 W	0.5 W	0.0 W	0.0 W
PAS-13 LTWS	1.7 W	1.7 W	1.7 W	1.7 W	0.9 W	1.7 W	0.9 W	1.7 W	0.0 W	0.4 W	0.4 W	0.4 W	0.0 W	0.0 W
PAS-13 MTWS	2.2 W	2.2 W	2.2 W	2.2 W	1.1 W	2.2 W	1.1 W	2.2 W	0.0 W	0.5 W	0.5 W	0.5 W	0.0 W	0.0 W
PAS-13 HTWS	2.7 W	2.7 W	2.7 W	2.7 W	1.4 W	2.7 W	1.4 W	2.7 W	0.0 W	0.7 W	0.7 W	0.7 W	0.0 W	0.0 W
Flashlight (Rifle)	0.0 W	0.0 W	0.0 W	0.5 W	0.0 W	0.0 W	0.0 W	0.5 W	0.0 W	0.5 W	0.0 W	0.5 W	0.0 W	0.0 W
TCAPS	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W	0.2 W
IR Strobe Light	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W
60W Solar Blanket	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	0.0 W	-38.2 W	0.0 W	-38.2 W	0.0 W

4. Results

4.1. Determining Energy Requirements

Table 2 displays the energy consumed by each piece of equipment over the course of the mission. This information was compiled by multiplying the average power draws in Table 1 by the time spent in each activity in Figure 2.

The battery weight required over the 72 hour mission can then be calculated from the energy required, by dividing the energy required by the energy capacity of the battery and rounding up. The battery weight for each piece of equipment is shown in Table 3. Note that since the PRC-154, PRC-148, Nett Warrior EUD, and DAGR receive power from a conformal battery, these devices are grouped together as one device when doing the battery calculation.

Since the analysis includes the solar panel for recharging, it is necessary to break up the energy consumption into those devices that can be recharged by the solar blanket and those that cannot be recharged. Larger batteries, such as the conformal batteries can be recharged. Smaller batteries, such as the AA and CR123 batteries used in the night visions and scopes, cannot be recharged. The solar blanket recharge calculations must consider how many batteries are available for recharge at the time in the mission when the blanket is deployed.

Table 2. Energy consumed (in WHr) for each piece of equipment for each phase of the mission

		PRC-154 Rifleman Radio	Nett Warrior EUD	PRC-148 MBITR	DAGR	PSQ-20 ENVG	PVS-14 MNVD	M150 ACOG	M68 CCO	M145 MGO	M320 Grenadier Optic	M320 LRF	PEQ-15	PAS-13 LTWS	PAS-13 MTWS	PAS-13 HTWS	Flashlight (Rifle)	TCAPS	IR Strobe Light	60W Solar Blanket	
Phase 1 - Day	12 hr																				
Movement (Low Threat)	100%	95.5	19.5	40.8	10.8	0.0	0.0	0.0	22.2	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	
Phase 2 - Night	12 hr																				
Stationary Security Position	67%	63.7	6.6	27.2	0.0	14.4	3.6	0.0	14.8	14.8	0.9	0.0	3.6	3.5	4.3	5.4	4.0	1.4	0.0	0.0	
Sleeping	33%	31.5	1.3	12.0	0.0	0.0	0.0	0.0	7.4	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	
Phase 3 - Day	6 hr																				
Movement (High Threat)	100%	48.5	9.8	24.0	5.4	0.0	0.0	0.0	11.1	11.1	0.0	6.0	0.0	5.2	6.5	8.1	0.0	1.0	0.0	0.0	
Phase 4 - Day	6 hr																				
Stationary Security Position	33%	15.9	1.6	6.8	0.0	0.0	0.0	0.0	3.7	3.7	0.2	0.0	0.0	0.9	1.1	1.4	0.0	0.3	0.0	-76.4	
Surveillance	33%	16.2	3.3	8.0	0.9	0.5	0.1	0.0	3.7	3.7	0.0	2.0	0.2	1.7	2.2	2.7	0.0	0.3	0.0	0.0	
Sleeping	33%	15.8	0.7	6.0	0.0	0.0	0.0	0.0	3.7	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	-76.4	
Phase 5 - Night	2 hr																				
Engaging with Enemy	100%	16.9	4.6	12.0	1.8	4.8	1.2	0.0	3.7	3.7	1.1	4.0	1.0	3.5	4.3	5.4	0.0	0.3	0.0	0.0	
Phase 6 - Night	4 hr																				
Stationary Security Position	50%	15.9	1.6	6.8	0.0	3.6	0.9	0.0	3.7	3.7	0.2	0.0	0.9	0.9	1.1	1.4	1.0	0.3	0.0	0.0	
Sleeping	50%	15.8	0.7	6.0	0.0	0.0	0.0	0.0	3.7	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	
Phase 7 - Night	6 hr																				
Movement (High Threat)	100%	48.5	9.8	24.0	5.4	14.4	3.6	0.0	11.1	11.1	1.7	6.0	3.0	10.4	13.0	16.2	0.0	1.0	0.0	0.0	
Phase 8 - Day	2 hr																				
Engaging with Enemy	100%	16.9	4.6	12.0	1.8	4.8	1.2	0.0	3.7	3.7	1.1	4.0	1.0	3.5	4.3	5.4	0.0	0.3	0.0	0.0	
Phase 9 - Day	10 hr																				
Stationary Security Position	50%	39.8	4.1	17.0	0.0	0.0	0.0	0.0	9.2	9.2	0.6	0.0	0.0	2.2	2.7	3.4	0.0	0.9	0.0	-191.0	
Sleeping	50%	39.4	1.7	15.0	0.0	0.0	0.0	0.0	9.2	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	-191.0	
Phase 10 - Night	12 hr																				
Movement (Low Threat)	100%	95.5	19.5	40.8	10.8	14.4	3.6	0.0	22.2	22.2	1.3	0.0	4.8	5.2	6.5	8.1	6.0	2.0	0.0	0.0	
Energy for 1x Equipment (WHr)		**576**	**89**	**258**	**37**	**57**	**14**	**0**	**133**	**133**	**7**	**22**	**14**	**37**	**46**	**57**	**11**	**12**	**0**	**-535**	
Quantity of Equipment in Squad		**3**	**3**	**1**	**3**	**1**	**8**	**3**	**4**	**3**	**2**	**2**	**9**	**2**	**2**	**1**	**7**	**9**	**9**	**1**	
Total for Squad (WHr)		**1727**	**268**	**258**	**111**	**57**	**114**	**0**	**532**	**399**	**14**	**44**	**130**	**74**	**92**	**57**	**77**	**110**	**0**	**-535**	**= 3530 WHr**

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Table 3. Batteries required for each piece of equipment over the 72-hour mission

Equipment	Battery Type	Battery Quantity	Battery Capacity	Battery Weight	Energy Consumed	Total # of Batteries	Weight of Batteries
SL ISPDS System: PRC-154, PRC-148, EUD, DAGR	Conformal	1	150.0 WHr	2.60 lb	960 WHr	7	18.20 lb
TL ISPDS System: PRC-154, EUD, DAGR	Conformal	1	150.0 WHr	2.60 lb	702 WHr	5	13.00 lb
PSQ-20 ENVG	AA	4	13.2 WHr	0.20 lb	57 WHr	20	1.01 lb
PVS-14 MNVD	AA	2	6.6 WHr	0.10 lb	14 WHr	6	0.30 lb
M150 ACOG	Solar	N/A	N/A	N/A	0.0 WHr	0	0.00 lb
M68 CCO	DL 1/3N	1	0.6 WHr	0.01 lb	0.1 WHr	1	0.01 lb
M145 MGO	DL 1/3N	1	0.6 WHr	0.01 lb	0.1 WHr	1	0.01 lb
M320 Grenadier Optic	AA	1	3.3 WHr	0.05 lb	7 WHr	3	0.15 lb
M320 LRF	CR123	2	6.0 WHr	0.07 lb	22 WHr	8	0.30 lb
PEQ-15	CR123	1.00	3.00	0.04	14 WHr	5	0.19 lb
PAS-13 LTWS	AA	4	13.2 WHr	0.20 lb	37 WHr	12	0.61 lb
PAS-13 MTWS	AA	6	19.8 WHr	0.30 lb	46 WHr	18	0.91 lb
PAS-13 HTWS	AA	6	19.8 WHr	0.30 lb	57 WHr	18	0.91 lb
Flashlight (Rifle)	CR123	2	6.0 WHr	0.07 lb	11 WHr	4	0.15 lb
TCAPS	AA	1	3.3 WHr	0.05 lb	12 WHr	4	0.20 lb
IR Strobe Light	9V	1	5.1 WHr	0.10 lb	0.0 WHr	1	0.10 lb
60W Solar Blanket	Conformal (Recharge)	1	150.0 WHr	-2.60 lb	-535 WHr	-3	-7.80 lb

The energy consumption/recharging analysis is analogous to bank withdrawals/deposits. The electronics draw energy out from the batteries and deplete their energy stores. The recharging equipment, such as the solar panel, deposits energy back into the battery storage. In an ideal situation, the amount deposited would be equal to the amount withdrawn. However, in this analysis 1662 WHr are used from rechargeable batteries; the solar panels only provide 535 WHr.

4.2. Analysis of Energy Requirements

The operational energy requirements provide insight into the energy needs and requirements for dismounted Soldiers. In particular, the time-component of the analysis provides insight that the time-independent SWAP parameters do not provide. For example, the PRC-154 Rifleman Radio weighs 2 lb and has a power draw of 7.8 W on average. Over the mission profile, this equates to 4 conformal batteries, weighing 10.4 lb in conformal batteries, 5 times the weight of the radio itself. Therefore, a 10 percent reduction in power results in a larger weight saving than a 50 percent reduction in radio weight. As such, more resources should be allocated in the engineer design process to reduce the power draw from the radio than for reducing the radio weight.

On the power supply side, the solar blanket has a weight of 5 lb and produces 60 W in ideal conditions. By purely looking at the power independent of the use case, the 60 W solar blanket would produce 4320 WHr in 72 hours. However, due to the limited amount of the stationary time spent in the sunlight, the solar blanket only produces 535 WHr only recharging 3 of the 17 conformal batteries that are used over the mission.

5. Extension to Other Analyses

Engineer management requires that key system attributes be tracked and evaluated in the design of the system. These attributes are often stated as time independent variables, such as size, weight, and power, in order to avoid variability based on the use case. However, as displayed through the operational energy analysis, certain parameters are only truly defined through applying a time-based use case to the equipment.

Another key system attribute is the weight of the device; this parameter mapped over time relates to the physical burden of the Soldier. Though more abstract, the analysis for determining the physical burden of the Soldier would be similar to that of the operational energy analysis. The Soldier has a fixed reserve of energy that he can expend physically carrying equipment. As he moves, his energy stores are depleted. His energy stores are further depleted as he engages with the enemy or does other physical activity associated with his mission. His energy stores are recharged when he rests. When the Soldier's energy stores drop below a certain point, the Soldier is no longer combat effective.

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A similar analysis can be performed for cognitive loading, which is a usability parameter mapped over time. A Soldier can tolerate performing a mentally taxing task sporadically through a mission. However, if that task is performed frequently, the Soldier's cognitive stores would be drained. His cognitive stores can be recharged through rest. And just like his physical energy stores, when his cognitive energy stores drops below a certain level, the Soldier is no longer combat effective.

These time-based analyses provide significantly more insight into system attributes that are typically independent of use and duty cycle. Physical and cognitive burden can be readily analyzed through the process outlined for operational energy; however, any attribute that has variability in time can follow a similar process. This analysis allows for a more complete description of the attribute and for more informed design decisions.

6. Conclusions

An operational energy analysis was conducted to serve as a case study to display a process for analyzing a key system attribute, in this case power, over a given mission. The resulting operational energy analysis provided insight into design parameters that are not fully captured by the power attribute alone.

The process begins by identifying the power users, mission sets, and equipment loads. These parameters are fused together to generate a power usage profile that can be used to determine the operational energy requirement. The process serves as a guide for calculating other time-based operational requirements, including physical and cognitive burdens, for adding any piece of equipment into a small unit.

7. References

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