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SYSTEMS ENGINEERING CAPSTONE REPORT

ASSESSING THE IMPACT OF TACTICAL MISSION PROFILES ON THE DEVELOPMENT OF POWER PREDICTION SOFTWARE

by

Rasida Alisa, Mark A. Kotwicki II, and Peter J. Marbach

September 2019

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The United States Marine Corps (USMC) Expeditionary Energy Office (E2O) needs to conduct an analysis of small unit power requirements. This study assesses both current and future (approx. 2024) small unit configurations, and the impact that operational conditions and tactical scenarios have on power requirements, beyond a straightforward reference to technical data. This analysis accounts for potential changes to the USMC force structure, as well as technological changes that alter access to and implementation of equipment. In support of that broader need, this study uses a systems engineering analysis of the impact that alterations to operating conditions have on power requirements. This study starts with the mission set currently defined within IPOWER, an energy simulation tool, as a starting point but also further develops possible system structure, and methodologically analyzes appropriate options to use in both acquisition and operational environments. This study creates architectural representations of mission profiles and mission blocks to define candidate duty cycles and assess the impact that alterations to those mission profiles have on power usage.

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ABSTRACT

The United States Marine Corps (USMC) Expeditionary Energy Office (E2O) needs to conduct an analysis of small unit power requirements. This study assesses both current and future (approx. 2024) small unit configurations, and the impact that operational conditions and tactical scenarios have on power requirements, beyond a straightforward reference to technical data. This analysis accounts for potential changes to the USMC force structure, as well as technological changes that alter access to and implementation of equipment. In support of that broader need, this study uses a systems engineering analysis of the impact that alterations to operating conditions have on power requirements. This study starts with the mission set currently defined within IPOWER, an energy simulation tool, as a starting point but also further develops possible system structure, and methodologically analyzes appropriate options to use in both acquisition and operational environments. This study creates architectural representations of mission profiles and mission blocks to define candidate duty cycles and assess the impact that alterations to those mission profiles have on power usage.

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LIST OF ACRONYMS AND ABBREVIATIONS

AH	Ampere Hour
BLUFOR	Blue Force
C4I	Communication and Command, Control, Communications, Computers, and Intelligence
CK	Check Point
COA	Course of Action
CONOPS	Concept of Operations
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DOORS	Dynamic Object Oriented Requirements System
E2O	Expeditionary Energy Office
E2W2	Expeditionary Energy, Water, and Waste
EL	End Line
GCE	Ground Combat Element
ICD	Initial Capabilities Document
IDEA	Individual Dismounted Energy Application
IPOWER	Intelligent Power Optimization with Environmental Reactivity
MAGTF	Marine Air Ground Task Force
MC	Marine Corps
MCCDC	Marine Corps Combat Development Command
MCCDI	Marine Corps Combat Development and Integration
MCPP	Marine Corps Planning Process
MCT	Marine Corps Task
MCTFS	Marine Corps Total Force System
MCTL	Marine Corps Task List
MOE	Measures of Effectiveness
MOUT	Military Operations on Urbanized Terrain
NAI	Named Area of Interest
NRL	Naval Research Lab

OBJ	Objective
OPFOR	Opposition Force
R2P2	Rapid Response Planning Process
SL	Start Line
SoC	State of Charge
SOP	Standard Operating Procedures
TO&E	Table of Organization and Equipment
USMC	United States Marine Corps
WFF	Warfighting Functions
WH	Watt Hour

EXECUTIVE SUMMARY

The battlefield is evolving based on the changes in technology. Technological advances pose a new concern to the warfighter as they manage not only the battle space and logistical support related to the battlespace but also power requirements. Over the last 40 years, the new technology brought to bear against the enemy or in support of a tactical advantage has increased the energy use requirement. Radios alone account for a 250% increase over the last ten years (Marine Corps Expeditionary Energy Office [E2O] 2011). The United States Marine Corps (USMC) continues to evaluate their energy usage and seeks to maintain a fast, lethal, and austere force.

The USMC created the Expeditionary Energy Office (E2O) to optimize expeditionary energy across all warfighting functions (E2O 2011). E20 created an energy analysis tool named the Intelligent Power Optimization with Environmental Reactivity (IPOWER) and this tool is the focus of this project. IPOWER is an energy simulation tool that focuses on acquisition and mission planning with future goals for real time assessment in the operational environment (South 2017).

A. PROBLEM DEFINITION AND RESEARCH OBJECTIVES

This study aims to define mission profiles, mission blocks, and mission activities used in the IPOWER tool through an analysis of USMC doctrine and equipment used by the operational forces. The development of requirement definitions and an architectural description of mission profiles, blocks, and activities will allow the accurate evaluation of IPOWER. The analysis of these units will support utilization of IPOWER during the acquisition process for new equipment and real-time operations. The study will also present recommendations to utilize IPOWER for a realistic power-planning system.

IPOWER focuses on the small unit force. The tool uses data input by the user to describe the power usage and inform the user regarding their predicted energy need. IPOWER software is currently in early development; this project used version 3.0.0 for the early stages of the report and version 3.1.0 for the analysis. The goal of the project is to

define mission profiles, mission blocks, and mission activities used in the IPOWER tool through an analysis of USMC doctrine. The research objectives for this project are:

1. Define a set of mission profiles/mission blocks and operating conditions relevant to both current and future USMC small unit operations.

2. Provide an overall systems architecture that captures the operational activities and system elements associated with USMC small unit operations. Alternatively stated, this research will produce standardized representations of what the units will do (operational activities) and what will be used to do it (system elements). This architecture will include identification of dependencies on unit composition and operating environment.

3. Provide analysis of an operational simulation using IPOWER to identify key performance drivers (in terms of operational activities and system elements) that inform comparisons of duty cycle dependent operational frameworks.

The approach for this project used systems engineering Vee model with a focus on capabilities and requirements leading to verification and validation of the mission.

B. ARCHITECTURE DEFINITIONS AND SCENARIO DEFINITIONS

The mission analysis approach examined doctrinal publications, current and future operations, and traced user needs through mission analysis and operational requirements, which derive system requirements. Once defined, any analysis works iteratively to refine systems requirements for IPOWER. With this process, examining the architecture of IPOWER, the team created a relationship diagram to map out how information is used with each model. Figure 1 describes the relationship model developed for IPOWER. The relationship map is comprised of two distinct domains: an operational domain and an IPOWER domain.

USMC doctrine is critical to informing the mission development and in the decomposition to operational needs requirements. The mission development relates to the mission activities, which build into mission blocks. The operational needs guide IPOWER

system requirements. As a mission scenario develops, personnel requirements and equipment requirements are defined, and the data drives the cross-domain transfer of information into the IPOWER tool. To define the personnel and equipment that execute the scenarios, the project team looked to USMC doctrine and examined the Table of Organization and Equipment (TO&E). These documents define the USMC organization structure and equipment, both current and projected over ten years. Within the TO&E, units are assigned specific tasks. These tasks, from the Marine Corps Task List, define the capabilities of the unit.

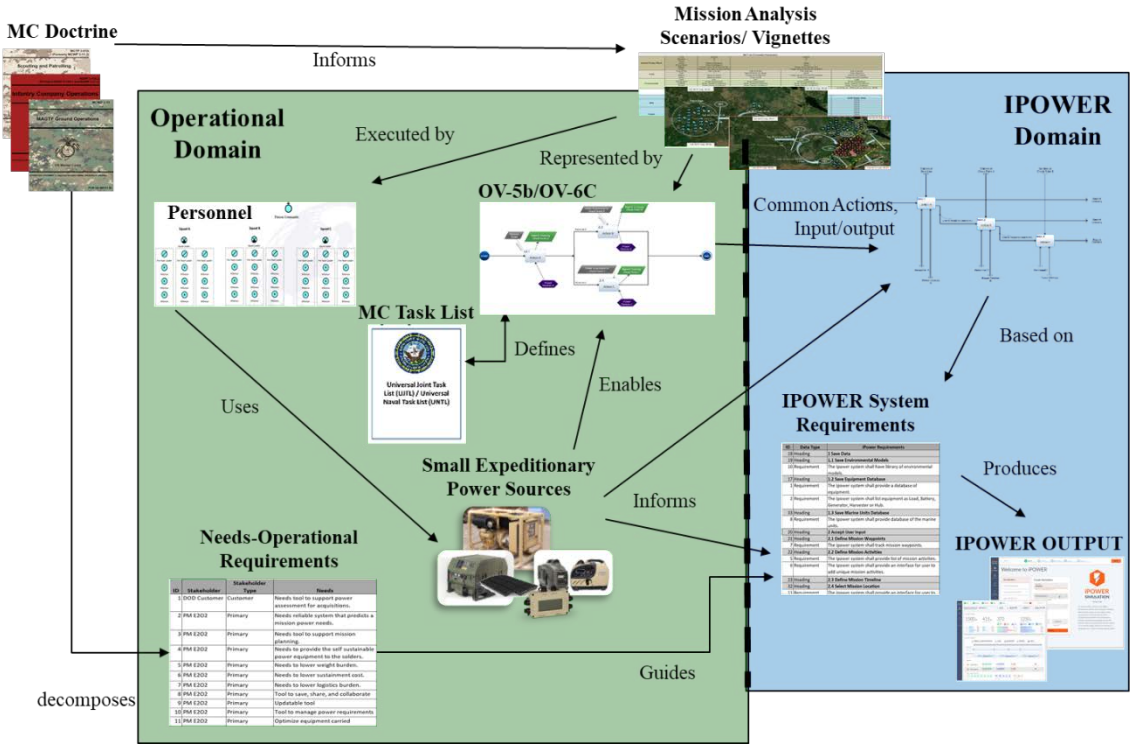

Figure 1: Project Relationships

C. MODELING AND SIMULATION

IPOWER is designed as an acquisition tool and a mission-planning tool. The modeling and simulation analysis looks at four scenarios that cover a range of capabilities to meet the intent of the tool. The four simulations are listed below.

- Baseline. The baseline simulation holds the defined scenario as a constant to which the other simulations are compared. The baseline uses a platoon-sized element in a 24-hour mission consisting of six mission activities.

- Change to the equipment usage rate. In this simulation, the radio duty cycle parameter "transmit" increased by 50% in all activities. This portrays an increased usage of the radio. In this variation, the team increased the load to the radio, which depleted the associated battery more quickly and would need more power available throughout the mission.

- Change to the AN/PRC-153 battery power available. In this simulation, the batteries' power available associated with each radio is increased by 50%. In the baseline database, the AN/PRC-153 has a 3.6 Ah battery rating. Variation 2 modifies this battery to a 5.4 Ah power rating. This portrays a more efficient system or an improved battery capability in development within the requirements definition phase of the acquisition process.

- Change to activity duration. The final simulation adjusts the duration of several activities within the mission block. During mission planning, it is possible to develop multiple courses of action (COA). As the COAs develop, activities may change, or the length of activity may change. An example could be changing from a mechanized insert of personnel by helicopter. In this simulation, the equipment use may be the same, but certain activities may be shortened or lengthened based on detailed mission planning.

D. CONCLUSIONS

The analysis conducted demonstrated that the IPOWER tool is capable of producing detailed results regarding power consumption and prediction. In this analysis, the variations showed a consistent picture of how power is consumed over time and how the results can shape mission planning. A part of the research project is to identify

limitations and gaps within the tool. The project team collected software limitations to aid the development of the IPOWER tool. Areas of software limitation that affect system performance include the inability to account for environmental effects, parallel activities, and equipment efficiency parameters.

Environmental effects may affect the performance of equipment. High temperatures found in desert environments or cold environments may negatively affect equipment performance such as batteries. Accounting for temperature ranges in an activity or locality may allow a more accurate prediction of energy depletion. Additionally, varying cloud cover will affect solar harvesters (solar panels) at different rates. Allowing the user to select these parameters within the mission will also help the accuracy of the data.

Parallel activities are important at the platoon and higher organizational level. Within a platoon activity currently supported by version 3.1.0, it is important to allow individual units to perform different activities within the same simulation. Parallel activities within a platoon are typical. Modeling parallel activities will align mission development with small unit level tactics.

Equipment efficiency parameters will allow the user to account for older, underpowered, or under charged equipment that may not act as a perfect specimen. The efficiency of equipment is an important aspect of developing a customized simulation.

E. FURTHER RESEARCH

The project team also identified areas of further research to refine and standardize mission activities, expand equipment database entry, and define equipment usage parameters. The research in these areas will require human research, which was outside of the scope of this project. Actual evaluation of units and understanding the equipment usage patterns will provide needed accuracy as it relates to duty cycles. Item managers should define equipment parameters to ensure accuracy in the equipment database. User-defined equipment is still valuable and necessary for commercial of the shelf equipment or equipment not managed within the DoD.

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Marine Corps Expeditionary Energy Office. 2011. *Marine Corps Expeditionary Energy Strategy and Implementation Plan*. Washington, DC: Expiditionary Energy Office. https://www.hqmc.marines.mil/Portals/160/Docs/USMC%20Expeditionary%20Energy%20Strategy%20%20Implementation%20Planning%20Guidance.pdf.

South, Eric J. 2017. *Quantifying Energy Sustainment: Individual Dismounted Power App (IDEA)*. Quantico, VA: Marine Corps Systems Command Systems Engineering Acquisition Logistics Energy Team.

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I. INTRODUCTION

A. BACKGROUND

Technological advancement enables greater command, control, communications, computers, and intelligence (C4I) technologies on the battlefield. These advancements create greater capability and information flow across the world and have affected military strategy across the entire Department of Defense (DoD). The United States Marine Corps (USMC) is not immune. In the last ten years, the energy consumption of the USMC increased exponentially with a 250% increase in radios and a 300% increase in IT/computers (Marine Corps Expeditionary Energy Office [E2O] 2011). Since Vietnam, there has been over a 175% increase in gallons of fuel consumed per U.S. soldier, sailor and Marine (average annual growth of 2.6% in last 40 years) (E2O 2011). These increases put capability in the battlefield, but it comes at a cost to maneuverability, speed, and logistical sustainment. The power requirements and support requirements have left the USMC burdened with increased weight and logistics complications, which continue to hinder the speed, maneuverability, and lethality for which the USMC is known. The USMC needs to reset the balance and return to a fast, lethal, and austere force. Figure 1 characterizes the USMC as a lethal force but is removed from the austere and fast categories. To shift the USMC back to the center, the USMC must change how it uses and manages energy.

Created in 2009, E2O seeks to "analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all warfighting functions" (E2O 2011). Additionally, the E2O is responsible for "advising the Marine Requirements Oversight Council on all energy and resource-related requirements, acquisitions, and programmatic decisions" (E2O 2011). Given E2O's mission, it is necessary to conduct analysis of how small units of Marines, operating both now and in the future, will obtain, utilize, maintain, and replenish power during a broad range of operations. The analysis will require a definition of duty cycles, defined by mission profiles, unit composition, equipment, and the operating environment.

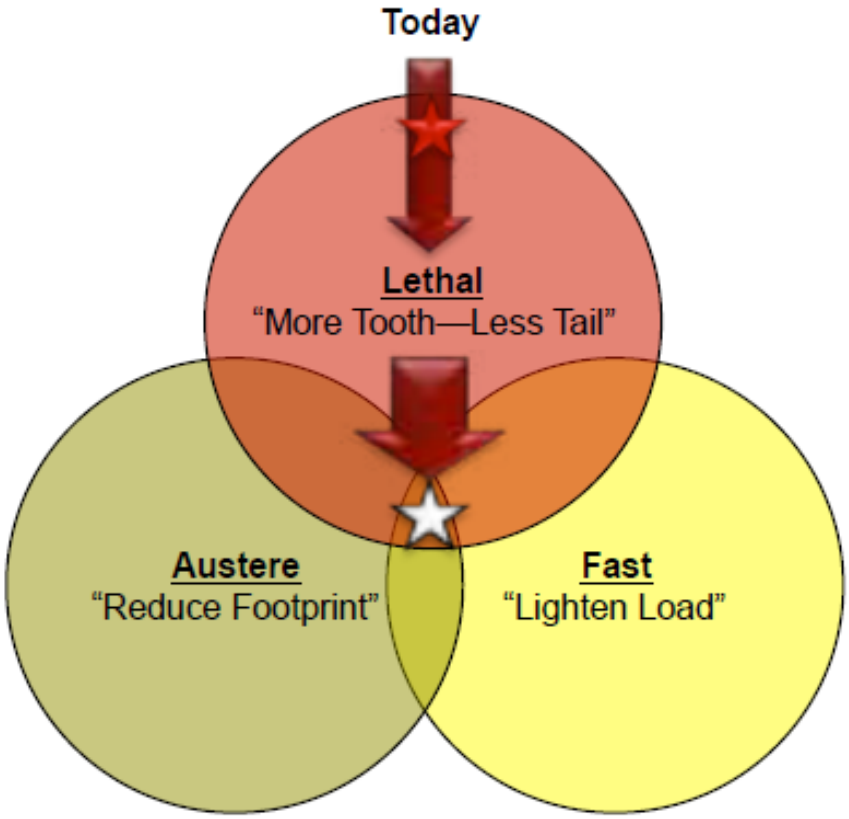

Figure 1: Venn Diagram USMC Today. Source: E20 (2011).

The Intelligent Power Optimization with Environmental Reactivity (IPOWER) tool is the combination of two power analysis tools (one for the Army and the other for the USMC). IPOWER is an energy simulation tool intended to inform every step of the energy management process, from use in acquisition (requirement and concept of operations (CONOPS) development and equipment evaluation) to mission planning and eventually real-time assessment (South 2017).

B. PROBLEM DEFINITION

IPOWER describes power usage in a small unit environment. IPOWER uses a user interface, which accepts data provided by the individual to predict power usage and inform the operator of unit energy usage. In this early stage of development, IPOWER draws from information based on the environment, equipment, and mission parameters. These

parameter data points are not fully developed or defined to provide useful information to the user.

This study aims to define mission profiles, mission blocks, and mission activities used in the IPOWER tool through an analysis of USMC doctrine and equipment used by the operational forces. The team's evaluation of IPOWER will allow the development of accurate requirement definitions and architectural description of these mission profiles, blocks, and activities. The analysis of these units will support utilization of IPOWER during the acquisition process for new equipment and real-time operations. The study will also present recommendations to utilize IPOWER for a realistic energy-planning system.

C. RESEARCH OBJECTIVES

This research will inform the development of current and future power requirements for USMC small units. The research will define operating conditions to facilitate an in-depth analysis of the duty cycle dependent energy requirements of a squad and platoon-sized USMC elements. In support of that broader objective, this research has the following specific objectives:

1. Define a set of mission profiles/mission blocks and operating conditions relevant to both current and future USMC small unit operations

2. Provide an overall systems architecture that captures the operational activities and system elements associated with USMC small unit operations. Alternatively stated, this research will produce standardized representations of what the units will do (operational activities) and what will be used to do it (system elements). This architecture will include identification of dependencies on unit composition and operating environment.

3. Provide analysis of an operational simulation using IPOWER to identify key performance drivers (in terms of operational activities and system elements) that inform comparisons of duty cycle dependent operational frameworks.

D. SYSTEMS ENGINEERING PROCESS

The project team tailored the Vee model to develop the systems engineering process for this project. The Vee model is well suited to support the analysis approach that this capstone project uses to structure operational analysis of USMC small unit power requirements. Specifically, the report leverages the analysis approach detailed in Van Bossuyt et al. (2019) as the basis for the application of the Vee model. The team tasks are centered on capabilities and requirements, which feed the verification and validation of the mission, the associated unit's equipment, the IPOWER tool, and the analysis process.

The analysis begins with understanding the problem and defining the end state. The top left of Figure 2, initiates analyses of warfighter capabilities and requirements. Mission requirements and architecture are developed in parallel through a recursive process. Once the mission architecture, IPOWER performance specifications and IPOWER architecture is defined, moving up the right side of the Vee, the analysis is done to validate the user interfaces, IPOWER model, and IPOWER requirements.

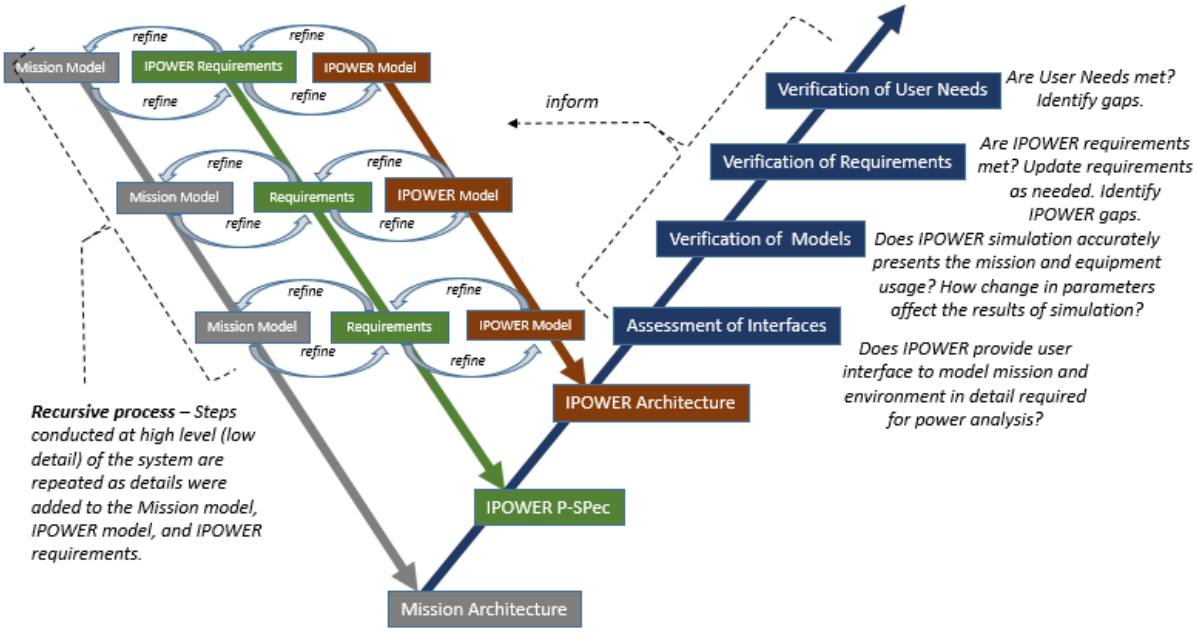

Figure 2: Tailored System Engineering "Vee" Model. Adapted from Naval Postgraduate School (2012).

II. LITERATURE REVIEW

A. IPOWER

The objective of this research is to conduct an in-depth examination of USMC small unit power requirements using the IPOWER software. Understanding how IPOWER combines information to make accurate predictions may drive architectural and system requirements. The IPOWER tool also integrates USMC operational requirements. Reviewing both IPOWER literature and USMC doctrine will provide background and guide the research team within the analysis approach.

1. Simulation Process

Due to the domain specific applicability of IPOWER, it is important to review the fundamental steps associated with construction of models within the software. IPOWER runs an algorithm against a mission scenario to produce analysis results. The mission scenario is comprised of two major elements: mission definition and equipment. Within IPOWER, mission definition is based on a start time and an end time in a specific location or defined as a series of waypoints where each has a different arrival time, departure time, and location (South 2017). In IPOWER, a mission definition allows a finite number of standard activities during a mission. Users can assemble a schedule of activities by assigning these pre-defined "mission blocks" to portions of the mission timeline.

Equipment falls into three categories: loads, energy harvesters, and batteries. The tool presents the user with a menu from which they can select equipment and assign the equipment to specific individuals. Next, the user may select any energy harvesters used. An energy harvester is a piece of equipment that creates energy (i.e., solar panels, kinetic generators). Finally, the user may choose one or more batteries for the simulation, or rely on IPOWER to select the minimum weight combination that completes the mission. IPOWER assumes that batteries are always fully charged at the start of the mission.

Once the mission scenario is complete, IPOWER runs the simulation and optimization functions seen in Figure 3. IPOWER's analysis identifies the minimum number of batteries the soldier must carry to complete the mission and determines the

minimum weight combination of energy sources (batteries and energy harvesters) that will satisfy the mission energy required, given all the equipment in the database. The main result is a plot of the battery state of charge (SoC) throughout the mission (Stroman 2018).

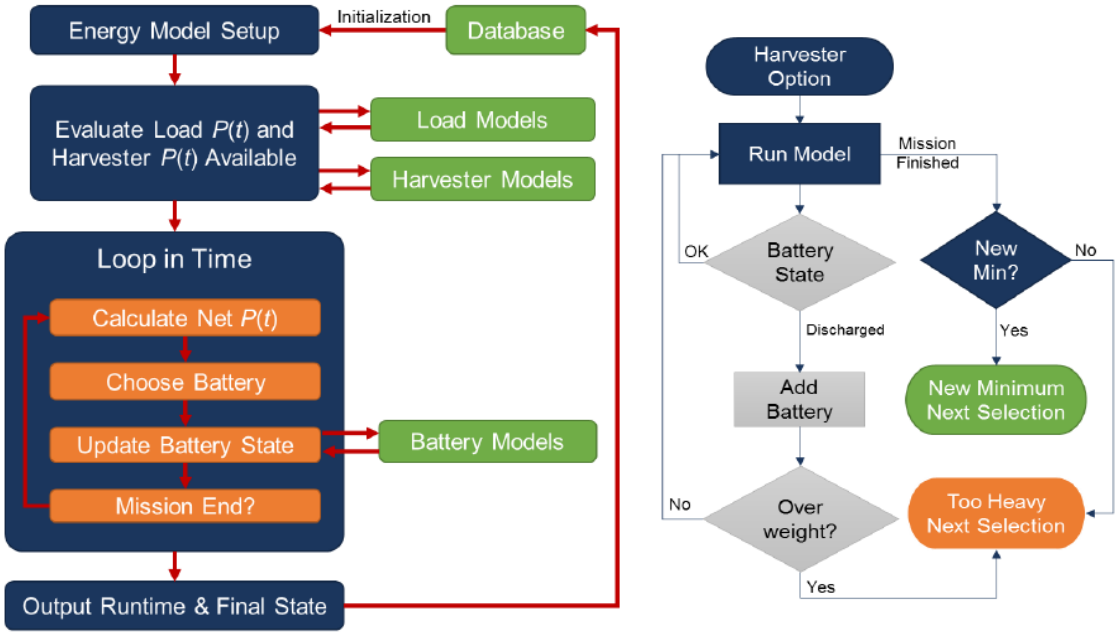

Figure 3: IPOWER Simulation and Weight Optimization Process. Source: Stroman (2018).

2. IPOWER Inputs

IPOWER requires user input to conduct an accurate assessment and simulation. Inputs from the user include mission location, unit structure, mission timeline, equipment carried, and power system topology. IPOWER saves this information to use in additional simulations.

Unit location is used to pull environmental data for the operational area, which will account for average seasonal temperatures and overlays the diurnal cycle for solar and lunar influences. This capability is useful in specific equipment where solar and lunar availability affects usage (e.g., night vision devices and solar panels).

The unit structure allows the user to create fire teams, squads, and platoons while assigning specific equipment to individual soldiers. This structural hierarchy allows the results to display power usage and energy needs at each level from the platoon to the individual.

3. Equipment Database

IPOWER utilizes a modifiable equipment database to query data for equipment used in a simulation. The database contains data on the equipment that pertains to the equipment weight, battery size/material, battery voltage, usage rates per activity, and duty cycle. These values are adjustable to the user but apply globally to all simulations. Equipment falls into three categories: energy harvesters, loads, and batteries.

- Energy Harvesters: Harvesters are separated into two classes: solar harvesters and kinetic harvesters. Solar harvesters are photovoltaic solar panels, whereas kinetic harvesters include knee-brace, rucksack, and other energy harvesters that convert soldier motion into electrical power (South 2017). The average rate of power generation for each kinetic harvester, for each soldier activity, is defined in the database and retrieved during execution. This model could be expanded to more accurately capture performance-using terrain to include the influence of ascent/descent rate.

- Load: Each load draws power at a rate dictated by a load model parameterized by soldier activity. A load is the basis of most equipment and is a focus of IPOWER because loads are the primary power consumer of the system. The load database processes power consumption in two ways: as an average power consumption or by a specific duty cycle. A duty cycle is a cycle of operation of equipment, which operates intermittently.

- Battery: Battery usage and operation is the most detailed sub-model within IPOWER to capture real-world performance as accurately as possible. SoC is tracked by integrating the flow of charge into/out of the battery and

comparing to the total charge capacity of the battery. Charge capacity varies with ambient temperature and SoC according to an empirical model created through battery measurements in an environmental chamber (South 2017). Batteries are considered discharged when SoC reaches an adjustable lower bound, or terminal voltage reaches the minimum. IPOWER assumes batteries charge until they reach 100% SoC or the terminal voltage reaches the maximum.

B. USMC DOCTRINE

The team reviewed several key Marine Corps documents to ensure an accurate account of the unit structure, mission types, and also that Marine Corps Tasks were applied in IPOWER. This study focuses on the infantry fire team, squad, and platoon organization structure and uses data from the MCRP 1-10.1 (Marine Corps Combat Development and Integration [MCCDI] 2015). The study also uses the USMC Table of Organization and Equipment (TO&E) for unit structure and equipment assigned to these levels of the organization (MCCDI 2018b). An infantry rifle company is described in Figure 4. The team found specific equipment parameters and definitions in open source documentation. This study will focus on a single rifle platoon within the company structure.

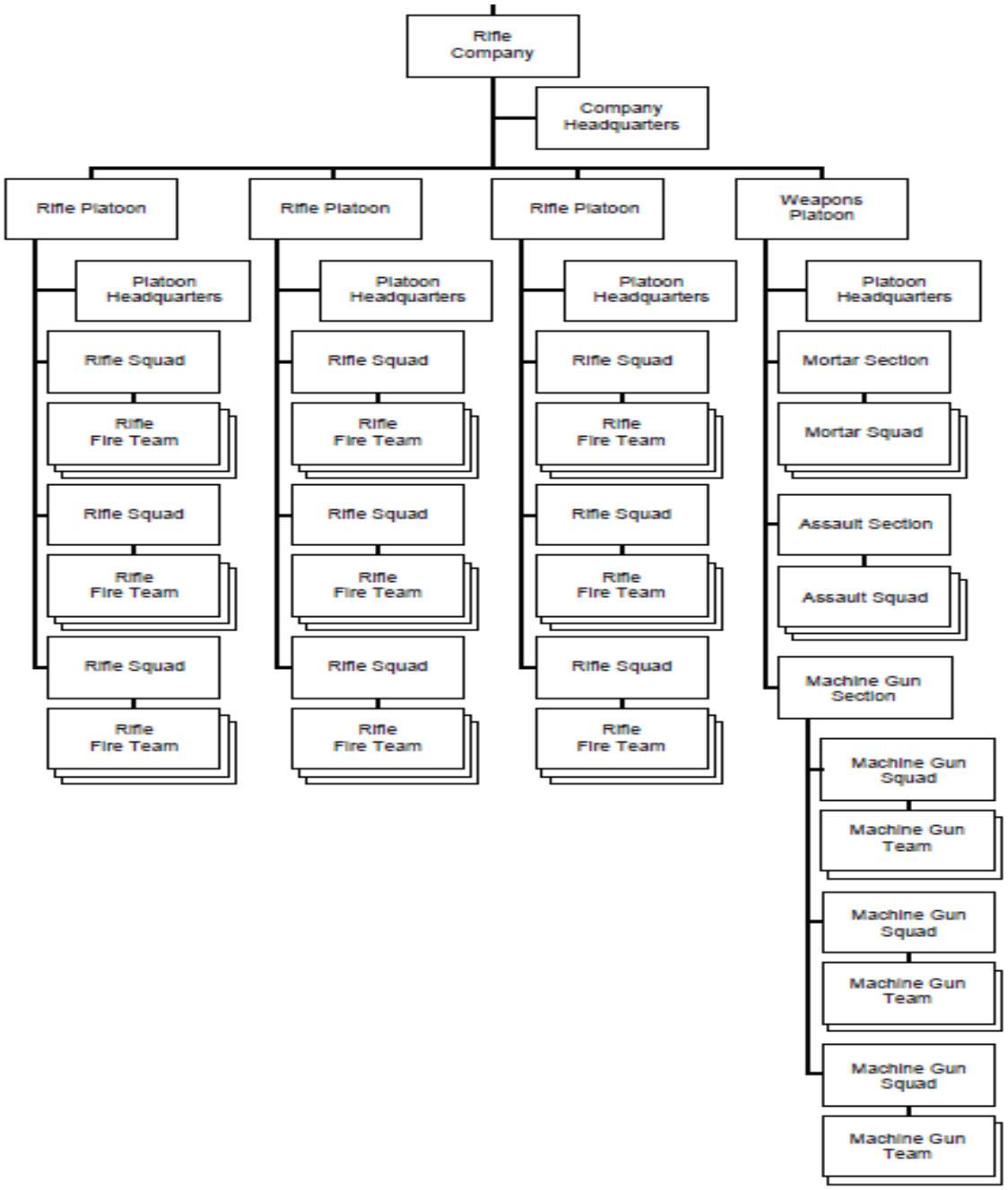

Figure 4: Typical Rifle Company. Source: MCCDI (2015).

The USMC publishes the TO&E twice a year. Each publication identifies expected changes over the next 20 years. As of March 2019, the USMC published the second TO&E for years FY19 through 2039 (MCCDI 2018b). Table 1 shows a partial list of equipment for the infantry battalion. While not complete, it does show a portion of individual

equipment items within a battalion. The USMC is in a state of change. In recent updates to the TO&E, the USMC has increased the size of the rifle squad to 15 but is manned and staffed at 12 (MCCDI 2018b). The FY29 TO&E was chosen as a mid-point for future planning.

Table 1: Infantry Battalion Equipment List. Source: MCCDI (2018b).

TAM Number	Item	Quantity		
		Infantry Battalion (Each)	Headquarters Company Infantry Regiment (Each)	
A0662	FMF end-user computer	13	13	
A0815	Heliport lighting set	1	1	
A1530	Radar transponder beacon, AN/PPN-19	2	4	
A1815	Radio set, AN/GRC 160	21	43	
A1930	Radio set, AN/MRC 110A	5	5	
A1935	Radio set, AN/MRC 138A	3	5	
A1957	Radio set, AN/MRC 145	5	7	
A2030	Radio set, AN/PRC 68A	94	6	
A2050	Radio set, AN/PRC 119	72	21	
A2051	Radio set, position location reporting system (PLRS)	15	6	
A2065	Radio set, AN/PRC 104(B)	5	5	
A2069	Radio set, VHF, AN/PRC 113	5	2	
A2070	Radio set, PRC 119	58	11	
B0730	Generator set, 3 kW, 60 Hz, MEP 016B	1	2	
B1650	Refrigeration unit, 100 ft^3	2	2	
D1002	Truck, ambulance, two litter, 1/4 ton, HMMWV, M1035	2	1	
D1016	Truck, cargo, 1 1/4 ton, diesel, 4 x 4, M1008	4	3	
D1158	Truck, utility, cargo troop carrier, 1 1/4 ton, M998	27	12	
D1159	Truck, utility, armament carrier, M1043	10		
E0892	Launcher, grenade, 40 mm, M203	107	0	
E0310	Dragon day/night tracker	12	0	
E0915	Launcher, assault rocket, 83 mm, MK153 (SMAW)	18	0	
E0935	TOW launcher	8		
E0960	Machine gun, light squad, M249	81	6	
E0980	Machine gun, .50 cal	6	0	
E0980	Machine gun, 7.62 mm, 240G		29	2
E0994	Machine gun, 40 mm, MK14	11	8	
E1065	Mortar, 60 mm, M224	9	0	
E1090	Mortar, infantry, 81 mm, M252 8	0		
H2045	Antenna, RC292	12	15	
H2442	Telephone set, TA-1/PT	44	12	
H2443	Telephone set, TA-312/PT	35	36	

FY29 TO&E provides a future look into potential organization and equipment that are projected to be in service ten years from now. The organization structure and size were determined using a Capability Level 2. The capability Level 2 projects unit strength of 90%, which is a common planning level for the operational forces. At Capability Level 2, the unit can accomplish all the activities assessed in the current version of the IPOWER tool.

The MCRP 3-10A was leveraged to help guide the activities used in the scenarios and to a lesser extent, expand on characteristics of the force structure *(Marine Corps Combat Development and Integration [MCCDI] 2019a).* Additional publications, such as the MCTP 3-01A, MCRP 12-10B.1, and MCTP 3-10F were also used to guide the development of the scenarios and expand the understanding of the study to portray the usage of the simulation better (MCCDI 2019b, 2016, 2019c).

The MCWP 3-10A.2 describes an extensive list of infantry operations; this study focuses on offensive operations for the scenarios but includes other operations to show the depth of activities utilized for a natural progression of activities (MCCDI 2019a). While this research study cannot evaluate all infantry operations, the operations the team selected to analyze within IPOWER describe a wide range of expeditionary operations.

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III. ARCHITECTURE DEFINITIONS AND SCENARIO DEFINITIONS

A. PROBLEM FRAMING

1. Mission Analysis Approach

The research team used a mission analysis approach adapted from the Marine Corps Planning Process (MCPP). MCPP is a deliberate planning process using a six-step process to support decision making (MCCDI 2018a). The adapted approach focuses on the entire system starting with doctrine, which drives course of action (COA) development and the equipment usage, to orders development and ultimately leading to mission execution with the algorithms that IPOWER uses to model the energy usage. After IPOWER performs its simulation, the analysis is conducted. Figure 5 depicts the flow of information as the mission analysis funnels data collected through current field manuals, task lists, and technology studies. The analysis combines the information within the documents to provide specific missions and activities useful to the stakeholder.

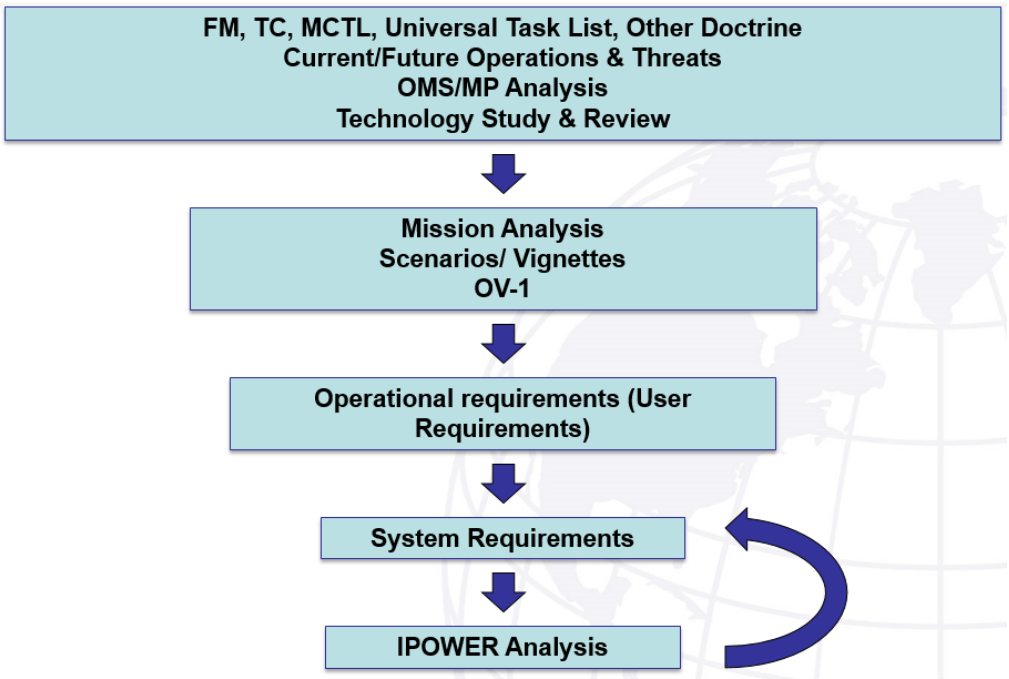

Figure 5: Mission Analysis Approach

The team created scenarios and vignettes from the IPOWER Operational view diagram (OV-1) to describe the mission. From the scenarios, the research team developed operational requirements decomposed the requirements into system requirements. The team further refined these requirements through analysis of the IPOWER simulation.

2. Input/Output Diagram

The input/output diagram depicts key parameters entering and exiting the system. Viewing the inputs and outputs of the system early in the analysis of IPOWER was critical in forming proper relationships and mission profiles. These factors describe the systems in a black box allowing a better understanding of the important information entering and exiting, which allowed the team to focus on key requirements. To provide the black box analysis, the team characterized the controlled inputs and intended outputs. In the process, however, the team discovered that there are uncontrolled inputs and by-products that exit which have to be considered for improved analysis. Figure 6 describes these inputs and outputs for the IPOWER System.

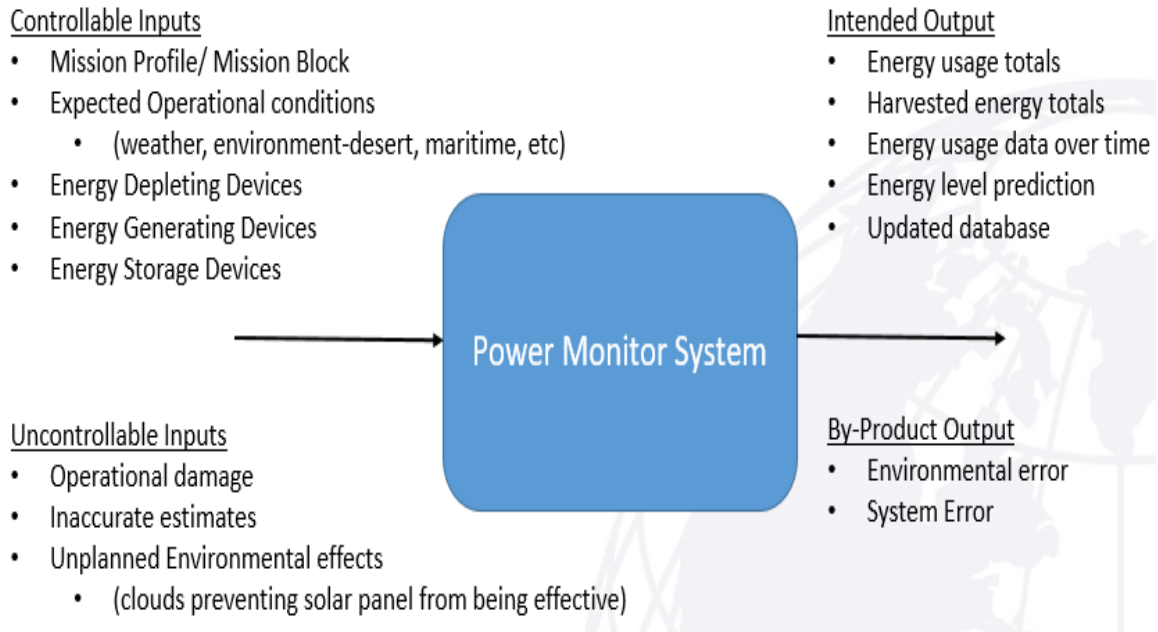

Figure 6: Input/Output Diagram

Controllable inputs are the primary source of data used in the system to derive the output. For this project, the controlled key inputs are the pre-established mission profiles and blocks. This input would also include the expected operational conditions such as weather forecasts and the actual environment (desert, maritime, tropical). Key inputs that can refine the equipment include identifying which equipment is depleting energy, generating energy, or storing energy.

Intended outputs are the subject of the diagram. IPOWER intends to determine usage statistics, monitor energy use, and predict future outcomes. The research team also expects to gain information to refine and validate the mission profiles and blocks. Ultimately, the results could also be used to build a robust database for continued system accuracy and refinement.

Uncontrolled inputs are inputs that we cannot control. Examples of uncontrolled inputs include when equipment is damaged during a mission, initial charge state is not accurate, or unplanned action is taken. Uncontrolled input will affect the overall outcome.

Unintended outputs account mostly for the errors from the environmental differences and model errors that IPOWER cannot forecast. Due to mission sensitivities, growing digital footprints, and increasing power usage and capability, estimates will continue to vary, and the uncontrolled inputs will input error into the system. Outputs focus on energy usage and system performance prediction.

3. Context Model

From the input/output diagram, where specific inputs are addressed, the research team can step back to see how IPOWER interacts with other systems. The context model in Figure 7 describes the interaction between these systems. The focus is the power monitor and control system, which is the IPOWER tool.

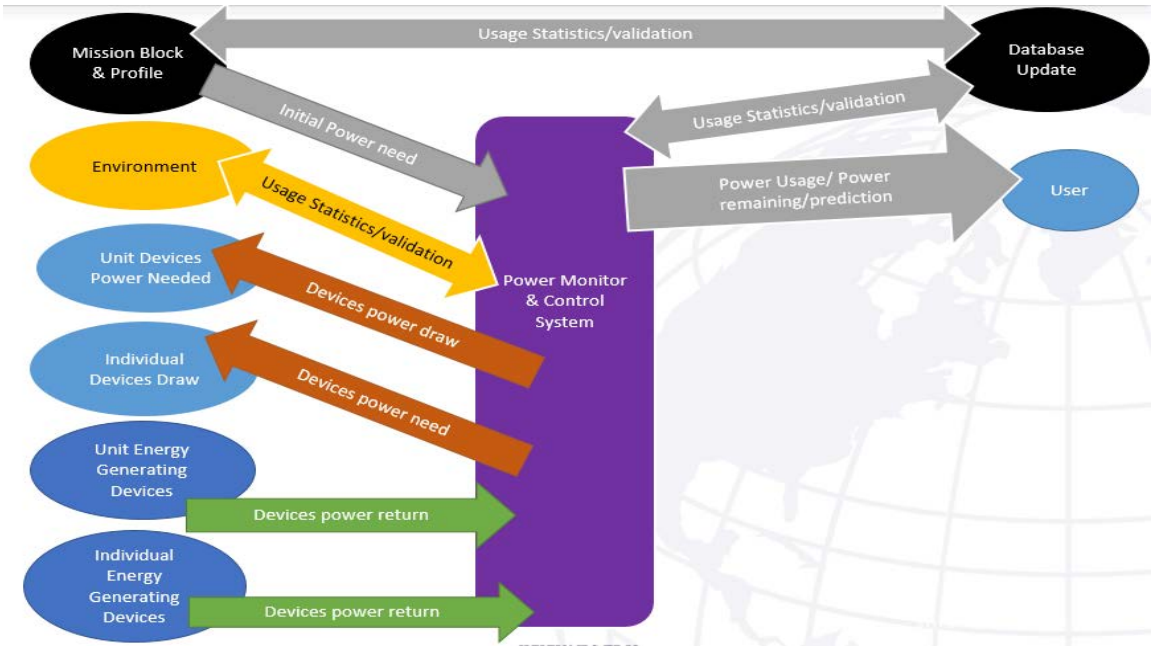

Figure 7: Context Model

Figure 7 shows how the baseline mission block and profile (in black) initializes the basic values for the power monitor and control system. The objective of the system is to account accurately for all energy-relevant mission variables (which include power depleting equipment, power generating equipment, and environmental impacts). Additional factors feed into the system by means of the environment, user, and individual equipment (those devices that consume, generate, and store). As the power control system feeds power and information to/from these devices, it will provide the user with critical information on power remaining and energy projections for the remainder of the mission.

Predicting a baseline configuration and describing real-time usage statistics defines the systems. IPOWER's mission blocks, profiles, and models are updated. In doing this, the predictive nature of the mission blocks and profiles can more accurately define equipment requirements.

4. Operational Concept

IPOWER is designed for both a mobile and desktop use. This operational concept describes the use in both new acquisition and requirements generation as well as an expected transition to real-time execution. Both situations allow the systems to manage and monitor power usage throughout the battlespace. As a predictive tool within the acquisition field, the tool can generate usage characteristics that will highlight needed values for power generation based on expected usage. The results will help generate requirements, which could be used in the development and procurement of new acquisitions. The top left corner of Figure 8 shows this aspect within the operational view of IPOWER.

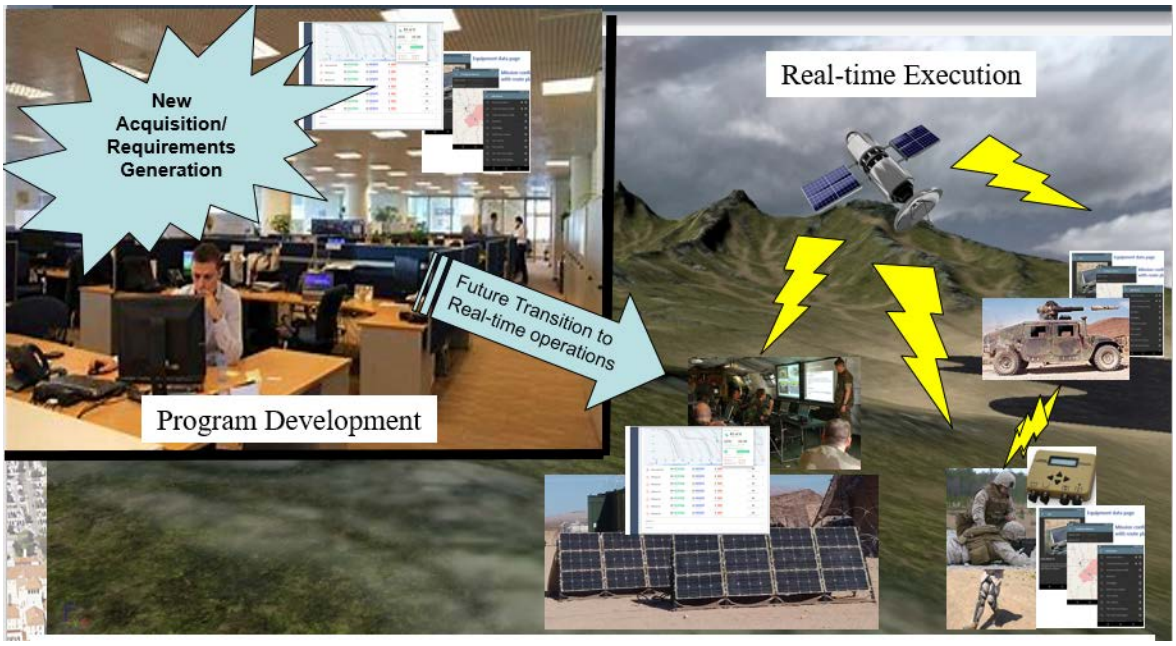

Figure 8: OV-1: Operational Concept for IPOWER Employment

Real-time execution is a future capability that needs to be considered through the development of the tool. Tying real-time execution into the operational concept, individual, as well as unit-level tracking, could account for power consumption and generation to predict energy need for the individual and unit executing each mission block. The data can be transmitted inside a network for real-time use in a command post environment, enabling quick updates allowing the warfighter to manage energy needs across the operational

environment. The ability to manage energy allows the warfighter to integrate a logistics solution. A power management update will also provide important actual data, which IPOWER could use to refine and improve the accuracy of the overall mission profile.

B. NEEDS ANALYSIS

A needs analysis was conducted to define primary stakeholder considerations for all life cycle stages of the IPOWER project. The stakeholders are people or groups of people who "have a vested interest, or personal stake, in the problem or its eventual solution" (Kwinn 2015). The goal of stakeholder analysis is to "determine [the] needs, wants, and desires" of the "people who are relevant to the problem" (Kwinn 2015).

The work on this project did not include any human subjects. The team defined the user needs based on a literature review and interactions with advisors. The assumed primitive needs were refined into mature needs to support decomposition to the system requirements. The stakeholder needs and prioritization found in Appendix A shows the assumed needs from the top six stakeholders.

C. FUNCTIONAL ANALYSIS

This study decomposed IPOWER into eight primary functions, as shown in Figure 9. Three of these primary functions are further decomposed based on their impact on the systems: Save Data, Accept User Input, and Display Results. These three primary functions are further decomposed to highlight critical functions necessary for IPOWER to successfully operate.

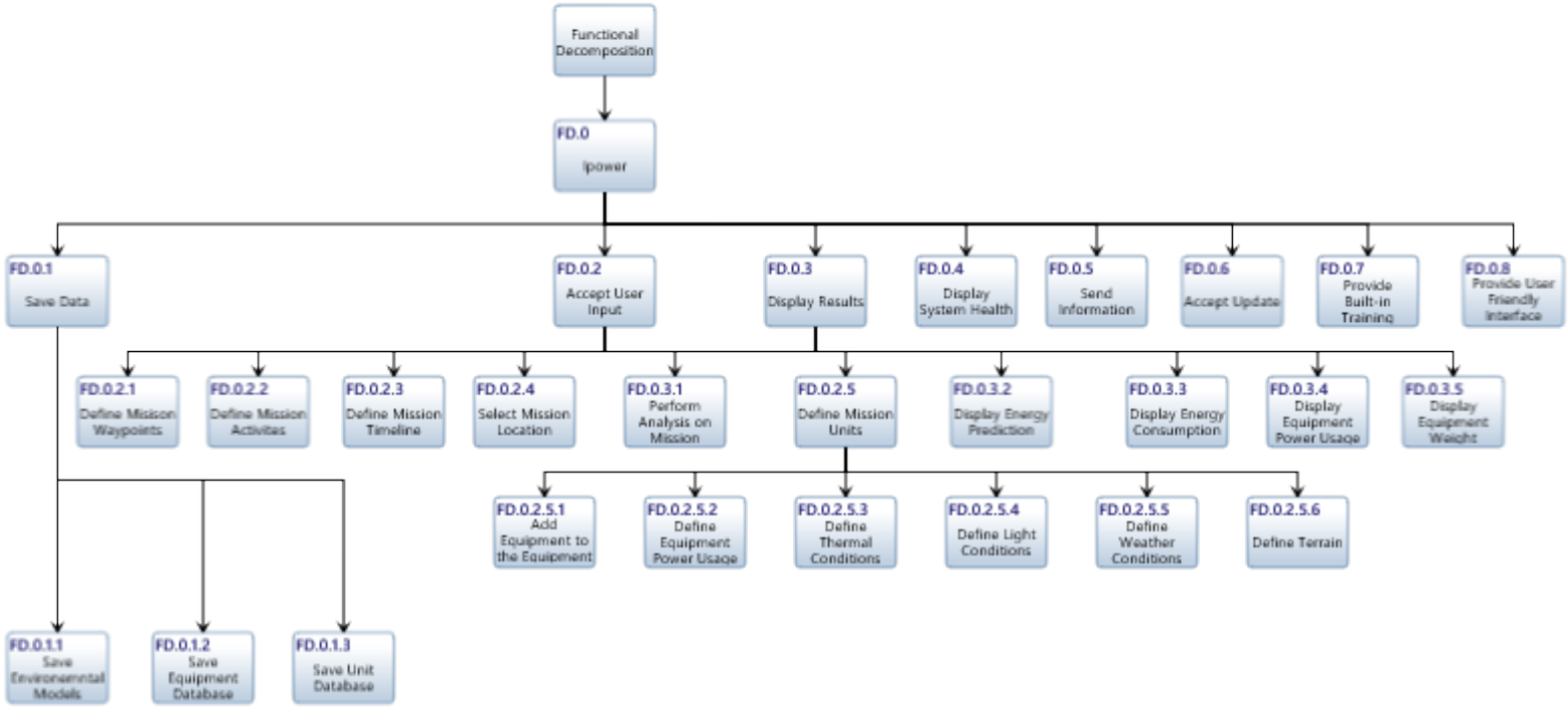

Figure 9: Functional Decomposition

The Save Data function focuses on saving data for the environmental database, equipment database, and the personnel database. Each of these three data sets serve as a library of specific data used to model the mission elements, constraints, and resources. Without a database, users would need to input each field of each parameter, which would render the system ineffective.

The Accept User Input function allows the user to model specific scenarios based on their needs. The user interface allows the end-user to select characteristics and modify systems parameters necessary to provide a useful simulation that is actable. Such characteristics include waypoints, equipment variations, and mission activities. A customizable user interface function allows the user to interact fully with the system, improving capability. Table 2 presents the eight high-level functions decomposed to level three functions.

Table 2: IPOWER Functional Decomposition

IPOWER Functional Decomposition
1 Save Data
1.1 Save Environmental Models
1.2 Save Equipment Database
1.3 Save Units Database
2 Accept User Input
2.1 Define Mission Waypoints
2.2 Define Mission Activities
2.3 Define Mission Timeline
2.4 Select Mission Location
2.5 Define Mission Units
2.5.1 Add Equipment to the Equipment Database
2.5.2 Define Equipment Power Usage
2.5.3 Define Thermal Conditions
2.5.4 Define Light Conditions
2.5.5 Define Weather Conditions
2.5.6 Define Terrain
3 Display Results
3.1 Perform Analysis on Mission
3.2 Display Energy Prediction
3.3 Display Energy Consumptions
3.4 Display Equipment Power Usage
3.5 Display Equipment Weight
3.6 Display Recommended Equipment for Mission
4 Display System Health
5 Send Information
6 Accept Update
7 Provide Build-in Training
8 Provide User Friendly Interface Design

D. REQUIREMENTS ANALYSIS

The research team conducted an operational requirements analysis to ensure all needs trace to IPOWER system requirements. First, needs were characterized as either IPOWER system needs or other needs. The IPOWER development team only reviewed IPOWER needs when developing requirements. The team performed a traceability analysis to ensure that all parent requirements (needs) had one or more child requirements (system requirements). Dynamic Object Oriented Requirements System (DOORS) tool manages the requirements. Figure 10 shows the IPOWER structure diagram built to organize requirements. Appendix B lists the IPOWER requirements and operational requirements traceability to needs.

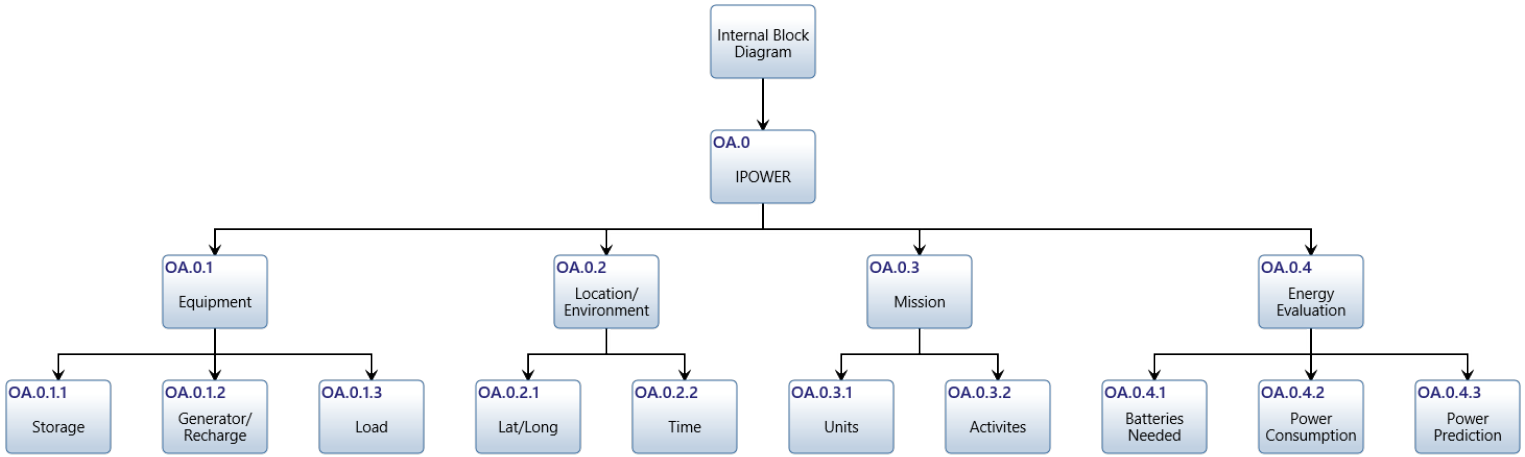

Figure 10: IPOWER Structure Diagram

E. MISSION ANALYSIS

When developing the needs, functions, and structure of IPOWER it is important to consider the missions that the tool is expected to analyze. New technologies demand more energy and create the logistics burden to resupply energy. The systems that have energy self-sufficiency will operate longer in missions with less dependency on supporting forces. The Expeditionary Energy, Water, and Waste (E2W2) OV-1 diagram CONOPS in Figure 11 shows that energy demand affects every warfighting function (E2O 2019). The focus of this project is infantry operations shown in the lower right corner of E2W2 OV-1 diagram.

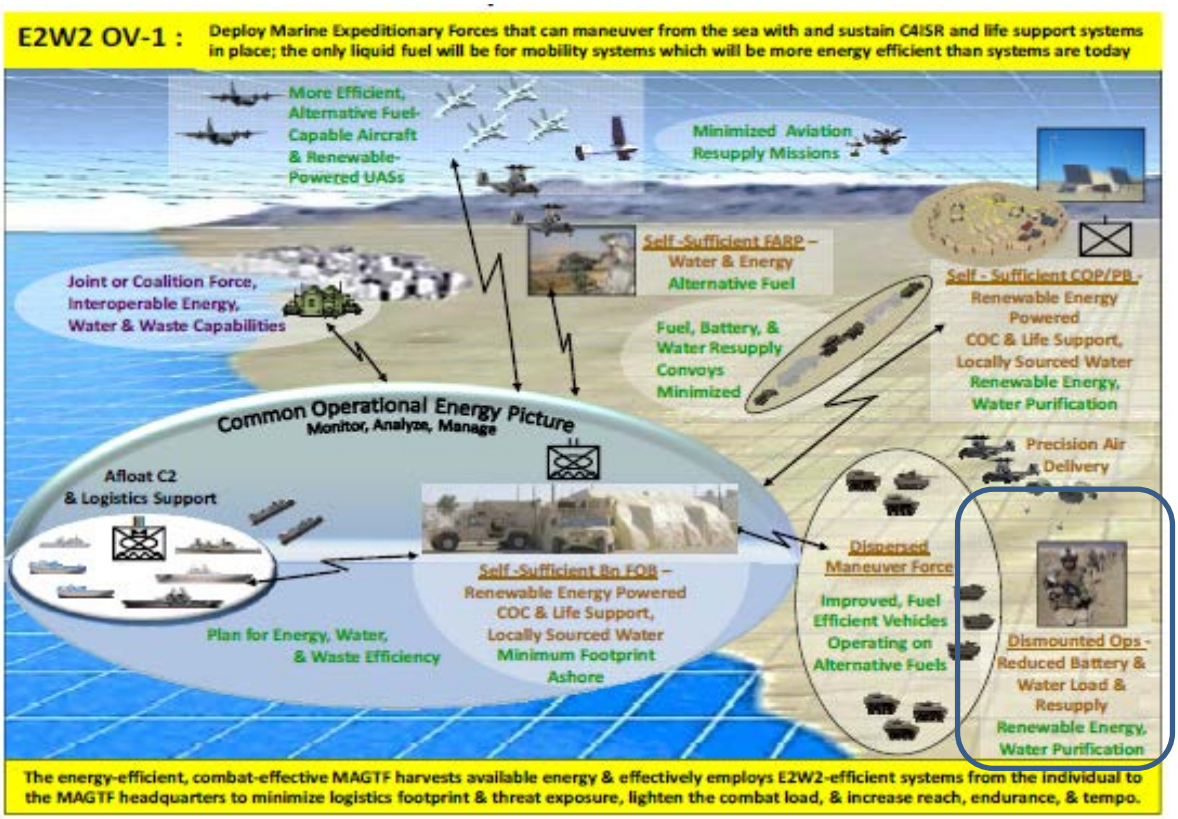

Figure 11: E2W2 OV-1. Source: E2O (2019).

1. Mission Development in IPOWER

To build an example of mission data that will be used as input to IPOWER, the project team selected the Conduct Penetration form of maneuver. Offensive maneuvers are the basic techniques a force conducting offensive operations uses to gain an advantage over the enemy.

The MAGTF Commander chooses the form of maneuver (i.e., frontal attack, flanking attack, envelopment, turning movement, infiltration, or penetration), that fully exploits all the dimensions of the battlespace and best accomplish his or her mission. The Conduct Penetration maneuver is an attack. A penetration is a form of maneuver where the attacking force seeks to rupture enemy defenses on a narrow front to disrupt the defensive system (MCCDI 2019b). Table 3 shows the Measures of Effectiveness (MOE) that a commander uses to assess the success of the action/ task execution.

Table 3: Measures of Effectiveness

M1	Percent	Of identified decisive points and enemy geography centers of gravity within the OA, under friendly control at operational end state.
M2	Number	Operations delayed/canceled due to enemy attack during execution.
M3	Percent	Of operations delayed/canceled due to enemy attacks during execution.
M4	Percent	Of critical terrain features under control of friendly forces.
M5	Percent	Of forces operating with areas under control of friendly ground forces.
M6	Y/N	Did assault meet the stated objective?
M7	Time	To conduct assault planning.
M8	Percent	Of execution checklist completed on time.
M9	Casualties	To friendly forces due to enemy actions.

2. Ground Combat Unit—Platoon

For this research project, the research team limited the unit size to the platoon level. A second or first lieutenant commands a platoon. A platoon consists of three rifle squads. A sergeant typically leads a rifle squad, which is made up of three identical fire teams. The fire team is the basis of the ground combat element (GCE) and consists of four Marines, which include the following.

- The team leader, corporal (E-4) (M4/M16 with attached M203)
- One rifleman, a rank of Pvt/E-1 (M4/M16)
- One assistant automatic rifleman, a rank of PFC/E-2 (M4/M16)
- One automatic rifleman, a rank of LCpl/E-3 (M27 Infantry Automatic Rifle or M249 light machine gun)

Figure 12 depicts the blue force (BLUFOR) platoon organization.

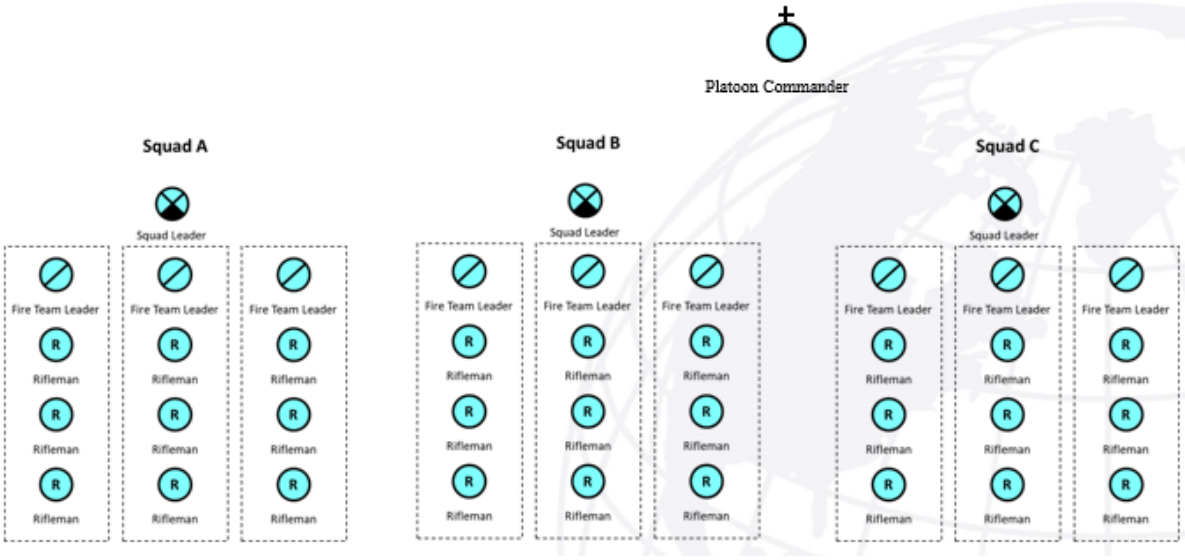

Figure 12: USMC Platoon Description

An opposing force (OPFOR) is a military unit that represents an enemy, usually for training purposes in war game scenarios. For the vignettes presented in next slides, the OPFOR force was selected to be of similar strength as the BLUFOR. Figure 13 shows the structure of the OPFOR force.

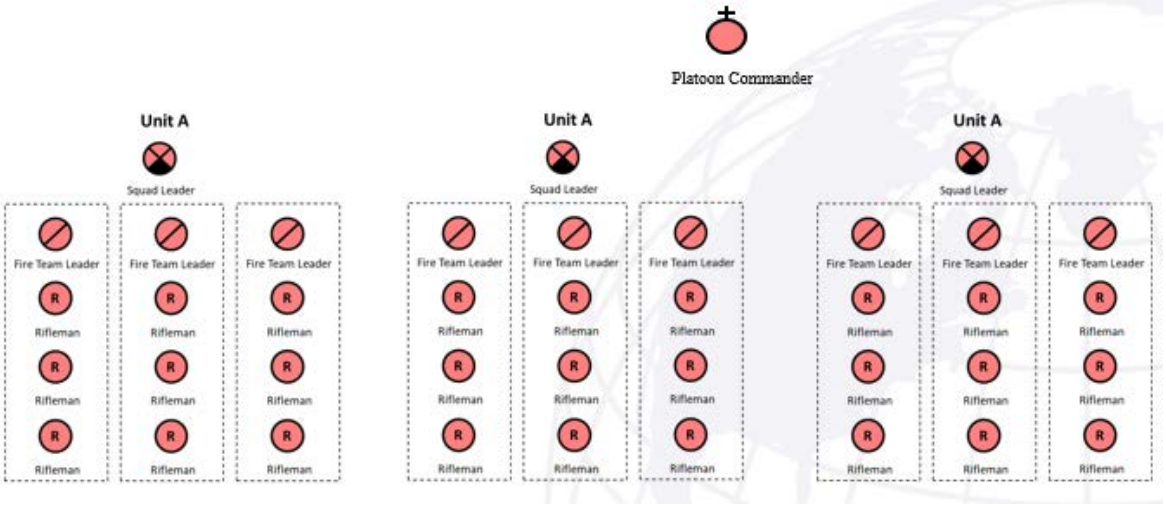

Figure 13: OPFOR Platoon Organization

3. Vignette 1: Conduct Penetration, Action 1 &2—Planning & Collect Area Intelligence

The project team created a vignette to describe a mission block. A vignette is brief account of a mission to help define a model. To build illustration for the vignette, the project team used an interactive map that shows latitude and longitude to collect location information for input in IPOWER. The Conduct Penetration Operation consists of three actions.

As shown in Figure 14, Action 1 involves the activities of mission planning and preparations for the mission at patrol base. During Action 1, the majority of Marines remain in their patrol base. Action 2 is Collect Area Intelligence. MCDP 1–0 defines Intelligence as a "directed effort to obtain detailed information on the terrain or enemy activity within a prescribed area" (MCCDI 2019). Action 2 starts when two fire teams arrive at Start Line 1 (denoted in Figure 14 as SL1). The BLUFOR moves to Checkpoint 1 (denoted as CK1 in Figure 14), where it separates into to two groups. The BLUFOR takes two routes, depicted by blue arrows, towards a Named Area of Interest (NAI). NAIs represent spots where a commander can collect assets and can best serve a commander's decisions. Teams collect intelligence on enemy forces and return following the same route to the Start Line 1.

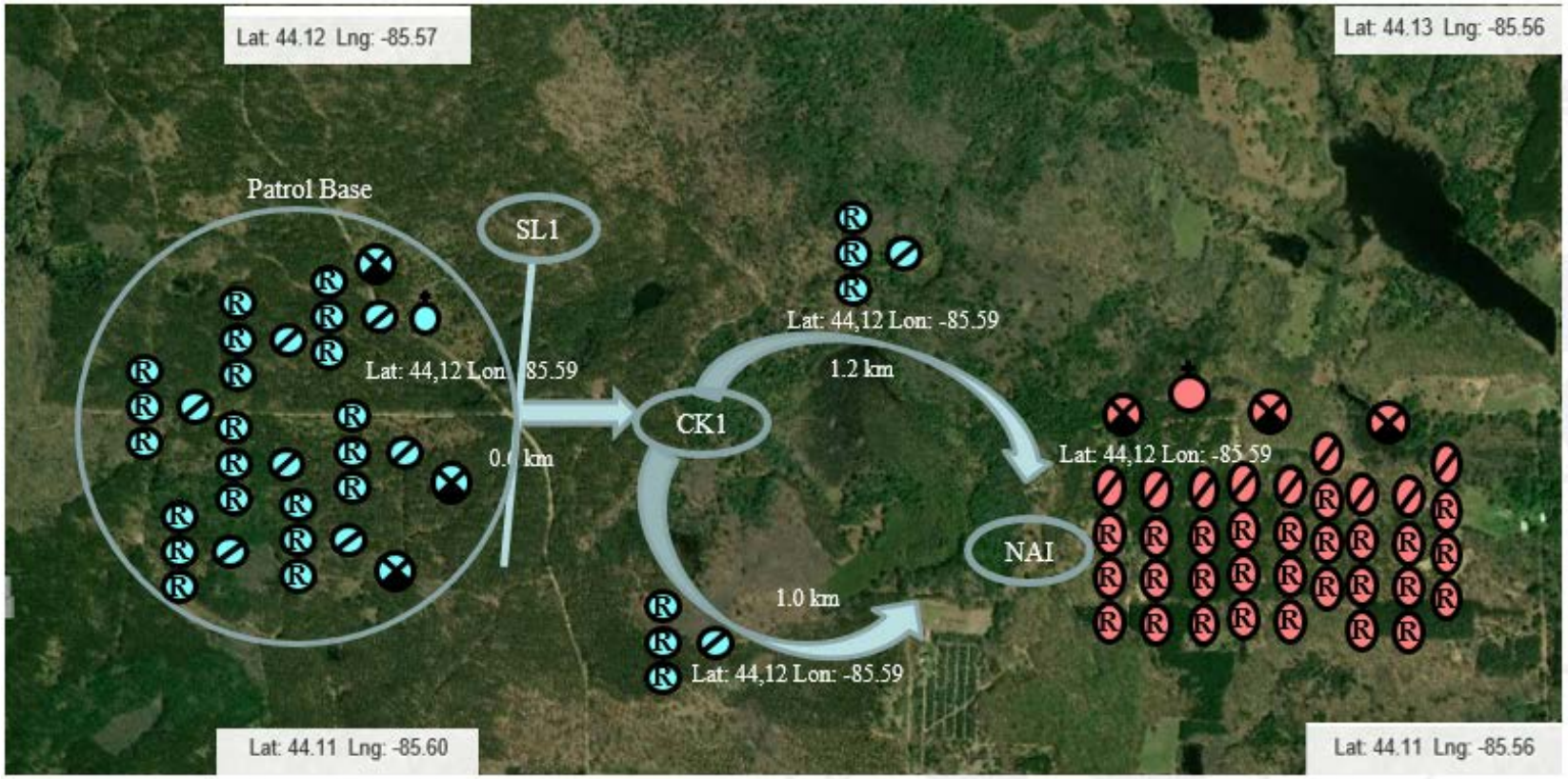

Figure 14: Scenario 1, Action 1 and Action 2

4. Vignette 1: Conduct Penetration, Action 3—Attack

Action 3 consists of three tasks. Figure 15 shows the start of Action 3 and Task 1 when BLUFOR is at Start Line 1. The BLUFOR moves to Checkpoint 1, where it separates into two groups. The group consisting of two fire teams moves to Checkpoint 3 and establishes support-by-fire position. The two fire teams will suppress OPFOR from a defensive position. The remaining BLUFOR moves to Checkpoint 2, which is its attack position.

Task 2 initiates when BLUFOR Marines are at Checkpoint 2 and Checkpoint 3 locations and the battle starts. The BLUFOR from Checkpoint 2 attack the OPFOR to seize the objective. Checkpoint 3 provides support fires to suppress the enemy around the objective. The dashed yellow and red lines show the Checkpoint 4 sector of fire.

Task 3: OPFOR retreats. Checkpoint 3 forces shift fire (depicted as yellow sectors to red sectors of fire) towards Enemy Line 2. BLUFOR at Checkpoint 2 clears the objective until reaching the Enemy Line 2. The BLUFOR, located at Checkpoint 3, cease-fires and clears the objective at Enemy Line 1.

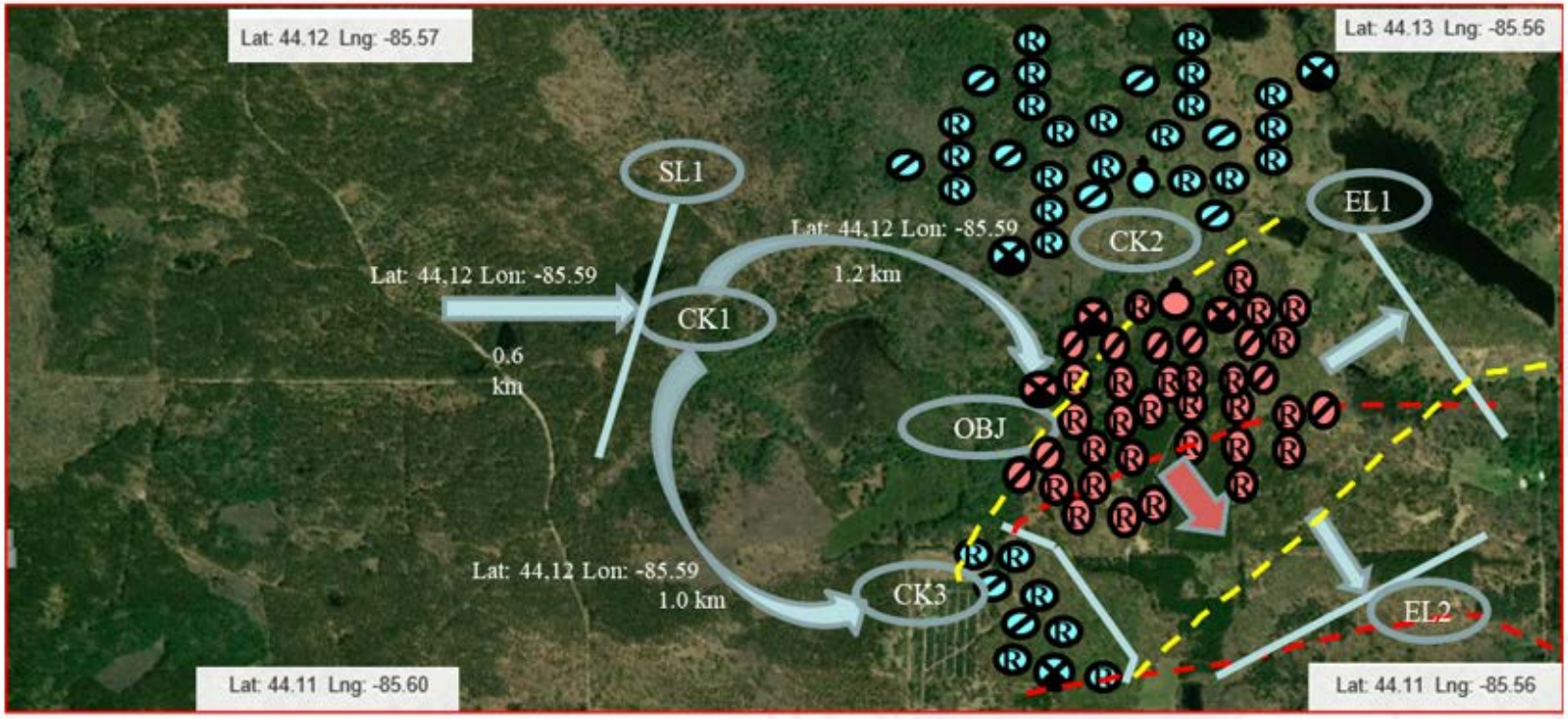

Figure 15: Scenario 1 Action 3

5. Preparing Data for Input to IPOWER

Table 4 summarizes the actions described in vignette Conduct Penetration. The vignette helps understand the mission actions and tasks as well as Marine involvement in the tasks. In IPOWER, activities drive equipment usages as it relates to power consumption. The mission was strategically selected to present actions that require a different number of marines to execute each action. In addition, the start time of the mission was selected to be 1500 so that the mission would start at night and end in daylight to maximize utilization of equipment.

The IPOWER tool uses the latitude and longitude data to determine the weather conditions from the weather models. The project team created an excel file to capture data, which includes action and task description, light, weather, temperature, and terrain conditions.

Table 4: IPOWER Inputs

MCT 1.6.2.6 Conduct Penetration						
Action/ iPower Block	Action	Plan Mission at Patrol base	Collect Area Intelligence	Attack		
	Time	9:00 PM	2:00 AM	4:30AM		
	Duration	5	3	7		
	Phase	1	1	2		
	iPower	Mission	Collect Intelligence	Attack		
	Begins	All units are at patrol base	Two fire units are at start line SL1	Troops are at start line SL1		
	Ends	leave the patrol base	Two fire units return to start line SL1	Troops are at end lines EL1 and EL2		
Task	Time (DTG)	9 PM - 2:00:00	2:00 - 5:00 AM	5:00 -7:00 AM	7:00 - 9:00 AM	9:00 - 11:00 AM
	Task	N/A	Collect Intelligence	Get to Position for	Attack	Clear Objective
	Begins	Same as Action	Same as Action	Troops are at start line	Troops are at CK2 and CK3 locations	Enemy fire Ceased
	Ends	Same as Action	Same as Action	Time is 5:30	Enemy fire ceased	Troops are at EL1 and
Environment	Light	Dark	Dark	Dark	Light	Light
	Temperatu	<EnterTempera	<EnterTemperature>	<EnterTemperature>	<EnterTemperature>	<EnterTemperature>
	Weather	<Enter Weather Conditions>	<Enter Weather Conditions>	<Enter Weather Conditions>	<Enter Weather Conditions>	<Enter Weather Conditions>
	Terrain	<Enter Terrain Conditions>	<Enter Terrain Conditions>	<Enter Terrain Conditions>	<Enter Terrain Conditions>	<Enter Terrain Conditions>
	Location	Lat: 44,12 Lon: - 85.59	Lat: 44,12 Lon: - 85.59	and Lat: 44,12 Lon: - 85.59	and Lat: 44,12 Lon: 85.59	and Lat: 44,12 Lon: - 85.59
Personnel		Unit/ Soldier State	Unit/ Soldier State	Unit/ Soldier State	Unit/ Soldier State	Unit/ Soldier State
Unit	Platoon	Inactive	Inactive	Active	Active	Active
	Squad A	Inactive	Inactive	Active	Active	Active
	Squad B	Inactive	Inactive	Active	Active	Active
	Squad C	Inactive	Inactive	Active	Active	Active
Soldier	Squad	Inactive	Inactive	Active	Active	Active
	Team	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active
	Team	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active
	Hilleman	Inactive	Active	Active	Active	Active

To identify equipment used during the mission, the unit activity and Marine activity states (or modes) are identified within IPOWER for each task. Most equipment has only two activity states: on or off; however, other equipment may have several modes identified. The user enters the active or inactive state of the units and Marines into IPOWER and based on those inputs the tool will determine the equipment used during the task and rate of equipment power usage or power generation.

The research team developed a table based on the USMC TO&E that provides specific equipment characteristics. The table identifies the key information needed to characterize the equipment and input properly for use into IPOWER (MCCDI 2018b). Table 5 pulls the pertinent equipment list form the TO&E produced by the Marine Corps Total Force System (MCTFS) and captures the key information needed to properly populate the IPOWER database (MCCDI 2018b). Equipment details include the battery used, equipment weight and activity usage (or duty cycle).

Table 5: Table of Equipment Details

Individual Marine Power Requirements								Mission			
Equipment	Company share	Platoon share	Battery	Battery Weight (oz)	Battery Qty	Equipment Weight (lb)	Overall Weight (lb)	Activity Full power	Activity 50% duty cycle	Activity Standby	Run Time (hr)
AN/ PAS-13Gv1	8	2	AA	0.88	4	4.5	1.85	12		5.5	
AN/ PEQ-16B	182	46	DI-123A	0.56	2	0.62	0.62				1.25
AN/PAS-13D(V3) SIGHT,THERMAL	1	1	AA		4		1				14
AN/PAS-28 SIGHT,THERMAL	10	3	AA or BA5590		4		3.6				7
AN/PAS-29A SURVEILLANCE,THERMAL	1	1	123A		1		0.35				3
AN/PEQ-13 COMMON LASER RANGEFINDER	5	2									
AN/PEQ-15 ILLUMINATOR, INFRARED	8	2	123A		1		0.46875				
AN/PRC-117F(V)1C RADIO SET	2	1	two BA-5590, BA-390A/U, or BB-590 batteries	97.6	2	9.8	15.9				
AN/PRC-117G(v)2	13	4	two BA-5590 or BA-5390 or	23.2	2	16.7	2.9				
AN/PRC-148	1	1	BA-5123	var	1	1.85	var				
AN/PRC-150C RADIO SET	2	1	BB-2590B/or BB-390B/UU			10					
AN/PRC-152	34	9	4.0 amps at 10.8 VDC (≤ 43 W at 10.8 VDC)	var	var	2.6	2.6				
AN/PRC-153	94	24	Unique	var	var	1.24	1.24				
AN/PSC-13 D-DACT	1	1	Unique or AA								
AN/PSN-13(B) DAGR	6	2	AA	0.88	4	.94					14
AN/PVS-14	182	46	AA	0.88	1	0.775	0.78				50
AN/PVS-17C	8	2	AA	0.88	1	2.5	2.5				25
AN/PVS-31A VIEWER,NIGHT VISION	1	1	AA	0.88	1	1	1				8
AN/UDR-13 RADIAC Set	15	4	AA	0.88	4		0.59375				150
AN/VRC-103(v)2	0	0	one or two BA-5590,BB-390A/U, BB-2590, or BB-590 batteries		1 or 2	55	55	25 Amps single, 50 Amps Dual at 20 VDS			
AN/VRC-110 Radio Set	2	1				23	23				
AN/VRC-114(v)1	1	1									
BTC-70870-1 CHARGER,BATTERY	4	1									
CAMERA, DIGITAL CHEAP	51	13									
FLASHLIGHT - 14032	182	46									
Hand-held Flashlight	1	1	AA	0.88	var						
I-CUGR RANGE FINDER-TARGET -	13	4									
JBC-P dismounted Product	4	1									
KGV-72 ENCRYPTION-DECRYPTI	2	1	28v nominal	na	na	4		6W			
LA-22/U LASER,DIRECTIONAL A	9	3	123A		3	1					
METAL DETECTOR - CEIA CMD 2.00	9	3	Ni-MH (6000 mAh)		2.1kg	1.98kg					6
MIOX Water Purifier	1	1	AA	0.88							
N/PVS-24A NIGHT VISION DEVICE - A (replaces 17Bs)	36	9	123A		1	1.7	1.7				16
NH11 VIEWING SET, INFRARE -	5	2									

IV. MODELING AND SIMULATION

A. ARCHITECTURE

The architecture of IPOWER needs to integrate the operational aspect of the USMC with the simulation aspect of the algorithm. Based on the vignette, the project team formulated the mission data into actionable information. The mission thread model includes mission preparation, execution, and post mission activities. The user assigns power usage for each mission activity. The project team developed Figure 16 to establish a linkage between the terminology used for mission refinement and development and the IPOWER specific terminology used in development of IPOWER models. In Figure 16, the left side describes the mission domain where the decomposition of a mission into actions occurs. Personnel execute these actions using equipment. IPOWER correlates these steps to a similar structure in the IPOWER domain on the right. The actions relate to activities. Because IPOWER is equipment focused, IPOWER follows the equipment structure of the units and warfighter. Environmental factors affect the equipment and model needs to account for these factors. These related structures refine the overarching requirements of the system.

The actions of the mission domain need further decomposition to allow for a differentiation of power usage during different stages of the mission block. Mission development, which accounts for how activities are assigned and combined to create mission blocks, is critical to developing a useful model.

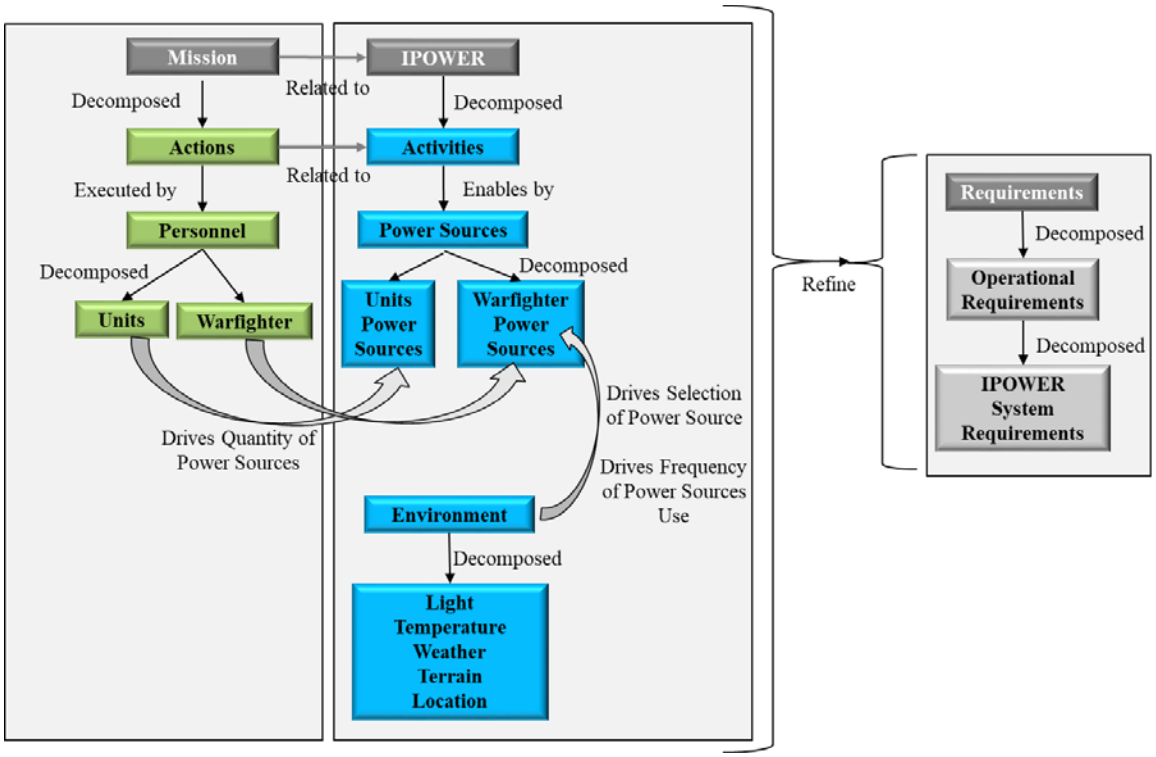

Figure 16: IPOWER/Operational Mission Comparison

The project team's assessment, using a USMC rifle company, helped determine how to characterize and assign tasks. The TO&E provides specific tasks for the unit selected. A rifle company is assigned four tasks from the MCTL (MCCDI 2018b). Figure 17 shows these tasks along the top row as 1.6.1, 1.6.4, 1.12.1, 1.14.

In the MCTL, tasks are further decomposed as shown for the first "Conduct Attack" down two levels (MCCDI 2019c). The study team determined that the tasks at the top level were too broad (low detail, high variability) and the tasks on the bottom level are too specific (high detail, low variability) to represent activities meaningfully in IPOWER. The middle tier may provide enough differentiation between activities to be useful in the IPOWER analysis while not creating an unmanageable database. The middle tier does provide a sufficient level of detail while maintaining sufficient variability. Allowing a unit to add specific details within this middle tier provides detail to lower-level activities that are necessary to establish specific characteristics of an activity.

This study uses the MCTL as a primary task and then allows the user group to develop one more tier, which may be used as a standard operating procedure (SOP) or similar among the user groups. Nomenclature is important, and the use of MCTs helps clarify activities across the USMC. These tasks mean specific things in a mission order. A multi-day mission is a combination of MCTs and further refines unit activities.

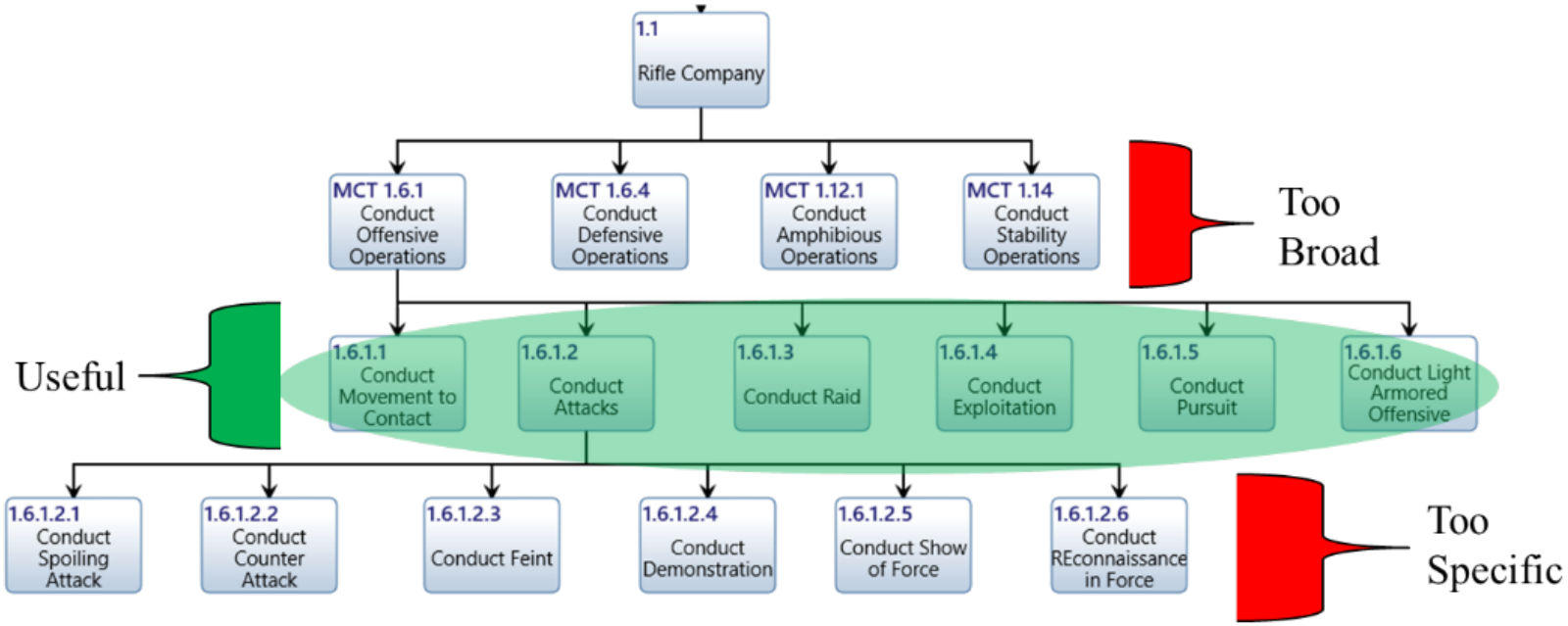

Figure 17: Task Decomposition of an Operational Rifle Company

In Figure 18, an example mission is broken down to demonstrate this important step. The example follows a series of actions which themselves break down into several activities. In each activity, the use of the equipment and the ability to charge batteries affects the overall performance modeling. These activities and the ability for equipment to have unique characteristics are critical for the proper execution of the IPOWER simulation.

The example of an infantry unit's task decomposition shows how the MCTs align with a mission. The project team assumed that a typical mission would start from a defensive stance. In the MCTL, "conduct defensive operation" breaks down into several tier two tasks; of those tasks, one is called, "position defense." In the position defense, the Marines can conduct other activities. These other activities would be user-specific and based on a unit's SOP. This example outlines several possibilities and highlights other possibilities a user may use for "power charging events."

When a commander gives an order, the mission transitions through several tasks. Each task has related activities. If IPOWER keeps tasks at the tier 1 level, the mission transitions through many "Conduct Offensive Operations," which in reality may have different energy needs that are lost lack of detail. The repetition of activities at the tier 1 level demonstrates why the MCTL tier 1 tasks are too broad. Most missions end back in some sort of defensive position. The two colors in Figure 18 show how two mission blocks may be stacked.

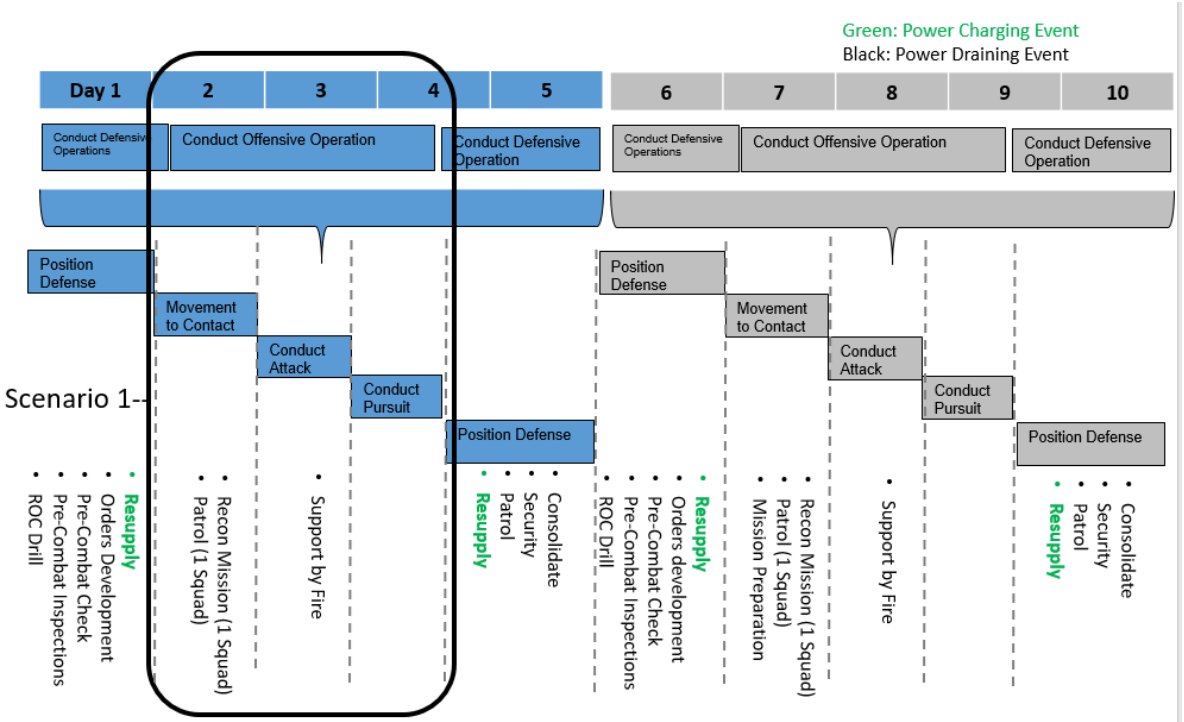

Figure 18: Mission Build-up Example

The project team describes the architecture of IPOWER in several typical DODAF views. Figure 19 presents two domains and the relationship between them. The two domains are the operational domain and the IPOWER domain. The USMC doctrine documents define operational needs and used by the project team to develop mission scenarios. From the scenarios, the project team defines mission elements and mission environment. The mission elements are allocated to resources (personnel and equipment) that enable task execution. The mission is represented by system functional flow diagram (OV-5b/6c). The OV-5b/6c and the operational requirements guide the formation of system requirements. The operational and power domains complement each other to provide the solution space.

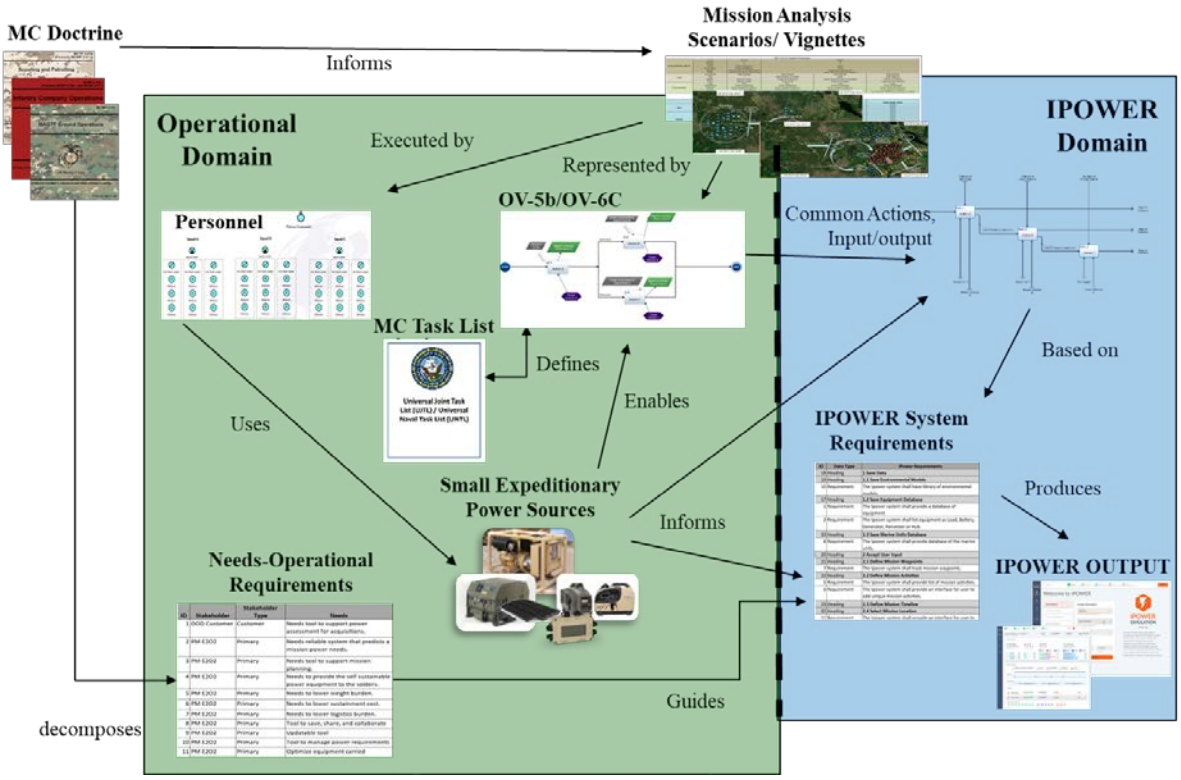

Figure 19: Project Relationships

The personnel groups are categorized into two groups: the unit and the individual warfighter as seen in Figure 20. Both groups can utilize different equipment on the battlefield. On the unit level, the commander assigns larger power devices, such as generators and solar panels, to units (not individuals). The project team limited the scope of the research to missions up to platoon level. Future developments of IPOWER may include a company-level and higher organization. Further decomposition identifies a diverse organization between the unit echelons (platoon, squad, etc.). In the typical USMC structure, a unit would breakdown beyond the squad level into fire-teams to create a basic unit. On the individual soldier category, IPOWER identifies only a few key billets at this time. These three billets are the squad leader, [fire] team leader, and rifleman.

Equipment is a critical aspect of IPOWER as the equipment power usage is the focus of the system. Figure 21 shows how the program uses power devices. In the IPOWER tool, individual soldiers do not swap or exchange equipment from each other. Because of this, the ‘Shared Assets’ are included to account for equipment used by multiple soldiers.

IPOWER separates shared assets (generators, battery chargers, etc.) from the soldier power units (loads, batteries, harvesters, etc.) based on who can use these items.

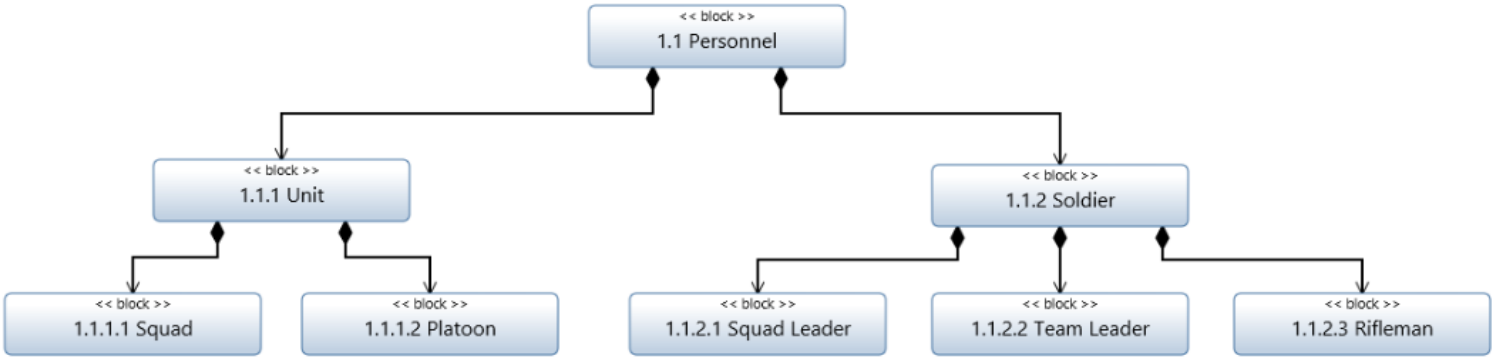

Figure 20: Mission Assets Personnel

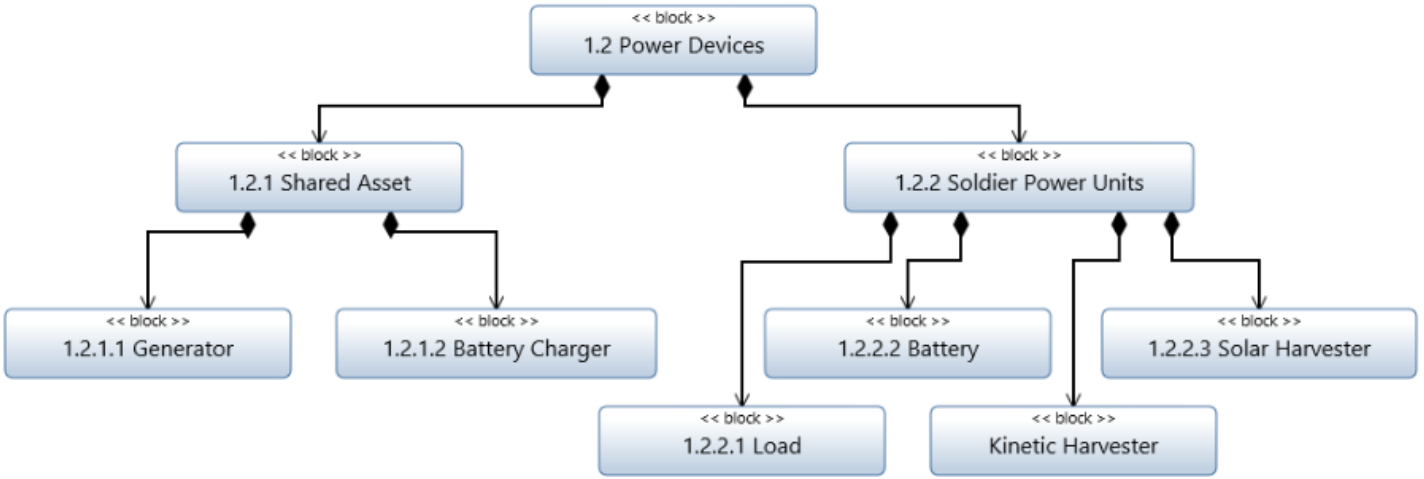

Figure 21: Mission Assets—Power Devices Level 2

As the power devices decompose from their tier 3 parent, individual equipment items are populated. Figure 22 adds the growth of equipment. This equipment grew based on expected equipment in a given platoon based on the TO&E. As the TO&E changes through each planning year and acquisition cycle, the equipment manager may add or replace equipment. Understanding the equipment decomposition allows IPOWER to accurately plan for the type of equipment used within the elements of the warfighter.

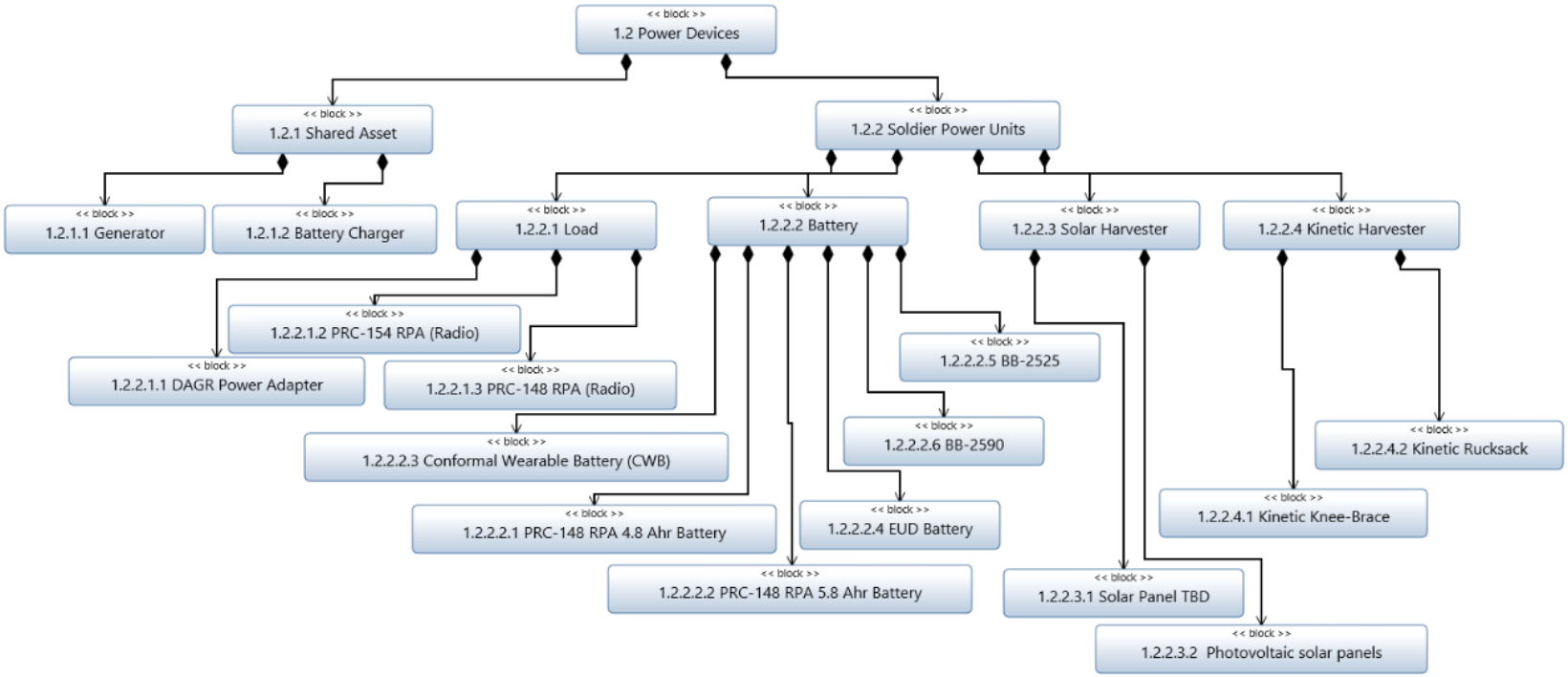

Figure 22: Mission Assets—Power Devices Level 3

The IPOWER architecture connects the personnel structure and the equipment structure to formulate the equipment usage at a basic level. Without knowing the personnel involved and the equipment these personnel are utilizing, IPOWER would not be able to simulate the equipment usage properly. Equipment usage within the scenarios and OV-5b/6c view formulate the actual usage of equipment in the mission blocks and scenarios. Figure 19 describes these relationships. At this point, the data transfers from the operation domain to the IPOWER domain allowing IPOWER to analyze the data with algorithms to calculate the desired information output.

B. IPOWER SOFTWARE LIMITATIONS

Since IPOWER is an ongoing development effort, several software limitations exist for creating models at this time. This section identifies those limitations in an effort to facilitate tool improvements. Table 6 and Appendix C list some of the key software limitations on the mission analysis presented in the previous section. Some of the key limitations relate to equipment usage, parallel activities, environmental factors, and power source assumptions.

IPOWER assumes equipment usage remains constant between all personnel. This is a limitation because a radio operator may have a higher radio usage than a basic rifleman. If the consumption rate is assumed equal, this will lead to an inaccurate prediction.

In a platoon level activity, it is typical that lower echelons may operate independently. In the initial vignette, the mission described how a squad detached and provided a support by fire position separate from another squad. The current IPOWER version does not allow parallel operations. This is a significant limitation if the intent is to operate at higher levels. However, there are potential workarounds, which can mitigate this limitation. An example of a possible work around is to run the simulation at smaller units (squad verses a platoon). Managed at the lower level, the user can add the needed detail, but the user will need to recombine the IPOWER results to determine a platoon power need.

Weather and environmental factors do not appear to make any affect to the result. In the simulation development, no weather adjustments are possible and the location tab

pulls temperature averages. Understanding the current weather impacts may greatly affect equipment performance, for example, solar panels on a cloudy day.

The algorithm that produces the data begins with a battery at 100% capacity. The algorithm also accounts for a battery change when the battery is at 0% capacity. These values are not realistic in an austere environment. Typically, batteries would be replaced prior to 0% especially if a known critical activity is about to occur such as a planned attack.

While IPOWER is underdevelopment, software limitations will exist. The key configuration and architecture appear to be sufficient for continued analysis.

C. MODELING AND SIMULATION

The purpose for modeling and simulation is to stress specific factors in a way that identifies the usefulness of the IPOWER system in the tools planned area of operation. The OV-1 in Figure 8 identifies two primary areas of operation: in acquisition (capability improvement) and in fleet use (COA development). Additionally, the project team assessed that database accuracy is an area of weakness as data accuracy is critical in the application of predictive energy use. The three variations developed sought to stress these areas in a way that validated the tool as a source of useful and reliable information.

Based on the mission analysis, the project team built a baseline model in IPOWER that corresponded to the sequence of activities presented in Table 4. The modeling and simulation approach compares a baseline simulation mission block described above and compares this result to alternative simulations. In all deviations, the only device modified is the radio which is the largest power draw seen in the IPOWER tool. This scenario was developed to describe a generic penetration maneuver mission block from orders delivery through consolidation in a defensive position. Subsequently, the team built alternative variations to support system analysis.

Variation 1 looks at data accuracy, which is a key limitation noticed within IPOWER. The project team estimated the duty cycle of equipment based on the scope of this project. If equipment usage is not correct, the IPOWER results will be inaccurate. Variation 1 highlights this point by increasing the usage of the AN/PRC-153 radio by 50%.

In this variation, the load to the radio is increased causing the associated battery to deplete rapidly and would need more power available throughout the mission. IPOWER results are expected to show an increased power consumption and increased battery requirement because of the increased equipment usage.

Variation 2 looks at the acquisition aspect of IPOWER where equipment requirement can be implemented within IPOWER to predict how a new requirement or change of equipment will affect a mission. Variation 2 increases the battery capacity of a radio battery to show how a new battery requirement (to have greater capacity) affects a mission block. The battery capacity is increased by 50%. The AN/PRC-153 radio has a 3.6 Ah battery rating in the baseline database. This variation modifies the battery to a 5.4 Ah power rating. This portrays a more efficient system or an improved battery capability. The project team expects the IPOWER results to indicate a consistent power consumption, but show a decreased battery requirement.

Variation 3 describes how IPOWER can affect mission planning and COA development. If activities accurately portray power consumption, war-gaming during mission planning can identify a COA and mission block that matches power needs prior to execution of the mission. As the COAs develop, activities may change or the length of activity may change. An example could be changing from a mechanized insert to an insert of personnel by helicopter. In this simulation, the equipment usage may be the same, but certain activities may be shortened or lengthened based on the chosen COA. IPOWER results are expected to show changing power consumption and battery needs as mission block timelines shift.

The project team can evaluate the four scenarios and compare the results. The analysis will show how the tool can describe the power usage and prediction across a wide spectrum of events and equipment.

D. SCENARIO DEVELOPMENT IN IPOWER

An IPOWER scenario is a buildup of several pieces of information taken from a group of databases. To create the simulation, the creates each database to account for the parameters of the activities, equipment, location, and personnel. Once created, the user runs

the simulation to produce the results. Figure 23 describes the steps used to create the necessary databases. The project team created the databases in the following order: activity database, battery database, load database, power manager database. Once the user creates the databases, the user can complete the remaining tasks (mission development, unit development, unit assignment) completing the process. While no particular order is required, some caution and awareness need to be understood because entries in one database will affect another database. In particular, this is true for the activities and loads databases where a load may use energy in different outputs during different activities. If the user does not enter the activity before applying usage parameters within the load database, the user will need to return to the load database and apply the appropriate data after entering the new activity. Being able to create scenarios within IPOWER is essential for gathering data for power usage.

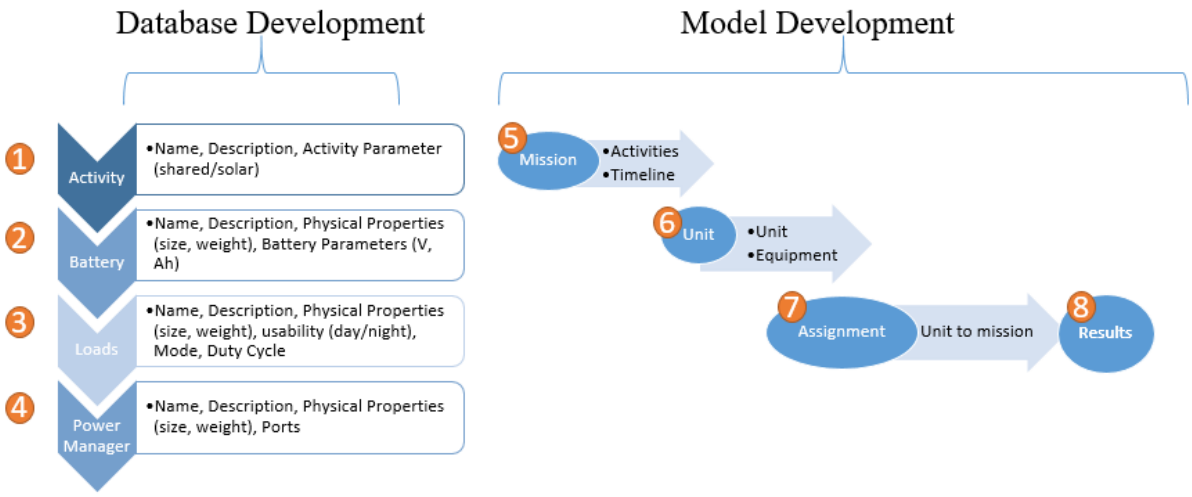

Figure 23: Block Diagram of Scenario Development in IPOWER

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V. ANALYSIS OF RESULTS

This analysis uses the IPOWER version 3.1.0 for the scenario development and analysis. Version 3.1.0 is the latest version of IPOWER as of July 2019. Some database construction used versions 3.0.0 and 3.0.3, and the database remained intact in the transfer to the latest version. The IPOWER program is a locally run web server using the Docker application. The project team downloaded the program files from the Defense Intelligence Information Enterprise website DI2E.net that hosts the IPOWER software.

Docker is an application that uses a container platform allowing increased development and operational integration. Once installed, IPOWER runs as a localhost in most internet browser programs. The Chrome web browser was used in the development and analysis, but several other applications appeared to work equally well.

The mission analysis created a mission block of six activities. The modeling and simulation plan used the six activities previously discussed over their respective timelines and equipment databases to produce results. The simulation results were analyzed and compared. This chapter presents the approach to the analysis of the baseline, analysis of each variation, and a summary of results.

A. BASELINE

The development of the baseline model takes into account the scenario described in Section III.E and data in Table 4. The scenario and data provide a simplified mission block to define a 24-hour mission from the development of mission orders through an attack and ends in a defensive position ready for further tasking. The baseline results from the IPOWER tool indicated that a platoon of 39 Marines with a standard complement of equipment would consume 3602.61Wh of power. This power consumption is spread over 375 batteries of various sizes equating 143.19 pounds of weight for the platoon. This power summary baseline is shown in Figure 24. Figure 24 also breaks down energy consumption, battery quantity, and weight per squad.

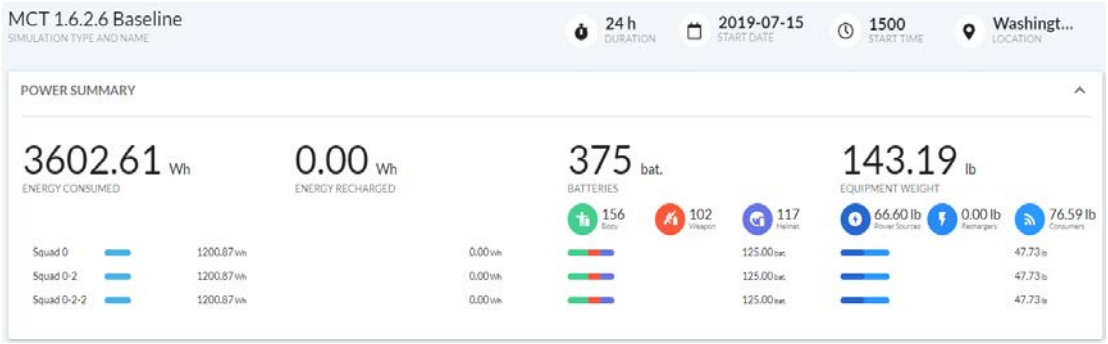

Figure 24: IPOWER Power Summary

Comparing the mission activities in Figure 25 with the batteries required in Figure 26 shows the correlation with an increased battery requirement across the mission blocks. This is an expected result. There is also an increasing energy consumption, seen in Figure 27, throughout the mission block as well. In a review of the simulation data, it was evident that certain pieces of equipment consumed a larger percent of the total energy consumption.

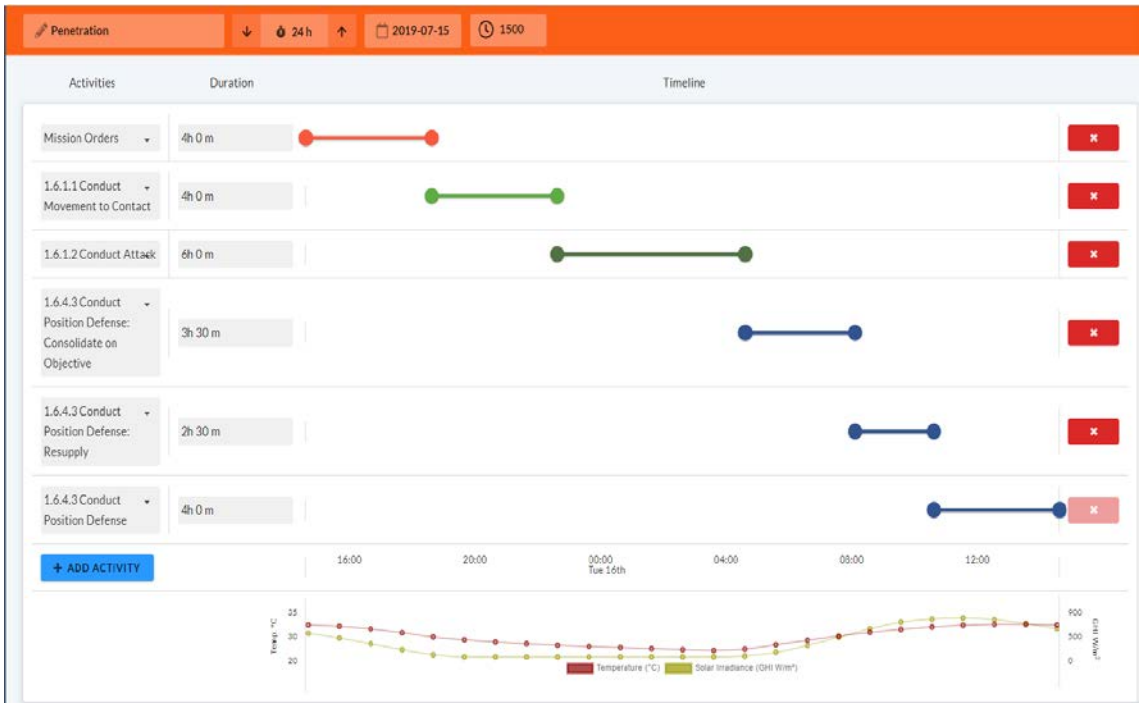

Figure 25: Baseline Mission Activities

In this scenario, the AN/PRC-153 radio was the leading consumer of power. This is an expected result based on the higher usage of the equipment across all activities.

Figure 26: Battery Requirements

Figure 27 shows a continuing rise in power consumption throughout the mission.

Figure 27: Power Consumption

In the analysis, the crux of the energy usage in this baseline simulation was the AN/PRC-153A radio. The radio is used in every activity to some extent and has a higher power consumption than all other equipment, even higher than a weapon mounted light, which has a low power draw and is only used in darkness.

Also of note is that IPOWER assumes all equipment is used from a full battery to a completely empty battery. In a real-world scenario, batteries may not start at 100% or be 100% efficient. This assumption will lead to an inaccurate prediction. A Marine will not typically continue using a piece of equipment until it is completely drained of power. At some point, the Marine will switch the battery before it reaches 0%. IPOWER does not account for an early replacement of a battery. These two examples are realistic expectations and are identified as a limitation for a field-usable system and for mission planning. These issues may be acceptable during use as an acquisition tool.

Equally important to note is that there is no delta in equipment usage between individual personnel. The assumption that a squad leader or radio operator uses a radio at a similar duty cycle as a basic rifleman may not be accurate. Without accounting for individual personnel usage rates, accurate prediction may not be accurate.

B. VARIATION 1: EQUIPMENT USAGE

Variation 1 makes a change to the equipment usage rate. In this variation, the radio duty cycle parameter transmit is increased by 50% in all activities equally. This portrays an increased usage of the radio. In Variation 1, the load to the radio would increase and deplete the associated battery more quickly and would need more power available throughout the mission. To portray the increase in usage, the duty cycle for the AN/PRC-153 radio is modified to the values found in Figure 28.

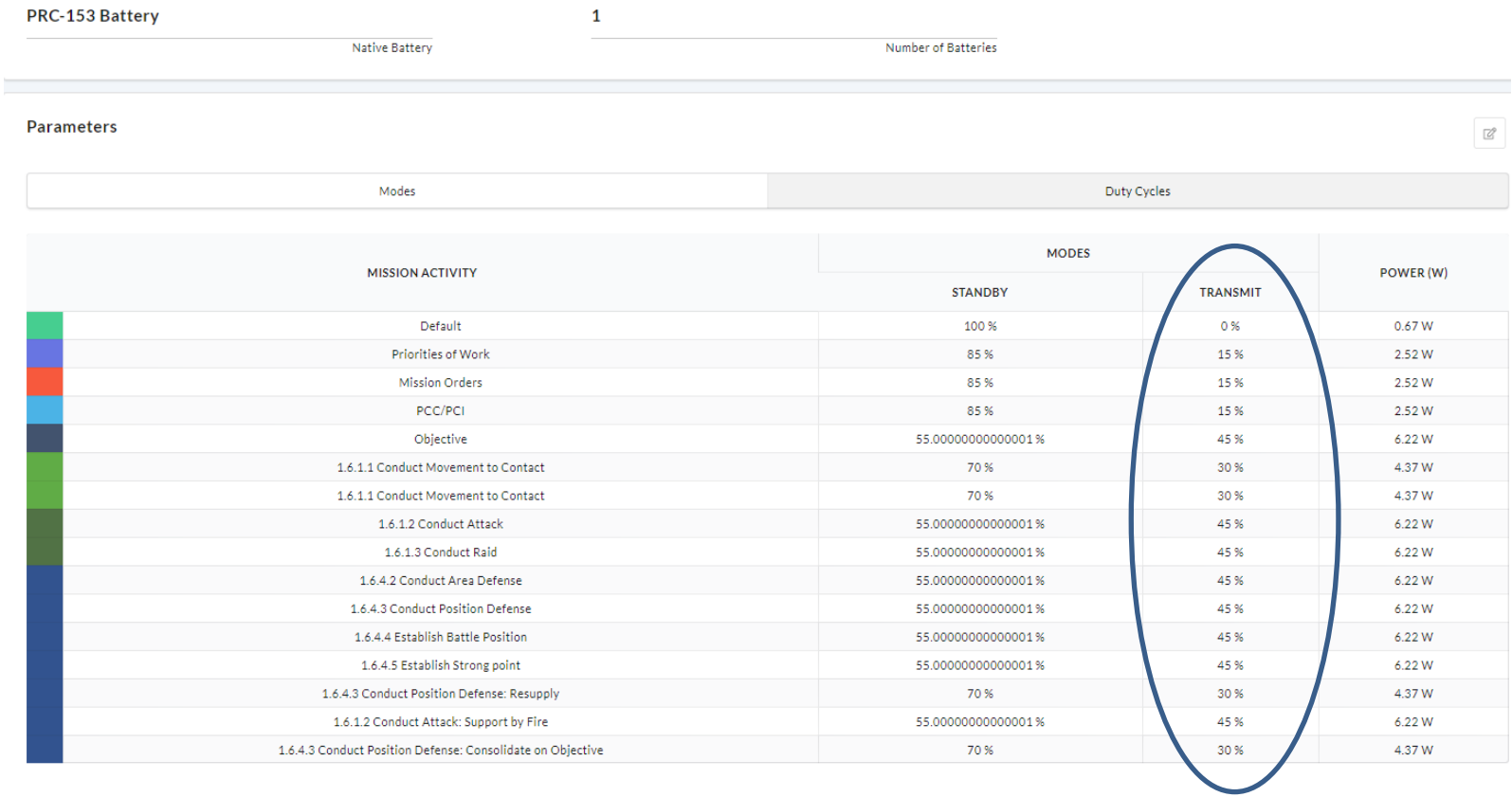

Figure 28: AN/PRC-153 TX Usage Increase

Table 6 details the duty cycle changes per activity from the baseline. For the Conduct attack activity, a change in usage from 30% to 45% equates to a transmit increase from 18 minutes in an hour to 27 minutes in an hour. This increase allows the system to be stressed to understand how IPOWER will calculate the change in usage.

Table 6: Variation 1 Duty Cycle Changes

Activity	Baseline TX (%)	Variation 1 TX (%)	Delta from Baseline (%)
Mission Orders	10	15	+5
1.6.1.1 Conduct Movement to Contact	20	30	+10
1.6.1.2 Conduct Attack	30	45	+15
1.6.4.3 Conduct Position Defense: Consolidate on Objective	20	30	+10
1.6.4.2: Conduct Positon Defense: Resupply	20	30	+10
1.6.4.2: Conduct Position Defense	30	45	+15

The delta from the baseline to Variation 1 in Table 7 shows an increase of 5 to 15% and is seen comparing Figure 29 and Figure 30. In these two figures, the orange triangular shaped bars depict the battery depletion from a fully charged battery to an empty battery needing replacement. The baseline Figure 29 shows a need of 3.3 batteries for the radio under the baseline usage.

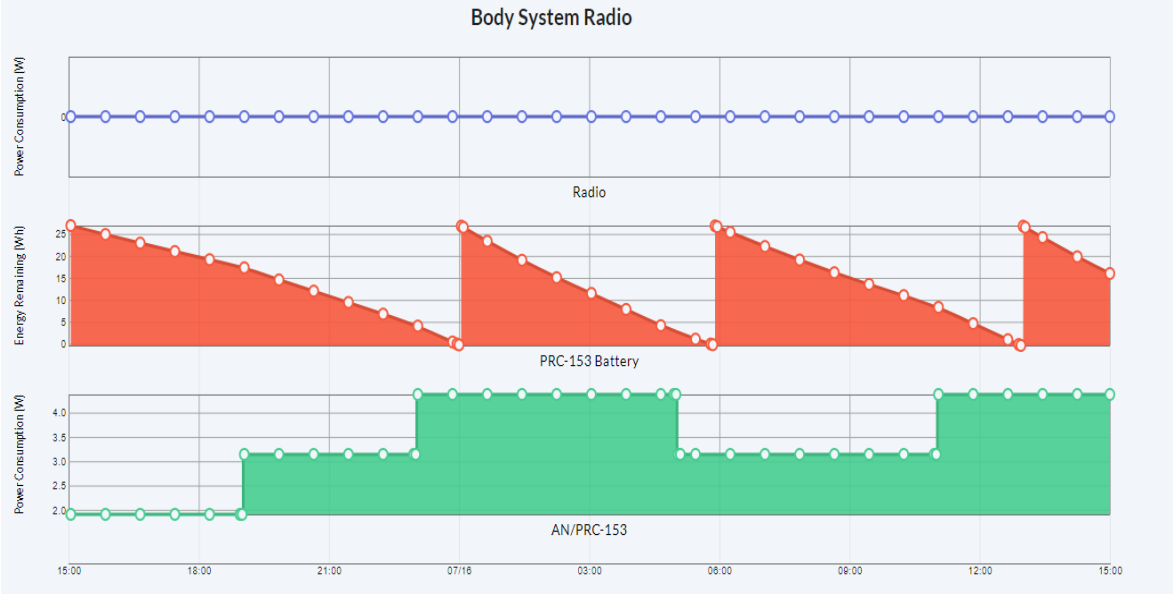

Figure 29: Baseline Usage of AN/PRC-153

When usage is increased in Variation 1, seen in Figure 30, approximately 4.5 batteries are needed to complete the mission. In both scenarios, the green graph describes the actual power consumption where a higher bar indicates greater power consumption. Figure 30 shows a higher power consumption, which correlates to the increased usage, defined within the Variation 1 data.

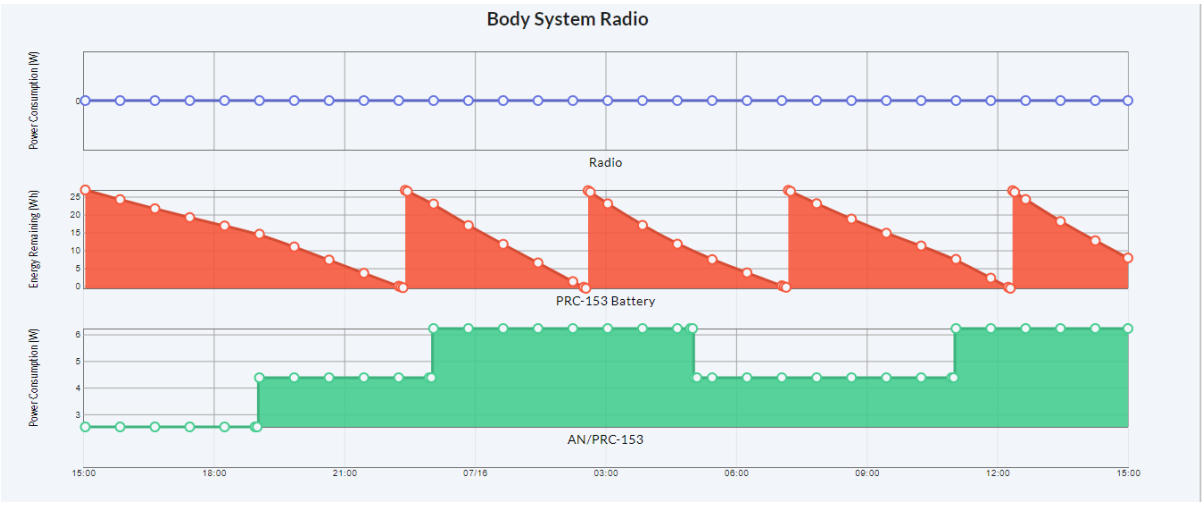

Figure 30: AN/PRC-153 Variation 1 Usage

In Variation 1, when the radio usage is increased, there is also an increase in energy consumed in the power summary section seen in Figure 31. Additionally, the research team noticed an increase in the batteries required and equipment weight. This increase in consumption is expected.

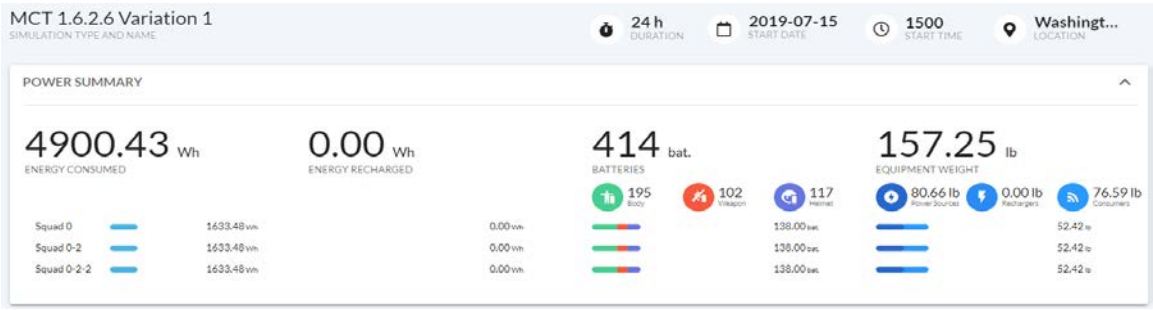

Figure 31: Variation 1 Power Summary

Table 7 describes the summary of changes between the baseline scenario and Variation 1. With a 50% increase in radio usage, there is a 36% increase in energy consumed and approximately 10% increase in the number of batteries required and 10% increase in weight carried within the platoon.

Table 7: Parameter Comparison (Baseline vs. Variation 1)

Parameter	Baseline	Variation 1	Deviation
Energy Consumed	3602.61 Wh	4900.43 Wh	+1297.82 Wh (36%)
Batteries (Total)	375	414	+39 (10%)
Batteries (Radio)	156	195	+39
Equipment Weight (total)	143.19 lb	157.25 lb	+14.06 lb (9.8%)
Equipment Weight (Radio)	66.60 lb	80.66 lb	+14.06 lb

The results suggest that IPOWER behaves as it should and is a reasonable tool for analysis in this scenario. All parameters remained the same except for the increased usage. It is unclear if other factors (weather, temperature) will have additional effect on the results.

Comparing the batteries required between the baseline scenario and Variation 1 in Figure 32 and Figure 33, shows that in Variation 1, the battery utilization increase more quickly than in the baseline indicating a higher power draw.

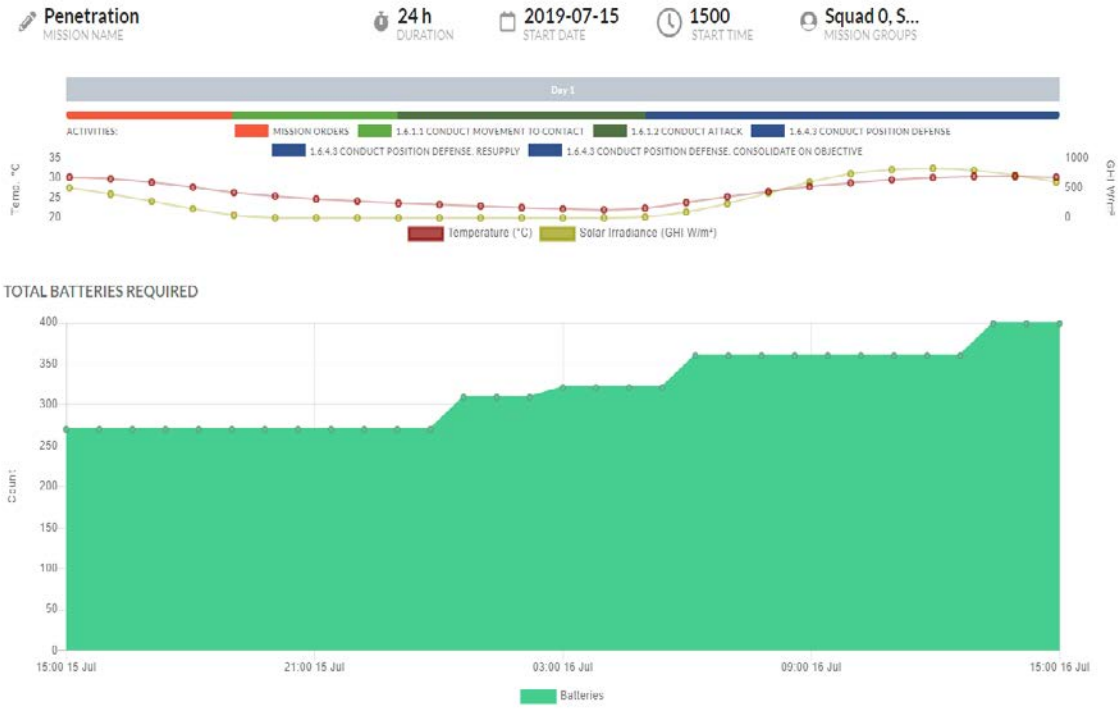

Figure 32: Baseline Battery Required Summary

Throughout Variation 1, the data shows that as the radio usage in increased by 50% in each activity, the power required also increases.

Figure 33: Variation 1 Batteries Required Summary

The increased utilization variation also is the area of greatest subjectivity in the data as IPOWER assumes each load is used the same by each member of the platoon. In reality, the typical rifleman may not talk on the radio as much as the squad leader. In all cases, the data added to each IPOWER database has a similar liability. This type of deviation in data may inhibit the IPOWER tool from a high level of accuracy.

C. VARIATION 2: EQUIPMENT PERFORMANCE

In Variation 2, the research team targeted the AN/PRC-153 radio battery for improvement. In the variation, the database entry for power available for the radio battery is modified to have 50% more capacity. The Amp Hour (AH) rating was modified from 3.6 AH to 5.4 AH to show this growth. When the baseline scenario is run with this new data, the summary shows a marked improvement in a reduction in batteries required for Body Systems (note that the radio is classified as a Body System). Figure 34 shows the power summary for Variation 2. The power summary shows the same power consumption as the baseline as well as the same batteries used for helmet systems (102 batteries) and weapons (117 Batteries). The batteries required for the body system are reduced from 156 to 117 batteries. These numbers indicate that with an increase of 50% battery capacity for the radio, there was a 25% decrease in batteries required. These numbers will change based

on other performance factors found in the other simulation variation runs where other parameters may affect these results.

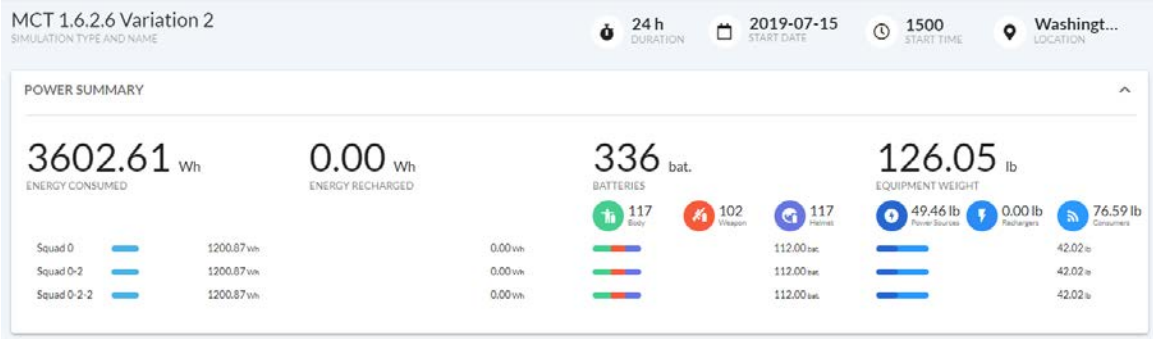

Figure 34: Power Summary Variation 2

Figure 35 and Figure 36 show a comparison between the baseline simulation and Variation 2. In Figure 35, the simulation shows a need for approximately 3.5 batteries shown in the orange triangles. These triangular shapes indicate a fully charged battery, which depletes over time based on radio usage (shown in the green rectangular areas). This usage is based on the activities performed over time.

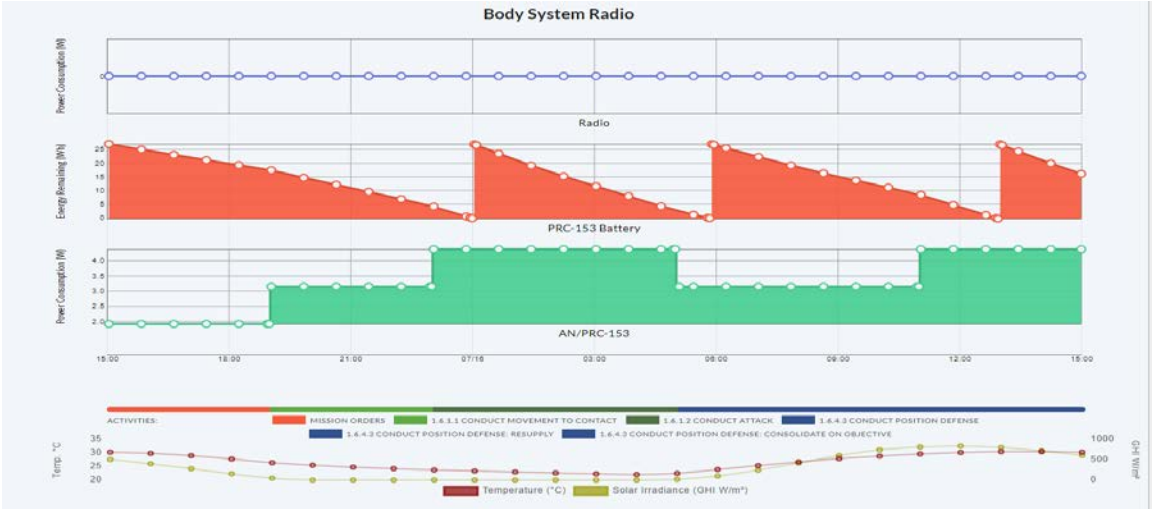

Figure 35: AN/PRC-153 Usage in Baseline

In Figure 36, approximately 2.5 batteries are needed for the scenario. The increased battery capacity in the Variation 2 simulation shows an increased performance under the same conditions. The increase in battery capacity of 50% corresponds in a reduction of 71% of the needed AN/PRC-153 radio batteries. Within the platoon equipment, a reduction in 10% of the total battery requirement and a reduction in 11.9% of the equipment weight is realized.

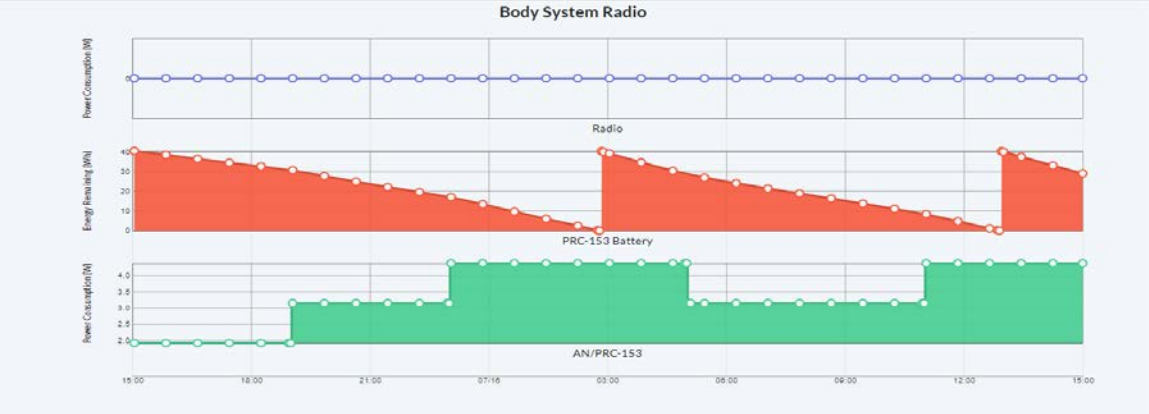

Figure 36: AN/PRC-153 Usage in Variation 2

The results of the Variation 2 analysis identify that IPOWER is suitable in predicting power consumption rates when adjusting the equipment parameters. In this analysis, only one parameter was changed (increase in battery capacity). The IPOWER tool was able to predict power consumption of the equipment utilized successfully.

D. VARIATION 3: MISSION ACTIVITY DURATION

Variation 3 highlights the change in mission activity duration. Change to the mission activity duration is an important aspect of mission development and planning. In the baseline simulation, the entire mission is conducted over 24-hours. In Variation 3, the 24-hour mission length is not modified, but activities within this period were adjusted. This adjustment demonstrates a change in mission development that may occur from COA development within MCPP, in which deliberate planning may take longer, or from the Rapid Response Planning Process (R2P2), which is typically conducted rapidly. Variation

3 makes several modifications to the baseline mission block timetable but did not change the activities or equipment used within the scenario. Figure 37 shows the change in Variation 3 of the mission blocks. This modified mission block is compared to the baseline found in Figure 24.

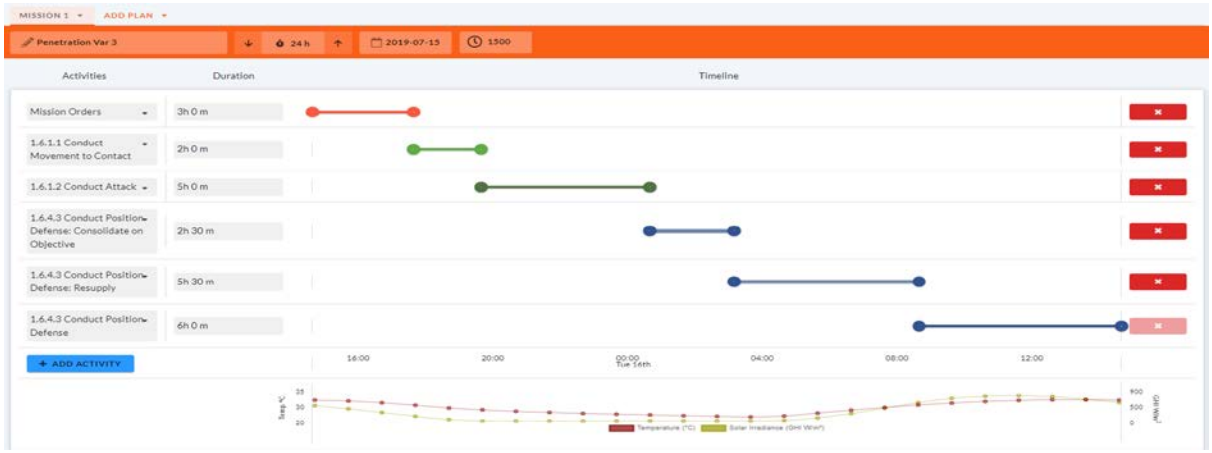

Figure 37: Mission Block for Variation 3

Table 8 shows the change from the baseline to Variation 3. The changes described are affecting the energy consumed throughout the simulation due to each activity having a different energy consumption rate for each equipment load. Figure 38 is the power summary for Variation 3.

Table 8: Mission Activity Duration Changes

Mission Activity	Baseline	Variation 3	Delta from Base
Mission Orders	4	3	-1
1.6.1.1 Conduct Movement to Contact	4	2	-2
1.6.1.2 Conduct Attack	6	5	-1
1.6.4.3 Conduct Positon Defense: Consolidate on Objective	3.5	2.5	-1
1.6.4.3 Conduct Position Defense: Resupply	2.5	5.5	+3
1.6.4.3 Conduct Position Defense	4	6	+2

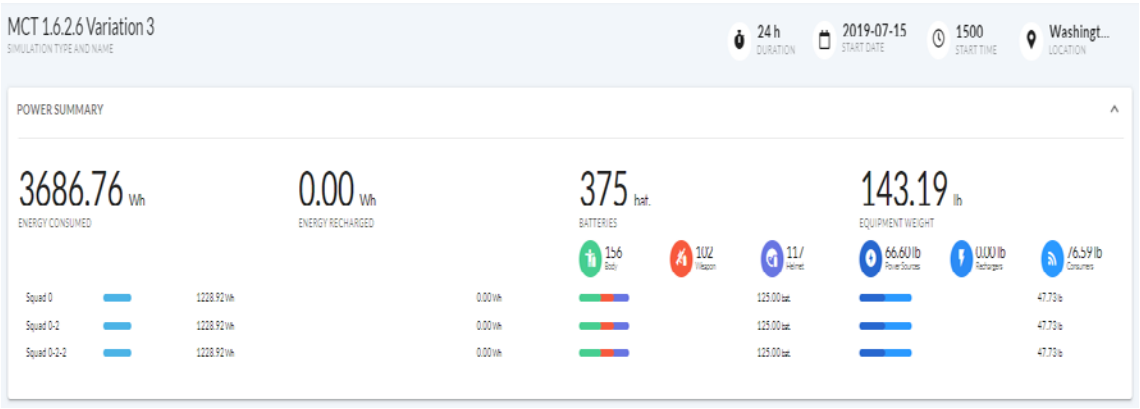

Figure 38: Power Summary for Variation 3

In comparison to the baseline, there is an energy consumption increase of 84.6 Wh. While there is an increase in energy consumed, there is no increase in the number of batteries required and therefore no change to the equipment weight. There were no significant changes to the power consumed in this simulation. As a variation from the baseline, no significant change was noticed. The study team identified the reason for this lack of change. The activity and load parameters within the database were too similar to distinguish a result. An example of the similarity is that while task 1.6.4.3 increased by three hours, the additional power consumed during this task was equal to the power reduced

during mission orders and 1.6.1.1. This created a net power consumption change of near zero. Further research and software development is warranted to ensure the accuracy of power consumption parameters for each load as it relates to an activity is accurate.

Table 9 summarizes the results of the four scenarios. This table highlights the essential factors across all of the simulations, which include power consumption, battery quantity, and equipment weight and are highlighted in blue. The team determined that the results shown from the analysis are consistent with the team's expectations. In Variation 1, the team saw an increase in all measured categories. This is indicative of an increased usage of equipment. Variation 2 shows a constant power consumption, but decreased quantity and weight carried by the warfighter. The results match the expectation that fewer batteries are needed if the battery performs at a higher capacity. Variation 3 shows minimal increases in consumption which corresponds to no change in the batteries needed and no weight change.

Table 9: Scenario Variation Summary

MCT 1.6.2.6 Conduct Penetration							
#	**Simulation Description**	**Energy Consumed (Wh)**	**# Batteries (bat.)**	Body (bat.)	**Equipment Weight (lb)**	Power Sources (lb)	**Results**
0	**Baseline**	3602.61	375	156	143.19	66.6	
1	**Equipment Usage Rate +50%**	4900.43	414	195	157.25	80.66	Increased duty cycle of communications equipment by 50% resulted in substantial increases to the number of batteries required and subsequent weight carried on the soldiers' bodies.
2	**Battery Power Available +50%**	3602.61	336	117	126.05	49.46	Increased battery capacity available for communication equipment by 50% resulted in reductions to the number of batteries required and subsequent weight carried on the soldiers' bodies. Possibly more importantly, fewer battery changes during critical mission phases.
3	**Activity Duration Changes**	3686.76	375	156	143.19	66.6	Adjustments to activity durations affected overall energy consumed. Impact more apparent in graphical depictions of results by phase

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The project team's objective was three-fold: 1) Define a set of mission profiles/mission blocks and conditions relevant to current and future small unit operations, 2) Provide an overall system architecture that captures the operational activities and system elements, and 3) Analyze power usage in an operational scenario using the IPOWER tool. The project team met these objectives through the mission analysis, architectural analysis, and through the analysis of four simulations. The team also sought to provide feedback to the development of the IPOWER software.

Overall, the team found that the IPOWER tool is an executable energy simulation tool, which has some useful capabilities now and potential to be a valuable tool with continued development. The methodology used in mission block development and simulation are consistent with USMC planning processes and the results appear accurate.

1. Mission Activity and Block Development

Prior to analyzing IPOWER, the team's mission analysis approach looked at the current force structure, activities and equipment through the USMC doctrine and TO&E as a primary source of current and future unit configuration. This data facilitated the development of a mission block and notional force and equipment-fielding plan.

The project team concluded that mission activities and block development should revolve around known USMC tasks assigned to a unit. These tasks established an overview perspective of the mission activities that are universally understood. Within the MCTL there are several levels for each task. Understanding the mission requirements allowed the development of an actionable method to develop a decomposition of mission activities derived from current rifle company tasks. The decomposition of a level 3 tasking showed an optimal activity level which would provide flexibility to the user, but reduce the burden of micro-changes. These micro-changes then lead to confusion and inaccuracies.

2. System Architecture

The team developed the architecture necessary to transfer requirements from the operational domain into the IPOWER system domain accurately. The team then compared this architecture to documentation relating to the current versions of IPOWER. The initial review led the team through several models to understand the current structure of IPOWER.

IPOWER's architecture is compatible with the project team's architecture design. IPOWER appears to be adaptable to USMC doctrine. This flexibility is important as it allows for potential changes of future doctrine. The structure of IPOWER appears to complement a continuous mission development from the creation of the required databases to the mission block and equipment allocation into the model. The project team found that IPOWER sufficiently accounts for the necessary user requirements with some noted limitations.

The project team found IPOWER system gaps as they traced the requirements from the mission domain to the IPOWER systems domain. These gaps are captures to help define IPOWER limitations, which will allow the IPOWER development team to improve the capability of the software. The majority of these gaps do not affect the system in its current state as a planning tool within a high-level acquisition environment, but in detailed planning of a field unit, these gaps may give inacurate results. For instance, the equipment assumes a full power charge from the onset of a mission and, unless programmed through a power monitor, 100% efficiency. IPOWER does not account for microclimate effects (temperature, cloud cover) and may affect equipment performance.

3. Model Analysis

IPOWER takes key performance data from multiple sources and, through an algorithm, predicts the power requirement, usage, and recharge of energy. The current state of IPOWER in version 3.1.0, requires the user to be familiar with the parameters of each piece of equipment and performance parameters of the equipment as they apply to mission activities. Having this knowledge of equipment may be difficult for an average user to create the necessary databases needed for an accurate model.

The analysis reviewed four simulations to assess the capabilities of the IPOWER tool. Each simulation attempted to highlight the capabilities of IPOWER to portray changes accurately to each scenario. The baseline simulation reviewed a typical 24-hour mission across several tasks at the platoon level consisting of three squads. Each of the three variations changed one parameter in comparison to the baseline. The team compared the results of each variation to the baseline independently.

Variation 1 increased radio usage by 50% to depict how accuracy of information affects the quality of the model. A 50% increase to the radio usage is equivalent to increasing talk time from 1 minute to 1.5 minutes over 10 minute period or 6 minutes to 9 minutes in an hour. The analysis of this variation shows a significant increase in power consumption with a relatively small increase in usage. Variation 1 highlights the important of data parameter accuracy. In IPOWER's current state, the user is responsible for accurate duty cycle information. The team concludes that while IPOWER is not necessarily responsible for confirming data accuracy, it is in the tool's interest to guide the user to accurate data. This is an area for further research to ensure usage parameters are accurate as this variation identifies with the greatest risk of IPOWER utilization.

Variation 2 increased the battery capacity of the radio. This variation is important in the acquisition planning aspect of the IPOWER tool. This variation looked at the baseline and increased the battery capacity, similar to developing a battery requirement in the acquisition of a new capability. Using the IPOWER tool, the acquisition professional can see the effect the increased capacity has on the mission as well as other physical properties such as weight and volume. In Variation 2, there were significant advantages to a larger capacity battery for both a weight perspective as well as a battery utilization perspective. With lower battery capacity, a battery change could occur at inopportune times such as during the conduct attack activity. The project team concludes that IPOWER can successfully model simulations with an acquisition type focus. A limitation identified with this variation is comparison to a baseline or alternate simulation is difficult because of how the user enters data into the databases and the lack of a comparison capability between two or more simulations within the software.

Variation 3 adjusts the activity duration. This variation is important for a user to use IPOWER as a mission-planning tool. Variation 3 modified mission activity durations, showing mission variations that may influence power requirements. As with the other variations, the team concluded that data accuracy is critical to provide actionable information. While the analysis showed minimal changes, the databases contained estimated load duty cycles for each activity. If different information is available, the data analysis may be different. Variation 3 also identifies the importance that users standardize activity nomenclature if there is intent for a wider integration of planning. Different users may categorize activities differently, and without a standardized database of activities, duplication or inaccuracies will complicate the database. This complication will lead to unmanageable sizes or activities will not be accurate, leading to poor output data. In its current state, IPOWER version 3.1.0 is limited to the platoon level but there is potential for work around to increase the scale.

B. RECOMMENDATIONS

The continued development of the IPOWER database is critical for the continued success of the system. The IPOWER simulation tool provides a valuable look at the development and usage of equipment. A holistic understanding of each database, and how it interacts within the simulation, is important for further development. While several idiosyncrasies exist within the user interface, key performance data is present. Three capability improvements are recommended: account for environmental factors, enable simulation of parallel activities, and account for equipment efficiency.

Environmental factors may affect the performance of equipment. High temperatures found in desert environments or cold environments may negatively affect equipment performance such as batteries. Accounting for temperature ranges in an activity or locality may allow a more accurate prediction of energy depletion. Additionally, varying cloud cover will affect solar harvesters (solar panels) at different rates. Allowing the user to select these parameters within the mission will also help the accuracy of the data.

Parallel activities are important at the platoon and higher organizational level. As IPOWER version 3.1.0 enables simulation of a platoon, it is important to allow individual

units to perform different activities within the same simulation. This will allow a more complicated mission development more in line with small unit level tactics.

An equipment efficiency parameter will allow the user to account for older, underpowered, or under-charged equipment that may not act as a perfect specimen. The efficiency of equipment is an important aspect of developing a customized simulation. It may not be as critical when using IPOWER as a high-level acquisition tool. A branch to the equipment efficiency parameter will include an option to replace a battery prior to a complete discharge.

C. AREAS OF FURTHER RESEARCH

Further research is necessary to gather pertinent data to populate the system databases. In the development of the mission blocks and simulations, it was clear this tool is flexible in the depth and breadth of customization. While IPOWER is an excellent tool for an experienced user, it is daunting and introduces many opportunities for errors for the occasional user. Three areas of further research will help the current version of IPOWER and refine these broad parameters, which will provide the occasional user quality data while also allowing the informed user an increased capability. The three areas of further research are: mission activities development, improving the equipment database, and adjusting equipment usage parameters.

Mission activities are the basis of how a mission is developed. In this report, mission activities are based on the MCTL at the tier 4 level. Tier 4 activities make sense in the analysis conducted but may be too restrictive to a specific unit. SOP's could be valuable in managing these activities within an organization. Caution needs to be taken due to the fact that while it is possible to derive several layers of activities, each activity requires a usage profile for each load. Data accuracy is critical. Problems may arise with activities added after the equipment database is populated. These new activities will not have accurate data for the equipment and may skew the results unless the equipment database is updated.

The equipment database is critical for the simulation. Without proper data, the IPOWER system cannot accurately predict the results. Equipment parameters need to be

validated with the product owner. Another recommendation is to research the feasibility to populate the equipment database from the TO&E list published by the USMC for the proper equipment allocated to a unit. This allows a baseline of equipment that a unit may pull from to equip the simulation. The user defined equipment is still necessary for the unique equipment a unit may have or when using the IPOWER software in the acquisition environment in the design of new equipment.

Equipment usage is the most important area for further research. Human research was out of scope for this report. As the system matures, it is critical to understand the usage profiles of each piece of equipment fully. Without a more direct approach into how equipment is used, all parameters entered for equipment usage are estimated and therefore will not give accurate results. For instance, this report estimated the duty cycle for the AN-153 radio to be 8:1:1 for the activity conduct attack. This means that 80% of the time the radio is in standby, 10% in receive, and 10% in transmit. Each of these parameters has a different power consumption rate. If the radio operator transmits at a rate of 20%, the power draw will be off by a significant margin. Human research will allow a study of the operator to understand the actual usage of equipment to produce an accurate depiction of power usage. Caution must be given to how this data is implemented into the activities. One unit's activity description and consumption rate may be different from another. Possible efforts may also include the algorithm providing a distributive parameter to allow variation within the simulation. This may help provide a realistic variation to the results for a more accurate prediction.

In all three of these areas of further research, it is important to properly analyze the impact of a too-restrictive approach where the user must only select predefined activities and equipment (to include usage) or a relaxed approach where the lack of standardization detracts from the predictive nature of the IPOWER system. Further research in these three areas will help to maximize the effectiveness of the IPOWER system and will help the usability of the system to a broader audience such as warfighter while still allowing the system to be used within the acquisition field.

APPENDIX A. STAKEHOLDER NEEDS AND PRIORITIZATION.

Table 10: Stakeholder Need and Prioritization

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
1	DoD Customer	Need tool to support power assessment for acquisitions.	IPOWER Need	1	Based on mission estimate and power usage prediction. Estimate how much batteries should be carried to ensure that mission would have enough power.	Adding additional burden on solders to estimate power and obtain training.
2	PM E2O2	Need reliable system that predicts a mission power Need.	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is caring the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
3	PM E2O2	Needs tool to support mission planning.	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters a solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
4	PM E2O2	Needs to provide the self-sustainable power equipment to the solders.	Other Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
5	PM E2O2	Needs to lower weight burden	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is caring the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
6	PM E2O2	Needs to lower sustainment cost.	Other Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
7	PM E2O2	Needs to lower logistics burden.	Other Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
8	PM E2O2	Tool to save, share, and collaborate information	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
9	PM E2O2	Updatable tool	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
10	PM E2O2	Tool to manage power requirements at a self-sufficient unit level.	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
11	PM E2O2	Optimize equipment carried	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
12	PM E2O2	Needs system that works for all of the missions	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
13	PM E2O2	Needs system that works for missions in range of thermal, light, weather, and terrain environments	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is caring the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
14	PM E2O2	Needs system that allows mission, environment, and equipment customization	IPOWER Need	2	1. Carry only equipment and power required to complete mission. 2. Power self-sustainment 3. Optimize Wight carried	1. Is carrying the harvesters solution for mission needs and when should harvesters be used? 2. What reserve in power should be available if mission is extended? What is likelihood and risk?
15	Operator	Needs to be able to operate the system with no more cognitive ability than an average Marine (Tool easy to use)	IPOWER Need	3	1. Get the job done. Provide interface that can scale with competence, to support learning and increase in efficiency. 2. Ergonomics design. 3. Durable - Be able to handle	1. Reliable system. 2. Easy to use. 3. Results easy to read and understand.

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
					bumps, scrapes, foot tapping, fist pounding. 4. Cleanable	
16	Operator	Built in training	IPOWER Need	3	1. Get the job done. Provide interface that can scale with competence, to support learning and increase in efficiency. 2. Ergonomics design. 3. Durable - Be able to handle bumps, scrapes, foot tapping, fist pounding. 4. Cleanable	1. Reliable system. 2. Easy to use. 3. Results easy to read and understand.
17	System owner	Needs to be able to design in necessary interfaces for all users and systems interacting with the system	IPOWER Need	4	1. User friendly system interface requirements. 2. Minimize service requirements.	1. Cost to Sustain. 2. Time to repair 3. Interoperability of IPOWER with other applications
18	System owner	Needs to make upgrade to the system to meet future user Needs.	IPOWER Need	4	1. User friendly system interface requirements. 2. Minimize service requirements.	1. Cost to Sustain. 2. Time to repair 3. Interoperability of IPOWER with other applications

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
19	System owner	Needs to develop training material/ and training for the system.	IPOWER Need	4	1. User friendly system interface requirements. 2. Minimize service requirements.	1. Cost to Sustain. 2. Time to repair 3. Interoperability of IPOWER with other applications
20	Maintainer	Needs to be able to identify/fix degraded components prior to failure	IPOWER Need	5	1. Survive environmental conditions. 2. Low maintenance mechanical and software systems. 3. Increase length of operation between maintenance cycles. 4. Fast update 5. Easy to navigate maintenance manual	1. Access to system in the environment, physical and communication. 2. Unplanned maintenance issues. 3. Data storage size
21	Maintainer	Needs to be able to diagnose failures (% of mission critical failures)	IPOWER Need	5	1. Survive environmental conditions. 2. Low maintenance mechanical and software systems. 3. Increase length of operation between maintenance cycles. 4. Fast update 5. Easy to navigate	1. Access to system in the environment, physical and communication. 2. Unplanned maintenance issues. 3. Data storage size

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
					maintenance manual	
22	Maintainer	Needs to be able to fix failures (% of mission critical failures)	Other Need	5	1. Survive environmental conditions. 2. Low maintenance mechanical and software systems. 3. Increase length of operation between maintenance cycles. 4. Fast update 5. Easy to navigate maintenance manual	1. Access to system in the environment, physical and communication. 2. Unplanned maintenance issues. 3. Data storage size
23	Maintainer	Needs to be able to upload updates to the system	IPOWER Need	5	1. Survive environmental conditions. 2. Low maintenance mechanical and software systems. 3. Increase length of operation between maintenance cycles. 4. Fast update 5. Easy to navigate maintenance manual	1. Access to system in the environment, physical and communication. 2. Unplanned maintenance issues. 3. Data storage size

ID	Stakeholder	Needs	Need Type	Priority	Goals	Concerns
24	Maintainer	Built in maintenance manual	IPOWER Need	5	1. Survive environmental conditions. 2. Low maintenance mechanical and software systems. 3. Increase length of operation between maintenance cycles. 4. Fast update 5. Easy to navigate maintenance manual	1. Access to system in the environment, physical and communication. 2. Unplanned maintenance issues. 3. Data storage size
25	Vendors	Design equipment for less weight/higher efficiency	Other Need	6	Competitive System	1. Research and development investments. 2. Protect proprietary data. 3. Ensure that system is safe to prevent recalls.
26	Vendors	Plan for replacement units and parts and their storage	Other Need	6	Competitive System	1. Research and development investments. 2. Protect proprietary data. 3. Ensure that system is safe to prevent recalls.
27	Vendors	Upgrade/ maintain manufacturing facilities.	Other Need	6	Competitive System	1. Research and development investments 2. Protect proprietary data. 3. Ensure that system is safe to prevent recalls.

APPENDIX B. IPOWER REQUIREMENTS

Table 11: Requirements-Needs Traceability

ID	Data Type	IPOWER Requirements	Needs
18	Heading	**1 Save Data**	
19	Heading	**1.1 Save Environmental Models**	
10	Requirement	The IPOWER system shall have library of environmental models.	8 Tool to save, share, and collaborate information
17	Heading	**1.2 Save Equipment Database**	
1	Requirement	The IPOWER system shall provide a database of equipment.	1 Needs tool to support power assessment for acquisitions 8 Tool to save, share, and collaborate information
2	Requirement	The IPOWER system shall list equipment as Load, Battery, Generator, Harvester or Hub.	8 Tool to save, share, and collaborate information
33	Heading	**1.3 Save Marine Units Database**	
8	Requirement	The IPOWER system shall provide database of the marine units.	8 Tool to save, share, and collaborate information
20	Heading	**2 Accept User Input**	
21	Heading	**2.1 Define Mission Waypoints**	
7	Requirement	The IPOWER system shall track mission waypoints.	3 Needs tool to support mission planning. 12 Needs system that works for all of the missions
22	Heading	**2.2 Define Mission Activities**	

ID	Data Type	IPOWER Requirements	Needs
5	Requirement	The IPOWER system shall provide list of mission activities.	3 Needs tool to support mission planning. 12 Needs system that works for all of the missions 14 Needs system that allows mission, environment, and equipment customization
6	Requirement	The IPOWER system shall provide an interface for user to add unique mission activities.	12 Needs system that works for all of the missions 14 Needs system that allows mission, environment, and equipment customization
23	Heading	**2.3 Define Mission Timeline**	
32	Heading	**2.4 Select Mission Location**	
11	Requirement	The IPOWER system shall provide an interface for user to select environmental location.	12 Needs system that works for all of the missions
24	Heading	**2.5 Define Mission Units**	
9	Requirement	The IPOWER system shall provide an interface for user to assign individual personnel across the organization to the Company level.	10 Tool to manage power requirements at a self-sufficient unit level. 12 Needs system that works for all of the missions
12	Heading	**2.5.1 Add Equipment to the Equipment Database**	

ID	Data Type	IPOWER Requirements	Needs
3	Requirement	The IPOWER system shall provide an interface for user to add unique equipment.	14 Needs system that allows mission, environment, and equipment customization
35	Heading	**2.5.2 Define Equipment Power Usage**	
4	Requirement	The IPOWER system shall provide an interface for user to assign power usage/generation of equipment for each mission activity.	14 Needs system that allows mission, environment, and equipment customization
50	Heading	**2.5.3 Define Thermal Conditions**	
51	Requirement	The IPOWER system shall provide an interface for user to assign thermal conditions.	13 Needs system that works for missions in range of thermal, light, weather, and terrain environments 14 Needs system that allows mission, environment, and equipment customization
52	Heading	**2.5.4 Define Light Conditions**	
47	Requirement	The IPOWER system shall provide an interface for user to assign light conditions.	13 Needs system that works for missions in range of thermal, light, weather, and terrain environments 14 Needs system that allows mission, environment, and equipment customization
53	Heading	**2.5.5 Define Weather Conditions**	

ID	Data Type	IPOWER Requirements	Needs
49	Requirement	The IPOWER system shall provide an interface for user to assign weather conditions.	13 Needs system that works for missions in range of thermal, light, weather, and terrain environments 14 Needs system that allows mission, environment, and equipment customization
37	Heading	**2.5.6 Define Terrain**	
44	Requirement	The IPOWER system shall provide an interface for user to assign terrain type to mission activities.	12 Needs system that works for all of the missions 13 Needs system that works for missions in range of thermal, light, weather, and terrain environments
25	Heading	**3 Display Results**	
26	Heading	**3.1 Perform Analysis on Mission**	
27	Heading	**3.2 Display Energy Prediction**	
15	Requirement	The IPOWER system shall display power needs for the mission.	2 Needs reliable system that predicts a mission power Needs.
28	Heading	**3.3 Display Energy Consumptions**	
14	Requirement	The IPOWER system shall graphically display power consumption rates.	2 Needs reliable system that predicts a mission power Needs.
34	Heading	**3.4 Display Equipment Power Usage**	

ID	Data Type	IPOWER Requirements	Needs
13	Requirement	The IPOWER system shall model power usage over the duration of the mission.	2 Needs reliable system that predicts a mission power Needs.
38	Heading	**3.5 Display Equipment Weight**	
16	Requirement	The IPOWER system shall display equipment weight broken down by power devices and other equipment.	5 Needs to lower weight burden.
45	Heading	**3.6 Display Recommended Equipment for Mission**	
46	Requirement	The IPOWER system shall display equipment assigned to individuals and units that will satisfy mission needs at lowest equipment weight.	11 Optimize equipment carried
29	Heading	**4 Display System Health**	
40	Requirement	The IPOWER system shall display the system operational status.	20 Needs to be able to identify/fix degraded components prior to failure.
41	Requirement	The IPOWER system shall the system faults.	20 Needs to be able to identify/fix degraded components prior to failure. 21 Needs to be able to diagnose failures (% of mission critical failures).
42	Requirement	Upon receiving user request, the IPOWER system shall display the system maintenance manual.	20 Needs to be able to identify/fix degraded components prior to failure. 24 Built in maintenance manual.
30	Heading	**5 Send Information**	

ID	Data Type	IPOWER Requirements	Needs
43	Requirement	The IPOWER system shall provide interface to send mission information to remote users.	8 Tool to save, share, and collaborate information
31	Heading	**6 Accept Update**	
39	Requirement	The IPOWER system shall provide an interface to receive the updates.	9 Updatable tool 23 Needs to be able to upload updates to the system.
55	Heading	**7 Provide Build-in Training**	
56	Requirement	The IPOWER system shall provide build-in training.	16 Built in training 19 Needs to develop training material/ and training for the system.
58	Heading	**8 Provide User Friendly Interface Design**	
59	Requirement	The IPOWER system shall provide hints for next user actions.	15 Needs to be able to operate the system with no more cognitive ability than an average marine (Tool easy to use).

APPENDIX C. SOFTWARE LIMITATIONS.

Table 12: IPOWER System Gaps

Number	IPOWER Gap	Gap Description	Impact
1	Parallel Activities	Mission action and tasks are executed in series, in parallel, or as combination of both. IPOWER activities are executed only in series.	IPOWER predictions will be average of needs for two parallel activities and will result in higher power carried by one unit then needed, and less power carried by other unit then required.
2	Additional Activities	IPOWER has limited set of activities.	Unit tasks are not expanded to the level of detail users may need.
3	Activities Names	Naming convention of activities and their meaning may not match user doctrine	Prediction of power usage may not be accurate.
4	Personnel Speed	IPOWER takes in account duration of activity, not the soldier speed. The soldier speed will impact power generation of some harvesters.	The harvesters power production estimate is not precise.
5	Terrain	Currently, IPOWER doesn't take in account soldier speed or terrain impact on speed. Terrain impacts speed of soldier and power generation.	The harvesters power production estimate is not precise.
6	IPOWER Calculations	Equipment duty cycle not well defined. (current model and plan guesses equipment duty cycle)	Predicted energy usage may not be accurate for the end user causing mission impact.

Number	IPOWER Gap	Gap Description	Impact
7	Data Input/ Interoperability	Data uploaded from TO&E will help with data entry into IPOWER	Data updated from TO&E can speed up user input and keep information accurate. The TOE will not have the technical data, but will list the equipment and what uses it/used by it
8	Partial Activity completion	Mission activities assume completion.	Disrupted activities may reduce accuracy of results
9	Partial charge of equipment	Equipment may not start with a full charge, or be fully charged during a recharge event	IPOWER will not be able to predict accurate data.
10	Environmental effects on equipment	IPOWER does not account for environmental conditions as it applies to equipment (such as microclimate weather)	Microclimate weather effects may greatly affect equipment performance.
11	Unit Database	Individual equipment may vary and will be difficult to track with generic data labels.	If specific users have specific equipment, it will be task intensive to keep track of the equipment
12	Power usage formula	Formula entry is not possible in the database	Formula entry may allow the user to use user specific data
13	Interoperability	IPOWER cannot combine scenarios at the higher level for a holistic view	If IPOWER is used at a squad level, the 3 simulations cannot be combined at the platoon level…etc.
14	Uploading data from excel	IPOWER doesn't provide upload of data from excel. For example, the equipment has to be entered one at the time.	It is time consuming to add large amount of data to IPOWER.

Number	IPOWER Gap	Gap Description	Impact
15	Waypoint usage	Currently waypoint feature cannot be tied to geographic location. The waypoint feature appears to be standalone and is unclear how is used.	Currently, the rate of movement is not calculated (speed). The speed is required for estimating the energy produced by harvesters. The waypoints could be useful for calculating distance and along with duration of activities used to calculate speed.
16	Saving File	IPOWER doesn't allow for saving file under different name. Each time file is saved, IPOWER creates a new file with same name and user cannot know which latest one is.	User will be annoyed and not efficient.

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APPENDIX D. DEVELOPMENT OF A SCENARIO IN IPOWER.

An IPOWER scenario is a buildup of several pieces of information taken from a group of databases. To create the simulation, each database was created to account for the parameters of the activities, equipment, location, and personnel. Once created, the scenario executes to produce the results. The team, in the creation of the necessary databases, used the following steps: activity database, battery database, load database, power manager database, mission development, and unit development. While no particular order is required, some caution and awareness needs to be understood because entries in one database will affect another database. Activity Database.

The activity database is the first database created. The activity database is a list of all activities used in the IPOWER tool. Each simulation will draw the desired activities from the database into the mission block. Within the IPOWER program, “Admin” is selected on the left column to access the six databases shown in Figure 39.

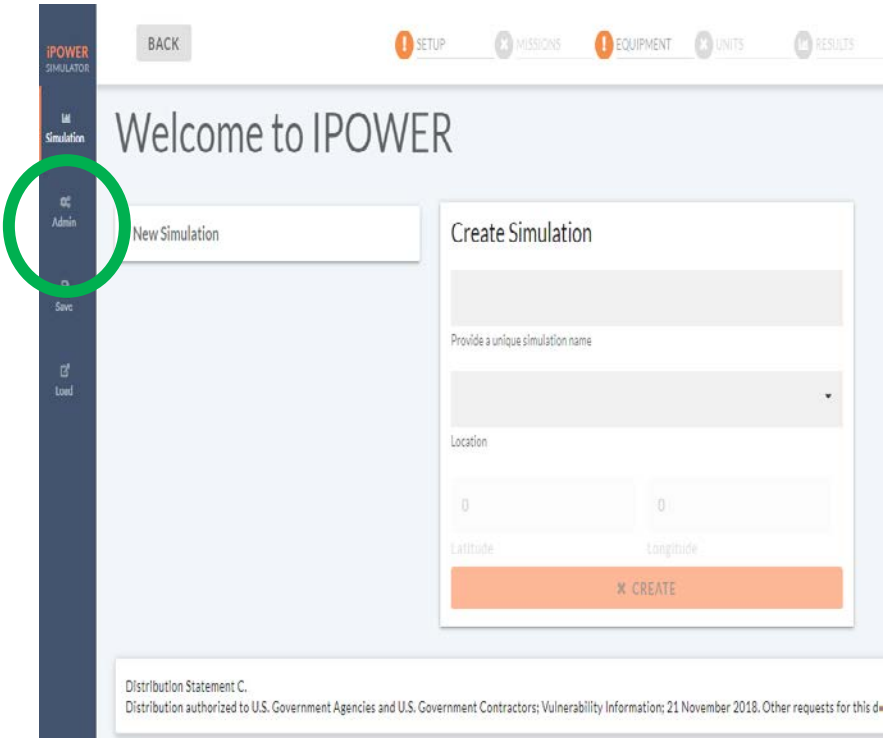

Figure 39: IPOWER Title Screen

From Figure 40 the user has the option to modify the Power Managers, Loads, Batteries, Harvesters, Generators, or Activities database. Selecting “activities” in Figure 40 brings up the mission activities database.

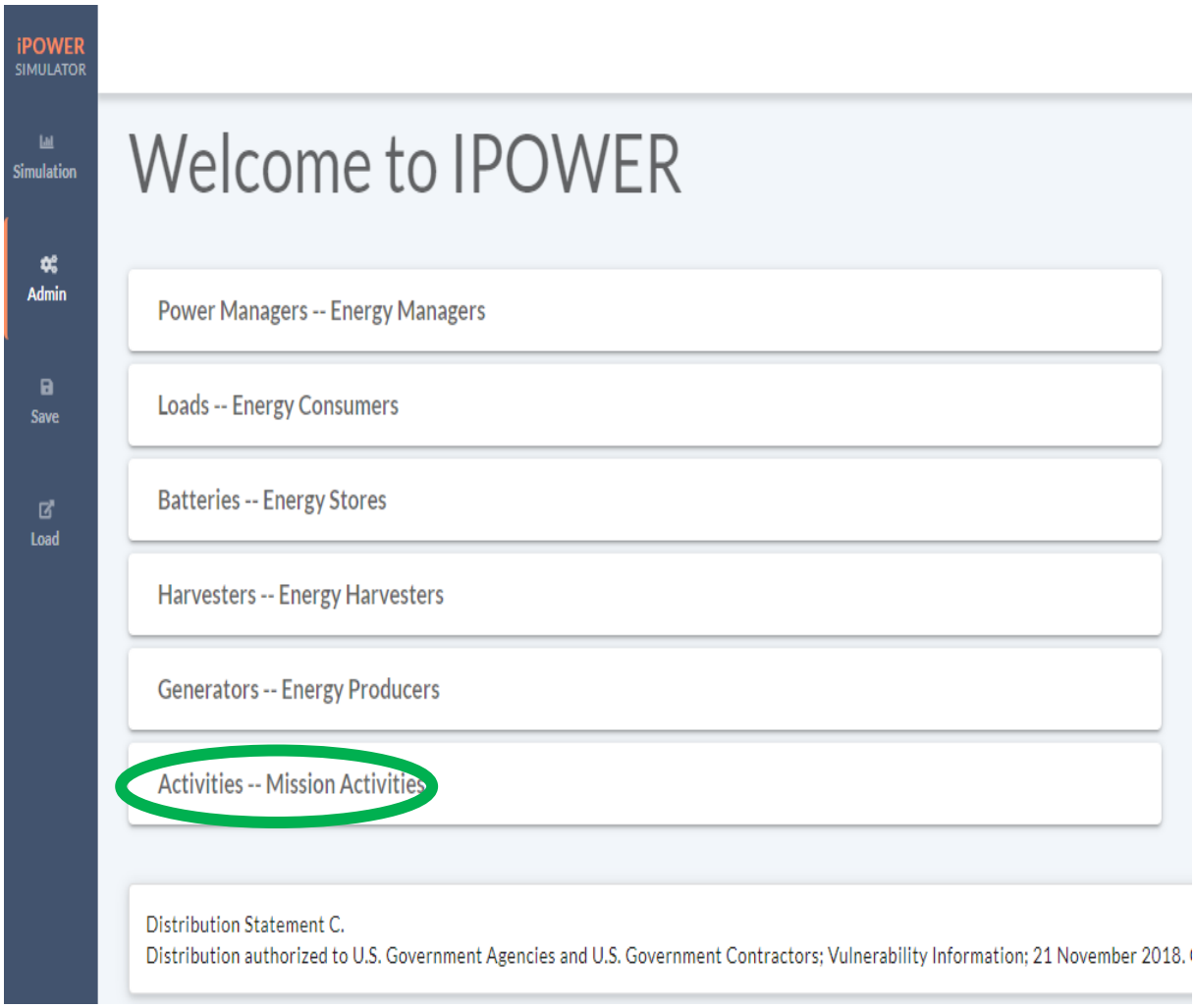

Figure 40: IPOWER Admin Section

Figure 41 shows the list of activities from Pre-Combat Checks through Consolidate on Objective described in Chapter IV. The bottom of the activities list in Figure 41 indicates the option to create new activities.

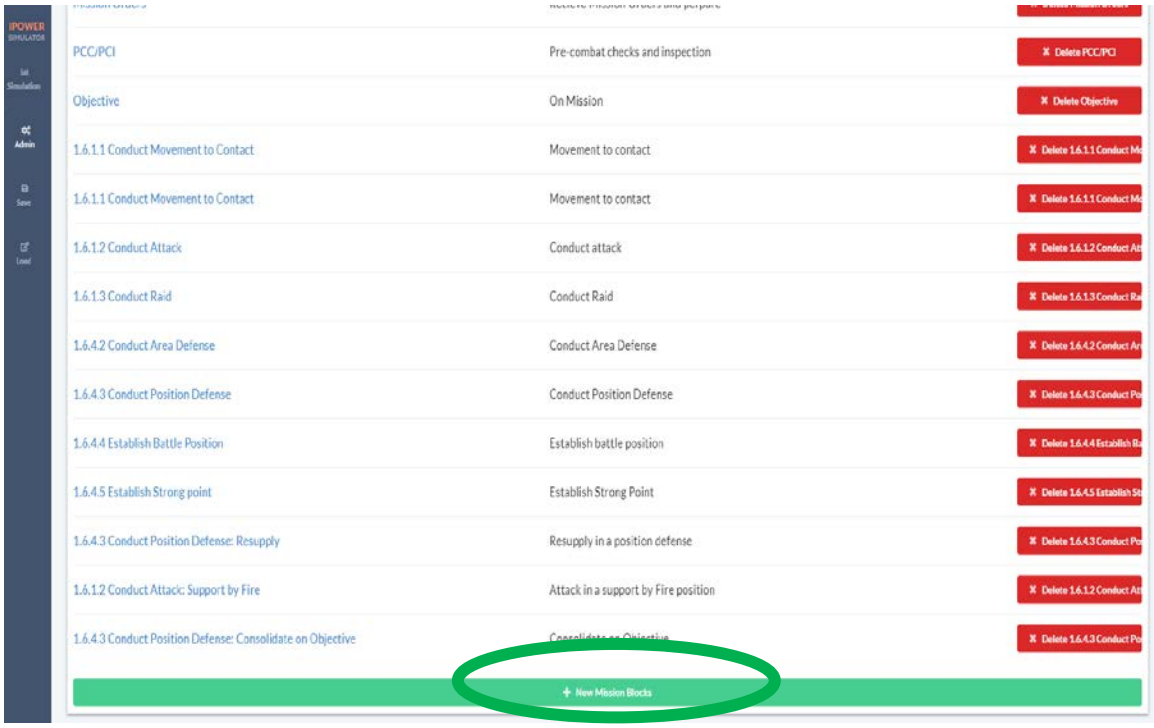

Figure 41: Mission Block List

In the “new activities” menu found in Figure 42, basic options exist, which include a name, description, day/night usage, and color. The color aspect applies to within the results page and helps identify the time intervals where the activity in question is occurring. This process to create new activities continues until all activities are entered. Once the new activity is created and saved, the next database to populate is the battery database.

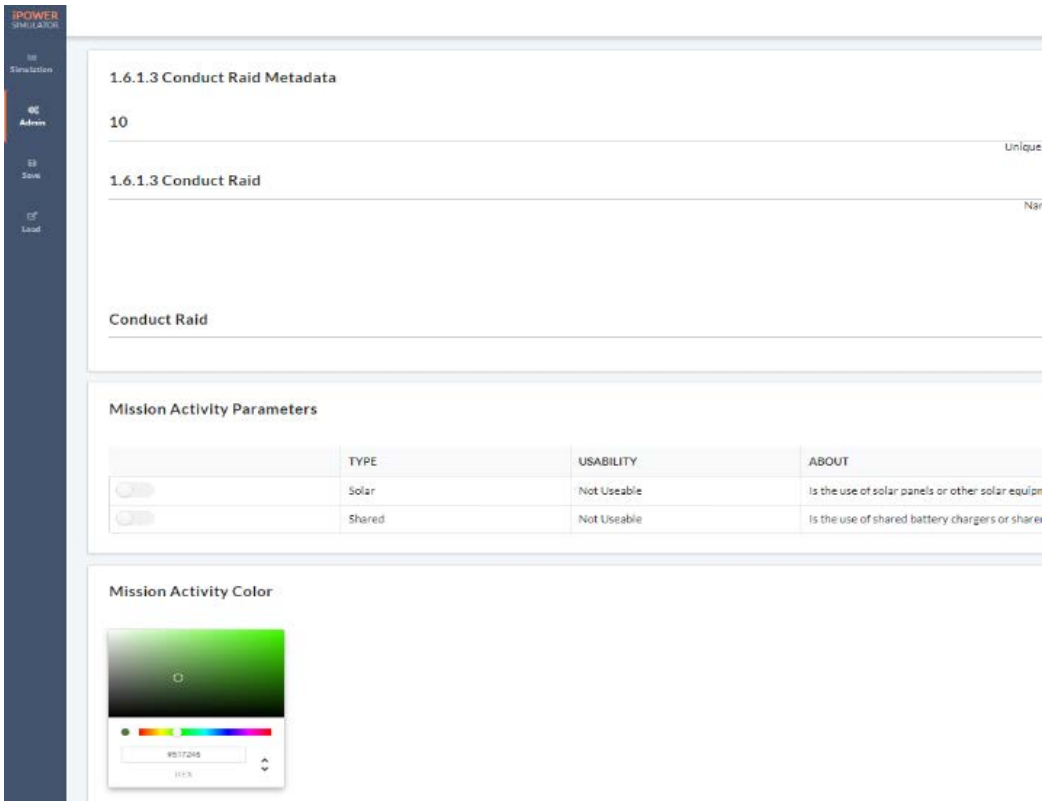

Figure 42: IPOWER Activity Creation

A. BATTERY DATABASE

The battery database was created similarly to the activities database. The battery database contains a list of batteries and their properties within the IPOWER tool. Reviewing the admin section, “batteries” was chosen, and “new batteries” was selected in Figure 43.

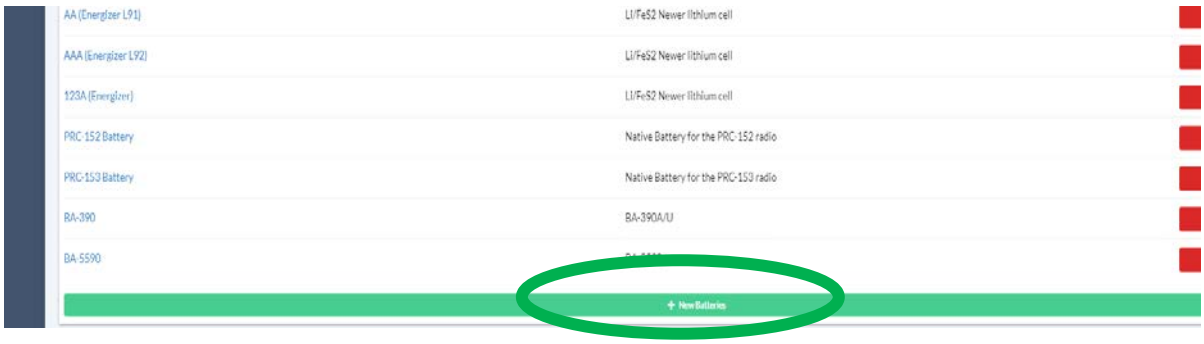

Figure 43: IPOWER Battery Database

The battery parameters are entered into the database through a graphical user interface with an output summarizing the data in Figure 44. The data entered into this section defines the energy within the batteries. Physical properties (weight and volume) and battery properties are also included. The input process repeats for all other batteries until the database is complete. Once the battery database is sufficiently complete, the load's database is built.

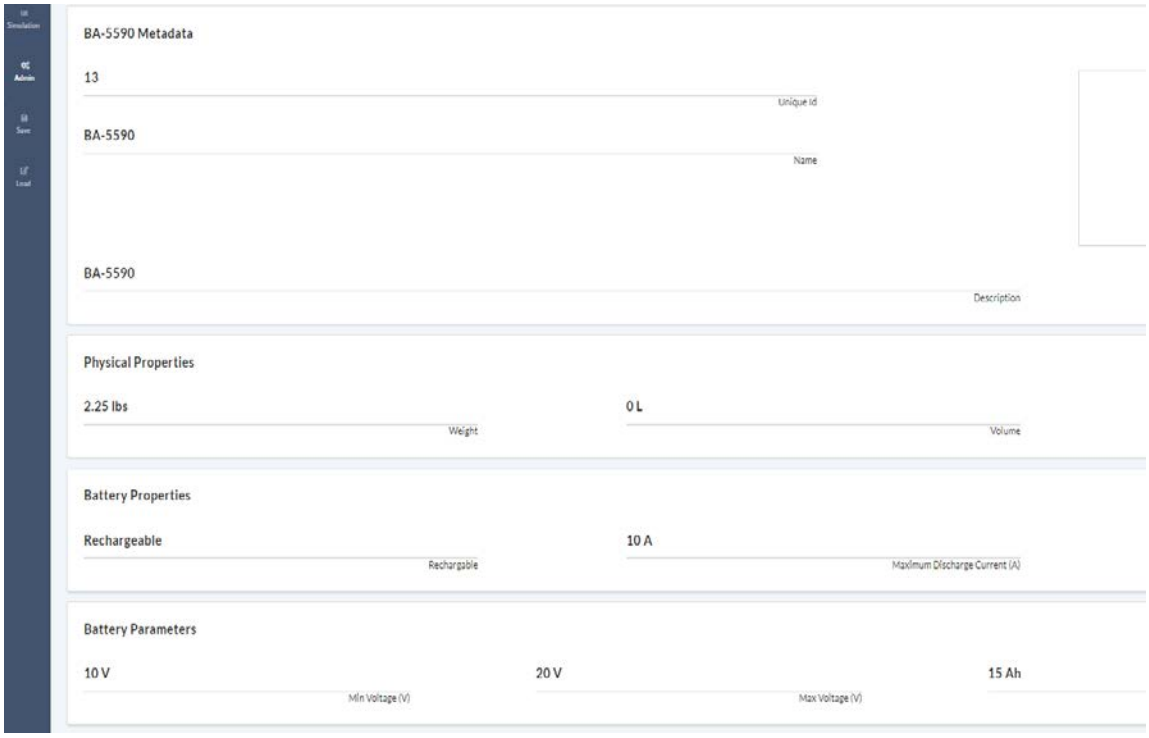

Figure 44: Battery Parameters

B. LOADS DATABASE

A load is a piece of equipment that consumes energy. The loads database collects equipment parameters necessary for the IPOWER algorithm to function. The loads database starts from the admin page in Figure 40. Selecting New Loads in Figure 45 starts the process to enter equipment data.

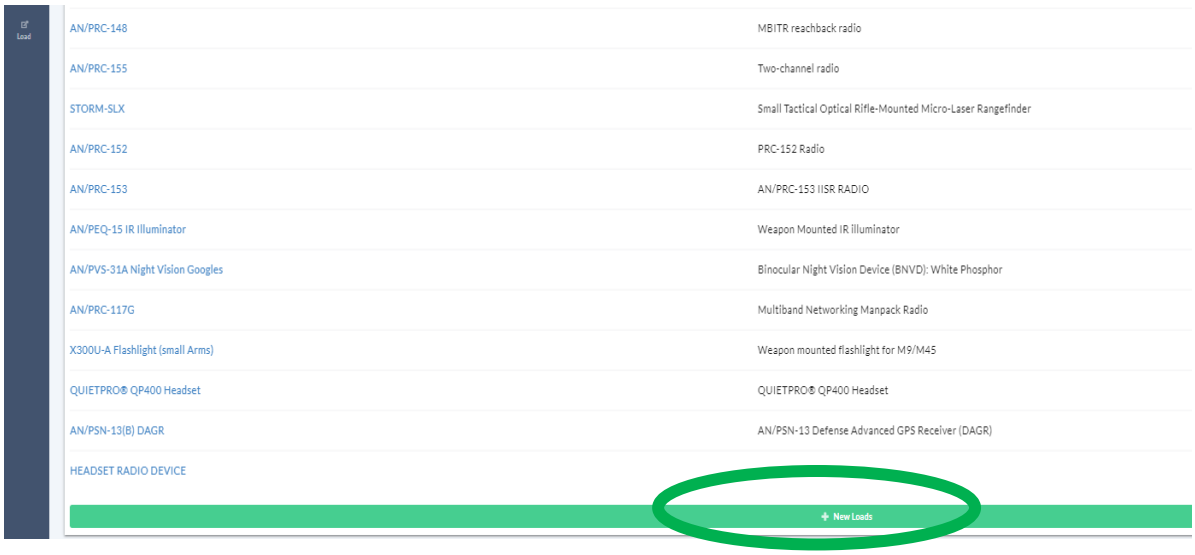

Figure 45: IPOWER Load Database

This starts with a name and description in Figure 46 and physical properties in the subsequent page depicted in Figure 47.

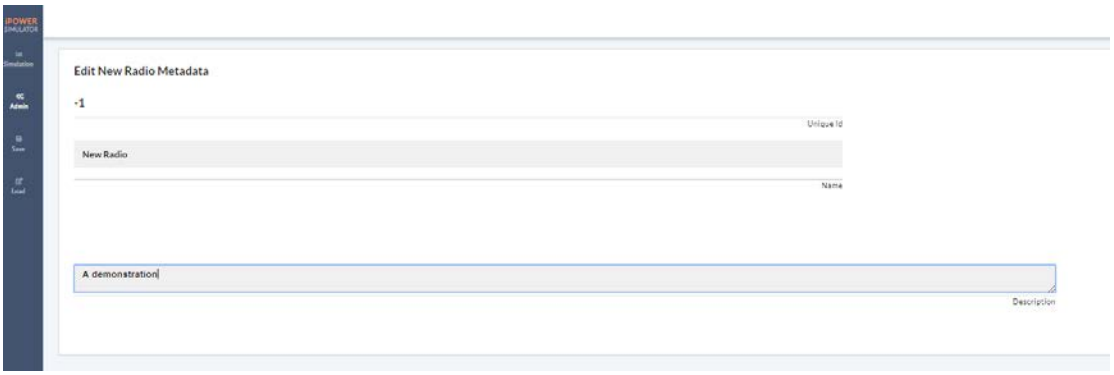

Figure 46: Load Name

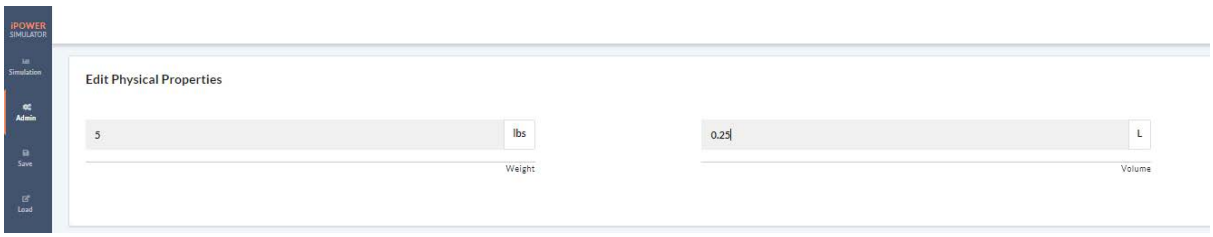

Figure 47: Load Weight and Size

Load usage shown in Figure 48 is self-explanatory but essential as IPOWER tracks the diurnal cycle of the sun based on latitude and longitude. If not appropriately selected, equipment usage may skew the results.

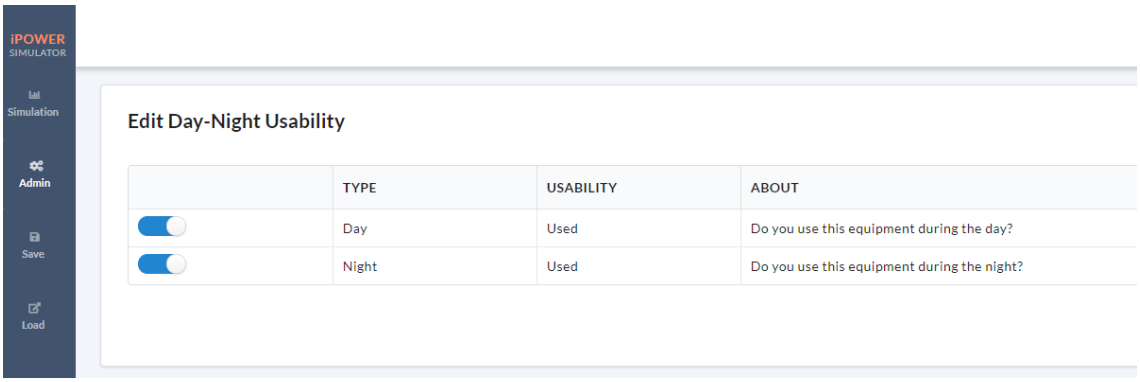

Figure 48: Load Usage

The next section begins a series of selections that can complicate the equipment parameters. Figure 49 allows the choice of a native battery or non-native battery. A native battery is a battery that is only used by a particular device. An example is a tablet, which uses an integrated battery within the device. Equipment with non-native batteries allows multiple types of battery. An example of this is the AN/AVS-31 Night Vision Goggles, which use a standard AA battery that can be alkaline or Lithium-ion.

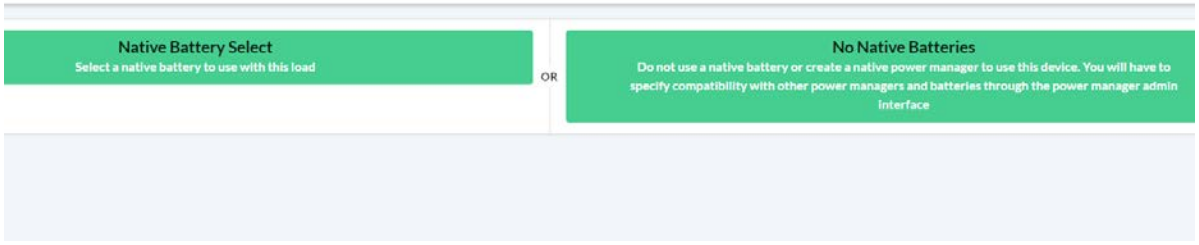

Figure 49: Load Battery Options

Selecting average power parameters or duty cycle parameters, shown in Figure 50, allow significant customization and complexity to the load. The average power parameters enable the user to specify an average load for each mission activity. The use of average power is a simplified method of inputting usage parameters.

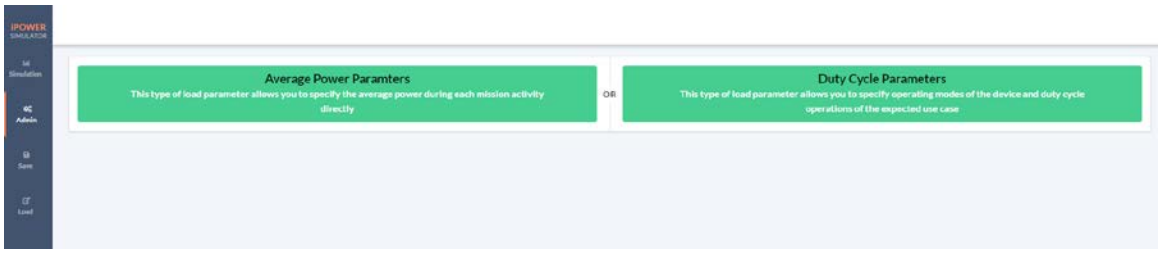

Figure 50: Load Power Options

The average power method is best for a load with consistent usage throughout an activity or when the average load is easily calculated. Figure 51 shows the average power data entry page.

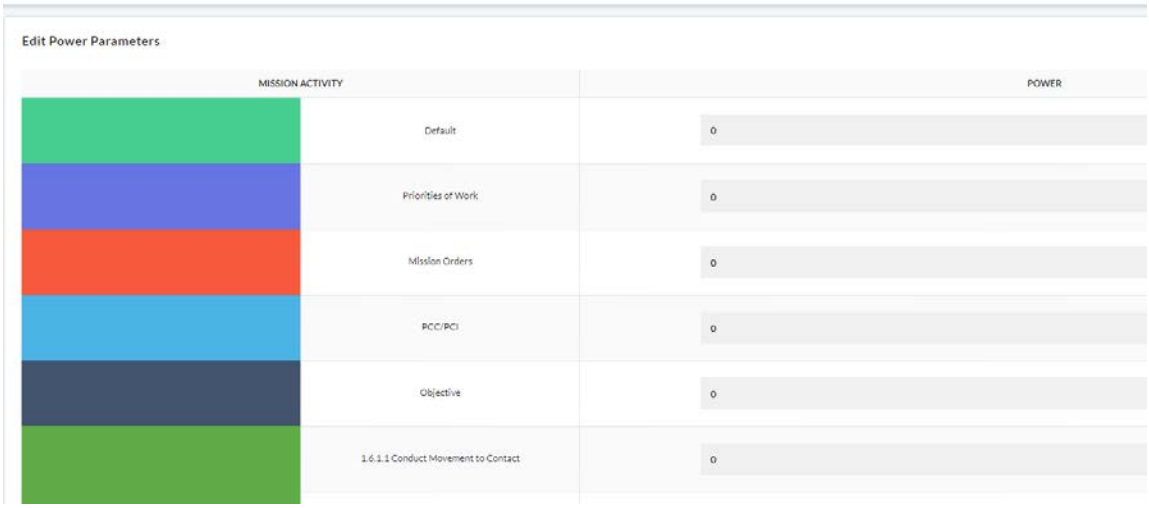

Figure 51: Load Power Usage by Activity (Average)

The duty cycle parameters entry is more complicated but allows better customization. Figure 52 depicts the first part of establishing the duty cycle parameters. Load modes are first defined. In the example load, modes are defined for radio as in transmit (TX), receive (RX), or standby. In each mode, a voltage and current is input.

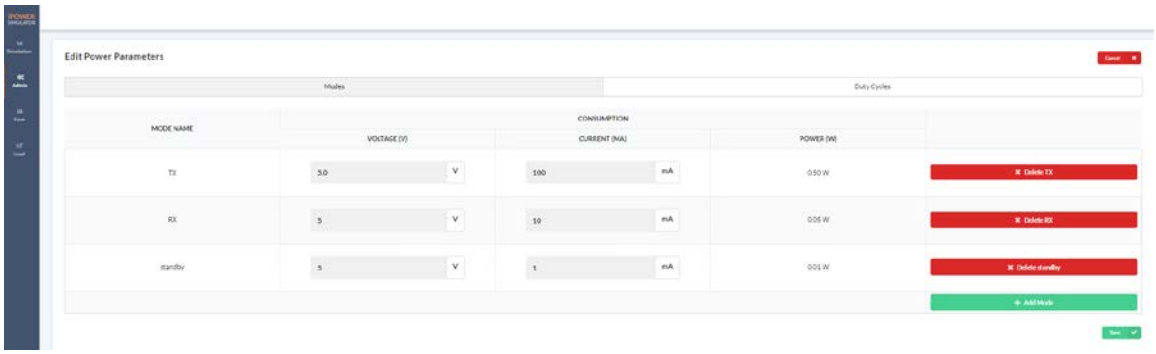

Figure 52: Load Power Usage by Activity (Mode)

Once complete, the user will select duty cycles. The duty cycle tab allows the user to enter percentages of mode usage per activity. Figure 53 shows this duty cycle array.

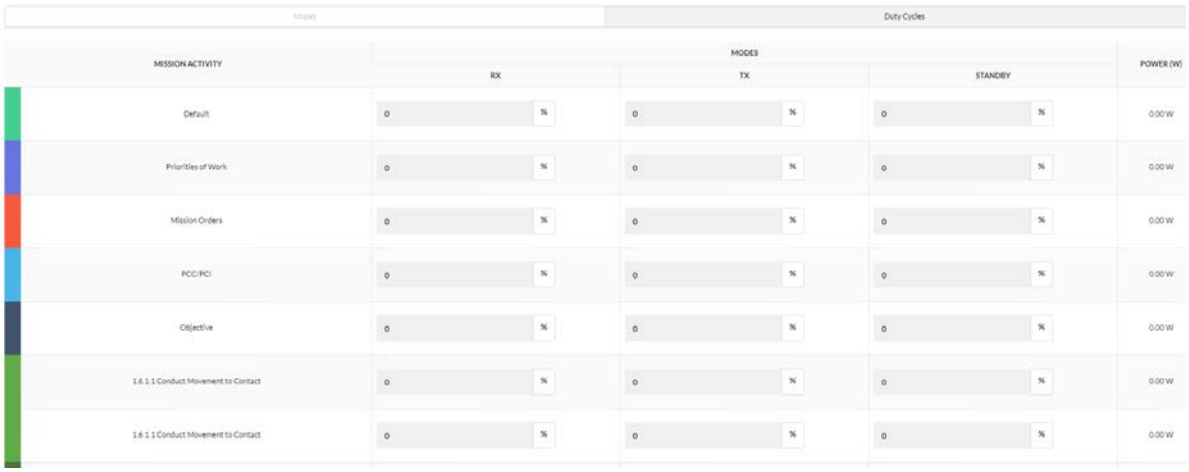

Figure 53: Load Power Usage by Activity (Duty Cycle)

Loads with only a few modes and an activity databases with few activities allow a simplified data entry process. Some loads have several modes which complicate the data entry process. An example is the AN/PEQ-15 Illuminator. The AN/PEQ-15 is a weapon-mounted sight that has a visible laser pointer, IR illuminator, and IR laser pointer with varying degrees of power output. In total, there are five modes to account for in each activity. The array for this device is in Figure 54 and is more complicated than most devices. Once the loads database is populated, the Power Manager database is built.

Modes	Duty Cycles					
MISSION ACTIVITY	MODES					POWER (W)
	IR ILLUMINATOR LOW	IR ILLUMINATOR HIGH	IR LASER	VISIBLE LASER	STANDBY	
Default	0 %	0 %	0 %	0 %	100 %	0.00 W
Priorities of Work	0 %	0 %	0 %	0 %	100 %	0.00 W
Mission Orders	0 %	0 %	0 %	0 %	100 %	0.00 W
PCC/PCI	1 %	1 %	1 %	1 %	96 %	0.00 W
Objective	10 %	5 %	10 %	5 %	70 %	0.01 W
1.6.1.1 Conduct Movement to Contact	5 %	5 %	5 %	5 %	80 %	0.01 W
1.6.1.1 Conduct Movement to Contact	5 %	5 %	5 %	5 %	80 %	0.01 W
1.6.1.2 Conduct Attack	15 %	10 %	15 %	10 %	50 %	0.01 W
1.6.1.3 Conduct Raid	15 %	10 %	15 %	10 %	50 %	0.01 W
1.6.4.2 Conduct Area Defense	10 %	5 %	10 %	5 %	70 %	0.01 W
1.6.4.3 Conduct Position Defense	10 %	5 %	10 %	5 %	70 %	0.01 W
1.6.4.4 Establish Battle Position	10 %	5 %	10 %	5 %	70 %	0.01 W
1.6.4.5 Establish Strong point	15 %	10 %	15 %	10 %	50 %	0.01 W
1.6.4.3 Conduct Position Defense: Resupply	15 %	10 %	15 %	10 %	50 %	0.01 W
1.6.1.2 Conduct Attack: Support by Fire	15 %	15 %	15 %	15 %	40 %	0.02 W
1.6.4.3 Conduct Position Defense: Consolidate on Objective	10 %	10 %	10 %	10 %	60 %	0.01 W

Figure 54: Load Usage Complexity Example (AN/PEQ-15)

C. POWER MANAGER DATABASE

Power managers are devices, virtual or physical, that manage the power into and out of other equipment. These other pieces of equipment are either a load, battery, or harvester. IPOWER does not distinguish between a virtual or physical manager; however, this report treated the power manager as a virtual interface between individual devices. For example, a battery connected though the power manager to the radio.

Similar to the other databases, the power manager database is found on the admin page. Selecting a new power manager on the power manager subpage in Figure 55 allows the creation of a new power manager.

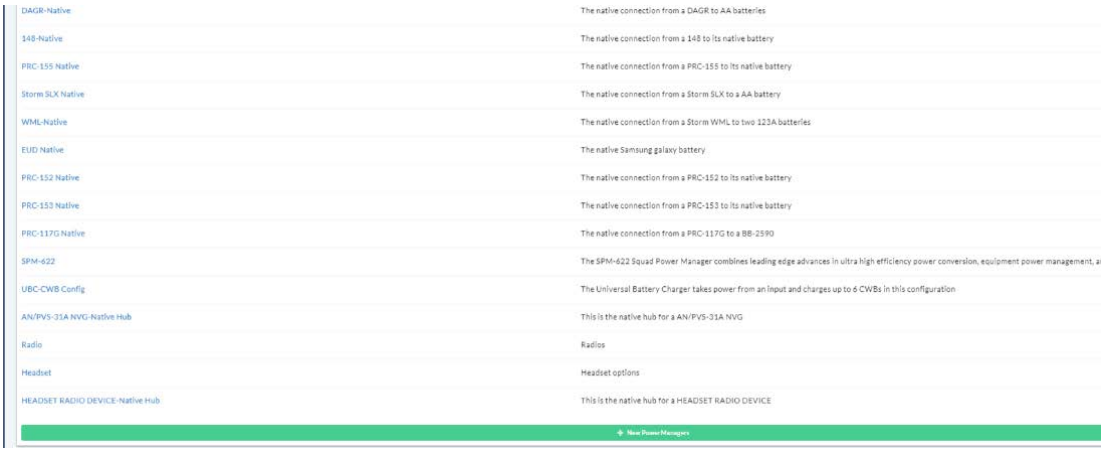

Figure 55: Power Manger Database

Figure 56 shows the parameters for these devices that include a name, description, physical properties, power consumption of the manager, and then user selectable ports.

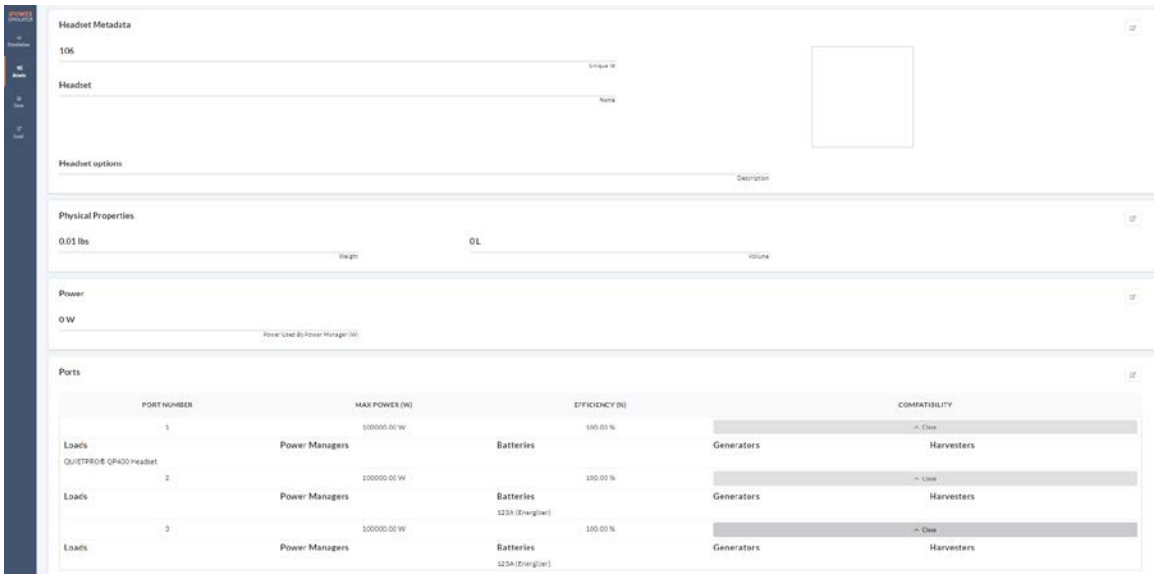

Figure 56: Power Manager Parameters (Single Item)

Power manager ports are how the individual devices interface with each other. In Figure 56, the example illustrates the “headset power manager.” This power manager has three ports: a single headset (QP400 Headset), and two batteries. In this example, each port has only one item. Two battery ports are needed because the QP400 headset uses two A123 batteries.

In Figure 57 a more complicated power manger is created. In this example, a “radio” power manager is created with only two ports were each port has multiple configuration options. Port 1 lists all the radio versions load database and port 2 lists all the batteries in the batteries database used by each radio. In the equipment selection phase of the scenario development, when the radio power manager is selected, dropdown boxes will allow the user to select a specific radio and the appropriate battery. Non-native batteries were used because there are several batteries that are compatible with each radio. If a native battery were used, the user would not have the option to choose between several possible batteries.

Each port also accounts for maximum power throughput and efficiency. Because we chose to use the power managers as a virtual interface, large maximum power and 100% efficiency was selected.

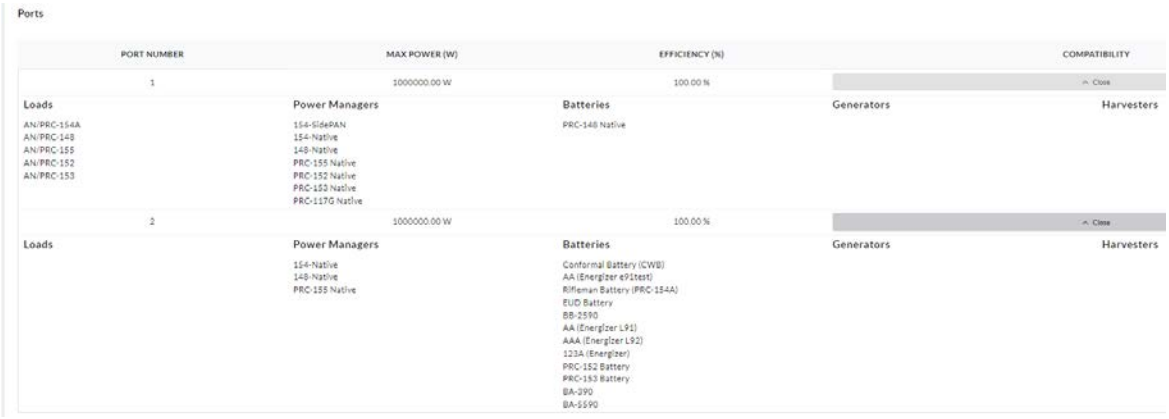

Figure 57: Power Manager Parameters (Complex Item)

D. MISSION BLOCK DEVELOPMENT

The mission block development starts at the IPOWER title screen, shown in Figure 39, where the user inputs a simulation name, location in latitude/longitude (limited to Washington, DC, and Aberdeen Proving Ground in IPOWER Version 3.1.0). Once created, the user adds activities from the activities database and inputs the activity into a Gantt style timeline. Figure 58 shows the mission data for the baseline mission scenario. The activity and duration are on the left side of the figure, and the bar lines describe the activity over time though the center of the figure. The sun's diurnal cycle and temperature (from the preexisting environmental database) is depicted along the bottom of Figure 58.

Once the necessary missions are added and the timeline is correct, the next section to complete is the equipment utilization section.

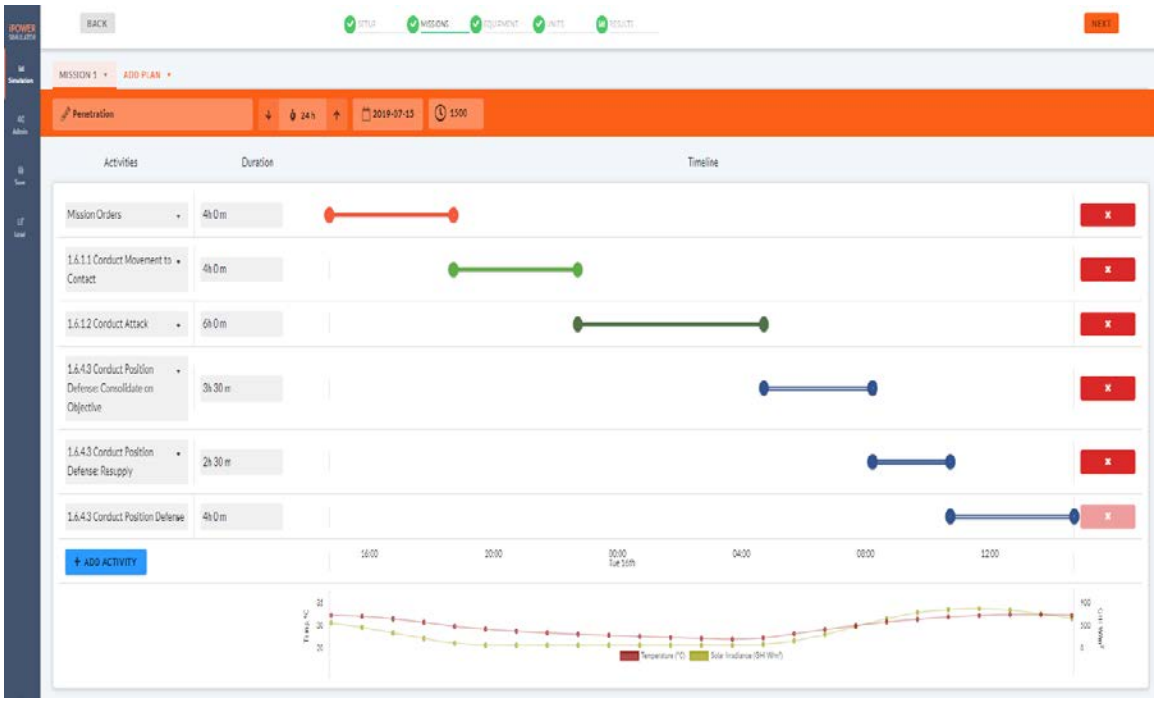

Figure 58: IPOWER Mission Development Screen

E. UNIT PERSONNEL/EQUIPMENT DATA

Equipment usage begins on the equipment tab. IPOWER version 3.1.0 is limited to the platoon level, which is sufficient for this analysis. Selecting “add squad” begins the process in Figure 59. Creating a squad begins with the first member. In this scenario, the squad leader is first.

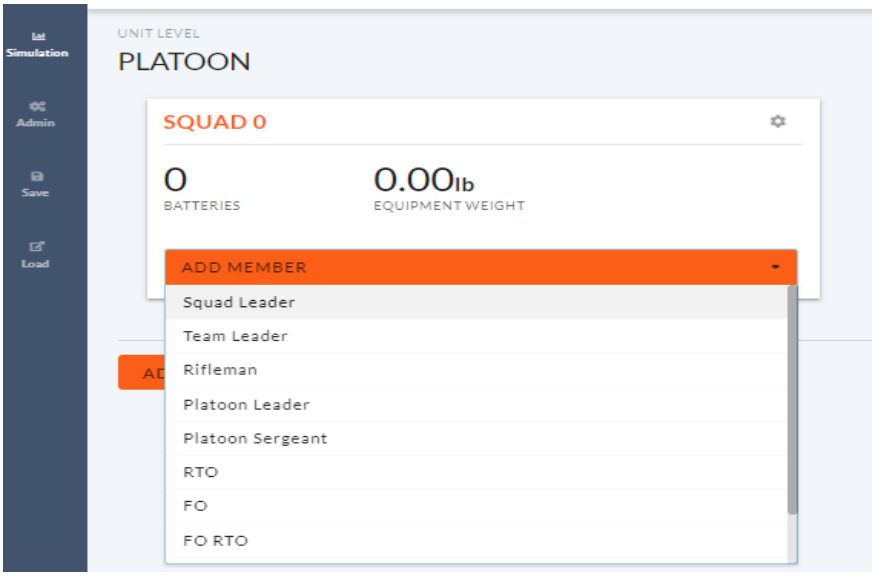

Figure 59: IPOWER Unit/Equipment Build-up

Within the member page, the “add system” button allows the addition of equipment as either a body system, helmet system, or weapon system. Figure 60 shows a partially built member. In the figure, a helmet system is added (QP400 headset with its two A123 batteries).

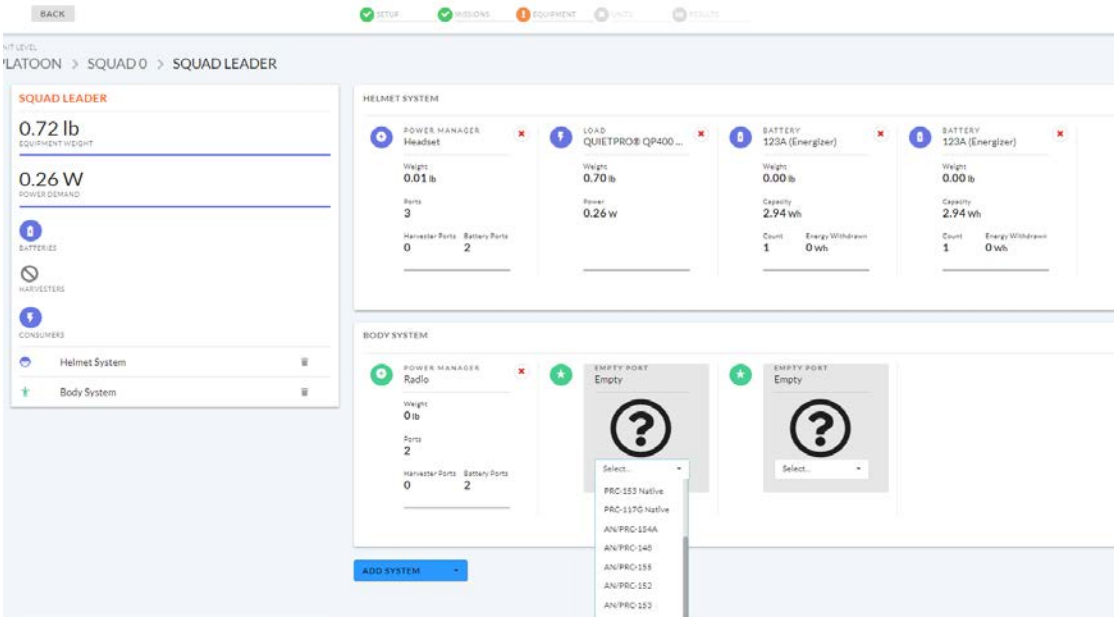

Figure 60: Add Equipment

Additionally, a body system is being added. The radio power manger is added and the user is in the process of selecting a specific radio and battery. On the left of the member page, shown in Figure 61, the weight and power demand updates as systems are populated.

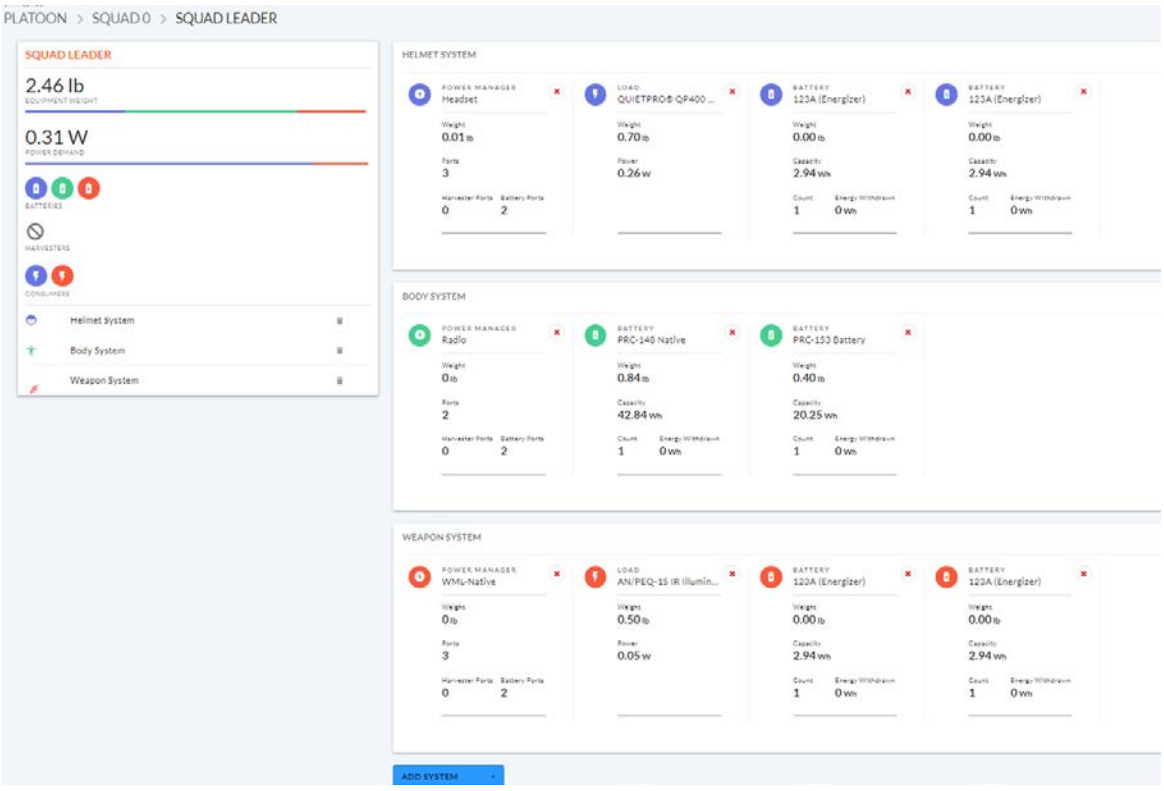

Figure 61: IPOWER Unit Buildup

Selecting the higher echelon in the top left of the member page returns the user to the higher level. At each of these higher echelons, the equipment weight and power demand are displayed. Once each squad is completed, the simulation can continue to the units tab, which assigns specific units to their mission.

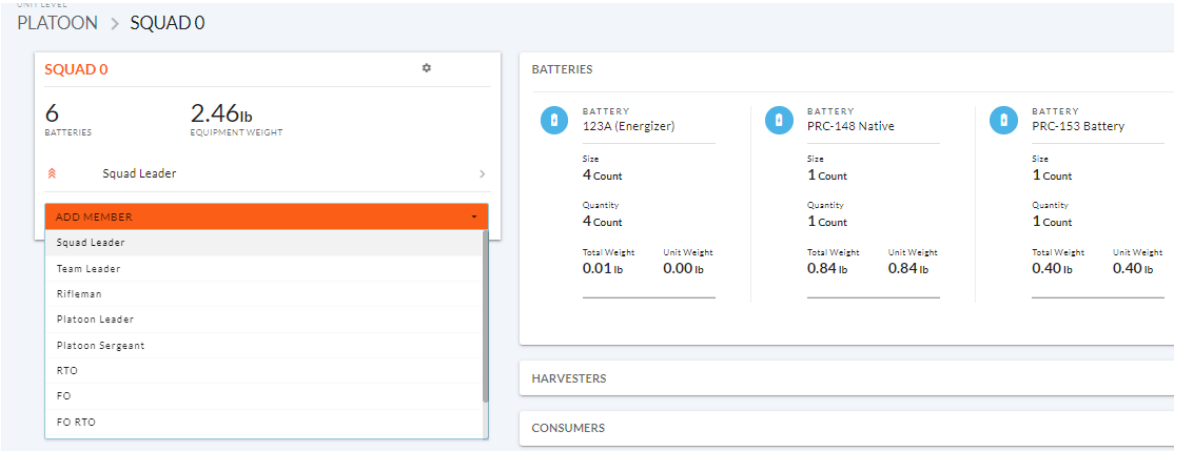

Figure 62: Unit Development Growth

F. MISSION ASSIGNMENT

The final section before the results assigns the units to missions. Figure 63 shows the user interface for this section. Only one mission was constructed in this scenario and was titled "penetration." Each squad is depicted below Mission 1. The first two are highlighted and have an orange check indicating they are assigned to Mission 1. Squad 0–2 is not selected for Mission 1 to show the options.

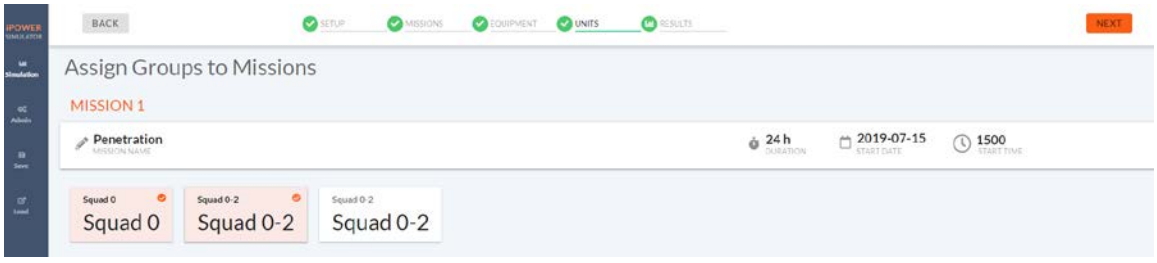

Figure 63: Assign Units to Missions

G. RESULTS

The Results section populates after the IPOWER algorithms run. Figure 64 shows the initial power summary section. The key information populates first at the top with the total energy consumed during the mission, batteries used, and the weight of the equipment. Bold numbers show the collective usage but the power summary will also describe the universal breakdown between helmet systems, body systems, and weapon systems.

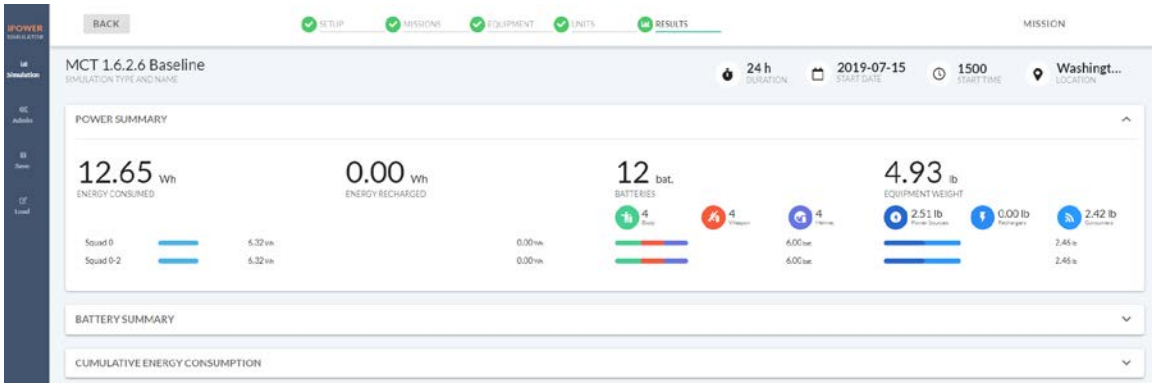

Figure 64: IPOWER Results Screen

The battery summary and cumulative energy consumption sections display further detailed data for each unit and individual. These results are analyzed for a specific mission.

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