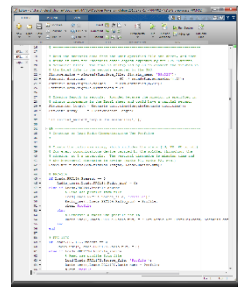
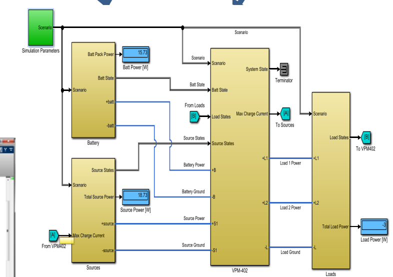
Improving Soldier Power System Performance Through Simulation





$$\Delta Q = \int_0^T I(t)\,dt$$

Richard Stroman and Karen Swider-Lyons

U.S. Naval Research Laboratory, Washington DC

2015 NDIA Joint Service Power Expo, Cincinnati OH

27 August 2015

Guiding Question

Can we use system-level modeling and simulation to improve soldier power systems?

Maybe… Investigating two approaches:

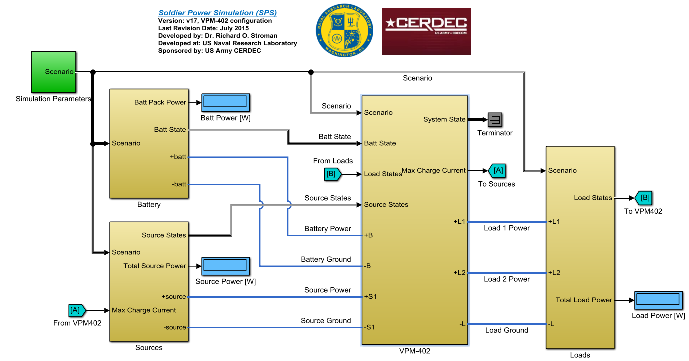
1. ***Develop a time-domain soldier power simulation to guide design, operation, and logistics decisions with quantitative and verifiable predictions.***

2. ***Develop software that runs on soldier-carried devices to aid system-level control and optimization.***

Soldier Power Simulation: Two Versions

Simulink model for detailed analysis

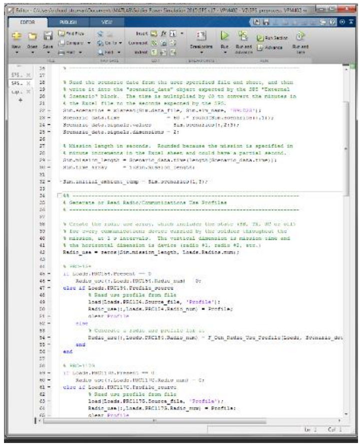
- Provides a clear graphical representation of the system
- Very flexible framework is easily changed to accommodate different topologies and components
- Users can easily interrogate any part of the power system
- Tends to run slowly (~5-15x real time)
- Status: Functional and in use



Simulink version of SPS

MATLAB model for real-time analysis

- Compiles into C++ to run on EUD or power manager
- Less flexible and less detailed than Simulink, but faster
- Status: In development



MATLAB version of SPS

Both Versions

- Step through time to resolve system state
- Rely on same component sub-models

Model Inputs and Outputs

Inputs

- Components & Connections
- Ambient Temperature, Location, Date, Time of Day
- Pre-defined Soldier Activities* and/or Device Use Profiles

Outputs

- Current and Voltage (Power) to/from each component
- Calculated environment variables (e.g. solar irradiance)
- Device states (e.g. battery SOC or radio TX/RX)

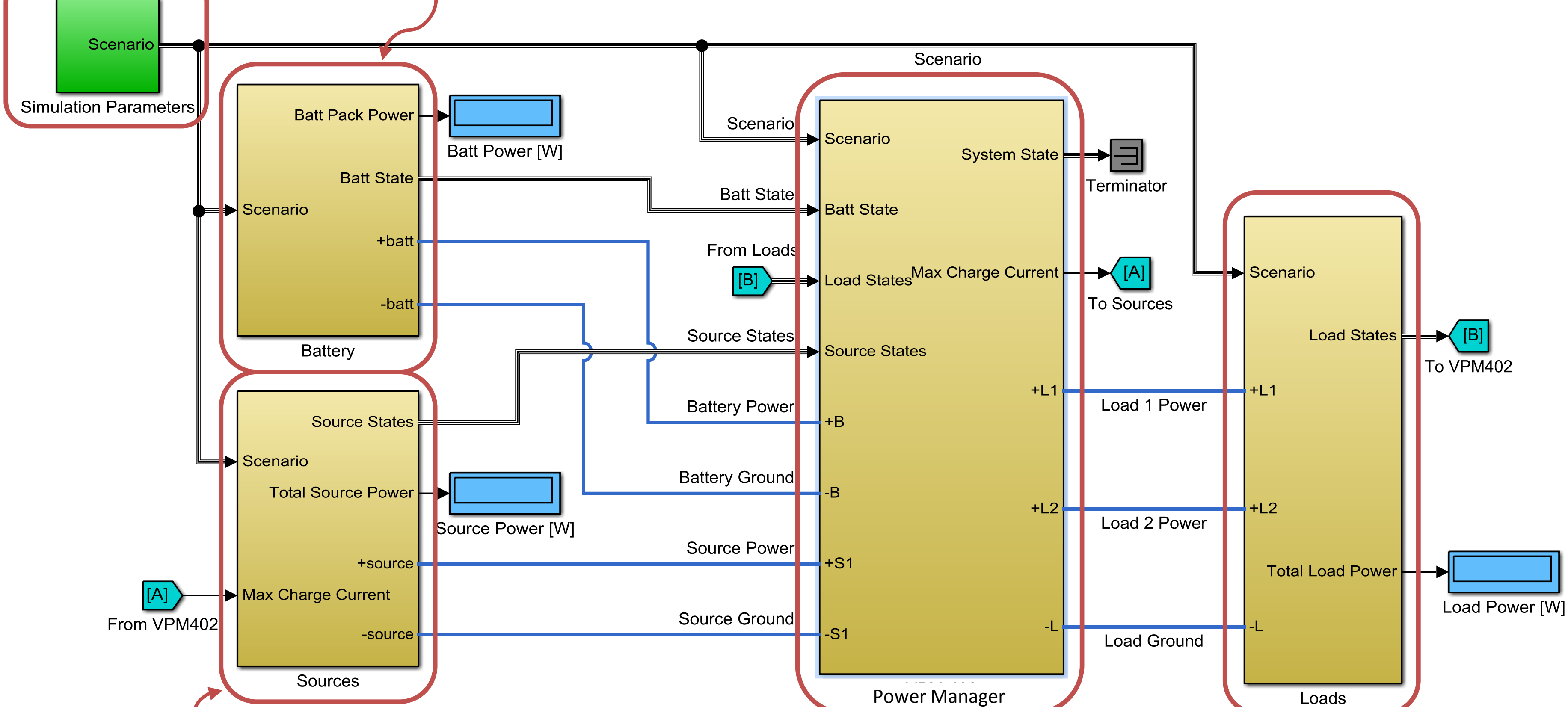
**NSRDEC 2021 Soldier and Small Unit Power and Data Architecture Study*

Soldier Activities: Marching, Camp Activities, Sleep, Scout/Patrol, Surveillance, Attack/Engage, React to Contact

Top Level Block Diagram

Defines the scenario to be simulated

Calculates battery SOC and voltage from integrated current & temperature



Calculates current from energy harvester(s)

Insures energy is conserved among components

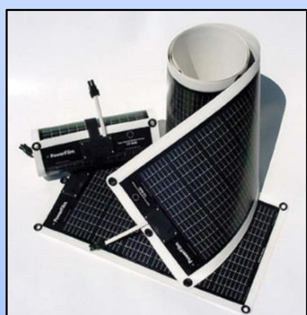
Calculates current drawn by energy load(s)

Case Study: Comparing Standard and Simulation Methods

- **Standard:** Time-averaged estimates of gross energy consumption and harvesting
- **Simulation:** Time-resolved estimates of energy flows among components using an integrated system model with sub-models sensitive to varying conditions.

Hypothetical Soldier Power System

Conformal Wearable Battery



Rollable solar panel

Power Usage (W) of Equipment by Activity
PRC-117G
PRC-154
Peltor Headset
EUD
PAS 13 LTWS
DAGR
PVS-20
PEQ-15

Typical Loads

Hypothetical 24 h mission begins at 06:45 and 42°N

Step Duration [min]	Soldier Activity	Temperature [°C]
180	Camp Activities	31
120	Scout/Patrol	31
45	Camp Activities	31
120	Marching	31
120	Camp Activities	22
60	Scout/Patrol	20
180	Surveillance	25
120	Sleep	23
30	Surveillance	23
30	Attack/Engage	23
120	Marching	23
30	Camp Activities	23
285	Sleep	23

Standard Method: Nominal Estimates

Total mission requires: 504 Wh

Case #1: Use nominal battery (CWB) and mission characteristics

- Battery: 14.8 V, 10 Ah → 148 Wh, 2.6 lb
- 504 Wh / 148 Wh = 3.4 batteries without harvesting… round to 4

Case #2: Use nominal solar panel (PF-R28) characteristics

- Solar Panel: 15.4 V, 1.8 A → 28 W (AM1.5), 1.8 lb
- Harvesting for 5.3 h eliminates 1 battery and saves 0.8 lb.

Conclusions

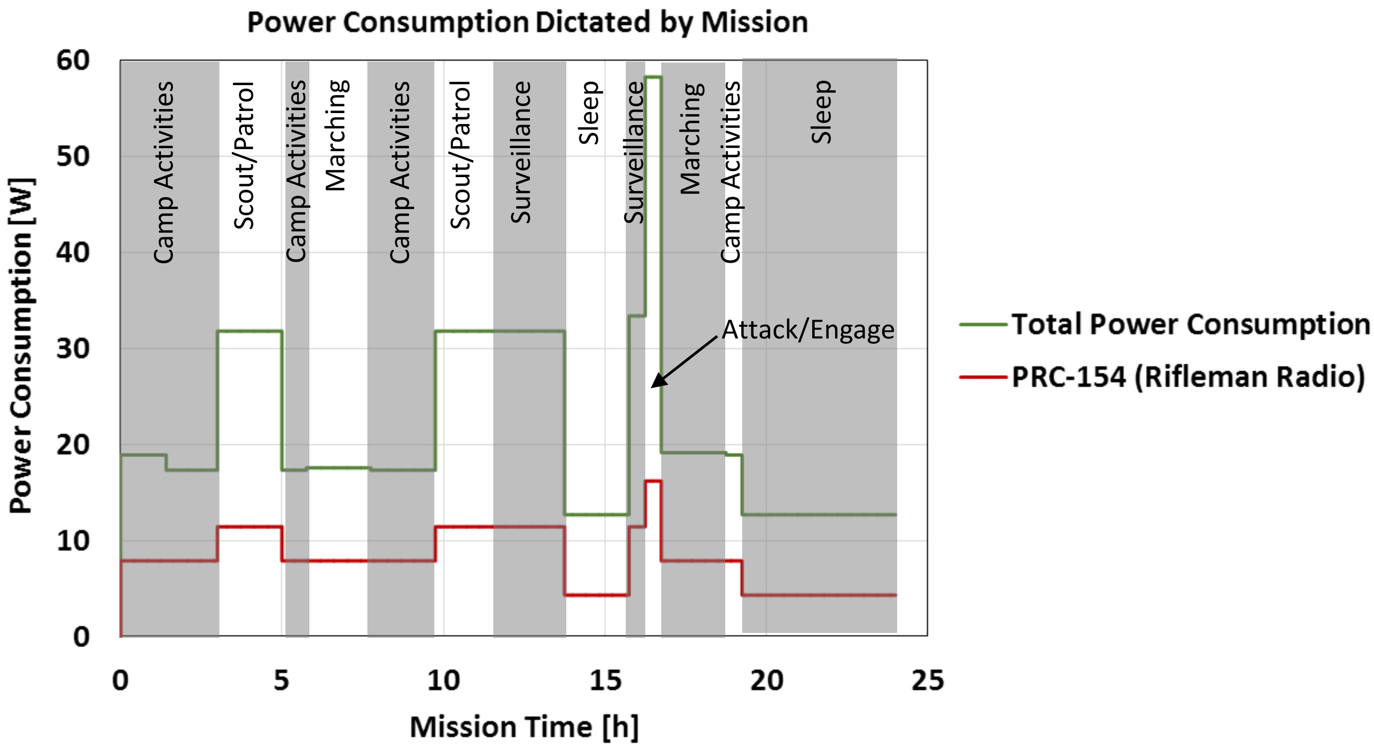
- Need at least 3 batteries; probably 4
- Solar panel may be justified if charging time > 2.5 h, or if mission runs longer than expected.

This analysis does not account for: high-energy use periods, environmental variation, or influence of soldier activities!

Simulation: Analyze Contributions of Loads

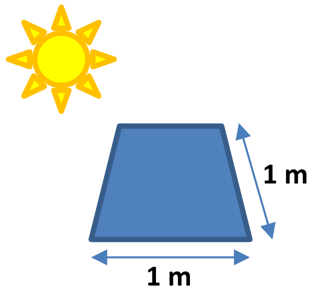
Total Power

Single Device (Rifleman Radio)



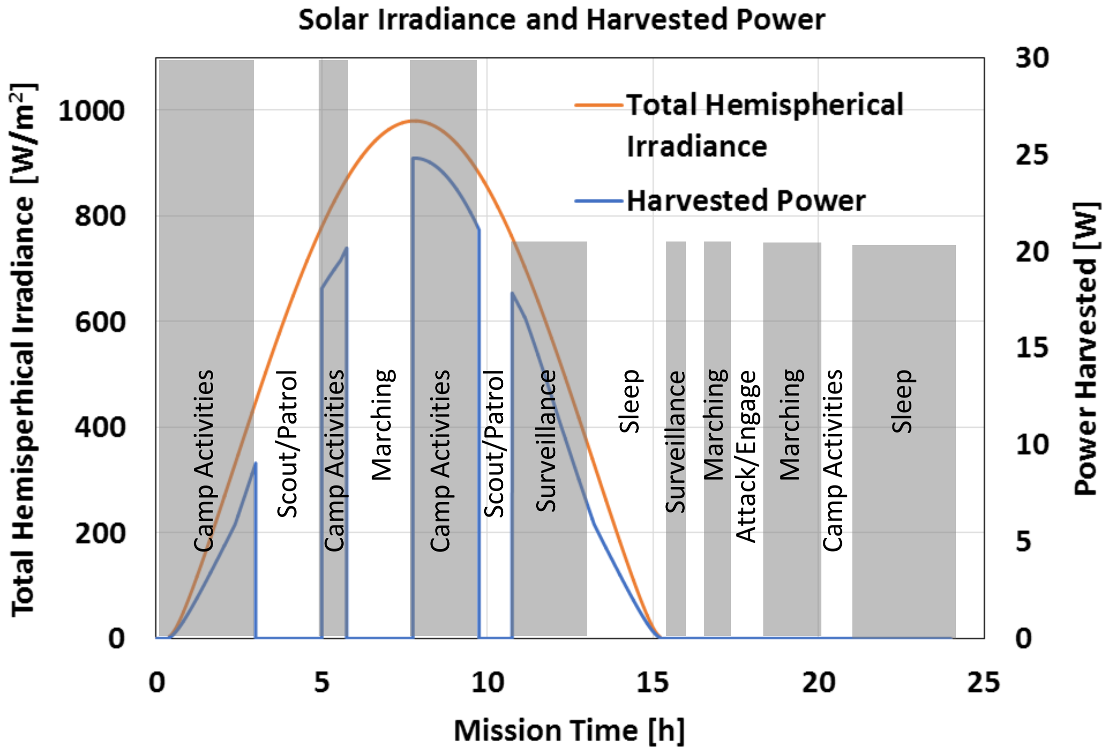
- Load power calculated at each timestep; average could be replaced by greater detail
- Shows how power consumption is related to soldier activity
- Variation in load captures nonlinear effects (i^2R losses in battery, etc.)
- Can be used to relate system performance to power demand

Simulation: Analyze Contributions of Sources



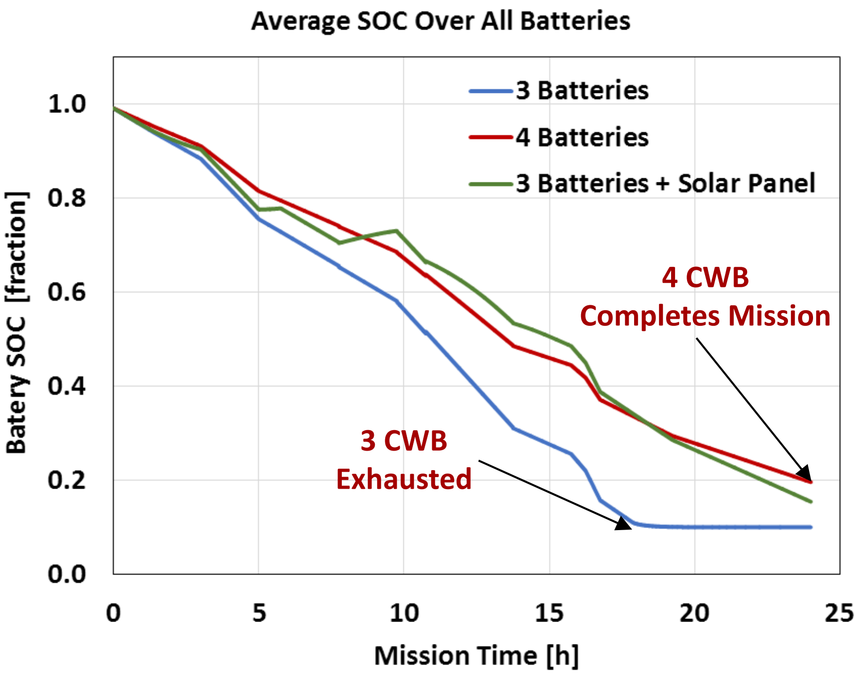
Solar Irradiance

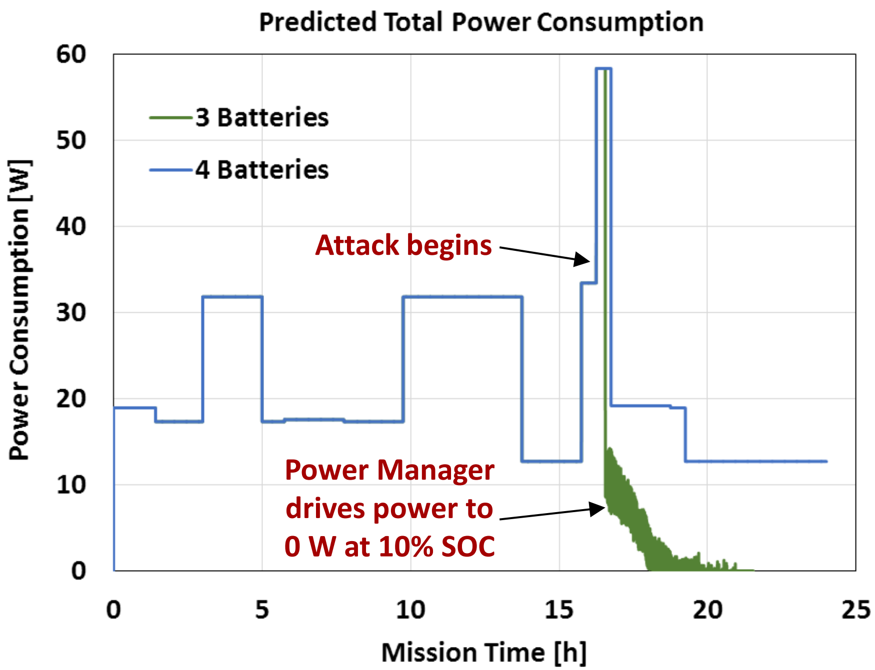
Harvested Power



- Energy harvesting only when appropriate
- Includes variation in solar availability and panel efficiency with temperature
- Future versions may use NREL data to scale irradiance curve to account for typical local weather

Simulation: Resolve Component States and Power Flows





- Simulation shows how ***power system state corresponds to the order and duration of soldier activities.***
- Example: Night attack occurs at low SOC, so the high power draw breaches V_{min} and shuts down the batteries in the 3 CWB case. They would have lasted longer if the soldier withdrew the energy more slowly, e.g. marching.

Case Study Conclusions

- **Nominal method can yield useful energy estimates, but neglects time-dependent factors which strongly influence energy availability at a given point in the mission.**

- **Simulation method resolves the time-dependent factors, such as: battery SOC, temperature, solar irradiance, and alignment of harvested energy availability with energy needs.**

- **What does the time-resolution of a simulation buy us?**
  - Greater insight when designing an energy system for a specific mission – Where are the bottlenecks and surpluses? What strongly influences performance?
  - Opportunity to optimize systems with respect to mission and environment
  - Fair comparisons of component performance with respect to standard scenarios
  - Springboard for developing intelligent energy management controls and hardware

Component Models: Battery Block

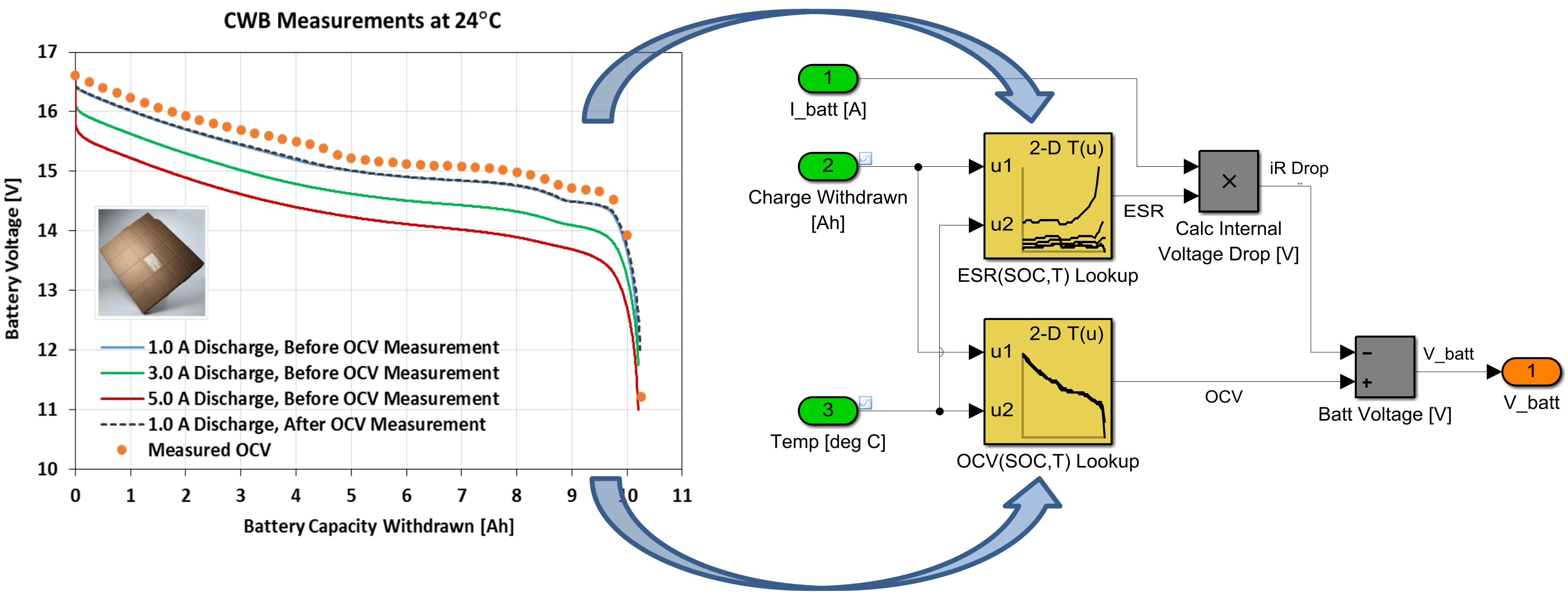
Battery Model Development

- Measured *OCV* as function of *SOC* and *T*
- Fitted *ESR* to multiple discharge curves at different temperatures

$$V_{batt} = V_{OCV}(SOC, T) - I * ESR(SOC, T)$$

Battery Model Functionality

- Predicts battery *V* as function of *SOC*, *T* and *I*…with slow (~second) transients
- Validated by comparing measured and predicted *V* for a hypothetical use profile
- Could be dynamic with reactive components



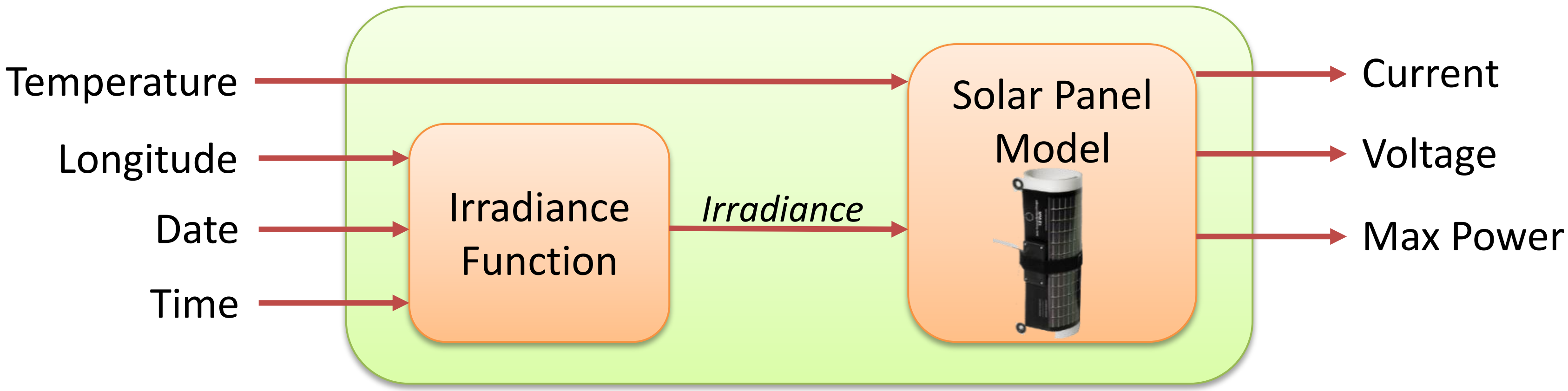
Component Models: Sources Block

Solar Panel Model Development

- Use *Bird, et al.** model to predict solar irradiance vs. date, time, and location
- Measured PF R28 panel voltage and current as functions of irradiance and temperature; built look-up table to capture relationship

Solar Panel Model Functionality

- Predicts harvested power as function of date, time, and location; assumes maximum power point tracking
- Power = 0 for incompatible soldier activities
- Does not include influence of weather



- Detailed model enables utility analysis vs. environment and mission.
- Could add other harvesters (knee flexion, Lightning Pack, etc.)

* R. E. Bird, *A Simple, Solar Spectral Model for Direct-Normal and Diffuse Horizontal Irradiance.* Solar Energy, 1984. **32**(4): p. 461-471.

Component Models: Loads Block

Each load model uses soldier activity *or* defined device state to estimate load power:

Increasing time resolution and complexity

Average Power

- Assume device draws constant (average) power during each soldier activity
- Device power from *NSRDEC 2021 Soldier and Small Unit Power and Data Architecture Study*

Power Usage (W) of Equipment by Activity	Marching	Camp Activities	Sleep	Scout / Patrol	Surveillance	Attack / Engage	React to Contact
PRC-117G	8.19 W	8.19 W	8.19 W	17.16 W	17.16 W	35.10 W	35.10 W
PRC-154	7.88 W	7.88 W	4.31 W	11.44 W	11.44 W	16.20 W	16.20 W
Peltor Headset	0.01 W	0.01 W	0.01 W	0.01 W	0.01 W	0.01 W	0.01 W
EUD	0.58 W	0.58 W	0.18 W	0.98 W	0.98 W	0.98 W	0.98 W
PAS 13 LTWS	0.00 W	0.66 W	0.00 W	1.32 W	1.32 W	1.32 W	1.32 W
DAGR	0.90 W	0.00 W	0.00 W	0.90 W	0.90 W	0.90 W	0.90 W
PVS-20	1.20 W	1.20 W	0.00 W	1.20 W	1.20 W	2.40 W	2.40 W
PEQ-15	0.40 W	0.20 W	0.00 W	0.40 W	0.40 W	0.50 W	0.50 W
Flashlight (Rifle)	0.00 W	0.17 W	0.00 W	0.00 W	0.00 W	0.83 W	0.83 W
Flashlight (Helmet)	0.00 W	0.02 W	0.00 W	0.00 W	0.00 W	0.05 W	0.05 W

Defined Device State

- Specify device state (e.g. radio TX, RX, standby) as a function of time
- Correlate device power consumption with state to estimate power consumption
- *Typical device use profiles not yet characterized or correlated to soldier activity!*

Component Models: Power Manager

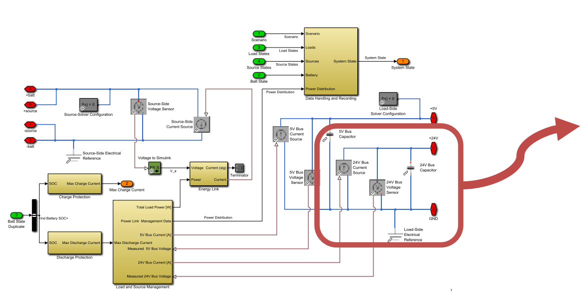
Capture main functions without duplicating specific hardware

- Ensure conservation of energy among batteries, sources, and loads
- Impose DC/DC converter inefficiency where appropriate
- Protect against battery overdischarge and overcharge
- Supply desired voltages to loads and manage harvested energy

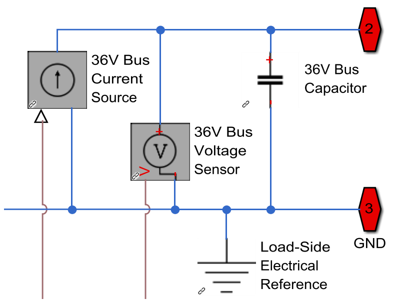
VPM-402

ISPDS

Others?



Power Manager Model



Example: Circuits are modeled explicitly

Become a platform for controls and energy management strategy development?

- Add state machines, external code, comms links, etc. to expand functionality and evaluate advanced controls
- Add greater electronics detail to evaluate hardware system architectures
- Evaluate energy management strategies vs. simulated environments and missions

Future Work: Defined Device States

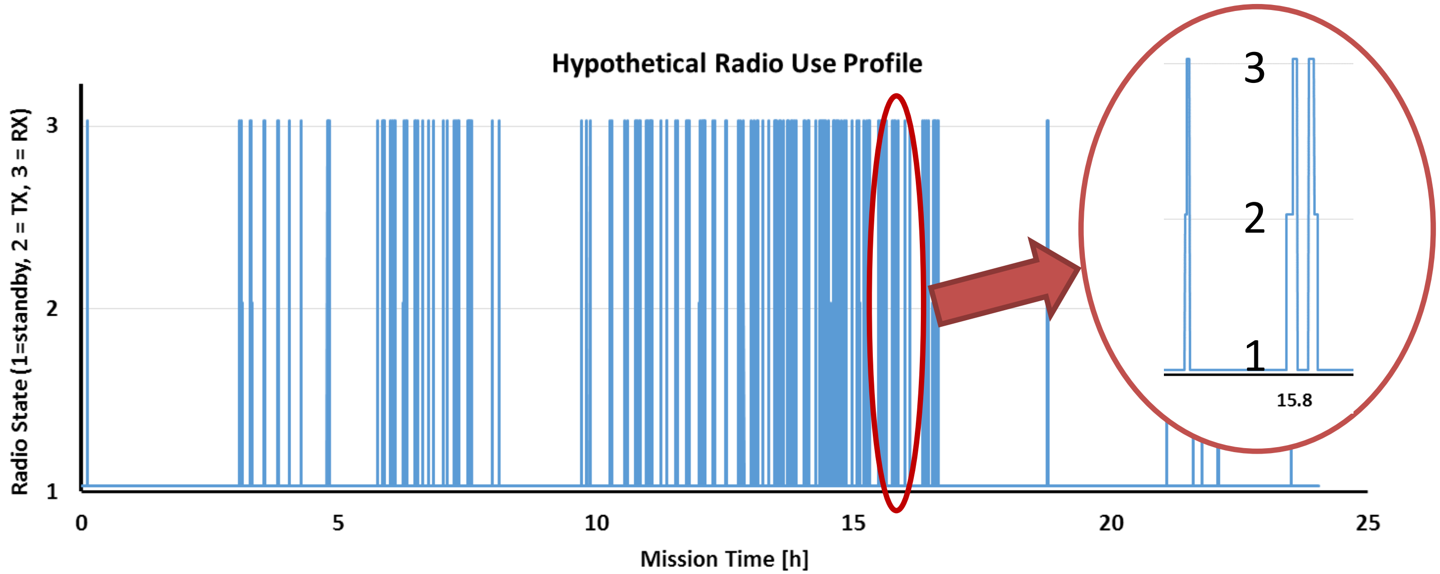
Assume radio use (state) can be characterized by four parameters:

1. Mean TX duration: 7 s
2. TX duration standard deviation: 2 s
3. Overall duty cycle: 0.1% to 5%
4. "Conversation" periodicity: 5 to 30 min

Duty cycle and periodicity vary with soldier activity… e.g. more frequent radio use during enemy engagement, or less frequent when in camp

Use stochastic approach to generate radio state profiles with above characteristics

- Radio use can occur at any time; most likely at middle of "conversation"



Future Work: Improving Energy Situational Awareness

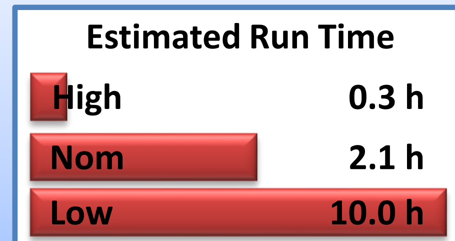
Leverage Component Models to Help Soldiers Make Energy-Informed Decisions

Mission Energy Planning Tool

- Adapt soldier power model to run on EUD with simplified interface
- Can use it to estimate energy resources (batteries) required and plan for harvesting

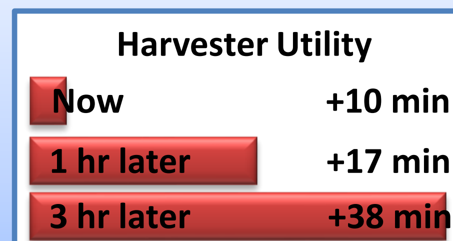
Estimate Run Time with Battery and Load Models

- High, Nominal, and Low power consumption scenarios…
- Adjust scenarios based on recent soldier activity; "learn"
- Soldier can modify behavior to use energy more efficiently



Identify and Compare Harvesting Opportunities

- Harvesting productivity as additional run time per hr harvesting
- Example: solar panel utility varies throughout day



How Might These Software Tools Be Useful?

System Design

How to make components work best together?

Conformal Battery

Rifleman Radio

System Operation

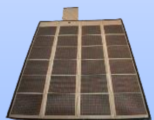
How to maximize harvesting opportunities?

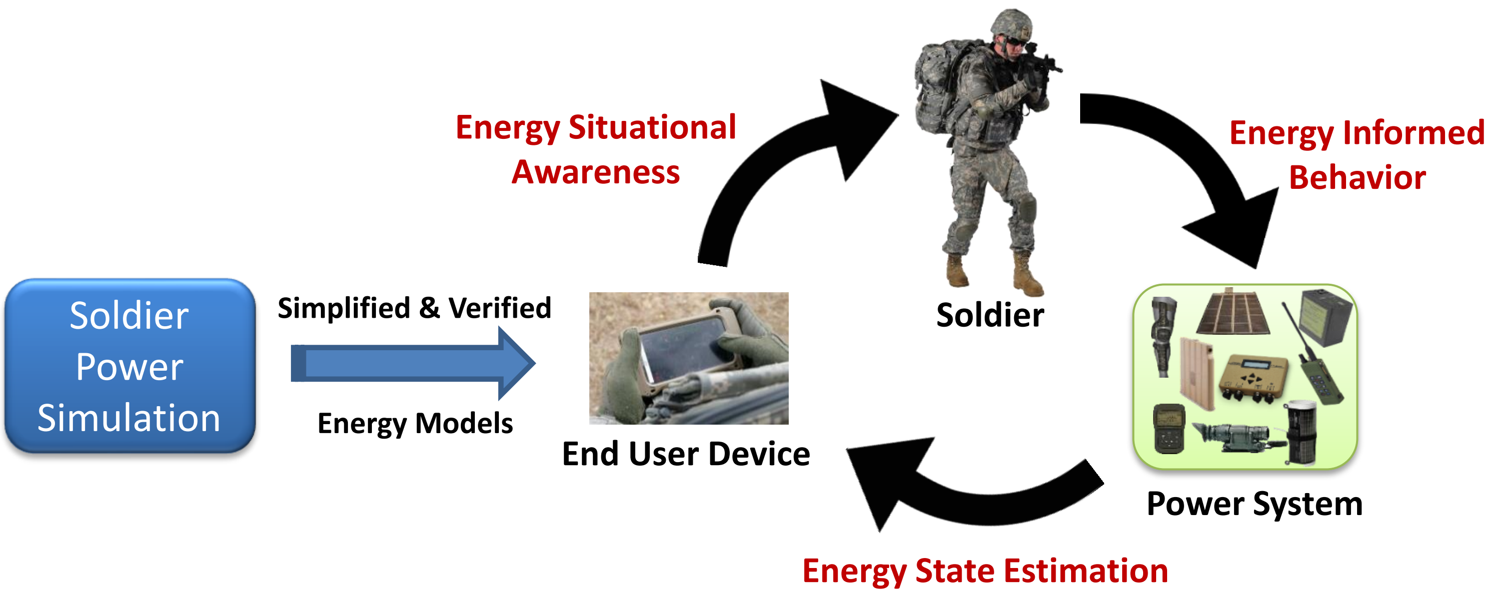
Rollable Solar Panel

Conformal Battery

Logistics

Which/how many components for a given mission & environment?





Wrap-Up

Conclusions Thus Far:

- **We have a model framework for detailed soldier power system simulations**
- **Simulations may provide greater insight into soldier power needs/opportunities**
- **Unclear yet whether simulation offers same advantages for other systems**

Possible Next Steps:

- ***Model validation with manager, battery, harvester, and load***
- ***Move from average power to specific device states***
- ***Improve component model fidelity***
- ***Add more batteries, harvesting devices, and/or loads to the library***
- ***Roll elements of the simulation tool into a mission planning tool***

Acknowledgements

Sponsor: US Army Communications and Electronics Research, Development and Engineering Command

Collaborator: Naval Surface Warfare Center, Dahlgren