Cost-Based Risk Management for Mission Critical Microgrids

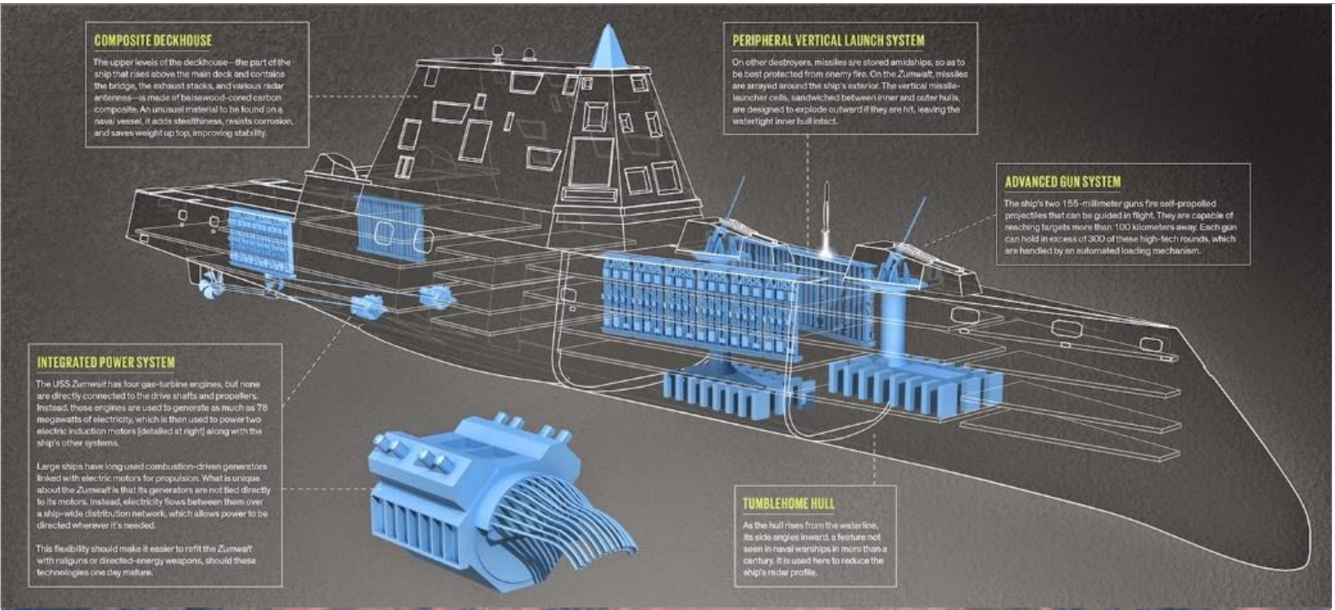
Robert Baker

Colorado State University

Systems Engineering PhD Student

Summary: Risk decisions for a remote based mission critical microgrid consider operational metrics in a value model unique to the mission owner. Incorporating a grid model with the mission model set can generate cost metrics over varying time horizons and inform a mission owner's tailored risk management process.

Mission Critical Microgrid Examples



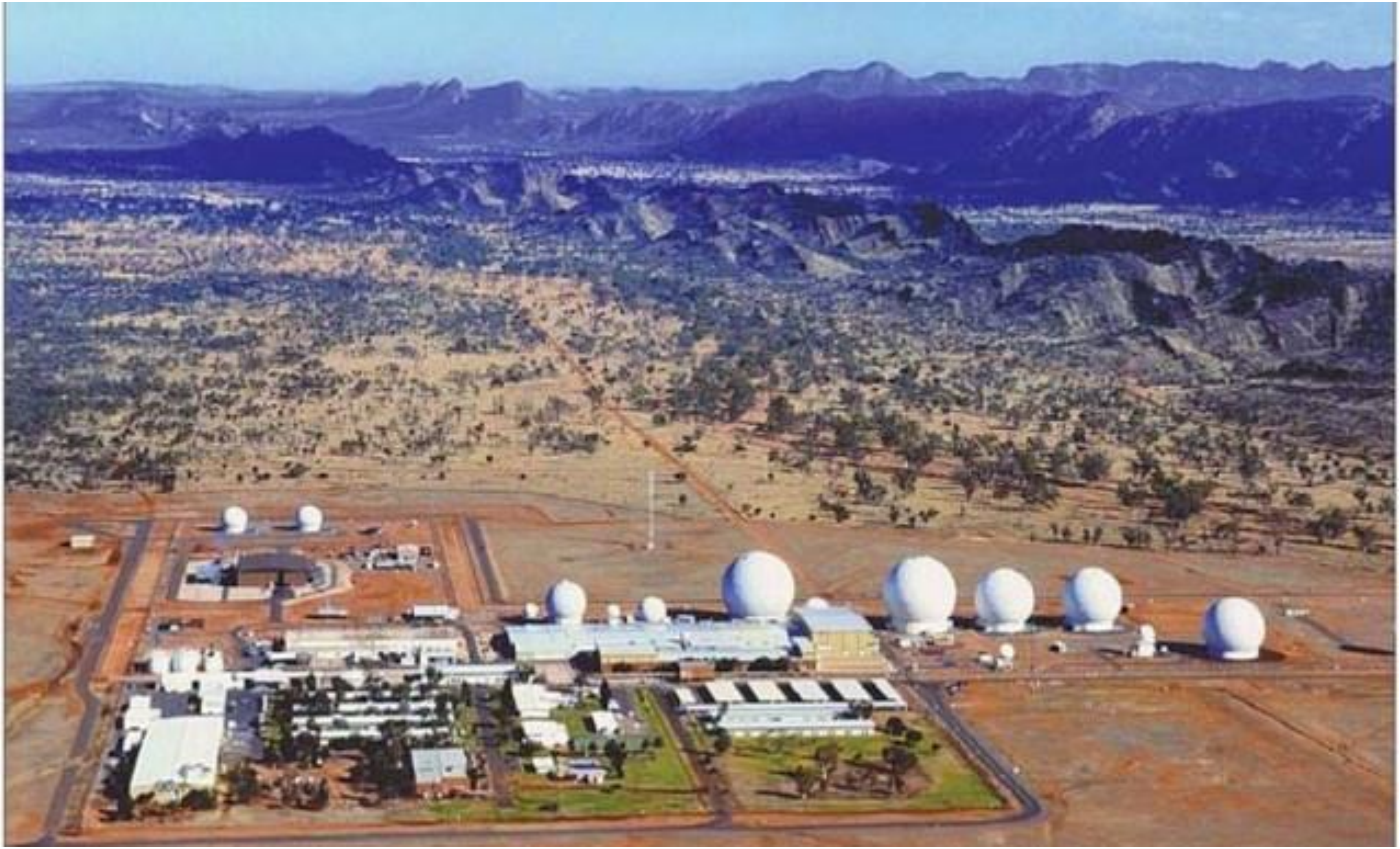
U.S. Navy destroyer with Integrated Power System architecture

illustration by John MacNeill
IEEE Spectrum Magazine, August 2013

Pine Gap
Satellite Tracking Station

a pattern for a remote outputs

Inherited system: remote outpost



© cover image, "Inside Pine Gap : the spy who came in from the desert" by David Rosenberg", 2011

Operational Decision Making

Operational risk management differs from that done during development and test.

Examples: changes in requirements, mission creep, contract support issues, limited spares or other resources, configuration changes, adversary and natural hazards.

Mission owners make risk decisions involving factors outside of the grid. Accordingly they may consider nonmyopic operational strategies.

Risk Management Process

Identify hazards. What can go wrong? Humans are good at this.

Often cannot quantify the return on investment in detail or develop controls with detailed cost data.

If you have a list of hazards and a list of controls but the decision maker never implements them, you should rethink your risk management process…it may not be useful.

Example hazards for inherited site:

Hazard 1. Adversary causes severe physical damage to primary generation, insufficient generation for all loads.

Hazard 2. Cyber intrustion forces system into protected mode, withholding privileges, unable to execute automatic demand response plans.

Hazard 3. Electric vehicle load tasked at 2x forcing occasional shedding of security and life support loads.

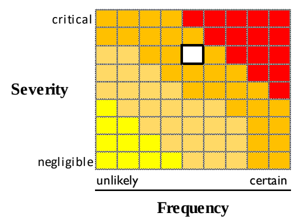
Risk Management Process

For each hazard, assess the risk. By convention we use a combination of frequency and severity, matrixed then banded as high, moderate, or low. Then we prioritize based on risk in order to develop controls.

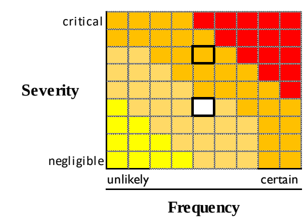
For each control developed, assess frequency and severity again. Often results in a reduction in severity from which we gauge the improved risk. The decision maker then is presented a cost-vs.-risk-reduction proposition.

Identify Hazards	Assess Initial Risk	Develop Controls	Assess Residual Risk

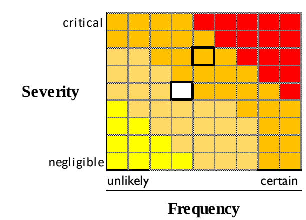
Adversary causes severe physical damage to primary generation, insufficient generation for all loads



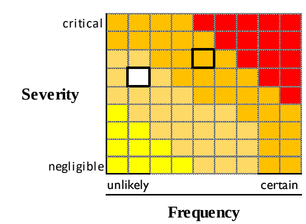
Re-task electric vehicle fleet to storage mode



Holistic demand response, maximize diesel gensets



Hasty grid tie to regular power grid



Problem of dollar costs vs. operational constructs, address by expanding metrics.

Common Metrics and their Limits

Availability. A_O is a function of reliability, maintainability, and supportability. A_O = MTBM / MTBM + MDT where MTBM is the mean time between maintenance, all corrective and preventative maintenance, and MDT is the mean downtime including actual time to perform maintenances, acquiring spares, etc.

Reliability. Generally defined as the probability that an item will not fail over a defined time. Drives MTBF projections. Accounted for in Monte Carlo simulations.

Survivability. Can be defined as "a reliable system with reconfiguration capability."

Cost. Funds provided to the mission owner from an overarching resource pool.

Average values like A_O lack fidelity to assess performance over short time horizons.
Funds are not always available to mission owner, but other mission resources are.
By what value model do decision makers weigh cost and performance?
Data, models, and framework required to project costs over time horizon of interest.

A Method for Metrics

Introduce metrics that support operational decision making.

Define metrics in that are relevant and usable in an operational impact statement

Use metrics to inform trade decisions on risk controls

Use metrics with the risk management process

Treat selection of controls as trade decisions

Data, modeling, simulation, algorithms to support generation of metrics

Metrics in Various Decision Techniques

It can be helpful to categorize cost metrics as m_C and performance metrics as m_P

Decision making techniques for trades can be:

- optimization — ***max*** $w_P m_P / w_C m_C$ subject to constraints
- weighted methods
- utility — Multi-Attribute Utility / Multi-Attribute Cost

Per the grid owner's perspective, and contract bounds, the only relevant metrics may be the AO of the mission critical loads and the sustainment costs.

Per the mission owner’s perspective, many more metrics may be useful, such as % time security coverage, area coverage of aerial EV reconnaissance, ground sensors emplaced by ground EVs, number of fuel resupply missions required.

Furthermore, the weights applied may vary given periods of operational interest.

Cost Metrics, or Operational Impact

Although we will treat operational impact as a cost, you could also treat its inverse (operational availability) as a performance. Since we are focusing on the available nature of the mission critical loads, it seems appropriate to consider anything that is spent to support that as a cost.

Operational impact is the cost to mission owner along all mission lines. It is the "so what" qualified on an "operationl impact statement" that justifies requests for support.

metrics usable to make trade decisions	m
cost metrics, a subset of m	m_C
maximum duration of load unavailable for mission	$m_{C,EV\_DURATION\_UNAVAILBLE}$
number of missed missions	$m_{C,EV\_MISSED\_MISSIONS}$
percent of area not covered by sensors	$m_{C,SENSOR\_MISSED\_AREA}$
amount of fuel required to run diesel gensets	$m_{C,FUEL}$
number of fuel convoys required to supply fuel	$m_{C,NUMBER\_OF\_CONVOYS}$
… etc.	

So $m_C \in \{m\}$ and $m_C =$
$\{ m_{C,EV\_DURATION\_UNAVAILBLE}, m_{C,EV\_MISSED\_MISSIONS}, m_{C,SENSOR\_MISSED\_AREA}, m_{C,FUEL}, m_{C,NUMBER\_OF\_CONVOYS}, \cdots \}$

Metrics in Risk Management Process

How can risk management include metrics?

The hazard can be written in terms of metrics.

Hazard 1, written without metrics.
Adversary causes severe physical damage to primary generation, insufficient generation for all loads.

Hazard 1 as a function of metrics.
Adversary causes severe physical damage to primary generation, resulting in A_O < 'threshold value'

Or

The risk can be assessed in terms of metrics.

Develop metrics that matter
Assess initial risk in terms of system metrics
Omit the translation to "high, moderate, or low"

When does this method apply? **NOT ALWAYS!** Look for:
- time horizon focused on operational events
- controls involve automated demand response trades
- incident response, hazard has already occurred

Data Requirements

A model of the inherited system, M_0

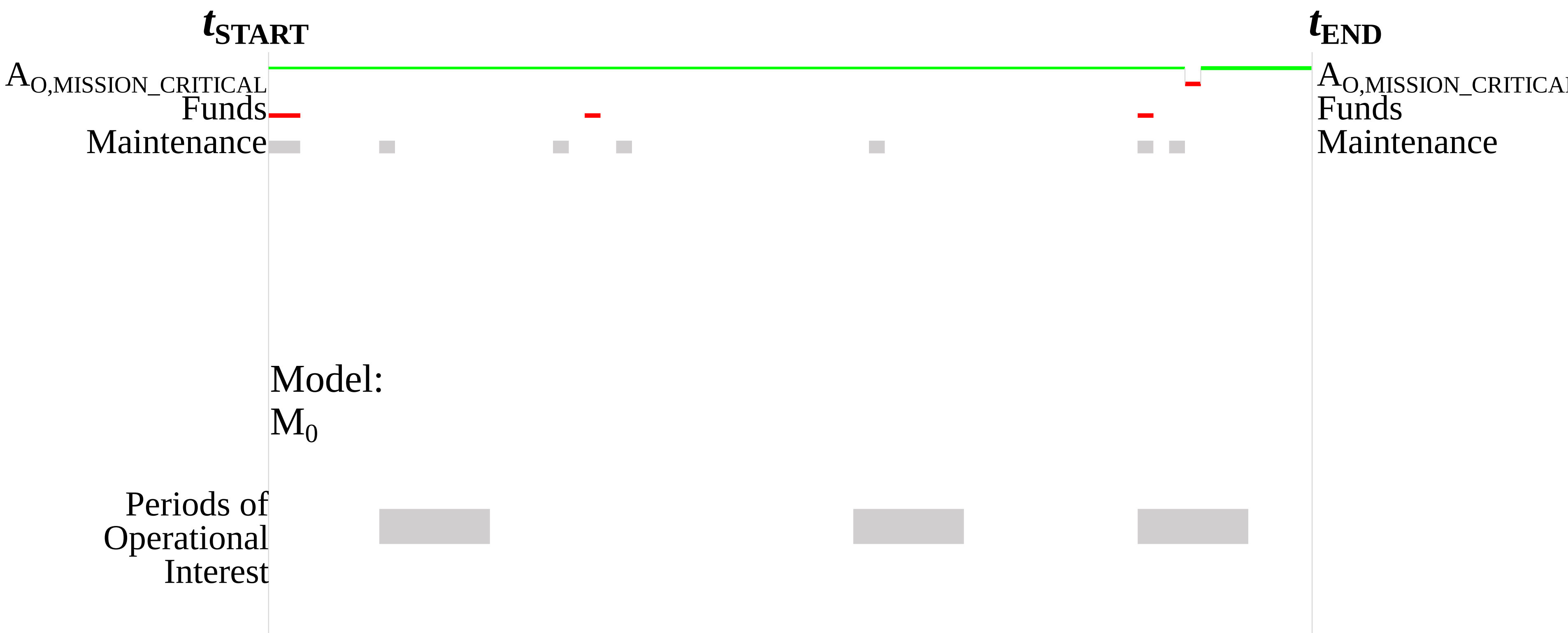
All data required to simulate such as weather forecasts, load profiles, and system control logic.

Identify Hazards	Assess Initial Risk	Develop Controls	Assess Residual Risk
A model of the system affected by hazard, M_H Possibly a large configuration change. System control logic should perform per original or changed configuration.		A model of the control to be implemented, M_C May have many resource requirements spread out in time to effect the controls.	

Goal: Decisions trace back to metrics, which are generated via modelset simulated over time horizon, dependent on data that spans the time horizon.

Example (1/6)

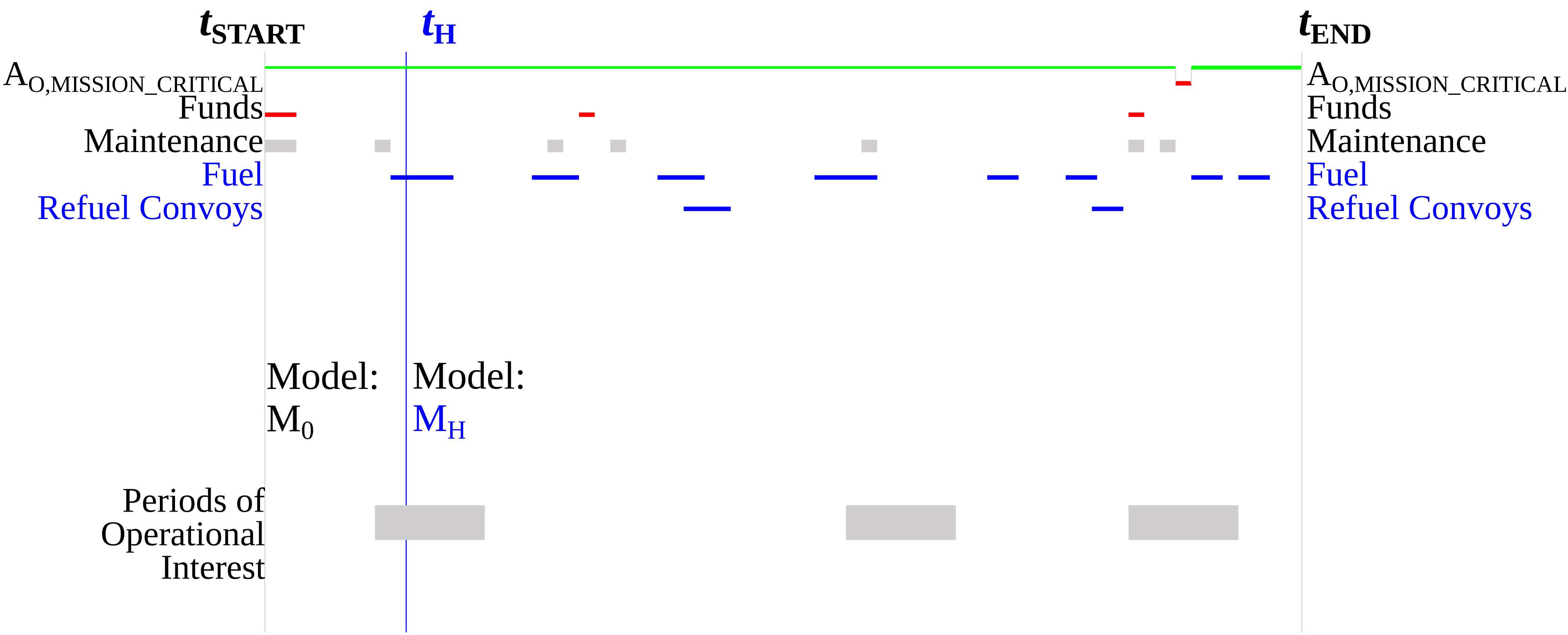
Set time horizon and define metrics



Select a time horizon of operational interest.

Example (2/6)

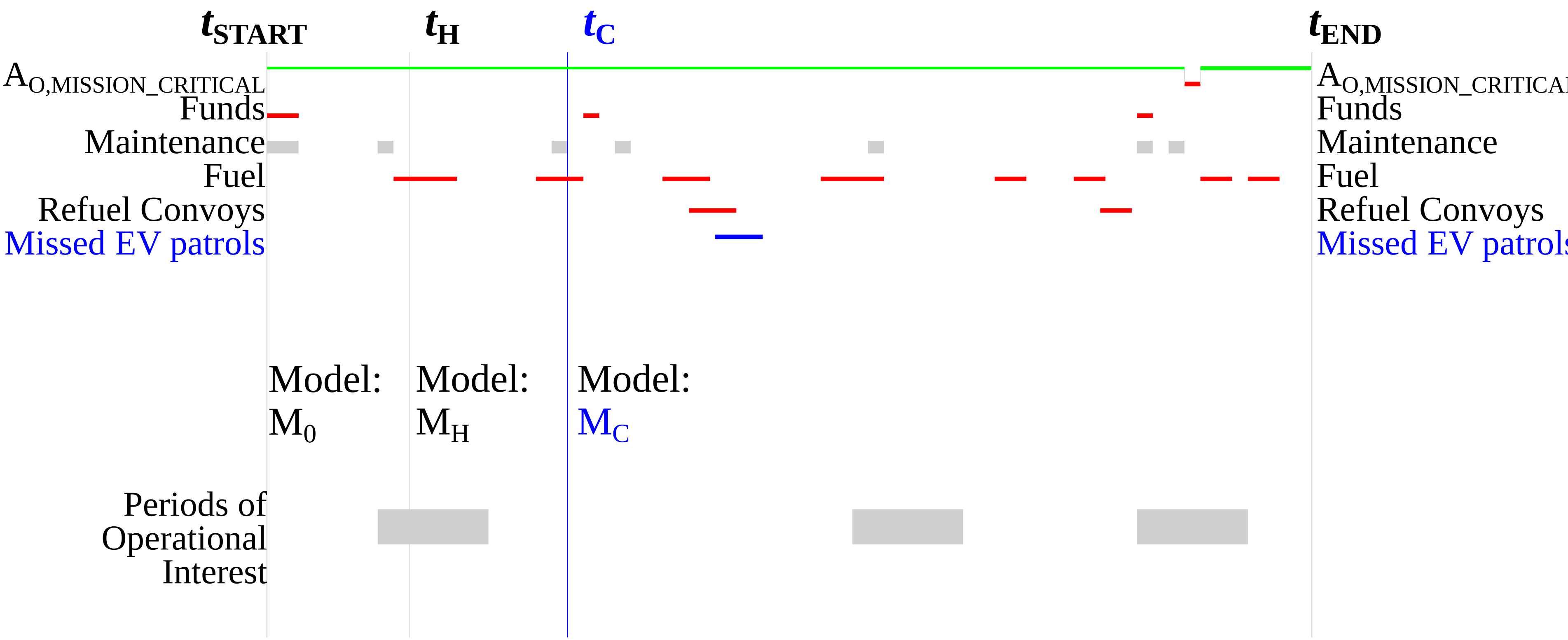
Introduce Hazard



Introduce a hazard where adversary causes severe physical damage to primary generation, leaving insufficient generation for all loads.

Example (3/6)

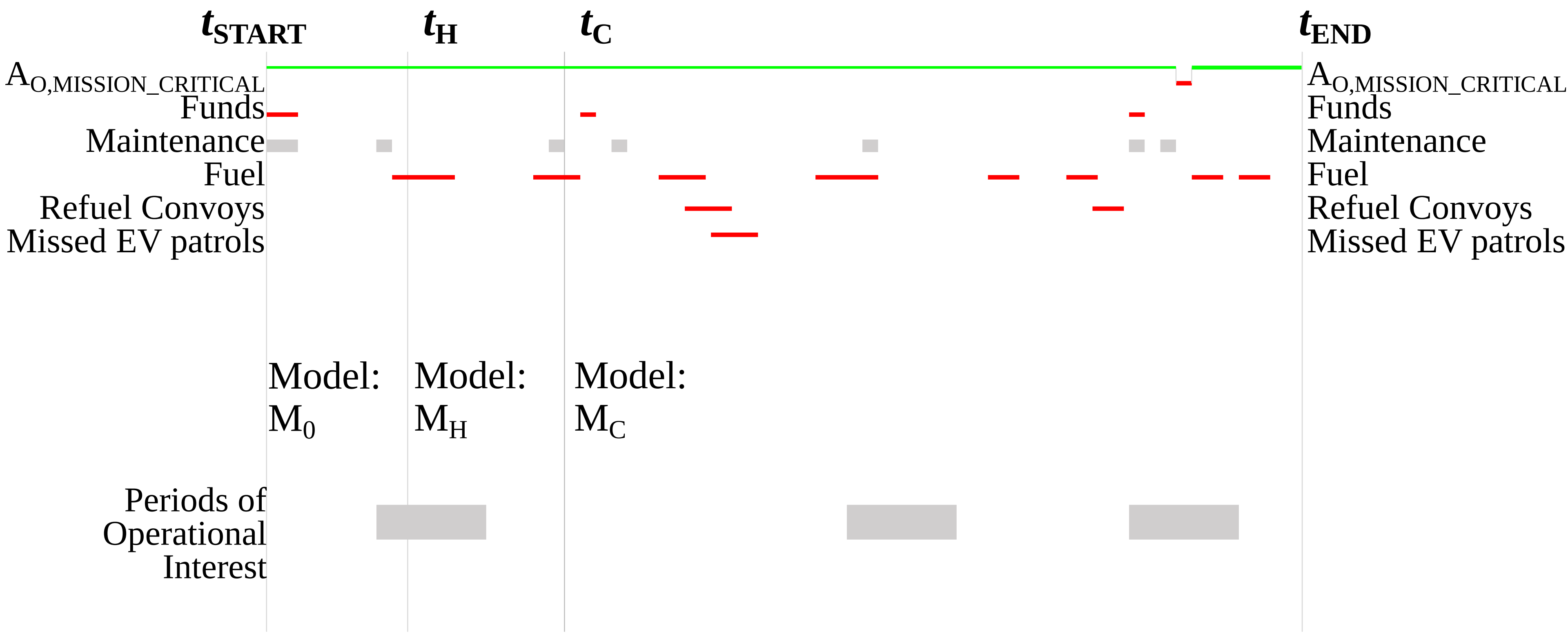
Implement Control



Introduce a control, curtailing the electric vehicle fleet, which changes the load on the grid and the storage available to the grid.

Example (4/6)

Metrics in the Risk Management Process

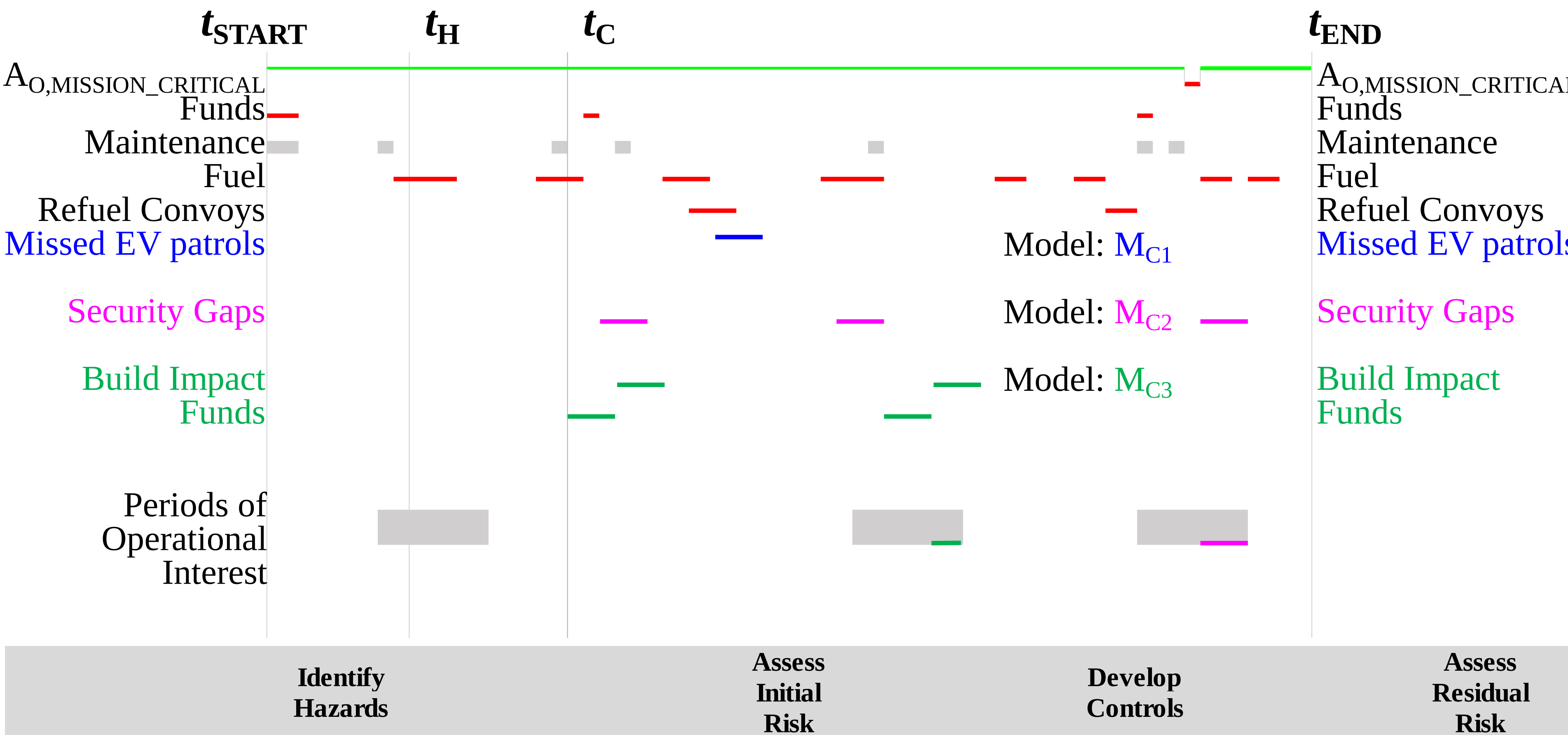


Identify Hazards	Assess Initial Risk	Develop Controls	Assess Residual Risk

Initial risk is a function of *m* generated by
M_0 evaluated from t_{START} to t_H +
M_H from evaluated from t_H to t_{END}

Residual risk is a function of *m* generated by
M_0 evaluated from t_{START} to t_H +
M_H from evaluated from t_H to t_C +
M_C from evaluated from t_C to t_{END}

Example (5/6)
Value Model



Initial Risk $\{ m_{FUNDS}, m_{MAINTENANCE}, m_{FUEL}, m_{REFUEL\_CONVOYS} \}$

Residual Risk, Control 1 $\{ m_{FUNDS}, m_{MAINTENANCE}, m_{FUEL}, m_{REFUEL\_CONVOYS}, m_{MISSED\_EV\_PATROLS} \}$

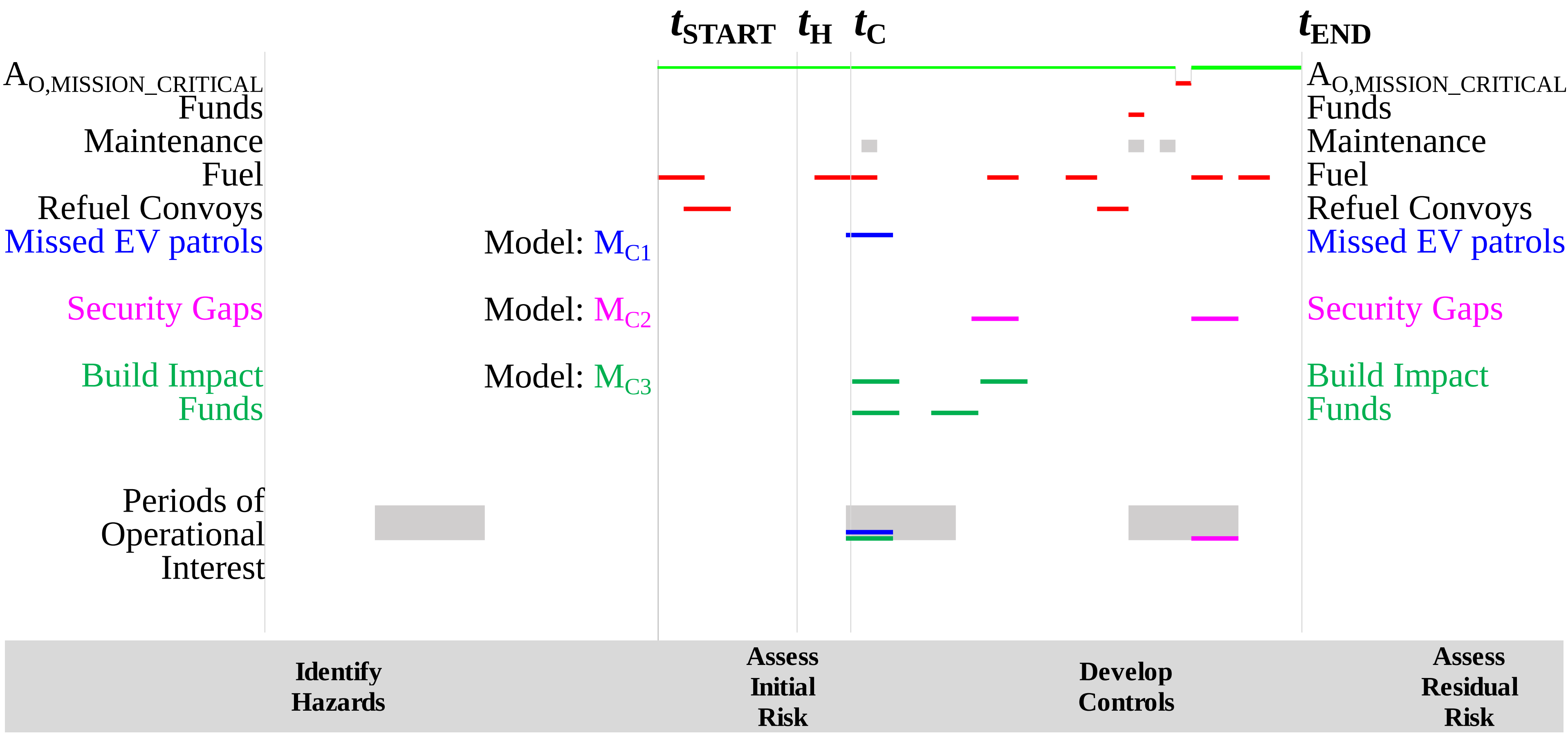
Residual Risk, Control 2 $\{ m_{FUNDS}, m_{MAINTENANCE}, m_{FUEL}, m_{REFUEL\_CONVOYS}, m_{SECURITY\_GAPS} \}$

Residual Risk, Control 3 $\{ m_{FUNDS}, m_{MAINTENANCE}, m_{FUEL}, m_{REFUEL\_CONVOYS}, m_{BUILD\_IMPACT} \}$

Value Model…choose your multi-criteria decision support method.

Example (6/6)

Vary Time Horizon



Refueling, missed patrols & security gaps intersect differently with operational periods of interest.

Metrics have changed, subsequently the weighted calculation of the value model may recommend a different course of action than the original time horizon.

Conclusions

Considerations for Metrics

Define cost metrics in terms of operational impact.

Define rationale for weighting metrics in the value model.

This technique works even if metrics are generated manually.

Iterate to determine appropriate metrics, weights, value models.

Time series data that is used to generate an 'average' metric can also be used to identify minimum and maximum durations, number of events, and collisions with other time series data.

Considerations for Modeling

High fidelity power system model may not suit models for energy projections.

How to represent demand response logic from real system in the model.

Can be used within a grids myopic demand response schema. An additional system requirement would be to output projected load availability as times series data.

Author Contact

Robert Baker is a Systems Engineering PhD student at Colorado State University. His research focus is on risk management for mission critical microgrids. He has a BS in Computer Engineering from the Milwaukee School of Engineering and a MS in Electrical Engineering from the University of Colorado - Boulder. He is a Lieutenant Colonel in the U.S. Army.

Contact: rjb2112@colostate.edu or 410.866.5680