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# Modeling Energy Systems for Peak Resilience and Sustainability

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**Author Note:** The views expressed herein are those of the authors and do not reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense. This long abstract is submitted in partial fulfillment of graduation requirements at USMA; for the full paper see the 2024 International Mechanical Engineer Congress and Exposition (IMECE) Conference Proceedings, once published, where it is currently pending acceptance.

**Extended Abstract:** The United States Army has begun an initiative to modernize its installations through an increase in system resilience and continued mitigation of climate change effects. Published in 2022, the Army Climate Strategy (ACS) provides a framework for this modernization effort, outlining installation improvements that will augment the Army's ability to be a resilient and sustainable land force. The adaptation of existing infrastructure to climate change risks and external threats requires that installations can survive and thrive in degraded environments. These extreme operating conditions are likely to place increased strain on existing infrastructure, particularly conventional energy systems, limiting the Army's ability to supply critical energy loads. Designing a solution to address this challenge is necessary, and the Systems Decision Process (SDP) provides guidance through the methodology development. The first stage of SDP, problem definition, demonstrates the variance of threats by location, stressing that Army installations must tailor their energy needs to meet resilience and distribution requirements. This increased resilience will enable Army installations to mitigate threats and satisfy the needs of present operations without compromising the ability of future generations to meet their own. The Problem Definition phase yielded the following problem statement:

> *To investigate, analyze, and model the energy infrastructure at West Point to increase resilience against any future hazard, natural or man-made. We will focus on the energy security, resilience, and sustainability of contemporary and potential systems with an emphasis on heating, electricity, and transportation. Solutions must fulfill three sustainability criteria - social, environmental, and economic.*

Following problem definition, the second phase of the SDP, solution design, resulted in a methodology aimed at creating possible alternatives for energy infrastructure at installations throughout the Army. The novel modeling process utilizes the United States Military Academy at West Point as a case study, tailoring the process for application to the larger Army. The model incorporates three aspects of energy, optimizing combinations of energy systems to obtain several of the most resilient and cost-effective infrastructure options.

First, the optimization model incorporates resiliency and sustainable energy with renewable electrical power sources. These supplemental energy sources, such as wind and solar, are used to enhance the main electrical grid during regular and extreme operations. These sources are implemented into the model with the use of geospatial data from the National Aeronautics and Space Administration (NASA) and the National Renewable Energy Laboratory (NREL), respectively. The geospatial information is then paired with several years of historical data from West Point to develop multiple energy generation models. Each energy generation model is combined into a larger optimization algorithm that obtains a graph of "Critical Failure Terms [Hours]" versus "Cost of the System [$]" to represent the system resilience and cost-effectiveness of each energy combination. Every point on this graph represents a unique combination of energy technologies including, but not limited to, solar and wind, allowing commanders to determine energy frameworks that are most resilient and cost-effective for their installation needs.

Outside of electricity, this paper also incorporates energy demands for heating and transportation into the optimization algorithm, assessing sustainability and resilience implications of incorporating heat pumps and electrification of vehicles into traditional energy infrastructure. Through the model, decision-makers within the Army and beyond will be able to accurately choose energy infrastructure that increases resilience, maximizes sustainability, and minimizes cost. Modeling clean energy in conjunction with traditional energy systems requires a holistic view of the benefits and impacts of an Army installation. The SDP, specifically model development in the solution design phase, enables a robust methodology to analyze and model energy infrastructure across Army installations. The modeling framework integrates stochastic elements to account for inherent uncertainties and variability in energy demand and supply. Through integration of stochastic modeling, decision makers can

assess the sustainability and resilience implications of alternative solutions, aiding the selection of infrastructure that maximizes resilience, sustainability, and cost efficiency.

The third phase of the SDP, decision making, deals with solution scoring of each infrastructure option. The model incorporates a solution scoring methodology that assigns values to each alternative solution based off performance factors. The Energy Resilience Model accounts for the stakeholder's attitude towards cost, effect on environment, resilience, and threat to resilience. Through pairwise comparisons, the level of importance of one factor is weighed against another on a scale of 0 to 100. Ultimately, the sum of each factor's importance weight equates to 100%. The importance weight is pivotal in determining the final values of our alternative solutions and, subsequently, the decision for which alternative solution should be implemented to maximize value and stakeholder satisfaction. The weighted value score is generated by multiplying the value of the alternative solutions by the importance levels for each factor. The decision making phase of the SDP culminates with a recommendation to the decision maker, as the solutions are weighted and scored based on stakeholder values, becoming a quantitative resource supporting that decision to be implemented.

The model and solution scoring organically allow decision-makers to decide the direction of their installation, leading to the final step in the SDP, solution implementation. Stakeholders not only use the model and solution scoring to decide which avenue to choose but can also use the model and its outputs to make decisions about how solutions are integrated on installations. In the future, this modeling process can be further refined to include blended solutions and alternative idea generation. Modeling and solution scoring allows stakeholders to evaluate their energy options with their preferences but without their bias. It weighs each option based on the actual data collected and how stakeholders value that data.

The entire SDP process was applied to work through defining the problem in coordination with stakeholders and subsequently designing a methodology to propose solution alternatives. These alternatives generated by the model of varying energy infrastructure compositions were combined with stakeholder value so that a decision could be made for not just West Point, but any Army installation looking to improve its resilience and sustainability. This model provides Army decision makers with a framework to implement the best possible solution for their specific location and operational challenges and can play a key role in reaching the Army Climate Strategy goals.