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Going Off the Grid: Optimizing for the Location of US Army's Micro Mobile Nuclear Power Plant (MMNPP)

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Abstract: This study sought to determine the necessary criteria to best evaluate where the US Army should emplace and operate a Micro Mobile Nuclear Power Plant (MMNPP) and provide policy makers with a decision analysis tool to both subjectively and objectively evaluate said criteria in determining the best location(s) for an MMNPP. The US Army is currently investigating the feasibility of a MMNPP for sustained ground operations to minimize its logistical burden and its reliance on fossil fuels. The decision analysis tool created measures values of five unique criteria for 26 potential locations within and outside the continental US (CONUS) not engaged in nor in immediate vicinity of combat operations. Weights and input values are adjusted according to analyst preferences, subjective reasoning and objective data: the most optimal location for an MMNPP is Mountain Home Air Force Base, Idaho. This study is immediately applicable in informing and shaping defense policy.

Keywords: Decision Analysis, Value Model, Optimization

1. Background

The pace of technological change and concern over our military forces' sustainability are forcing defense planners and policy makers to consider all possible material solutions needed to ensure the US Army's future ability to wage and win land warfare. Near peer adversaries such as China and Russia are currently evolving their military doctrines by aggressively adopting novel yet cost-efficient technologies such as integrating artificial intelligence and machine learning into command and control platforms; hypersonics into missile platforms; and nanotechnology and robotics in maneuver platforms (TRADOC, 2018; Giridharadas, 2019; Stone, 2020). Additionally, both are exploring the use of emerging and legacy alternative energy technologies for both state and military use (Law, 2019; Dudley, 2019). The US Army once enjoyed a marked technological advantage over our adversaries; however, to compete and win in the changing future operating environment, the Army must continue to aggressively explore, build, and procure technology that reestablishes its competitive advantages.

One such area the US Army is attempting to regain competitive advantage is through energy production and use. The Army's fighting power is highly dependent on its ability to sustain itself both in the field and in garrison. Operation Iraqi Freedom exposed the true sustainment burden of deploying a large land force in combat on the opposite side of the planet. Local electrical grids were built to bypass Iraqi energy infrastructure to ensure continuity of operations; all powered by diesel generators. The fuel required had to be trucked in great distances exposing one of the Army's greatest vulnerability to insurgent attacks – its supply chain. Approximately 52% of US deaths over the first nine years of Operation Iraqi Freedom occurred while conducting overland fuel resupply missions (Vitali J. A., 2018). The Army and DoD believe integrating alternative energy throughout the force can reduce vulnerabilities in the supply chain (Lengyel, 2008).

1.1 Problem Statement

The Micro Mobile Nuclear Power Plant (MMNPP) capitalizes on uranium's unparalleled energy density and abundancy and would require years to decades between refueling depending on reactor design. This concept is not a novel application to legacy technology as the US Army previously explored this concept starting in 1954 only to ultimately abandoned its efforts in 1976 due to technological challenges (Corliss, 1968). However, modern nuclear technological advances offer the US Army the ability adopt a small mobile reactor design that would allow forces to safely operate in austere environments continuously without the need to divert fuel from maneuver forces for sustainment. The Department of Defense (DoD) has already begun the material design solution for this concept and recently awarded three contracts to commercial firms to design and build prototypes (Mehta, 2020). One of the DoD's next major decisions in developing this acquisition lifecycle is to select the location(s) to conduct all phases of Test and Evaluation (T&E) and to sustain operations following production; however, given a spectrum of economic, social and political obstacles, the DoD will be challenged to finalize the necessary decision analysis to account for such considerations to determine the best location(s).

1.2 Research Objective

This study seeks to develop the categorical criteria through the DSRP (distinctions, systems, relationships, and perspectives) systems thinking methodology for a value model decision analysis tool which will inform and aid policy makers in determining where within CONUS and/or overseas bases to emplace and operate an MMNPP. Such a tool will prescribe value to and assess potential test locations on the aforementioned criteria to establish the best overall location(s) based upon a mix of the user's subjective reasoning and objective data.

2. Technology Background

This study will address only those aspects of reactor design and the governing physics that directly relate to MMNPP emplacement considerations and assume design characteristics for developing a value model based on the Army's 2018 study of MMNPP feasibility. The MMNPP is assumed to be reasonably transportable by all common means of US military and commercial cargo land, air, sea, and rail transport platforms, can fit into a standard International Organization of Safety (ISO) 40' shipping container, or be built into a container that meets ISO standards (Vitali J. A., 2018). It is passively safe in that electrical power is needed to ensure a chain reaction and no physical mechanism prevents the reactor's automatic shutdown in the event of damage or disruption. It is designed for quick manual shutdown and the latent radioactivity reduces to acceptable handling levels in a reasonable amount of time. It is also assumed to be highly tamper-resistant with the fuel source not easily assessable (Vitali J. A., 2018). Additionally, it is assumed the reactor operates such that both the moderator and any coolant are internal, self-contained, and never in need of resupply. One prominent reactor design currently proposed is predicated upon a closed-loop Brayton turbo-jet engine that uses either helium or carbon dioxide as the working fluid for turbine propulsion and waste heat removal greatly improving turbine efficiency. This also has the benefit of eliminating the need for water for cooling and moderation and, as the reactor already operates in a gas environment, there is no threat of steam overpressure. The design proposes to use tristructual isotropic (TRISO) fuel which is uranium pellets encased in carbon and ceramic that greatly reduces the release of fission products into the systems and ensures against meltdown (HolosGen™, 2020). This general design helps meet all the assumptions necessary for this study.

3. Methodology

3.1 Development of Cognitive Evaluation Framework

The DSRP (distinctions, systems, relationships, and perspectives) systems thinking methodology was employed to develop a cognitive framework to define and evaluate all possible factors affecting emplacement decision making. The methodologies of one published study and two commercial decision analysis case studies were heavily drawn upon in the creation of this study's cognitive framework. The US Army G4 published a study on the development of MMNPPs in 2018 analyzing the feasibility of the technology through a cognitive framework made up of political, economic, social, technological, environmental, and legal factors – also known as PESTLE. Additionally, this study analyzed Amazon Inc.'s decision criteria for its recent decision on which major US metropolitan area would receive its second headquarters (Hanbury, 2018). These considerations and evaluation criteria helped influence this study's employment of the DSRP systems thinking methodology in creating a cognitive framework that evaluates specific and measurable objective and subjective criteria under five broad categories: sociopolitical, technological, energy, environmental, and legal (STEEL).

3.2 Value Model Design

The sociopolitical category of STEEL evaluates three measurable areas surrounding nuclear technology and its relationship with the public: existence of nuclear energy and technology in the area, local populace polling favorability, and the existence of or potential for waste disposal or confinement. Each criterion is uniquely scored on a scale of 1 to 5 in ascending importance using various government and open source platforms. Local opinion about the MNPP's won't affect the design or operation of the plant, but strong local opposition to emplacement would certainly result in political ramifications the government seeks to avoid. Areas where polling data exists and showcases favorable public opinion are more desirable than not. Additionally, areas where nuclear power already serves the local electrical grid, where nuclear technology and industry greatly benefit the local economy, and where nuclear waste disposal and confinement already exist are most desirable.

The technology category evaluates seven criteria that affect the establishment and sustainment of the MMNPP supply chain and surrounds modes of transportation other than the traditional road/highway freight. Each criterion is uniquely scored on a scale of 1 to 5 in ascending importance using government and scientific geospatial reporting platforms and defense logistics and transportation data. Organic access at the location to additional modes of transportation (i.e., rail, port and airfield at site) above traditional road freight were measured with more access valued highest. Next, the distance from the next nearest mode of transportation (i.e., rail yard, airfield, port) was measured with shorter distances valued highest. Lastly, the distance to the next closest military installation was measured with shorter distances valued highest.

The energy category evaluates five criteria that affects how viable a location is based on energy production and energy demand. Each criterion is uniquely scored on a scale of 1 to 5 in ascending importance using government and public utility sources. The existence of credible backup to grid power, plans for future construction of new power sources, the use or planned use of large-scale alternative energy sources were measured with lack of or absence of presence for each criterion valued highest. The current primary energy sources for each location were also objectively measured with city grid valued lowest and site organic oil/gas sources highest. Lastly, the average price of electricity per kilowatt hour for that area was objectively measured for any location whose primary power supply is the local grid.

The environmental category evaluates potential locations on ten objective criteria that impacts logistics of MMNPP emplacement and operation, each uniquely scored on a scale of 1 to 5 in ascending importance. Average annual temperature range, annual precipitation levels, and annual occurrences of extreme weather are objectively determined from government and scientific weather reporting service data with lower measures valued highest as extremes in any of these three will significantly impact logistics and operation. Next, using government and scientific geospatial reporting service platforms, each proposed site's distance was objectively measured for five specific criteria; distance from ecologically sensitive aquatic and terrestrial wildlife habitats, elevation above and distance from large bodies of waters prone to flooding or tide swell, and from seismically active fault lines. Further distances and higher elevations above flooding waters were valued highest. Lastly, distance from population centers following Nuclear Regulatory Commission (NRC) Exposure Planning Zone (EPZ) regulations were measured in similar fashion giving the highest weight to the furthest distances.

A legal category measure whether the state or territory has laws and regulations regarding nuclear power or technology above what the NRC has established. Legislation preventing or hindering the construction of nuclear power plant in those states and/or areas were researched where there was no such legislation was valued highest. Additionally, states whose efforts to construct new nuclear power plants were thwarted or whose existing power plants were forced into early retirement through litigation were valued lowest. Lastly, states whose members of Congress sit on the Senate's and House's respective energy committees were valued highest.

In order to not have to evaluate every military CONUS and OCONUS installation, those installations that were in close proximity to major urban centers and were located in states perceived to be socially unfavorable to nuclear technology were immediately excluded from consideration. For example, military installations in the highly congested greater New York City and Washington D.C. metropolitan areas to include those in many Northeastern states ambivalent to nuclear energy were removed from consideration as emplacement of a MMNPP would draw considerable social, political, and legal pushback. This process ruled out all military installations east of the Mississippi River and most naval ports. Despite the fact that many naval bases surrounded by large urban areas, such as those in San Diego and Hawaii, are accustomed to nuclear technology as they regularly have nuclear powered ships docked in their ports, this study excluded those areas solely due to their urban density. Those military installations west of the Mississippi River in and around the Rocky Mountains and deserts proved the best CONUS candidates. OCONUS installations were selected for consideration based on how remote they were (i.e., Kwajalein Atoll Island), how far from lands belonging to geopolitical rivals, how impactful would an MMNPP be to military operations at that location (i.e., Camp Buehring, Kuwait), and how beneficial would a reliable power source be to that area (i.e., Fort Buchanan, Puerto Rico). This process reduced the list of candidates down to 26 potential locations.

Table 1. Initial Value Weights

Sociopolitical	Tech/Supply Chain	Energy	Environmental	Legal/Regulatory
10%	30%	20%	30%	10%

For each location, all criteria under each category are added to produce a category summation. These summations are normalized by an adjustment factor leaving the best scoring location in that category with a score of ten with the remaining locations scoring below ten down to a one. Then weights are assigned, as shown in Table 1, to each category based on three considerations: the number of criteria in the category, the availability of data for each criterion in each category, and the ratio of objective to subjective criteria in each category. Those categories with more objective criteria that could be researched through many sources of data were weighted more heavily so long as the five sets of weights added up to one. Weights are then multiplied by the individual categorical scores as shown in (1) to produce each overall location raw score. The raw scores are then normalized to a scale of 100% for ease of understanding.

$$Weighted\ Mean = \frac{\sum_{i=1}^{n}(x_i * w_i)}{\sum_{i=1}^{n}(w_i)} \qquad (1)$$

4. Results

4.1 Initial Model Results

All 26 locations were evaluated per the methodology discussed above with Figure 1 illustrating the initial model results. Per the weights and subjective measured identified in this study, Mountain View Air Force Base (AFB) Idaho is the ideal test location for the MMNPP. The results of the model are subject to change given stakeholder input on the value weights for each category. The initial model results indicate that the more remote locations performed better overall with locations in colder regions generally scoring higher than those in warmer/drier regions and warmer/tropical regions. Despite their remoteness, transportation infrastructure still heavily influenced the results as Kwajalein Atoll and Thule AFB were not high considering their remoteness.

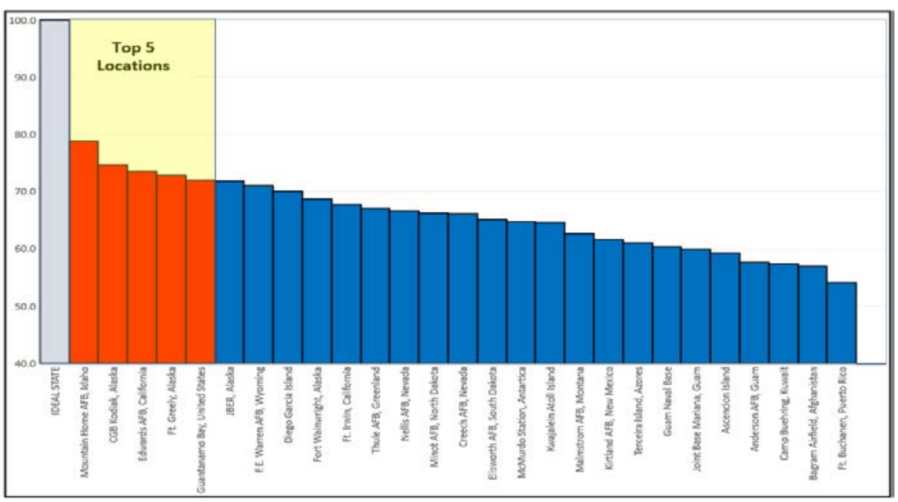

Figure 1. Locations by Score

4.2 Sensitivity Analysis

This study employed a sensitivity analysis to determine how independent variable values will impact a particular dependent variable under a given set of assumptions by using the One at a Time (OAT) technique (EduPristine, 2018). The weights of each category were individually adjusted up and down while keeping the other categories constant. The results were most sensitive to the environmental category as it had the most objective criteria within it and the criteria scores were so disparate from location to location. The results were least sensitive to the adjustment of the sociopolitical category weights due to fewer categorical criteria and greater reliance on subjectivity in scoring each criterion. However, given greater insight into this sociopolitical criterion, such as those possessed by governmental policy makers and analysts, the sociopolitical criteria scoring methodology could be more appropriately adjusted and thus the categories' sensitivity would increase.

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5. Conclusion

The purpose of the study was to determine the necessary criteria to best evaluate where the US Army should emplace and operate a Micro Mobile Nuclear Power Plant (MMNPP) and provide policy makers with a decision analysis tool to both subjectively and objectively evaluate said criteria in determining the best location(s) for an MMNPP. This study accomplished creating such a tool for evaluating locations by first creating an evaluation framework through the DSRP systems thinking methodology. This framework manifested itself as select criteria within five unique categories used to evaluate locations by providing values scores to each criteria and weights to each category according to the perceived importance. Given the objective and subjective criterion measures and the categorical weights discussed above, Mountain Home Air Force Base is the most desirable location of the 26 evaluated for the first location of the MMNPP. This tool will assist defense planners and policy makers determining which MMNPP location is best according to their own subjective reasoning.

The largest limitations on this study was access to enough information allowing for the most robust objective measurements of the criteria. Additionally, access to more information would allow for refinement of existing criterion and creation of additional criteria thus increasing the reliability of the model and equalizing the sensitivity of the categories. The next evolution of this study will seek further refinement of the criteria while making the tool more automated by coding it to retrieve objective geospatial data from available sources.

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