Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
April 23, 2026
*A Regional Conference of the Society for Industrial and Systems Engineering*

# Decision-Support Model for VA Healthcare Facility Resilience to Disaster Risk

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**Author Note:** The authors conducted a year-long Capstone project in partnership with the Veterans Affairs (VA) Office of Construction & Facilities Management through the Department of Systems Engineering at the United States Military Academy under the advisement of Captain Caitlin Marriner. The views expressed in this paper are those of the authors and do not reflect those of the United States Army, the United States Military Academy, or the Department of Systems Engineering.

**Abstract:** This paper examines the increasing threat of natural disasters on vulnerable healthcare systems, specifically VA facilities, who must maintain continuity of care through catastrophic disasters despite interdependency risks. Existing frameworks lack structured prioritization regarding vulnerable facilities and VA decision-makers lack integrated decision-support tools, ultimately demonstrating that risk identification does not translate into operational or actionable prioritization. The capstone team used the Systems Decision Process (SDP) to develop a hierarchical value model that incorporates stakeholder-informed weighting based on interdependency analysis and trade-offs between stabilization and resilience. Sensitivity analysis demonstrated ranking stability across weighting variations, confirming the model's robustness. This research enables transparent prioritization of facility vulnerabilities and the maintenance of continuity of care. This project demonstrates the application of systems engineering to healthcare resilience in the face of natural disaster.

*Keywords:* Healthcare Interdependency, Resilience, Disaster Mitigation, Capital Investment Prioritization

## 1. Introduction & Background

In recent years, the frequency and severity of natural disasters have increased, placing a growing strain on healthcare infrastructure (U.S. GAO, 2025). The Department of Veterans Affairs (VA) operates more than 1,100 facilities and serves over nine million veterans nationwide, making it particularly vulnerable to disaster-related disruptions (VHA, 2025). To be of successful service, VA medical centers must provide continuous care and fulfill their Fourth Mission of supporting national emergency backup during crises (VA, 2025).

Historical disasters demonstrate how failures in lifeline infrastructure systems disrupt healthcare operations, exemplifying recurring vulnerabilities in continuous patient care and infrastructure reliability. Hurricane Katrina rendered the New Orleans VA Medical Center nonfunctional, and Hurricane Sandy disabled electrical systems in Manhattan VA facilities, both forcing facility shutdowns and damaging clinical equipment (U.S. GAO, 2008; HUD, 2013). Such events illustrate that disaster impacts are rarely single-point failures, and rather cascade across clinical, operational, and logistical functions.

Although federal frameworks, such as the Stafford Act, the Post-Katrina Emergency Management Reform Act (PKEMRA), and the National Response Framework (NRF), exist to guide disaster response efforts, gaps in implementation and execution exist (United States Congress, 1974; PKEMRA, 2006; U.S. GAO, 2008). The VA currently conducts Facilities Condition Assessments (FCA) every three years to identify infrastructure risks, however, they do not account for dynamic reassessment of disaster conditions (CFM, 2015). Although assessments identify risks, decision-makers lack structured tools to translate these risks into an understanding of prioritized facility vulnerabilities (U.S. GAO, 2024). This study addresses this gap by developing a decision support model that ranks facilities based on three key factors: facility conditions, location interconnectivity, and population demand. Our model enables the VA to proactively prioritize and implement targeted mitigation actions to high-demand medical facilities before disasters occur, which are capabilities not provided by FCA outputs alone.

## 2. Methodology

This study utilized the SDP to develop a decision-support model for the VA regarding the prioritization of facility vulnerabilities resulting from catastrophic disasters. The methodology followed four primary phases: problem definition, solution design, decision making, and solution implementation.

### 2.1 Problem Definition

The primary stakeholder is the Department of Veterans Affairs Office of Construction and Facilities Management (OCFM) and all associated personnel. These stakeholders emphasized the effects of infrastructure degradation and catastrophic disasters due to their role in maintaining veteran continuity of care. Additionally, the VA operates in a network of federal, state, and local emergency response agencies, further increasing interdependency during disaster response. Due to these stakeholder considerations, this study focuses on VA medical facilities as systems dependent on interconnected infrastructure and resource lifelines. The resulting system boundary identifies continuity of care as the central value objective, including continuous facility operations and infrastructure support during catastrophic conditions. The objective of this project is to identify high-risk facilities that will need proper allocation of investment prior to and during catastrophic events. Analyzing a facility's proximity and natural disaster risk will enable stakeholders to identify gaps in ensuring continuous support.

### 2.2 Solution Design & Decision Making

The team structured a model using a value-focused approach to ensure that facility prioritization aligns with the primary objective of continuity of care during natural disasters. The first step in the process was developing a hierarchical value model to decompose the primary objective into various measurable evaluation criteria. These criteria were derived from stakeholder input, background research, and historical disaster case analysis.

The resulting model captured both infrastructure stability and operational continuity. To quantify and order relevant priorities, the team assigned weights to each criterion to reflect relative importance in sustaining continuity of care and adjusted weights based off stakeholder feedback and literature review research examining healthcare system resilience during natural disasters. Stakeholder input was incorporated through discussions with VA OCFM representatives. Relative priorities, like patient risk, infrastructure dependencies, and demand, were compared and translated into proportional weights across the model criteria.

Based upon previous capstone work and guidance from stakeholders, the team selected Veterans Integrated Service Network (VISN) 7 as the project's primary study region. VISNs are regional networks within the VA that are responsible for managing healthcare delivery and coordinating and facility operations across multiple medical centers. VISN 7 facilities in Georgia, Alabama, and South Carolina provide a suitable control environment due to the available infrastructure data and exposure to well-recorded natural hazards like hurricanes and flooding. These recurring threats provide a realistic context to evaluate infrastructure vulnerability and disaster response prioritization.

FCA data informed understanding of infrastructure vulnerabilities, while the study used historical disaster case studies to contextualize related system impacts. Together, these inputs allow the model to integrate both qualitative and quantitative inputs to evaluate each response alternative against defined criterion. Our stakeholders coordinated an on-site visit at San Juan VA Medical Center in Puerto Rico (VISN 8) to provide insight into how VA facilities maintain operations during natural disasters. The visit highlighted the importance of infrastructure redundancy and emergency preparedness planning.

Guided by the hierarchical value model, the team developed three complementary analytical models to evaluate facility vulnerability and response prioritization. Each model captures a different dimension of risk affecting continuity of care: (1) facility infrastructure condition, (2) natural disaster exposure and network connectivity, and (3) veteran population demand. Together, these models form the analytical foundation to prioritize facilities most vulnerable during natural disaster disruption.

## 3. Model Descriptions

### 3.1 Model 1: Facility Condition Score

Model 1 evaluates facility condition across VISN 7 to identify facilities least prepared to maintain operations during and after a natural disaster. The model consists of seven value measures with supporting sub-measures. For example, the value measure 1.1, Condition of Steam Generation Systems, comprises the four sub-measures: *1.1.1 Condition of Boiler*, *1.1.2 Condition of Boiler Feed Pumps*, *1.1.3 Condition of Steam Distribution*, and *1.1.4 Number of Boilers*. Evaluating these components together allows the model to identify which infrastructure systems within a facility present the greatest operations risk during disaster conditions. Each value measure is assigned to a global weight, developed by the team, and refined through stakeholder feedback These weights reflect the relative importance of each system in sustaining clinical operations. Systems such as boilers, electrical infrastructure, and steam generators received higher weights due to their critical role in maintaining hospital functionality. Our sub-measures considered redundancy and efficacy as important long-term facility resiliency.

The final output sums the scores for each facility's value measures to obtain the facility condition score with a higher score being better. Model 1 displays the data as a stacked bar chart to quickly identify both the facilities with the highest infrastructure risk and the specific systems contributing most significantly to those vulnerabilities. This visualization enables stakeholders to prioritize infrastructure investments and provides supporting evidence for facility improvement funding requests. If a facility receives a high Model 1 score, a decision-maker can interpret this as a high risk to operational continuity during a disaster. Conversely, facilities with lower scores may require less immediate intervention, allowing for more effective prioritization across the VISN.

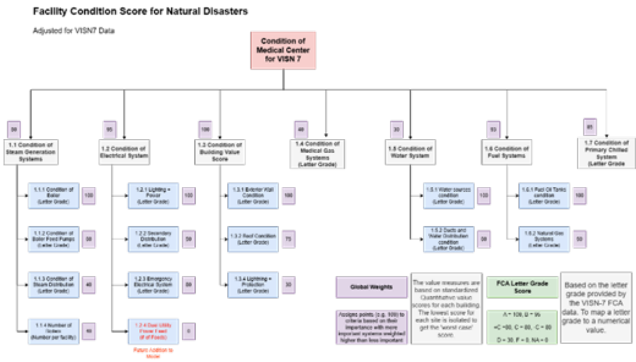


Figure 1. Model 1 Quantitative Value Model

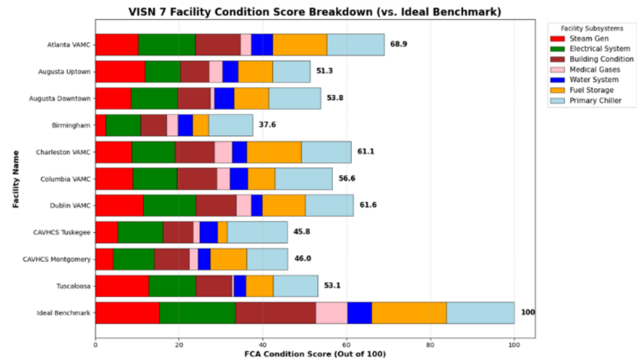


Figure 2. Model 1 Output

### 3.2 Model 2: Disaster & Location Score

Model 2 evaluates facility risk by combining two key factors: facility network connectivity and disaster exposure risk. Network connectivity is measured using normalized closeness centrality and betweenness centrality, which quantify how connected a facility is within the broader VISN facility network. To quantify isolation, the equation averages normalized betweenness and closeness centralities ($B_{Norm}$ and $C_{Norm}$) and inverts the result onto a 100-point scale, mathematically penalizing disconnected facilities. This isolation penalty is equally weighted with a normalized raw disaster score, ensuring that a facility only receives a critical rating if it faces compounding geographic hazards and lacks the network infrastructure necessary for emergency patient evacuation.

These components are combined into Equation 1, where the average of the connectivity measures is inverted to represent an isolation penalty, then equally weighted with disaster exposure:

$$Risk_{Model\ 2} = \frac{\left[100 - \left(\frac{(B_{Norm} + C_{Norm})}{2} * 100\right)\right] + \left[\left(\frac{Disaster_{raw}}{Disaster_{max}}\right) * 100\right]}{2} \quad (1)$$

The final output sums up the risk score for the identified natural disasters, resulting in a 0-100 score for each VA facility within VISN 7. Operationally, this score reflects a facility's vulnerability due to both geographic risk and limited network support. Higher scores indicate facilities that are both highly exposed to natural disasters and insufficiently connected within the VISN network, making them more susceptible to disruption and less capable of maintaining continuity of care.

### 3.3 Model 3: Veteran Population Score

Model 3 is a population demand model that quantifies the external demographic strain on each facility, which is demonstrated by Equation 2. The model integrates county-level veteran population statistics from census data by establishing an adjustable 60-mile catchment radius around each facility's exact coordinates due to Fourth Mission requirements of specialty care access in a 60-minute drive time.

$$Pressure\ Score\ (S) = \sum_{i=1}^{n} (Density_i) \quad where\ Distance_i \leq 60\ miles \quad (2)$$

The veteran population density in this catchment area is aggregated to calculate the raw demand score of total number of veterans served by county area. It is subsequently normalized on a 0-100 risk scale. The normalized score treats higher scores as more critical because of the high localized demand. Facilities that receive a higher risk rating have a heightened risk of becoming overwhelmed during an environmental crisis or sudden network disruption. In the final HTML output, the larger, red nodes show greater market pressure, and the smaller, green nodes show lower demand.

### 3.4 Final Integrated Model

The final prioritization model combines the results of the three individual models: facility condition, disaster and location, and veteran population. Each model contributes equally to the final facility prioritization score, with equal weighting used as a baseline assumption to provide a neutral point of comparison for subsequent analysis, demonstrated by Equation 3.

$$Final\ Risk = \frac{Model\ 1 + Model\ 2 + Model\ 3}{3} \tag{3}$$

This integrated approach ensures that infrastructure vulnerabilities, environmental risk exposures, and patient demand pressures are all considered when determining facility prioritization. To evaluate the robustness of the results, the team conducted sensitivity analysis by varying model weights and observing resulting changes in facility rankings. Through this structured approach, the model transforms qualitative risk awareness into transparent, value-aligned decision support, proving VA leadership with both qualitative insight and quantitative justification when prioritizing infrastructure investments and disaster preparedness strategies under resource constraints. A visualization product of all VISN 7 facilities with model information overlayed was also produced for stakeholders to easily visualize final cumulative model output and the output of each individual model.

## 4. Discussion

### 4.1 Solution Implementation, Interpretations & Implications

These models shift disaster planning from reactive risk identification toward structured decision support and proactive prioritization. Since healthcare facilities depend on multiple interconnected infrastructure systems, value-focused modeling provides a structured method for evaluating competing objectives and operational constraints. Continuity of care emerged as the central objective of the models, reflecting the VA's Fourth Mission of ensuring "continued service to Veterans" while supporting "local emergency management efforts" (VA, 2025). By incorporating infrastructure interdependencies and stakeholder priorities, the resulting models provide transparent prioritization of facility vulnerabilities and capital investment projects. Decision-makers can evaluate tradeoffs between infrastructure stabilization efforts and operational vulnerabilities across facilities within the network.

The study performed sensitivity analysis on the final output score, as demonstrated in Figure 3. Our final model assigns equal weight to each component where each model contributes a third to the final score. The analysis demonstrated that the final rankings are sensitive to weight changes. Using python to collect and simulate the different weight scenarios, sensitivity analysis shows that the location ranking changes when the swing weights for one model are varied from 0-100, and the other two models remain equally weighted. This indicates that each model contributes to the overall prioritization. The models were found to be significantly sensitive as the preferred solution changed within 10 percent of the baseline. The sensitivity analysis showed that the Atlanta facility is significantly impacted when the Market Demand model was weighted more heavily, becoming the least significant model when the Conditions Model was leveraged as the most significant. The clustering of the facilities in Model 1 and Model 3 results demonstrates that there is not a clear gap between the VISN's facility conditions or population demand, excluding Atlanta. This suggests that while vulnerabilities exist across the network, certain facilities demonstrate consistently higher risk profiles depending on the evaluation criteria.


Figure 3. Sensitivity Analysis for Final Model Output

Operationally, these models could support VA emergency operations by guiding disaster preparedness planning, facility-level contingency development, and pre-disaster resource staging. The framework can inform infrastructure investment decisions by identifying vulnerabilities where resilience improvements would have the greatest impact. By integrating infrastructure management with clinical continuity requirements, the models support a shift toward proactive resilience planning and improved coordination between emergency management and facility operations. Although this study developed the framework for VA facilities, it also demonstrates how healthcare resilience planning can be operationalized through systems engineering methods and applied to other healthcare systems facing similar disaster risks.

## 4.2 Model Validation

For the provided models, the team obtained information through direct collaboration with Department of VA personnel to ensure accuracy and reliability. For Model 2, geographic and disaster exposure variables were derived from publicly available sources. Distances between facilities and relevant geographic features were calculated from Google Maps, and the team used the National Centers for Environmental Information to obtain data on the frequency of given natural disasters during a 25-year period (01JAN2000-31DEC2025). All data used in the provided models are primary sources of information.

Ideally, the team would have validated the models using VISN-8, given the on-site visit to the San Juan Medical Center. However, the model was validated using VISN-6 data through collaboration with the project stakeholder. While additional validation across multiple VISNs would further strengthen the results, the use of primary data sources and stakeholder validation provides confidence in the reliability and applicability of the model outputs.

## 4.3 Contribution to Systems Engineering

The development of these models demonstrates the application of the SDP in healthcare resilience, illustrating the importance for value-focused thinking in disaster management. The integration of qualitative and quantitative inputs encourages a structure for the prioritization of values within complex and interdependent systems. By bridging infrastructure engineering and healthcare operations, this process operationalizes abstract resilience into measurable criteria, enabling actionable decision support.

# 5. Conclusion

## 5.1 Results

Through facility condition, geographic, and population data analysis, our model can help the VA prioritize which facilities should receive capital investment. Under the baseline scenario, where all three models are weighted equally, the Joseph Maxwell Cleland Veterans Affairs Medical Center in Atlanta received the highest overall risk score within VISN-7. This result is primarily driven by the significantly larger veteran population served by the Atlanta facility relative to other facilities within the network, as depicted by the orange segment in the stacked bar chart in Figure 4.

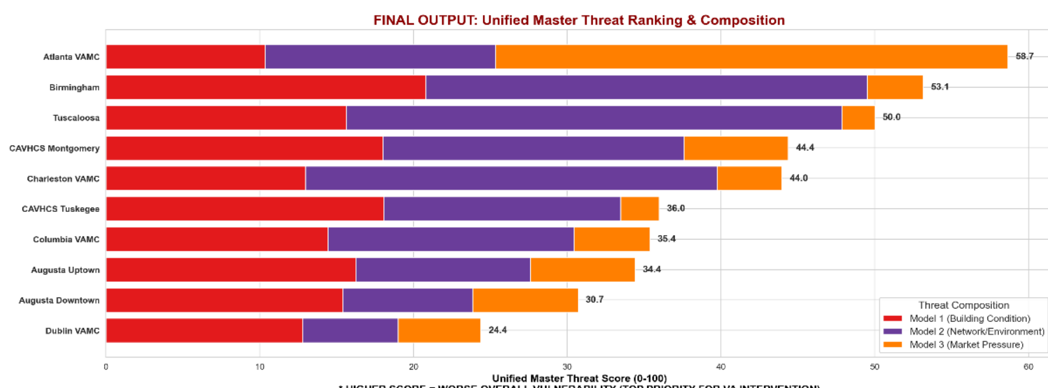

Figure 4. VISN-7 Final Baseline Model Output

From our sensitivity analysis, all three models are significantly sensitive within 10 points of the baseline. Along with 0-100 sensitivity analysis for each model, the final baseline output was simulated by giving one Model a weight three times higher than the other two. Instead of a 33-33-33 split, it would be varied 60-20-20. Atlanta, having an extremely large disparity in the veteran population it serves as compared to the other facilities in the VISN, had the highest risk score when Market Demand (population demand model) was weighed three times more compared to the other models. When Model 1 (facility condition) was weighted more heavily, the model identifies Birmingham and Tuscaloosa as the most at-risk facilities; when Model 2 (location risk) was prioritized, the model again ranked Tuscaloosa and Birmingham as the highest-risk facilities, respectively. Across the weighting scenarios, four of the five highest-risk facilities remain consistent. This consistency suggests that certain facilities demonstrate persistent vulnerabilities across infrastructure condition, geographic risk, and population demand. These findings indicate that the model effectively highlights facilities that may require targeted resilience improvements. This model has the potential to be a valuable tool for VA capital investment projects enabling them to establish priority areas ranging from facility conditions, connectivity and accessibility, and populations served.

## 5.2 Key Takeaways & Future Work

The increasing frequency and severity of natural disasters threatens healthcare infrastructure and requires improved prioritization of vulnerabilities. VA facilities face unique vulnerabilities due to their geographic distribution, reliance on lifeline infrastructure systems, and responsibility to maintain continuity of care for a medically complex veteran populations, all while supporting the VA's Fourth Mission during national emergencies. Although existing disaster frameworks identify risks, they lack structured mechanisms for translating these risks into actionable prioritization of capital investment strategies.

Using the SDP, the study developed value-focused decision-support models that integrate stakeholder priorities, infrastructure interdependencies, and FCA data to evaluate disaster response alternatives. The resulting multi-criteria framework enables transparent comparison of response actions and supports evidence-based prioritization of resources. By incorporating cascading infrastructure dependencies and sensitivity analysis, the models move beyond static risk identification toward dynamic prioritization strategies that can guide preparedness planning and resilience investment.

This study demonstrates how systems engineering can support healthcare disaster resilience by translating complex infrastructure and operational risks into actionable decision support. While the framework provides meaningful insights, several limitations remain. The analysis relies on periodic Facility Condition Assessment reports, stakeholder-informed weighting assumptions, and uncertainty in future disaster scenarios. Future research could strengthen the models through validation using historical disaster case studies, incorporation of real-time infrastructure monitoring data, and expansion to additional hazard scenarios. Additionally, we recommend adjusting the Veteran Population Score to stabilize the results, making it not significantly sensitive. Despite these limitations, the framework provides a repeatable approach for improving disaster preparedness across VA healthcare networks. With further development and validation, the model could be expanded to support resilience planning across all VA VISNs, helping ensure continuity of care for veterans during future disaster events.

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