Resilience: Modeling for Conditions of Uncertainty and Change

COL (Ret) Paul Roege	Dr. Timothy Hope	Mr. Patrick Delaney
Idaho National Laboratory	Whitney, Bradley and Brown Inc.	Davies Consulting LLC
Idaho Falls, ID	Reston, VA	Chevy Chase, MD
paul.roege@inl.gov	thope@wbbinc.com	pdelaney@daviescon.com

ABSTRACT

Resilience is an adaptive approach for managing a wide-range of energy/infrastructure-related risks. Simply stated, resilient entities survive and thrive under changing conditions. In contrast with traditional risk management approaches, which address discrete events or threats, resilience is a proactive, holistic approach to structuring fundamental processes and relationships to make them robust but flexible to respond to any type of challenge or change. Moreover, resiliency objectives focus on outcomes, such as protecting life and property or achieving a mission, in the face of change, rather than on simply protecting systems designed for nominal performance. Resilient systems may retain health through passive features, operational flexibility and decentralized decisions, which are more likely to manifest through iterative, even experimental processes, rather than traditional linear-design processes. In the context of communities and infrastructure, most traditional analysis techniques have focused upon preservation of essential functions, with some attention given to physical system interdependencies such as reliance upon power supplies. Considering the fundamental contrasts between deterministic design optimization concepts and the broader consideration of complex, cross-domain relationships in resilience thinking, there is an evident need for new models and techniques. Two relevant but contrasting approaches offer useful examples to explore in the context of this challenge. Military capability development procedures exemplify structured analysis toward a complex outcome, integrating qualitative operational analysis (war-gaming) with quantitative system (engineering) models in a correlated manner. Civilian emergency response communities focus on more flexible, descriptive processes that examine operational scenarios and gather expert insights which in turn inform stakeholder action, such as electric utility investments to improve reliability. This paper compares these techniques and offers recommendations for a hybrid approach to resilient design and energy portfolio development.

ABOUT THE AUTHORS

Colonel (Ret) Paul Roege. Paul Roege has 35 years of experience in research, engineering, construction and operations, primarily in military and energy sectors. He specializes in establishing vision and implementing change, as demonstrated in his recent initiative to establish the new domain of Operational Energy within Army doctrine and business processes. His current focus is on development and implementation of models which promote resilience in American communities and regions, and promotion of opportunities for innovation and participation in new energy technologies. COL (Ret) Roege holds science and engineering degrees from the U.S. Military Academy and the Massachusetts Institute of Technology, and a business degree from Boston University.

Dr. Timothy Hope serves as a Senior Manager for Army Systems Analysis with WBB. While working at WBB, he has led several joint WBB, Government and Industry efforts in investigating and resolving critical current issues within and outside the National Capitol region. While on active duty, Dr. Hope served in multiple senior Operations and Systems Analysis positions at U.S. Special Operations Command and with the Center for Army Analysis supporting Headquarters, Department of the Army. Dr. Hope has an undergraduate degree in engineering from the U.S. Military Academy, a Masters in Industrial Engineering from Kansas State University and a doctorate in Human and Organizational Learning from The George Washington University.

Mr. Patrick Delaney is a Partner and the Asset Management Line of Business lead for Davies Consulting, LLC. He has more than 20 years of experience in strategic and operational decision development, modeling, and analysis. Mr. Delaney has extensive experience in the simulation modeling and analysis associated with asset management, electric system resiliency and hardening, storm restoration, and other utility areas with regulatory oversight. His expertise in Industrial Engineering and Operations Research and Systems Analysis methods has helped utilities, the Department of Defense, and other federal agencies implement strategic processes to support strategic decision-making, asset management, risk mitigation, logistics, and information management, as well as policy execution. Mr. Delaney has worked with more than 20 utilities on different aspects of risk, grid resilience, and asset and investment management performance improvement. Mr. Delaney holds a Bachelor of Science in Mechanical Engineering from the United States Military Academy and a Master's of Science in Systems Engineering from the University of Virginia. He is a member of the Institute for Operations Research and Management Sciences and the Institute of Electrical and Electronics Engineers.

Resilience: Modeling for Conditions of Uncertainty and Change

COL (Ret) Paul Roege
Idaho National Laboratory
Idaho Falls, ID
paul.roege@inl.gov

Dr. Timothy Hope
Whitney, Bradley and Brown Inc.
Reston, VA
thope@wbbinc.com

Mr. Patrick Delaney
Davies Consulting LLC
Chevy Chase, MD
pdelaney@daviescon.com

INTRODUCTION AND BACKGROUND

Our social order, economic growth and national security have benefitted greatly from advances in energy resources and technologies. This has led to complex interdependencies that are inadequately understood and poorly managed. More generally, modern design optimization techniques have evolved to emphasize design-point performance while investments target near-term returns with limited consideration of long-term uncertainties and effects. Especially in the context of security and community services, such short-sightedness generates a lack of preparedness for increasingly frequent emergency events and consequences like major power outages in North America, widespread impacts of storms, price fluctuations and bank failures. Meanwhile, as climate change and globalization continue to define new realities, natural and social conditions are becoming more variable and less predictable. Collectively, these factors suggest the need for alternative design and decision approaches which supplant rigid systems and behaviors, incorporating a greater tolerance for change, and flexibility to adapt without disrupting overall system outcomes.

The growing incidence and impact of natural events, combined with concerns about broader socio-economic and cyber threats, have motivated concerns about energy security and protection of other community capabilities. During the late 20th Century, U.S. military services responded through risk management guidance and techniques that sought to prevent disruption to their ongoing security missions by protecting systems deemed "mission essential." Civilian entities, such as utilities, likewise seek methods to target (and capitalize) investments which would improve their system reliability. While reinforcement of critical system elements can reduce impacts, especially in the face of repetitive and anticipated conditions, such processes overlook the option to overcome the basic dependency, and ignore broader community needs which are important in their own right, but which also inevitably impact continuity of those urgent security functions. Military installations depend heavily upon community services from utilities to medical care. Moreover, commanders invariably find themselves committed to supporting community recovery after natural disasters. Few military installations exist as islands.

The alternative risk management concept of resilience is emerging as a useful framework to provide greater overall value, and to facilitate broader collaboration and sector coordination. The National Academy of Sciences defines resilience as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events (NAS, 2012). This definition notably de-emphasizes nominal performance in favor of examining system response to change. Given the inevitability of change, such an approach may seem obvious, but the very idea of characterizing change response versus nominal performance suggests a fundamental shift from deterministic modeling to methods which embrace uncertainty. Moreover, resilience is a property of systems interacting to achieve some outcome (Thomas, 2010). This definition actually expands degrees of freedom in solution space, increasing opportunity but further complicating analysis. In the case of community health and survival, pursuit of resilience means opening the door to stakeholder interaction, engaging a proliferation of issues and seeking collaborative, decentralized solutions.

Due to the commensurate increase in complexity that results from this perspective, resilience demands new or modified analysis methodologies. This paper examines approaches that have been employed by military and civilian communities to structure their respective planning and capability development efforts. Department of Defense (DOD) guidance includes two distinct cases: development of operational capabilities to achieve military missions and protection of mission/supporting infrastructure against disruptive events. These processes invoke structure to identify and relate strategies, requirements and system interactions to support defined mission objectives. By contrast, civilian communities invoke more collaborative and experimental techniques to elicit insights from a diverse community of stakeholders, informing complex and qualitative descriptions of desired outcomes and diverse portfolios of solutions to be implemented by independent entities. While there are commonalities between these approaches, their differences offer the strongest learning opportunities, especially in light of the inevitable need for civil-military collaboration to forge community resilience.

Problem Statement

Both military and civilian community leaders face the challenge of preparing for and responding to change through policy development, budgeting, planning and infrastructure investment, as well as through periodic event management/recovery activities. These two communities have evolved characteristically distinct analytical approaches to assess and manage risks. Military analysts employ structured, deterministic methods that evolve from well-defined mission objectives and deliberate systems analysis to expose dependencies and key nodes, and to prescribe protective measures. The focus is to identify solutions within the control of military commanders who recognize and respect limitations on their span of authority. Civilian entities, especially local jurisdictions, use open ended emergency, infrastructure, and risk management planning processes to involve diverse stakeholders and to inform subsequent development of portfolio solutions for implementation by respective stakeholders such as electric utilities.

Neither existing analytical paradigm fully satisfies the new challenges of resilience, which demand robust but flexible systems and underlying collaboration across the community. This paper considers modeling approaches currently used within the respective military and civilian communities to identify strengths, potential synergies and application implications. The authors illustrate the potential to invoke selected elements from each domain, applied to an example historical scenario, examining end resilience implications. The research suggests future development of hybrid methodologies which facilitate civil-military collaboration toward the new objective of community resilience.

THE DEPARTMENT OF DEFENSE CAPABILITIES DEVELOPMENT PROCESS

The DOD approach to capability development is a focused and competitive process that allows organizations within the Department to identify, assess, recommend and source capabilities for a broad range of activities – from war fighting to managing installations. The competition within the DOD is fierce with the available resourcing decreasing in the future. Modeling and Simulation competencies are critical enablers that allow the Department to reach informed decisions in capability development and importantly in the energy resilience domain.

Four overarching activities comprise the DOD capability development and fulfillment activities that enable installation energy resilience. Each of these activities is largely sequential and time-phased. The activities are inexorably linked to the Planning, Programming, Budgeting and Execution System (PPBE) and the DOD Acquisition System for resourcing and timing. The four capability development and fulfillment activities are: ***Guidance; Assessment and Analysis; Reconciliation and Recommendations;*** and ***Decision and Action*** (US DOD, 2003) (Figure 1).

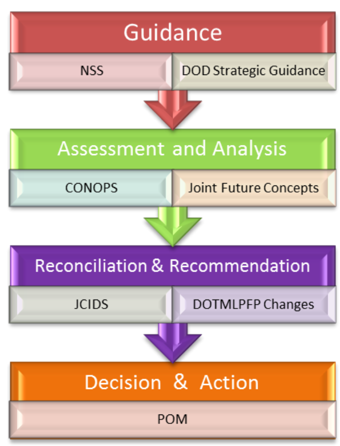

Figure 1. DOD Capabilities Development Process

The ***Guidance*** activity is the foundation upon which the remaining activities are built. In theory and practice, a capability must trace to an existing current strategic or operational tenet. The ***Assessment and Analysis*** activity is the opportunity for DOD or its Components to link the tenets identified within the Guidance activity to existing or projected uses and employment means. From the Service perspective, this activity allows DOD to explore possibilities in a resource-informed context. One of the most useful models and frameworks to ensure the alignment of guidance mission requirements is the Department of Defense Architecture Framework (DoDAF). The framework allows the Services to ensure there is synchronization of intent and structure of organizational missions, system interfaces and technical interfaces, and that *all* are aligned within the Guidance from the Department.

The third activity, ***Reconciliation and Recommendation***, transitions military capabilities from concepts to programs competing for resourcing visibility. The Joint Capabilities Integration and Development System (JCIDS) is the deliberate process to identify capability gaps in war fighting capability that are defined by stakeholders (US DOD, 2012). The output of the JCIDS process is a guided path for the development of future acquisition systems that reflect the needs of all four Services (Army, Navy, Marines and Air Force) that are shaped by the needed capabilities of the Combatant Commanders. The outcome JCIDS process is not exclusively a *material* solution. A valuable framework to scrutinize other potential solutions is to examine the solution space through a Doctrine, Organization, Training, Leadership and Education, Materiel, Personnel, Facilities, and Policy (DOTLMPF-P) lens.

The fourth activity is the ***Decision and Action*** activity. It links the guidance to the programs of execution across the Future Years Defense Program using the results of the middle two activities. Each activity has a component of the modeling and simulation (M&S) competency that enables informed decisions and progress through, and on to, the next activity. The range of M&S competencies are evidenced in discrete engineering models that inform the effectiveness of a proposed alternative weapon or support system within the JCIDS timeline, to the employment of decision support tools (e.g., computer-based or table-top) to support the prioritization of capability gaps.

EMERGENT MILITARY ENERGY RESILIENCE GUIDANCE

Within this deliberate capability development process, the requirement for energy resilience must compete for resources. The DOD has established guidance in the DOD Directives, DOD Instructions, DOD Manuals, and Policy Memorandums that are aligned with the current strategic and operational requirements established in Public Law and Executive Orders. From the DOD perspective, DOD Memorandum 3020.45, *Defense Critical Infrastructure Program Execution Timeline*, is intended to bridge the Guidance activity previously mentioned to the Decision and Action activity. The memorandum assigns the Services responsibilities for completion of key functional imperatives (e.g.: Criticality; Threats and Hazards; Vulnerability; Risk Response; and, Resourcing) and adherence to a timeline (US DOD, 2010). As a Direct Reporting Unit to the Department of the Army Headquarters, the Installation Management Command (IMCOM) manages the majority of the Army's installations. The IMCOM synchronizes, integrates and delivers installations services and sustains facilities in support of senior commanders to enable a ready and resilient Army (USA, IMCOM, 2014). This responsibility entails interpreting the ***Guidance***, ***Assessing and Analyzing*** the capability gaps, participating in the ***Reconciliation and Recommendation*** activities and ultimately executing the ***Decisions and Actions*** arrived through the PPBE process.

Responding to emergent resilience concepts, the Acting Deputy Undersecretary of Defense for Installations and Environment directed a *power resilience* review to examine DOD installations adherence to resilience policies, ascertain gaps in system capabilities required to satisfy critical energy requirements (e.g., generators, fuel contracts, scheduled maintenance, trained operators), and develop remediation plans that mitigate major mission risks (US DOD, 2013). In his other role, the IMCOM Commander is the Assistant Chief of the Army for Installation Management (ACSIM); the proponent to ensure compliance with DOD guidance regarding energy resilience for all Army installations, not only those he manages. The complexity, enormity and interdependencies of the challenges associated with installation energy resilience within a broader community are daunting. Moreover, recent discussion with senior leaders at ACSIM highlighted growing challenges in balancing installations' mission requirements with fiscal realities. Modeling and simulation competencies are being employed to an increasing degree to decompose aspects of the larger challenge; new developments must recognize resource constraints while seeking to provide workable solutions. A recent joint Department of Homeland Security-DOD table-top review of Hurricane Sandy emphasized partnerships in resilience, and senior leaders acknowledge that tremendous work remains to reconcile critical infrastructure protection and community resilience.

COMMERCIAL UTILITY CAPABILITIES DEVELOPMENT PROCESS

Similar to the DOD capabilities process, the regulated utility industry follows a process, but within a constrained regulatory compact. This compact requires investor owned utility companies to balance business requirements and shareholder pressures while simultaneously meeting community, rate payer and regulatory expectations of safe and reliable service. Often expectations are unrealistic as to what a utility company can proactively invest in resilience while still meeting financial and shareholder requirements. Therefore (and in contrast to the military model), utilities must assess the potential impact of Guidance before it moves forward to implement resiliency measures (Figure 2).

In a regulated utility, guidance is generated through a regulatory compact where utilities apply for a rate structure they believe would allow them to manage their system and earn a fair profit. On the other hand, consumer advocates challenge the utility filings in an attempt to keep rates low and mitigate the quasi monopoly a utility has in providing a service everyone needs. This adversarial process and eventual decision by a regulatory commission impacts the resiliency strategy and tactics that a utility employs.

Upon receiving ***Guidance*** input, utility managers ***Assess and Analyze*** the potential impacts in terms of their asset and emergency management processes, programs and procedures. Leading practices for utilities also include an assessment of risk exposure created by the specific decisions and the corporate strategic guidance.

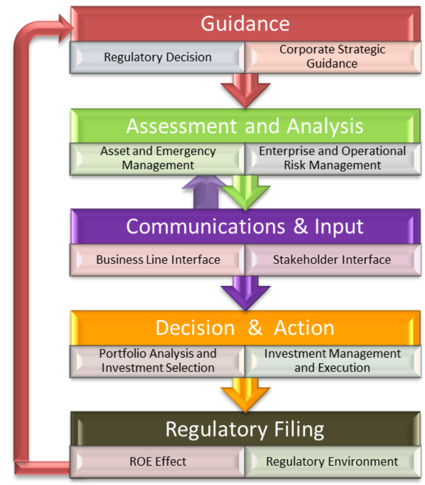

Figure 2. Utility Capabilities Process

Analysis elements for utilities often involve ***Communications and Input*** from the utility's internal and external stakeholders. These activities can include town hall meetings and local hearings that allow consumers to provide input as well as legislative liaisons to assist in the two-way communication between political entities and the utility. Nowhere is this give and take more prevalent than when utilities prepare for severe events, when utilities collaborate with local and state leaders to improve community resilience. Stakeholders often find themselves constrained by ***Guidance*** from regulators, which can make it difficult to reduce risk in an economically constrained environment.

After positions are established and the utility direction for action is developed, the ***Decision and Action*** step generates an actual investment and budgeting process resulting in funding levels and investment selection. Investment options are evaluated and a portfolio of investments is prioritized to support the corporate strategic objectives (***Guidance***). Selected investments are executed and managed through completion.

This entire process repeats itself on a cyclical basis, through ***Regulatory Filings*** that assess emergent risks, asset and emergency management requirements, and utility growth and expansion goals that necessitate changes to the bottom line. The goal is to evolve deliberately and maintain a viable company, which necessitates a new regulatory rate request or other regulatory filing from time to time. The decision to submit a filing initiates the process steps again, by prompting new regulatory ***Guidance***.

MODELING ENERGY RESILIENCE - A COMMERCIAL APPROACH

Recognizing the DOD is still evolving its approach to modeling energy resilience, the commercial utility sector has a promising approach that balances long-term investment (their capabilities development activities) with the *practical reality* of societal pressures (fiscal concerns raised by stakeholders and investors, political realities, regulatory challenges, the economic consequences of scores of businesses or residences being without power) for modeling energy resilience. While the utility industries account for 1.2% of the nation's GDP (US DOC, 2014), when considering the impact the energy sector has on civil order, defense, manufacturing, government, education, and basically all other sectors, the ability to produce safe and reliable power is essential to the nation's overall economic health. Energy utilities are considered a "lifeline sector" with respect to regional resilience (NIAC, 2013). In fact, massive storms, earthquakes and floods causing major power outages can literally shut down entire regions of the country, both physically and economically. Cyber threats (Gorman, 2009), physical attacks (Halper & Lifsher, 2014) and technical failures have similar potential to inflict extended power outages and related economic damage. The resilience of our energy infrastructure, and especially that of electric utility companies, has become a national economic priority.

One thing is clear - utilities will never completely eliminate the risks of service interruptions. Furthermore, regulatory pressure and political criticism follow any event that results in a large outage. Post-event (after-action) reviews enable improvements. However, when extreme events interrupt service for significant lengths of time, the same set of questions always arises: what could have been done to reduce the impact of the event; what can be done to improve the system's resilience? When addressing significant events, FEMA, Homeland Security (US DHS, 2008) and other Federal agencies use processes with four common elements: ***Prepare, Respond, Recover and Mitigate***. Utilities use the ***Prepare, Respond, Recover and Mitigate*** process to identify resiliency solutions that are timely, cost-effective accepted by internal and external stakeholders and beneficial for the entire system (Figure 3).

Figure 3. Utility Resilience Model

Prepare - Asset Management Decisions and Investment in Human Response Capabilities

Utilities often address competing priorities such as resilience. A utility may choose not to invest heavily in resilience efforts to harden the system against severe events but instead invest in the company's ability to respond to threats and possible events. Rather than investing billions of dollars in a *potential* hazard, the company can invest in its employees and its communities' capabilities to respond to any type of hazard.

Respond and Recover - Risk Realized or Consequence Management

Using the preparation and planning that has occurred over a historical timeframe, a utility typically responds by addressing system issues or failures that are vulnerable to severe events. This involves a range of investments including outage restoration, system/equipment repair, restoration review, staff training, and technology upgrades. Regardless of the event, concerns about system vulnerability are sure to exist after the fact. These must be evaluated and addressed as part of the recovery process. Utilities utilize historical data, analytics and modeling to prioritize investments against corporate and community goals. These tools point to an optimal path of mitigating investments that boost resilience throughout the system.

Mitigate

Once a vulnerability or risk is realized through an actual event, stakeholders (e.g., politicians, rate payers, consumer advocates, etc.) typically become more supportive of investments that would protect against a similar event with similar consequences in the future. The utility and regulators also see the value in the adaptive or dynamic response that human systems – a response-capable workforce - had on avoiding catastrophe. This reinforces the value of hardening of the human system as well as the hardening of the engineering systems. Regulators often agree to increase investment in both systems to mitigate the effects of another catastrophic hazard, which once again initiates the ***Prepare, Respond, Recover, Mitigate*** cycle. It is difficult to plan contingencies for unknown risks and even harder to get rate payers to pay for them, so the extremely low probability event remains outside of the typical regulatory cost recovery allowance.

Lessons learned through the electric utility ***Prepare, Respond, Recover Mitigate*** process can provide other sectors with valuable ideas for making risk mitigation decisions. Other sectors can certainly learn from the utility process, smartly applying analytics and data-based decision making models instead of starting from scratch, learning from their own experience and adaptation.

COMMERCIAL UTILITY COMPANIES DECISION SUPPORT

Analytic models for decision support have increased penetration in the utility sector because of the requirement for informed decisions in a highly regulated and financially constrained environment where multiple variables are in play. Utility leaders understand that within the regulatory compact robust analysis must support compelling arguments. Gone are the days of subject matter experts "gutting it out" through intuition and years of expertise as to when certain assets will fail. "Years in the field" is no longer held in the same regard as in the past.

Today, regulators and decision makers *(and DOD stakeholders)* need to understand the likelihood of possible events (e.g., asset failures, cyber-attacks, substation shootings, severe weather, etc.) as well as the likely consequences of these events (e.g., numerous customers without power for multiple days or months) as they work to make the most informed risk mitigation decisions possible. One example of a data-driven analytic model is a life cycle analysis representation of an infrastructure asset. Its foundation is the use of asset failure probability curves, which require detailed analysis of actual, historical failures and root-cause analysis. Many utilities do not have long-term historical data, but they acknowledge a need for it and are beginning to collect and analyze the data. Still, using expert judgment and partial data is better than solely relying on expert judgment.

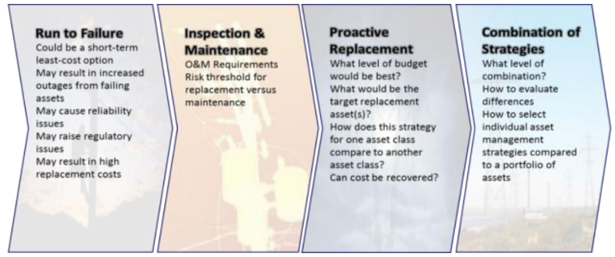

Figure 4. Asset Management Strategy Components

Figure 5. Comparison of Asset Management Strategies

Once there is an understanding of the asset failure probabilities, utilities need to understand the implication of different asset management strategies (Figure 4). Modeling asset strategies provides a utility the ability to understand tradeoffs in costs and risks associated with each of its different management strategies (Figure 5). The consequences of different management strategies are incorporated into the model's base case scenario, and output provides inputs to a greater question - what collection of investment options (in other words, what *portfolio* of options) should be analyzed?

Today, utilities employ various modeling techniques. Ultimately, models produce a portfolio of potential decisions. Figure 6 depicts one example of a system resilience portfolio model. The purpose is to provide structure, assessment and input into the strategic decision making process. The outputs of tactical models provide inputs into the strategic portfolio analysis models. In doing so, utility companies integrate the decision making process from top to bottom. The process end state is reliable, safe and secure energy that is now more than ever resilient and durable; all within the current and future regulatory compact.

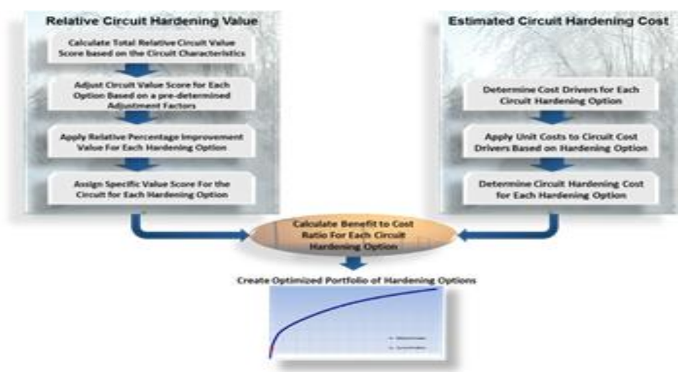

Figure 6. Electric Resilience/Hardening Options Analysis Method

INTEGRATED APPROACH TO M&S BLENDING BOTH APPROACHES

As resilience shifts the objective from system protection to community survival and health, the corresponding analytical exercise becomes necessarily more complex and collaborative. Emergency planning has been the domain of emergency managers and public service providers while the engineering community and those operating specific infrastructure have focused on maintaining functionality of specific physical systems. Adaptation, as an essential step in the resilience cycle, remains largely the responsibility of individual stakeholders, manifested through such steps as zoning changes, building code updates, and revisions to domain-specific plans or training. Here, the authors utilize a generic process template to organize a comparison of practices from the respective military and civilian analytical approaches. The resulting process can be used to inform future development, integration and employment within the emerging resilience analysis field.

Resilience is a flexible principle that may be applied to various systems and on different scales. Therefore, the first step must establish a "***world view***" of the community, key actors and important functions and interfaces. Next, the process must probe that "world" model to characterize ***how the world reacts*** to various stimuli (change). The insights exposed in these initial steps should then be structured into ***logical relationships*** (mapping) to enable further analysis, allowing integration of other process relationships (i.e., political or financial). The last two steps are ***assessment*** and ***implementation of prospective solutions***. By indexing the military and civilian analytical schema to this generic framework (Figure 7), it becomes possible to correlate opportunities to combine the relatively strong social mechanisms involved in civilian community interactions while drawing upon more typically structured techniques prescribed within military guidance and tools.

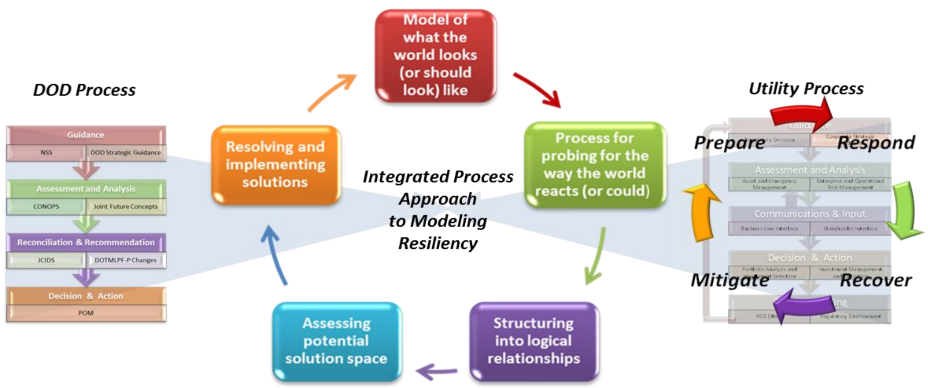

Figure 7. Integrated Approach to Resilience M&S

The exercise of establishing a world view for community resilience requires an open-ended process that invokes participation among diverse stakeholders. Since the 1970s, the Incident Command System (ICS) has evolved with a focus on coordinated planning and response to emergencies at community levels and above. Activities such as conferences and community response exercises have helped to open dialogue among stakeholders, and generate opportunities for collaboration. The resultant holistic and socially-integrated view generally focuses on operational solutions and emergency situations, not necessarily broader resilience considerations such as infrastructure improvements or community adaptation. Military capability development processes systematically develop concepts to achieve assigned military missions. Stakeholders, comprising well-defined populations of operational and functional proponents, focus on objectives which are explicitly or implicitly necessary to achieve the prescribed mission.

Military and civilian communities utilize roughly parallel techniques to characterize system response to change. Planning conferences, tabletop exercises and role-playing events conducted in both domains generally employ tangible scenarios to provide a common basis for visualization and to evoke adequate detail about interactions such as response time and capacity to a specific consequence (e.g., local flooding or enemy counterattack). Civilian communities lack the common cultural framework of military organizations. Their exercises provide deliberate and open-ended investigation of the breadth of effects, for example, from impacts of energy loss to medical or water treatment facilities to regulatory requirements at local, state and national levels. Military analysts are able to utilize defined system structure and well-resourced systems analysis tools to conduct deliberate simulations, such as role-playing war games, which yields specific information about system response, often capturing results directly into useable databases.

System mapping for resilience is a particular challenge due to the inherent system complexity. Posturing a community for constructive response to generalized change evokes a relatively broader scope than do existing programs such as emergency response or critical infrastructure, with the added complication of uncertainty across a broad range of potential circumstances and time frames. Frequent employment of the ICS has prompted evolution of a broader construct of the National Planning Frameworks, which address Prepare, Respond, Recover and Mitigate; roughly corresponding to resilience concepts, but still focused on emergencies and not necessarily long-term learning and adaptation (US DHS, 2013). Conversely, military systems and requirements are mapped through a highly structured set of "views," from an initial Operational View ("OV-1") diagram to detailed, interrelated products that map functions, interfaces, information flows and design requirements. Notably, military installations traditionally have not utilized this approach because few had recognized direct mission relationships, making cost and other policy considerations predominant. In some cases, this may represent an opportunity for installation managers to blend the emergent civilian planning framework with the military architectural framework to improve analysis and pursue solutions.

The process of building community resilience demands consideration of diverse measures which collectively can improve system response under a range of conditions. Portfolio management approaches and assessment methods expose cumulative outcomes under a range of conditions. Civilian emergency planning exercises focus on anticipated or historical scenarios to elicit expert insights regarding best practices and likely outcomes. They are particularly effective at identifying "soft" solutions such as plans, training and information. Individual entities such as utilities (and military installation managers) tend to focus upon "hard" investments in infrastructure systems, where system interactions are more deterministic and therefore easier to characterize. The military capability development framework of "DOTMLPF-P" offers a useful construct through which to capture a combined suite of "hard" and "soft" solutions.

Ultimately, stakeholders must agree and act upon the solution portfolio. Soft solutions often can be motivated through qualitative assessment, judgment and negotiation, but infrastructure investment invariably requires quantification of value – particularly difficult in light of the uncertainty manifested in resilience concepts. Military capability development generally identifies must-have "requirements" rather than calculating a "return on investment". The described utility approach of reconciling risk assessment with regulatory requirements may be useful to justify investments by military or other civilian entities.

Clearly, the respective analytic methodologies offer promising ideas for joint and separate application by military and civilian communities to advance resilience. In the following section, we utilize an historical example to illustrate how a hybrid approach might help achieve a more resilient response.

A PROPOSED HYBRID APPROACH - CASE STUDY OBSERVATIONS

In 1992, South Florida was devastated by Hurricane Andrew. In 2004, three hurricanes hit rapid fire within two months and crippled the state again. In each case, storm impacts were devastating and the public outcry dramatic, especially with respect to the inability of electric utility companies to sustain or restore electrical power. The impact to Homestead Air Force Base in 1992 was so severe that active missions have since been relocated to other bases. Homestead now supports Air Force Reserve unit operations. How might outcomes have differed if Florida communities and the region had implemented a different set of analytical practices?

Most substantially, collaboration among military and civilian stakeholders consistent with National Planning Framework guidance could have helped establish an integrated world view of community processes and needs, illuminating interrelationships among functions such as energy, transportation, communication and life support. Combining military and civilian practices, communities could employ scenario-based experimentation to develop system responses to prospective events such as storms or terrorist attacks. System insights could have been captured into architectural products that enabled coordinated planning among industry, community and military stakeholders.

With an appropriate focus on outcomes rather than system protection, such collaborative inductive analysis would yield a broader set of potential solutions and a more useful framework through which to assess and coordinate implementation. The collaborative solution portfolio also might include such measures as evacuation, establishment of community shelters, staging of response capabilities, and installation of connections for portable generators at fueling stations. (Some of these mitigation strategies were implemented – such as relocation of aircraft from Homestead AFB.) Nearly any solution could be implemented by an individual stakeholder, but clearly represented concepts, strategies and system interactions would facilitate solution-set synergies and could even be strong enough to motivate alternative resourcing strategies.

Meanwhile, military installations, utility companies and other infrastructure owners are being informed by increasingly capable predictive models for rapid and accurate damage estimation. Utilities have sought assistance in developing decision support models to aid in making strategic, operational and tactical management decisions before, during and after extreme events as well as for the management of their infrastructure. Preparing for and managing restoration after a major storm requires managers to consider prospective solution portfolios in light of resource requirements, priorities, social implications and resource allocation across areas of responsibility and using various cost recovery methods.

Finally, in anticipation of a severe weather event, communities employ the ***Prepare, Respond, Recover, Mitigate*** process. Civilian and military authorities inform the public of impending hazards and implement coordinated actions consistent with planning and anticipated situations. Based upon weather predictions, utilities begin to model the impact of the storm on their service territory 72 hours prior to landfall. Damage estimate models provide inputs into resource allocation and deployment decisions as utilities plan and prepare for storm response. Using models and analytics, utilities continue this process 48 hours in advance, 24 hours in advance, at time of landfall, landfall +24 hours, landfall +48 hours, and landfall +72 hours. Once the +72 hour time milestone has passed, tactical decisions may change slightly, but typically do not require significant modeling efforts.

By integrating a major Florida utility's storm damage estimate model into a logic-based model for service area site selection and the resource acquisition and allocation business rules, a holistic simulation model allows utilities to estimate costs, timelines, resource requirements and allocation, restoration site requirements, etc. Additionally, a prioritization value of critical infrastructure items embedded in the model logic make storms evaluated in the model unique in input and output. Integrating these processes with logic and associated data, a simulation model allows decision makers to adjust their restoration strategy (the priority of restoration) and resource allocation strategy (the percentage of resources assigned to each task). This integrated model provides decision makers with the ability to evaluate the impact of strategic decisions on key metrics such as system restoration timelines, priority of restoration timelines, utilization of resources, and costs associated with storm restoration. Providing this information in graphical and tabular reports allows for better decision making prior to a storm and during the restoration effort itself (Figure 8).

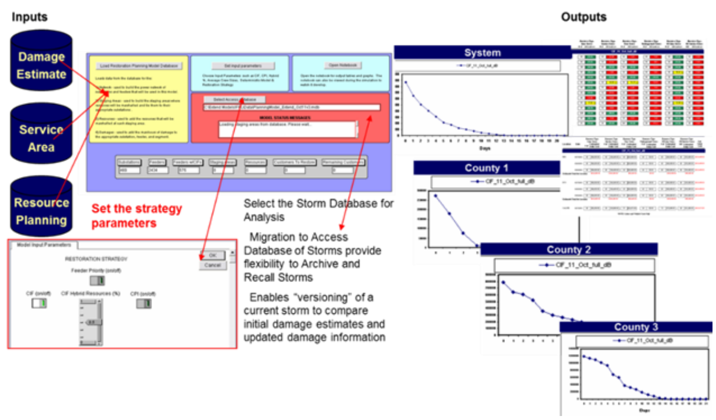

Figure 8. Example Analytics for Utility Emergency

Post event, utilities always attempt to learn from the event. After-action reviews identify what went well, what went not very well and what actions need to be taken to improve. Forensics analysis of assets that failed provides detailed engineering data concerning the asset failures. Data visualization overlaid on the service area provides insights to weather impacts on the system that also help correlate damage understanding. Using OMS, SCADA, and weather and mapping data, utilities can see a post-storm simulation to gain more insights for the after-action review process (Figure 9).

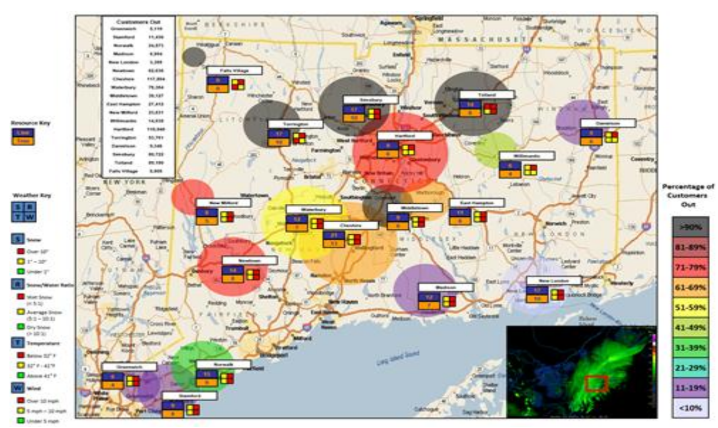

Figure 9. Example Storm Simulation Model

CONCLUSIONS

Military and civilian communities must expand their collaboration to advance community resilience. Existing practices provide useful analytical methods to support such collaboration, and a hybrid approach can leverage the diversity and outreach embodied in civilian models with the military's highly structured processes. Moreover, practitioners must tailor such tools to accommodate the inherent shift in focus from system protection to maintaining operational outcomes through flexible and adaptive solutions.

Sound execution may not only improve disaster preparedness and response, it can foster true community resilience by developing greater understanding, stronger relationships and more a robust, sustainable foundational approach. Many of the stakeholders are in place and possibly well-prepared, but military and civilian communities may have maintained an artificial and counterproductive level of separation during 20th Century. Collaboration offers the added benefit of diversity. In general, civilians bring deep domain expertise, commitment and ability to leverage diversity, while military participants can bring structure, resources and organizational capability – and the general public trust that can be important to motivating teamwork.

Sensitivities to recent natural disasters and concerns for cyber and physical vulnerabilities have motivated substantial attention and action to increase resiliency among military installations and civilian communities. The situation is ripe to develop and implement appropriate analytical protocols which draw up from the breadth of methodologies embodied in these respective domains.

REFERENCES

Gorman, S. (2009). "Electricity Grid in U.S. Penetrated By Spies." *The Wall Street Journal*. Retrieved April 8, 2009, from http://online.wsj.com/news/articles/SB123914805204099085

Halper, E. & Lifsher, M. (2014). "Attack on Electric Grid Raises Alarm." *Los Angeles Times*. Retrieved February 6, 2014, from http://www.latimes.com/business/la-fi-grid-terror-20140207,0,5892405.story#axzz2sdxqoI6k

National Academy of Sciences (NAS). (2012). *Disaster Resilience: A National Imperative*. Washington D.C.: National Academic Press.

National Infrastructure Advisory Council (NIAC). (2013). Strengthening Regional Resilience through National, Regional, and Sector Partnerships, DRAFT Report and Recommendations.

Thomas, S., & Kerner, D. (2010). *Defense Energy Resilience: Lessons from Ecology*. Carlisle Barracks, PA: Strategic Studies Institute, U.S. Army War College.

U.S. Army Installation Management Command (IMCOM). (2014). Mission Statement. Retrieved February 12, 2014, from http://www. imcom.army.mil/About.aspx.

U.S. Department of Commerce (DOC). (2014). Bureau of Economic Analysis. Retrieved February 15, 2014, from http://www.bea.gov/iTable/itable.cfm?reqid=51&step=1#reqid=51&step=51&isuri=1&5102=15/

U.S. Department of Defense (DOD). (2013). Memorandum, Subject: Depart of Defense Electric Power Resilience. Washington, D.C.: Office of the Under Secretary of Defense (Installations and Environment).

U.S. Department of Defense. (2012). Chairman of the Joint Chiefs of Staff Instruction 3170.01H, *Joint Capabilities Integration and Development System*. Washington, D.C.: Chairman of the Joint Chiefs of Staff.

U.S. Department of Defense. (2003). Briefing, *Introduction to the Joint Capabilities Integration and Development System*. Washington, D.C.: Chairman of the Joint Chiefs of Staff.

U.S. Department of Defense. (2009). Department of Defense Instruction 4170.11, *Installation Energy Management*. Washington, D.C.: Under Secretary of Defense, Acquisition, Technology & Logistics.

U.S. Department of Defense. (2010). Department of Defense Memorandum 3020.45, *Defense Critical Infrastructure Program*: Execution Timeline. Washington, D.C.: Principal Under Secretary of Defense, Policy.

U.S. Department of Homeland Security (DHS). (2008). National Incident Management System. Washington, D.C.

U.S. Department of Homeland Security. (2011). National Preparedness Goal, First Edition. Washington, D.C.: Federal Emergency Management Agency.

U.S. Department of Homeland Security. (2013). Overview of the National Planning Frameworks. Washington, D.C.: Federal Emergency Management Agency