RESILIENCE PROFILES: ONE APPROACH DOES NOT FIT ALL Casey Church, Mukta Agrawal, and Joel Mehler Analytic Services Inc. 2900 South Quincy Street, Suite 800, Arlington VA 22206 +1-703-416-3180, <u>casey.church@anser.org</u>

We propose a view of resilience consisting of four capability categories: Anticipation, Absorption, Adaptation, and Rapid Recovery. While all four of these capability categories may be beneficial to system resilience, it is suggested that the optimal **resilience profile** (percentage of resilience associated with each category) is dependent upon the organization's **mission**, **culture, and environment.** We propose a methodology to assess a system's optimal mix across the four capabilities and suggest that indirect measurement of resilience (use of proxies) offers the best pairing with our profile concept. We believe such an optimized resilience profile concept could contribute to more efficient investment of resilience enhancement resources.

Key Words: Resilience, Resilience Profile

INTRODUCTION

Our discussion begins with establishment of our definition of resilience and a spectrum of four component capability areas (Anticipation, Absorption, Adaptation, and Rapid Recovery). We next introduce the concept of an optimized resilience profile based on the system's mission, culture, and environment. Although our research into the necessary and sufficient parameters for each of these perspectives is ongoing, we describe a set of twelve variables for purposes of illustrating the concept. We then describe a methodology with three stages to assess a system's proactive/reactive posture (anticipation and absorption versus adaptation and rapid recovery), its defensive posture (anticipation versus absorption), and its responsive posture (adaptation versus rapid recovery). The result is a recommended profile across the four areas and a number of sample calculation are provided. We conclude with topics for future research and a summary. Discussion of a resilience profile is of little use without the ability to measure the existing resilience and monitor subsequent change. We therefore include by appendix, a review a number of examples of both direct and indirect measurement approaches.

BACKGROUND

Resilience Definition

This paper utilizes the definition of resilience provided in the National Infrastructure Advisory Council 2009 report – *Critical Infrastructure Resilience* (1).

Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends

upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.

This definition, with the inclusion of "anticipate" and "absorb," suggests resilience as a spectrum extending from pre- through post-event.

"The ability to reduce..." highlights that we can have resilience in advance of a disruptive event and that it is not defined solely by the system's response to any particular event. For example, the addition of a backup generator to an electrical supply system increases the system's ability to reduce both the magnitude and duration of an electrical blackout, thereby enhancing the system's resilience regardless of whether such a blackout ever occurs.

Through the use of the phrase "... a potentially disruptive event", we can infer that through effective anticipation and absorption, such as through the ability to switch immediately to a back-up power supply, it may be possible to prevent an event from becoming disruptive.

We emphasize these points out of necessity. Our approach to optimal partitioning of resilience is based on the perspective that resilience involves an ability, or capability, which exists and can be assessed independent of any particular disruptive event. Following our presentation of the profile concept and proposed calculation methodology, we discuss examples from the literature of direct and indirect measurement approaches and comment on their potential application.

RESILIENCE PROFILE CONCEPT

Should one size fit all?

The four elements of Anticipation, Absorption, Adaptation, and Rapid Recovery describe a spectrum of resilience and implicitly suggest that one resilience profile may not be best suited to all cases. Considering a cellular tower network, we have a system of comparatively inexpensive, exposed towers which could be replaced relatively quickly. Temporary loss of service would pose a significant inconvenience, but the land-line network offers an alternative to most essential traffic during the brief down-time. One might argue that for such a system a reactive posture focused on *rapid recovery* is probably the most relevant resilience approach. Considering an air traffic control system, we have a complex system, failure of which could result in widespread disruption to the population and economy and for which no alternative system exists. In this case a fairly level spread of both proactive *anticipation* and *absorption* and responsive posture of *adaptation* and *rapid recovery* seems appropriate. The Washington Monument represents an example where perpetual presence is the primary function. As such, a reactive posture to resilience seems much less relevant than a proactive posture.

These three examples demonstrate that one approach to resilience does not fit all. We propose a methodology that we believe fosters introspective insights and meaningful guidance to managers considering how to invest limited resilience resources. We suggest that the relative importance of the four elements, *Anticipation, Absorption, Adaptation* and *Rapid Recovery*, can be assessed

through examining three aspects (proactive/reactive, defensive posture, and responsive posture) from three different points of view (mission, environment, culture).

DETERMINERS OF THE OPTIMAL PROFILE

The identification of the necessary and sufficient set of determiners of the optimal resilience profile is an ongoing effort and is discussed in the subsequent section on Future Research. We suggest that the three perspectives of mission, environment, and culture offer a starting point. For purposes of illustration, ten topics have been postulated by our team to be used in our example calculations and are discussed below.

Mission

<u>Fault tolerance</u>: Intolerance to interruptions or degradations may indicate that a system requires emphasis on prevention of degradations versus a reliance on response.

<u>Threat transference</u>: Visible, anticipatory defenses may reduce man-made threats (terrorism or sabotage) only to transfer the attacker's focus to another potential vulnerability or target. Absorptive measures may be less readily recognizable.

<u>Stability of mission</u>: If it can safely be assumed that the enterprise's mission will remain the same post-event as it was pre-event, it may be most expeditious to pursue rapid-recovery to a steady-state as quickly as possible. If there is likelihood that the immediate need post-event may vary or evolve prior to settling to a steady-state, increased adaptability may be advantageous.

Environment

<u>Accessibility</u>: Within the context of Proactive/Reactive postures, accessibility impacts both the system's vulnerability to threat and the opportunity for repair/replacement. If access of adversaries to the system cannot be suitably restricted, the importance of response capabilities increases. Additionally, if access to repair/replacement of the system is limited, for example as with a satellite system, the relevance of response activities decreases. In both cases, the relevance of a reactive posture increase with greater accessibility.

<u>Exposure</u>: Within the context of defensive posture, the nature of some systems may necessitate being exposed and therefore vulnerable to threats. Electrical distribution networks are an example. Though many threats (both man-made and natural) to transfer lines are known, even the best protection and prevention efforts cannot ensure complete security. In such cases the ability of the network to absorb disruptive events becomes more relevant.

<u>Threat environment predictability</u>: Threat predictability impacts both the division between Proactive and Reactive postures and the allocation of proactive efforts between Anticipation and Absorption. In the first instance, an unpredictable threat environment (either due to changing actors, changing technology, or changing understanding of targets and their vulnerabilities), increases the necessity of reactive capabilities due to the increased likelihood that proactive measures will not be adequate for any eventuality. In the context of the defensive posture, a predictable threat environment increases the efficiency of anticipatory measures and decreases the need for a broader absorptive approach.

<u>Replacability</u>: If a system cannot be easily replaced (due perhaps to complexity or availability of replacement components), it likely will require short-term adaptability to achieve minimum output.

Culture

<u>Acceptability of fortification</u>: Cultural sensitivity to perceived fortification or militarization at sites traditionally open to the public may impact overt prevention efforts. For example, the implementation of sustained, high-visibility counter terrorist check points and barriers around national icons, embassies, commercial facilities, and cultural events, etc. would likely result in significant impact to public utilization and potentially lead to long-term public behavior modification.

<u>Hierarchical decision making</u>: Organizations which rely upon decision making at senior management levels are arguably less well-suited to an adaptive response approach and are better suited to implementation of pre-approved rapid recovery efforts.

<u>Interdependency</u>: Systems that are largely autonomous will likely have greater flexibility in adaptation than those that share a high degree of interdependency and which may be better suited to rapid recovery approach.

OPTIMAL PROFILE CALCULATION

The methodology we propose uses three stages to assess a system's **proactive/reactive posture** (*anticipation* and *absorption* versus *adaptation* and *rapid recovery*), its **defensive posture** (*anticipation* versus *absorption*), and its **responsive posture** (*adaptation* versus *rapid recovery*). The result is a recommended profile across the four areas. A number of sample calculations are provided.

We define the resilience capabilities of Anticipation and Absorption as being *proactive* in that they pertain to steps taken prior to a disruptive event that are focused on reducing the magnitude or duration of a disruption. In the case of Anticipation, the proactive measures are associated with identified threats (natural or man-made). Absorption is also considered to be *proactive*, but is not linked to a specific event and instead consists of more general characteristics that can be built into the system. Network redundancy or off-site back-up data centers are examples of absorptive resilience which could be beneficial in the aftermath of a wide range of events such as fire, bombing, acts of sabotage, or accidental line cutting. By contrast, counter-terrorist vehicle barriers are designed and installed in anticipation of a specific type of event.

Adapting to events as they unfold, and subsequent efforts toward rapidly recovering to a desired steady-state, are considered *reactive*. We consider *adaptation* to be associated with short-term

alignment of available resources with best-achievable outputs. As such, this element is the most dynamic of the four capability areas, recognizing that resources are likely to be impacted by the event and the system/enterprise purpose or desired output in the immediate aftermath of the event may differ from the system purpose or desired output prior to the event. As an example, a tornado-damaged high school might demonstrate *adaptability* in rapidly converting a gymnasium into a triage center or shelter for members of the community made homeless. *Rapid Recovery*, by contrast, pertains to the return to normalcy. In our example, the return to full-functionality might include considerations such as whether to repair the remaining structure or to build new, on the same or a different site. Pre-selecting contractors to be used in emergency and pre-identifying sources for materials and equipment might be examples of adding resilience in this area.

Calculation Mechanics

The proposed methodology utilizes three stages, the first to determine the relative importance of proactive and reactive postures, the next to further divide Proactive into Anticipation and Absorption (the Defensive Posture) and lastly, to similarly divide Reactive into Adaptation and Rapid Recovery (the Responsive Posture). The goal of this effort is an assessment of the relative importance of the four resilience capabilities based upon the answers to the twelve mission/environment/culture questions shown in the accompanying example (Figure 1).



Figure 1. Resilience profile example calculation for Air Traffic Control System

Initially it is assumed that proactive and reactive postures have equal relevance and therefore 50% is assigned to each. Answering each question within the proactive/reaction section results in shifting between the two components, with the maximum potential cumulative effect being to move all 50% from one side to the other. In our example, we have utilized equal weighting for each question within the section and therefore each of the four questions in this first division has the capacity to move one quarter of the 50%, or 12.5%. The combination of answers shown produces no net shift, yielding a balanced proportioning of 50% Proactive and 50% Reactive.

The second step is to determine the Defensive Posture through the partition of the Proactive component into either Anticipation or Absorption. This is done in a similar manner to the first step, with the exception that whereas the first step initially assumed a 50% - 50% division, the second step only divides the Proactive value from the first step. Therefore the initial assumption in Step 2 is to equally divide the 50% determined in step 1 into 25% Anticipation and 25% Absorption. Again, equal weighting within this section means that each question has the capacity to move one quarter of 25%, or 6%. The combination of answers in our example produces a net shift of 12%, yielding a final Defensive Posture proportioning of 37% Anticipation and 13% Absorption.

The third step, is to determine the Responsive Posture through the partitioning of the Reactive component into either Adaptation or Rapid recovery, is identical to the previous step, in this case starting with the even sharing of the 50% determined in step 1. The answers provided in this example result in no net shift, which yields a final proportioning of 25% Adaptation and 25% Rapid Recovery.

Finally, the results of Steps 2 and 3 are brought together, in this case suggesting an optimized resilience profile of 38% Anticipation -13% Absorption -25% Adaptation -25% Rapid recovery.

	Anticipation	Absorption	Adaptation	Recovery		
Cellular Tower Network	0%	0%	25%	75%		
High fault tolerance, easy accessibility, unpredictable threat environment, and low cost to replace maximize reactive posture. Stability of mission, ease of replacement, and lack of flexibility in output favor rapid recovery responsive posture.						
Air Traffic Control System	37%	13%	25%	25%		
Low fault tolerance and high cost to replace are balanced by accessibility and unpredictable threat environment to produce even proactive/reactive split. Low probability of threat transference, restricted environment and isolation from public encourage anticipation over absorption. Adaptation and recovery remain evenly weighted with mission stability and high level decision making, which favor recovery approach, balanced by system complexity and autonomous nature which favor adaptation.						
Washington Monument	0%	75%	6%	19%		
Predominantly proactive posture due to iconic function, emphasis on absorptive due to risk of threat transference, exposure, and probable public reaction to fortification.						

Table 1 provides a number of example calculations with discussion of profile drivers.

Hydroelectric Dam	37.5%	37.5%	6%	19%		
Low fault tolerance (any failure likely means total failure) combined with high costs-to-replace and						
lengthy time-to-replace encourage proactive posture. Acceptability of fortification measures, which points to anticipation, balanced by exposure of the structure, which points to absorption						
Electric Power Distribution System	6%	19%	19%	56%		
Drivers pushing reactive posture: exposed and vulnerable, threat environment unpredictable, costs-to- repair relatively low. Mission stability and relative ease of repair favor recovery over adaptation.						
First Responder Services	12.5%	12.5%	75%	0%		
Exposed, relatively high fault tolerance, and unpredictable threat environment encourage reactive posture. Adaptation encouraged over reliance on recovery based on multi-faceted mission which is subject to change, decision making localized, and operations relatively autonomous.						
Nuclear Power Plant	37.5%	37.5%	6%	19%		
Emphasis on proactive posture resulting from low fault tolerance (associated with potential cascading effects), difficult to access for repairs, threats unpredictable, high cost-to-replace and long time-to-replace.						

Table 1 Example profiles.

FUTURE RESEARCH AND SUMMARY

As stated previously, the proposed framework is intended to illustrate the concept of optimal resilience profiles. Substantial research remains ahead.

- Interviewing/surveying of subject matter experts will be useful for establishing a set of questions which are both necessary and sufficient to assess the underlying determiners. In our demonstration we have arbitrarily utilized four questions for each division, with at least one question coming from each category.
- We must also consider how to identify the most appropriate weighting within questions. At present we have used equal weighting as a default. Clearly some questions must touch on more critical determiners than others. It is conceivable that weighting may be sensitive to industry or even system uniqueness and therefore adjustments on a case-by-case basis may be appropriate.
- We have provided brief explanations of the questions used in our example, but interviews will help to assess whether the questions used convey to the respondent the intended meaning.
- We have opted in this demonstration to use binary yes-no responses to each question. An alternative deserving of consideration is the use of some more graduated scale such as 1-10. Surveying experts and comparing their answers within like-industries would yield

insight into whether the opportunity of greater resolution in the response resulted in a more precise response or only a more variable one.

We have utilized percentages here chiefly because we believe it intuitive and helpful in conveying the concept. Yet comparison among discrete values my lead to interpretation beyond the fidelity of the underlying models. While a recommended profile such as 10% - 45% - 10% - 35% might safely be interpreted as conveying that Absorption and Rapid Recovery should be primary focus areas, the significance of the 10% difference between the two might be questioned. An alternative would be to convert the results into a scale of high/medium/low so that binning may prevent interpretation beyond the fidelity of the calculations.

Despite the significant amount of validation work that remains ahead of us, and the need for substantial advances in the enabling capability of resilience measurement, we believe that the concept and framework show promise. In the not-too-distant future managers will be faced with decisions about various paths to enhance their system's resilience. We believe the concept of optimized resilience profiles could contribute to making these decisions and more efficient investment of resilience enhancement resources.

APPENDIX - ASSESSING SYSTEM RESILIENCE

Discussion of a resilience profile is of little use without the ability to measure the resilience. We therefore review a number of examples of direct and indirect measurement approaches.

Direct Measures

Bruneau et al. (2) stated that the complementary measures of resilience are "reduced failure probability, reduced consequences, and reduced time to recovery" and identified four interrelated dimensions – technical, organizational, social, and economic. The authors specify that "the concept can be thought of as spanning both pre-event measures that seek to prevent hazardrelated damage and losses and post-event strategies designed to cope with and minimize disaster impacts." A graphical depiction of a drop in, and subsequent restoration of, quality of infrastructure over time after a disruptive event, subsequently referred to as the "resilience triangle", has become somewhat ubiquitous, despite the challenges in showing through such a depiction the reduction in failure probabilities, reduction in consequences, and reduced time to recovery which the authors associate with a resilient system. Such reductions arguably require some baseline as a reference.

Cox et al. (3) examined the London transportation systems recovery in the aftermath of July 2005 terrorist attacks with economic resilience as the metric. Direct static economic resilience was defined "as the extent to which the estimated direct output reduction deviates from the likely maximum potential reduction given an external shock..." The authors point out that a predictive capability offers greater utility than a retrospective analysis of a single event and they propose a

predictive measure taxonomy aligned with Hollings (4) ecological work in which the ability of a system to adapt is related to (A) vulnerability to unpredictable shocks, (B) the resources available to a system to help it change (wealth) and (C) the internal controllability of relationships in a system (flexibility).

Zobel (5) offered advancement on the "resilience triangle" by instead focusing on the area under the curve, which he viewed as representative of system resilience (Bruneau et al. (2) associated the area above the curve with loss of resilience). Zobel associated the vertical distance between the disruption's peak impact and the x-axis with robustness and similarly, the horizontal measure (time) with the rapidity of recovery. Zobel pointed out that multiple recovery profile slopes could produce the same area under the curve, and thereby the same measure of resilience. Plotting lines of iso-resilience in robustness-rapidity space facilitates consideration of the best mix to achieve a desired level of resilience – an emphasis on robustness at the expense of rapidity of recovery, an emphasis on rapidity at the expense of robustness, or a balance of the two. Zobel (6) initiated exploration of simultaneous depictions of technical, organizational, social, and economic isoresilience lines, suggesting the potential of weighting among the four. The work was in early stages and approaches to measuring the other the organization, social, and economic components were not yet developed.

Henry and Ramirez-Marques (7) defined resilience as the ratio of recovery at a given time to the loss suffered by the system at some previous point in time. They tie this post-disruption-only view to an interpretation of the word "resilience" as indicative of the ability of a system to "bounce back." This definition means that resilience grows over time as restoration is achieved.

A common theme in these examples of attempts at direct measure is an emphasis on resilience metrics based upon the degree of, and rate of, restoration of system performance in the aftermath of recognizable disruption. Despite that fact that several of the authors identified prevention of disruption and reduction of magnitude as part of resilience, the metrics developed do not reflect either of these. Direct measure of resilience as defined by NIAC would require assessment of the system's *ability or inherent character*, rather than its performance in a single instance. Further, use of restoration plots provides no measure of how greater the magnitude might have been, or how much longer the restoration time might have been, without the existence of resilience in the system. Put differently, an initial degradation of performance of 50% provides no indication of whether a frail system gave up half its performance in the face of a minor event, or whether an extremely robust system maintained half of its performance in the face of extreme adversity. The same can be said of restoration time, which when depicted without comparison tells us little of the reduction associated with resilience. "With and without" comparisons of system performance in the face of the same disruptive event would support direct measure, but the complexity of systems of interest and the variety of potential disruptive events may make this impractical. As an alternative we will consider indirect measures of resilience.

Indirect Measures (Proxies)

Case study work by New Zealand's Resilient Organisations Research Programme (McManus et al. (8) identified "four qualities that more resilient organizations tend to exhibit over those that

are less resilient: an organizational ethos to constantly strive for improved resilience; good situational awareness of the threats and opportunities facing the organization through the active monitoring of strong and weak signals; a strong commitment to proactively identify and manage keystone vulnerabilities; and a culture that promotes adaptive capacity, agility, and innovation with the organization". A series of 23 behavioral indicators were identified under the framework listed above for subjective assessment on a scale of 1-10. While limitations were recognized, the authors point out the utility of comparing evaluations within industry sectors, monitoring trends within an organization, and for promoting internal analysis and debate.

Cutter et al. (9) proposed a model for regional resilience based on proxies within the categories of social, economic, institutional, infrastructure, and community. Potential variables, all of which were available from public databases, were collected from the literature and culled to eliminate overlap. The resulting list of 35 proxies include variables such as "% of population with a vehicle," "% vacant rental units," and "ratio of large to small businesses." The authors opted not to weight the variables due to the lack of data to substantiate their relative importance.

Renschler et al. (10) suggested a community resilience framework based on population and demographics, environmental/ecosystem, organized governmental services, physical infrastructure, lifestyle and community competence, economic development, and social-cultural capital (PEOPLES). The framework recognized the existence of interactions among elements but "a consistent formulation for the quantification of resilience" was recommended for future research.

Fisher et al. (11) provides a methodology for calculating a critical infrastructure resilience index based on over 1500 data points collected by survey. Five levels of aggregation funnel the data through the categories of robustness, resourcefulness, and recovery into a single index, with weighting at the various levels determined by subject matter experts. This approach was developed by Argonne National Laboratory as an expansion of the ECIP Protection Index tool produced for DHS use.

Indirect measurement approaches such as these have the benefit of being employable independent of any specific disruption and are well suited for comparison over time or within industry sectors. As the goal of our resilience profile concept is to support management decisions about future investments, indirect measurements appear better suited than retrospective analysis and direct measurement related to specific past events.

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