Response and Recovery:

A quantitative approach to emergency management

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Abstract— **The last decade has shown a compelling need for a model to measure effectively how communities fare in overcoming unexpected hazards. Many entities, including the UN, have made relevant contributions in this area. However, a majority of these organizations have proposed and implemented mechanisms that only assess qualitative aspects (such as the presence and completeness of emergency plans) of the community in question, thus making assessment highly subjective and difficult to standardize. This paper presents a resiliency score framework that reflects the Federal Emergency Management Agency (FEMA) recovery continuum phases and aligns with current Emergency Management Accreditation Program (EMAP) standards. The developed model includes operational and quantifiable metrics that will support the assessment of a community's recovery process by emergency management and community leaders.**

Keywords—emergency management; operational metrics; response; recovery; resilience.

I. Introduction

The expediency of a community's recovery process post crisis or a disaster event is directly proportional to the affected community's resilience. Here, resilience is defined as "the ability of an entity to anticipate, resist, absorb, adapt to, respond to and recover from a disturbance" [1]. In other words, the more effective the recovery, the more resilient the entity. The difficulty, however, lies in accurately measuring the active pursuit of resilience, response and recovery capacity. This situation suggests that achieving and maintaining resilience relies on both the system and its operational capability.

Many proposed methodologies exist to measure community resilience and recovery [2]. Organizations such as FEMA and the United Nations Office for Disaster Recovery (UNISDR), as well as researchers at the US Department of Energy's Argonne National Laboratories and other institutions have made significant attempts to build consistent indices categorizing communities in terms of resilience [2]. For example, UNISDR created a scorecard model consisting of several questions that assess ten important aspects of the entity being evaluated, from the organization composition, budget and financial contingency plans to critical infrastructure investments and pre/post disaster preparedness [3]. This assessment is highly complex and requires a subject matter expert to conduct the process. The qualitatively driven questions make it difficult to effectively monitor the progress of the community toward a successful recovery from an unexpected disastrous event.

FEMA's framework, focused on the recovery process, comprises four phases: preparedness (before any disaster occurs), short-term (days), intermediate (weeks/months) and long-term (months/years); within this continuum, there is "a sequence of interdependent and often concurrent activities that progressively advance a community toward a successful recovery" [4].

This paper proposes a set of operational metrics founded on the FEMA framework, resulting from a quantitative assessment of the community being considered. Unlike other approaches, this model is designed to be customized to community-specific parameter values and most importantly, reflect the focus of the emergency manager and an operations center. The result is a quantifiable model of a specific community's path to recovery. The baseline information, and results from subsequent disruptions, become benchmarks when new disruptive events occur. In this way, a community can track its progress over time toward becoming more resilient.

II. Background

Current efforts in resiliency research conducted across both the public and private sectors are primarily at strategic levels, i.e., policy and general framework recommendations in the form of guidance documents, coordination plans, and voluntary standards. Much of the research on comprehensive metrics for resiliency and disaster recovery still remains in the realm of theoretical models, with little field testing of the applications. Although the Rockefeller Foundation's 100 Resilient Cities effort has sought to implement resiliency strategies, this effort has yet to link to the scoring indexes [5].

FEMA's National Disaster Recovery Framework (NDRF) provides strategic direction for managing and unifying national response efforts across federal, state, local, tribal, and some private sector entities [4]. This framework addresses five key principles: engaged partnership, tiered response, scalable/flexible/adaptable operational capabilities, unity of effort, and readiness to act. NDRF provides a solid foundation for the coordination and prioritization of response and recovery efforts, as well as a general overview of the time horizons

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involved in disaster response. However, NDRF does not provide metrics for measuring the efficacy of the preparedness, response, and recovery that could help increase a community's resiliency.

The United Nations International Strategy for Disaster Reduction (UNISDR) ensures coordination and synergistic cooperation of disaster recovery efforts from a risk reduction perspective. UNISDR has adopted the Sendai Framework for Disaster Risk Reduction for implementation [6]. This framework is primarily a goal setting and prioritization structure for coordinating international efforts. Priority 4 of this framework does indicate the necessity of "building back better" referring to resiliency, vulnerability assessments, and hazard mapping [3].

Other appraoches have been taken to address direct measurement of disaster response and recovery efforts. The US Department of Energy's Argonne National Laboratory has created a Center for Integrated Resiliency Analysis whose mission is to "develop planning tools for local and federal decision makers to reduce vulnerabilities in physical and social infrastructures, as well as develop mitigation and recovery plans that can speed recovery times after events" [7]. Argonne and its center focus on plans to improve resiliency and critical infrastructure protection as well as models to quantify and simulate response and recovery efforts in both the natural hazard and homeland security threat arenas.

III. METHODOLOGY

We begin by assessing the metrics needed for a quantitative approach to *response and recovery*, focusing our model on the 'lifeline infrastructures' within the 16 sectors defined by Presidential Policy Directive 21 (PPD-21) Critical Infrastructure Security and Resilience [8]. Each category is chosen based on metrics that are indicative of various municipalities and communities, permitting model testing in a wide variety of circumstances.

The model reflects the operational elements within the disaster continuum defined in FEMA's NDRF [4], which divides a disaster into four time horizons: *preparedness*, *short term*, *intermediate*, and *long term*. In some cases, a metric may only be relevant for certain phases in the recovery continuum. For example, in the short-term phase, travel is usually restricted to first responders, and not allowed for the general population. Therefore, metrics focusing on open routes for first responders would not be relevant in the long-term phase, when all roads have been restored. Moreover, the identified set of metrics is neither comprehensive nor static, thus making it incumbent on communities to determine metrics that are relevant to their environment. Each metric is assigned a weight through input from subject matter experts in the operations center, and the sector resiliency score is calculated by multiplying the metric value by its weight, then summing all metrics, creating a combined score.

A. Resiliency score equations

The weights given to each sector, metrics, and subsector permit the end user to customize the implementation and measurement to reflect the community, thus providing modularity and scalability. The model will then calculate a resilience index for each sector. These partial indices will be weighted and summarized to obtain the final Resilience Score.

The equation for the Partial Resiliency Index per sector is:

$$PRI = \sum w_i * m_i \quad (1)$$

where

PRI = Partial Resilience Index

w_i = Sector subcategory weight. Expected value from 0 to 1.

m_i = Value for sector subcategory metric calculation. Expected value from 0 to 1.

The equation for the Overall Resiliency Index is:

$$ORI = \sum W_i * PRI_i \quad (2)$$

where

ORI = Overall Resilience Index

W_i = Predefined sector weight. Expected value from 0 to 1.

PRI_i = Partial Resilience Index per sector. Expected value from 0 to 1.

Borrowing a concept from new product development, we added a phase/gate approach to the model. In this method, moving from one FEMA phase to another requires passing a milestone, or gate. For example, if all food and agriculture metric values reach a pre-determined value, the sector is considered to have passed through the gate separating one phase from another. As values may not always improve, the community can decide how long a metric must be at or above this gate threshold before declaring the gate passed. The phase/gate approach may also be used as a resiliency benchmark: a short time period between gates implies an effective response and a more resilient community.

IV. EXAMPLE SCENARIO

A. Short term phase

Data collection is required prior to index calculation and as part of the gap analysis process. Community managers are surveyed for different parameters related to each sector; these values are then used to obtain a partial index that is tied to the weight for that specific metric.

For our example scenario, a blizzard focused on Monroe County, NY was selected, as this particular event type is the main scenario that informs the local emergency planning methodology, based on county level planning requirements. Monroe County has a population of 749,636 (2013 figures) and contains 627 roads within its 1,366 square mile area. It also has 203 bridges with spans greater than 20 feet.

In this blizzard scenario, the event lasted seven days, during which 100 inches of snow fell in a period of 24 hours. Maximum wind speeds up to 90 mpg were recorded. Damages incurred included residential homes isolated without heat for up to three days; no flow of food supplies for four days; several roads closed; the airport closed; power failure in several neighborhoods due to falling electric poles and trees; collapse of old buildings from ice accumulation; flooding; and

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inability of first responders to reach vulnerable populations during the first stages of the event.

In the hours and days immediately post-event, the emergency manager enters data, as it is received, on the status of the elements in the different metrics. The model is not meant to be static, but can be updated as often as necessary to keep abreast of the changing state of the county. Figure 1 shows this state in the immediate post-event time period. Roads are closed, no rail lines are running, few power sources are available, and many cell towers are off-line.

The assessment was divided into three sections: short-term, intermediate and long-term, following FEMA standards. For each section, values were input and the metrics were calculated at each phase in the event.

After inputting data for each section, we obtained the results given in Tables 1 through 3. Table 1 shows some of the metrics, parameters, user input, and partial index for the transportation sector shortly after a disruptive event has occurred. Since there are a large number of metrics for this sector, only a few are shown. Table 2 lists all the metrics for this sector, their percent available, and the PRI calculation. Table 3 shows the ORI calculation for all six sectors.

In Table 2, ST is the short term phase; Int stands for intermediate phase, and LT for long term phase. The efficiency score at the bottom of the table is calculated as estimated time to complete the phase divided by the actual completion time, in days. Note that some metrics are not operational during the short-term phase, but will be in later phases. The partial results for the remaining five sectors are calculated in the same way, and results are shown in Table 3.

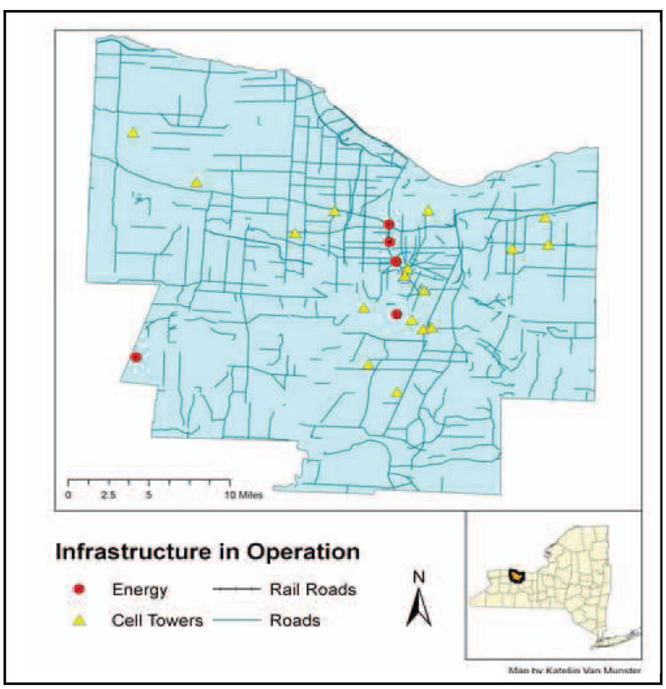

Fig. 1. Monroe County, short term phase status

TABLE I. TRANSPORTATION SECTOR SAMPLE METRICS AND INPUT

Transportation systems	Parameters	User input	Percent available
Critical personal access routes	Total number of routes meeting accepted response time	144	0.23
	Total number of routes in community	627	
Fire asset response	Fire response units available	7	0.64
	Total units	11	
Police asset response	Police units available	9	0.6
	Total units	15	
EMS asset response	Volunteer/Commercial/ Municipal units available	29	0.54
	Total all units	54	

Fig 2 plots the PRIs as color-coded bars with the short-term gate benchmark. For each disaster stage (short-term, intermediate and long-term) a gate or threshold is defined. For demonstration purposes, we chose 45% as the gate threshold for short-term, 75% for the intermediate threshold, and greater than 75% is considered long term. Similar to the weights, gate thresholds are subjective values that will vary to reflect the particular community's environment and capability.

Note that only the water and waste water systems sector is progressing; of the remainder, the PRI remains unchanged except for the food and agriculture sector. That PRI has decreased since the last input, shown by its red color. These visual indicators act as prompts for the emergency manager to investigate further when a sector lags or regresses, and allows for mitigative response.

B. *Intermediate phase*

Before we can declare the region has entered the intermediate phase, all sectors must pass the gate threshold (45% in this scenario). In this phase, several roads are open, some rail lines are operational, more energy sources are available, and more cell towers are on-line.

In this intermediate phase, metrics that were not included in the short term phase, such as commercial and commodities rail in the transportation sector, are now being tracked. Similarly, some metrics that are operable only during the short term phase would no longer be part of the PRI calculations.

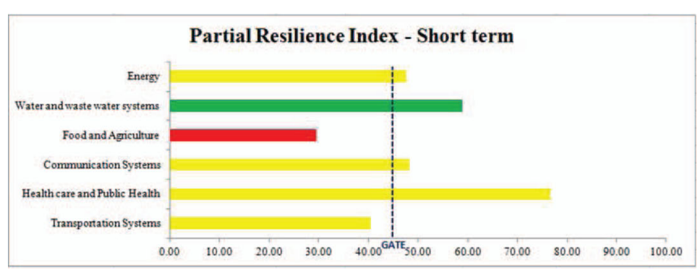

Fig. 2. PRI graph for the short term phase

TABLE II. PRI FOR TRANSPORTATION, SHORT TERM PHASE

Transportation systems	**FEMA disaster recovery phase**			**PRI = % avail * Wt**		
	ST	**Int**	**LT**	**% avail**	**Wt**	**PRI**
Critical personnel access/routes	√	√	√	0.23	15	0.03
Fire response	√	√	√	0.64	5	0.03
Police response	√	√	√	0.60	5	0.03
EMS response	√	√	√	0.54	5	0.03
Health care and Public Health route availability						
Route A	√	√	√	0.00	10.00	0.00
Route B	√	√	√	1.00	5.00	0.05
Food access points routes availability						
Route A	√	√	√	1.00	8.00	0.08
Route B	√	√	√	0.00	4.00	0.00
Functional roadways						
% Arterials	√	√	√	0.51	7.00	0.04
% Collectors	√	√	√	0.62	3.00	0.02
% Local Roads	√	√	√	0.86	2.00	0.02
Functional bridges						
% Arterial Bridges	√	√	√	0.28	6.0	0.02
% Collector Bridges	√	√	√	0.45	3.0	0.01
% Local Bridges	√	√	√	0.53	2.0	0.01
Rail Bridges	√	√	√	0.00	3.0	0.00
Functional railways						
% Commercial		√	√	0.00		
% Commuter	√	√	√	0.00	5	0.00
% Commodities		√	√	0.00		
Functional maritime ports		√	√	0.00		
Navigable waterways		√	√	0.00		
Airports - Landing location	√	√		0.00	3.00	0.00
Airstrip (non-commercial runways)	√	√		0.00	4.00	0.00
% Functional airports - Primary/Critical - in terms of location access		√	√	0.00		
% Functional airports - Secondary/non-critical		√	√	0.00		
Efficiency score	√	√	√	0.80	5	0.04
Partial Resiliency Index						0.41

TABLE III. PARTIAL AND OVERALL RESILIENCE INDEX CALCULATIONS, SHORT TERM PHASE

Critical sector	**Overall sector weight**	**Partial resilience index (%)**	**Overall resilience index (%)**
Energy	0.23	47.64	51.34
Water and wastewater systems	0.18	58.99	
Food and agriculture	0.15	29.51	
Communication systems	0.13	76.61	
Transportation systems	0.13	40.54	

Our scenario shows the resiliency index increasing to 77.78% in the intermediate phase, as almost all sectors begin to recover from the disruption. However, in a real event some sectors may experience a slow or stalled recovery, or even regress. Again, the phase/gate approach assists decision makers with identifying when a particular sector is not recovering as expected. For example, in Figure 2, the Food and Agriculture sector has not recovered enough to pass the first gate, and the red color of its bar indicates that the PRI has decreased since the last calculation. In Figure 3, we can see that the energy sector is nearly 100% recovered, while water and wastewater systems and the health sector are stalled. Three of the six sectors have not yet passed the intermediate gate threshold; therefore, the community has not yet reached the long-term recovery phase.

C. Long term phase

Before declaring the region to have entered the long term phase, all sectors must pass the gate threshold (75% in this scenario). Figure 4 shows the county map when much of the infrastructure has been re-established and is operational.

Table 4 shows the PRI and ORI figures for this phase, and Figure 5 shows the graph of the PRI at this point in the community's recovery. Note that five sectors are progressing well, but the energy sector progress has stalled. Again, these

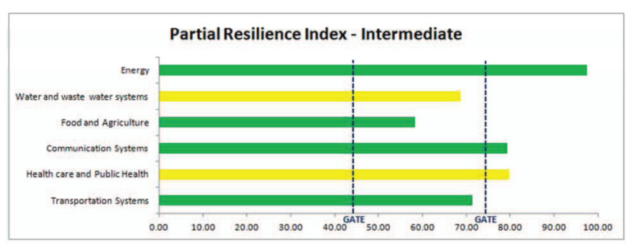

Fig. 3. PRI graph for the intermediate phase

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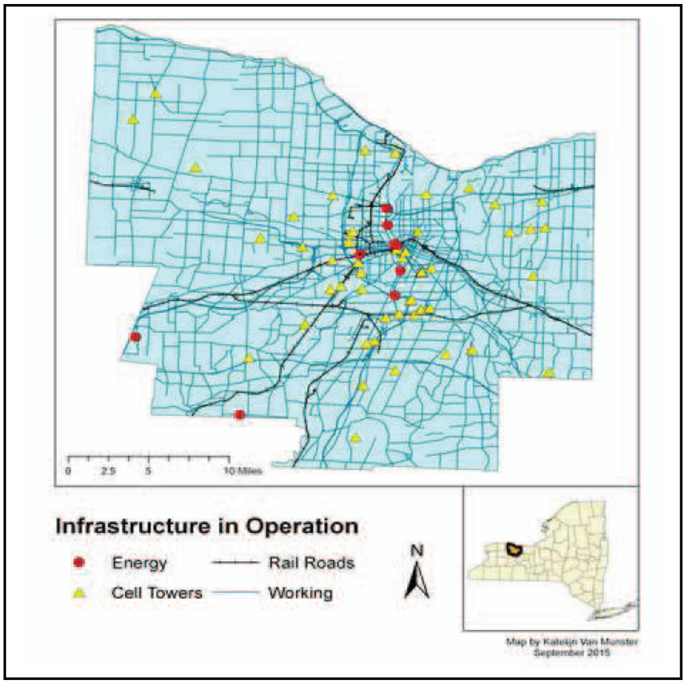

Fig. 4. Monroe County, long term phase status

bar colors are indicators to the emergency manager that further investigation may be needed to determine why a particular sector is not progressing in its recovery

These results would be available to the community leaders and emergency managers throughout the recovery phases, with the capability to drill down to the metrics to see the underlying data. The model is meant to be used more often than the three times we have used here for demonstration purposes; it should be run frequently (hours or days) at the outset of the short term phase, decreasing to weekly or monthly at the later stages.

We would caution emergency managers not to focus on the overall score too much, but to monitor the sector progress over time, and archive the data. The results obtained from an initial model then become predictors of resiliency for the next disaster, and a way for communities to gauge their resiliency with their own historical data.

TABLE IV. OVERALL RESILIENCE INDEX , LONG TERM PHASE

Critical sector	Overall sector weight	Partial resilience index (%)	Overall resilience index (%)
Energy	0.23	98.70	91.11
Water and wastewater systems	0.18	89.21	
Food and agriculture	0.15	81.56	
Communication systems	0.13	93.21	
Transportation systems	0.18	86.32	

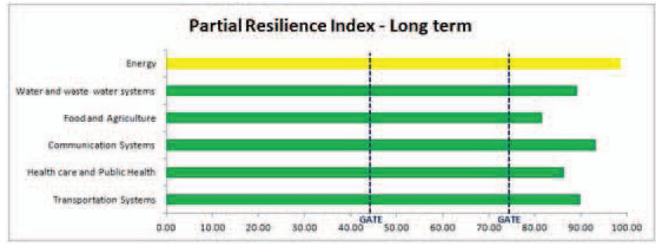

Fig. 5. PRI graph for the long term phase

V. CONCLUSIONS AND FUTURE WORK

Building resilient communities is an area of intense research, gaining national prominence especially since Hurricane Katrina in 2005. The proof-of-concept quantitative model presented here focused only on six "lifeline" critical infrastructure sectors of the16 defined by Department of Homeland Security. However, the model framework was designed to be flexible and can be customized to any community or sector.

To our knowledge, no locally focused quantitative resiliency assessment model currently exists for response and recovery at the local level. As mentioned in Section 2, efforts so far have been qualitative and theoretical in nature, which are difficult to transfer to real-world situations. Although our model represents a good start, since it is a proof-of-concept, we do not claim it is comprehensive, even within the six selected sectors. Additional work is needed to merge other metrics, including business continuity planning measures, with those relevant to emergency managers, first responders, and the general public. Moreover, successful use of these metric sets requires a vast amount of data to be collected and analyzed. Even communities, which may have access to the needed data, often lack the capacity or expertise to analyze it fully.

We thus find this system should be scaled to the size and hazard complexity of the community that applies it, much like an activated Emergency Operations center (EOC) reflects the size and scope of the response at hand. A major city might activate a hundred persons or more to the EOC, whereas a smaller locale may only activate twenty. The response and recovery measurement should reflect the capacity of the EOC itself in form and function. An ambitious long-term project would be to collect, collate, manage, and analyze historical data in order to calculate metric values and to set gate thresholds with sufficient confidence that truly reflects locality experience to guide future decision-making.

Further, this complete model should be integrated with computer-based management platforms, which are increasingly used as the communication tool of choice for many local and national emergency operations centers. A methodology and tool such as this model could be helpful to those tasked with managing and monitoring recovery, and integration into the recognized platform would support that task. Finally, we note that while many methodologies theorize the problem of resilience overall, only a few of these are being driven by those tasked with doing just that. Any further efforts in this domain must reflect the needs of those who actively pursue it.

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