The *Digital Crow's Nest*: A Framework for Proactive Disaster Informatics & Resilience by Open Source Intelligence

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ABSTRACT

The research on technology-assisted crisis management has primarily existed for two decades since 9/11. Although, the focus of technology research has been centered around tools to assist the response phase after a disaster. There has been a lack of emphasis on the role and design of technologies to assist the other phases of the crisis management cycle, particularly preparedness and mitigation phases to lead towards the vision of building resilient communities. In this paper, we first identify resilience characteristics of a community from the prior literature. We then analyze a co-occurrence network of concepts in the ISCRAM publications to validate the gap in relating technologies to resilience and conduct an indicator analysis of factors for proactive disaster informatics via a case study of recent disaster. Our analysis leads us to propose a conceptual framework "*Digital Crow's Nest*" based on Open Source Intelligence to improve the technology design for community resilience.

Keywords

Resilience, Emergency management, Crisis Management, Indicator Analysis, Open Source Intelligence.

INTRODUCTION

When standing to watch on a ship, a sailor looks both internally and externally to assess risk to the vessel. Internally, a watch will assess the ship's systems, status of the crew, and the integrity of the vessel. Externally, the same watch monitors navigation, the relative location of other vessels, broadcasted weather conditions, visible weather conditions, and the sea state. A Crow's Nest is the highest position on a sailing vessel where the watch has the broadest view of activity (Rouach and Santi, 2001). This long view in conjunction with continually monitoring of the immediate environment, allows sailors the greatest vantage point in their attempt to be proactive regarding the safety of the ship. Any change in the normal status is assessed for risk to the crew and vessel. When the watch stands down, all pertinent information is shared with the next watch during transition and the process begins again. This analogy has profound implications for disaster informatics to prepare emergency services of future resilient communities.

Consider the most active year for natural disasters in its history — 2017, the US territory of Puerto Rico remains in a state of crisis after hurricane Maria devastated the island in September of 2017. When the hurricane struck the island it had already endured two near-misses in the previous month. While it is tempting to lay blame on hurricane Maria alone, there were numerous factors that contributed to Puerto Rico's already weakened state. In 2006, the US Congress ended tax breaks that helped Puerto Rico's struggling economy (Greenberg and Ekins, 2015). Given the loss of income and the loss of 10 percent of its population fleeing to the US mainland for employment during the Great Recession, Puerto Rico was unable to fiscally recover and took on more debt as it tried to regain control over its finances (Alvarez, 2017). Such factors are often unaccounted in the disaster informatics solutions.

Likewise, during the time prior to hurricane Maria, the island was facing a problem of aging infrastructure. Fallout from the financial crisis resulted in the electrical grid - already known for higher rates, slow repairs, and minimal maintenance - not being properly maintained (Vives and Hennessy-Fiske, 2017). As a result, the Puerto Rico Electrical Power Authority declared bankruptcy in July 2017 ('Puerto Rican Power Utility PREPA Files

For Bankruptcy', 2017), months before the series of hurricanes passed through the Caribbean. And while a nearly Category 5 hurricane will always pose a heightened level of risk to any area, knowledge of certain areas of Puerto Rico's overall state might have provided a greater level of awareness where the risk was greatest throughout the island. A severely weakened electrical grid was all but destroyed with little skilled labor to repair it and no funds for replacement, hindering the islands' resiliency and capability for recovery. As of November 2017, direct deaths from the hurricane stood at 54 persons, while indirect deaths as a result of the cascading effects are speculated to be over one thousand (Santos-Lozada, 2018).

Given the state of the island's finances, labor pool, infrastructure, and the persistent issue of its location to the US mainland, by summer of 2017, Puerto Rico was already exposed to danger where any of the much weaker hurricanes or even tropical storms might have caused the similar catastrophic outcome. As Wybo and Lonka (2002) note, "emergencies become crises if the system's resilience and emergency preparedness is insufficient to manage the event response and recovery." Cracks in Puerto Rico's systems were largely known and the data was immediately available. The point of failure lies in no one taking a comprehensive look at the proverbial signposts and assessing the overall risk to the island and its citizens.

While risk management and analysis has been discussed in crisis management literature, the crisis informatics (Palen and Anderson, 2016) research has mainly focused on the use of ICT technologies for better emergency response, understanding public behavior in the response, and the design of efficient response technologies. The areas of technologies range from big data analytics to human computer interaction including information and knowledge management, machine learning, information retrieval, data mining, network science, social media mining, simulation and modeling, and information visualization across a genre of structured to unstructured big data sources (Castillo, 2016). Likewise, the existing tools are available as open source as well as proprietary emergency management platforms. However, the intended use-case of such existing technologies and tools has been centered around response and relief coordination after a disaster event (Hristidis *et al.*, 2010; Purohit *et al.*, 2013; Imran *et al.*, 2015; Li *et al.*, 2017; Reuter and Kaufhold, 2018). There is a lack of research interest on technologies to assist different phases of crisis management and also evaluating the cross-phase uses of the response-driven technologies, particularly, as exemplified by the illustration of hurricane Maria, there is a lack of technology use to create more resilience for a community.

If resiliency is the process and ability of a community to restore function after a disruption or disaster event (Patel *et al.*, 2017), then forewarning of the potential impacts of a crisis event is critical to the endeavor of recovery. Community resilience has characteristics that are not just specifically related to the long-standing research domain of risk management but rather have a relation to a comprehensive set of domains that also incorporate the elements of technology design. Therefore, this paper seeks to show that a proactive awareness of ground conditions and risks as "intelligence" prior to any inclination of a potential crisis is a part of the preparedness process and contributes to a community's resilience. Such awareness and intelligence can be thought as a foundation towards designing technologies for resilience. This is distinct from the phenomenon of situation awareness studied in recent years with a primary focus in the literature as a tactical, reactive awareness to crisis events after they occur, and not predictive. To this end, we pose the following research questions:

RQ1. What is the current state of the art regarding the technology-assisted community resilience and preparedness in the disaster informatics research area?

RQ2: What is the role of open data sources and technologies in preparing the emergency services of the future resilient communities?

To address RQ1, we demonstrate the lack of emphasis on the role of technology for resilience and preparedness by performing co-occurrence network analysis of concepts in the scholarly data of all publications in the ISCRAM conference series on crisis management. For RQ2, we conduct an indicator analysis — a structured analytical technique — using open source data to help determine the level of risk or emergency prior to the onset of a crisis.

The rest of the paper is organized as follows. We first discuss the background on resilience characteristics for a community and open source intelligence, followed by our scholarly data analysis method to analyze the existing literature on resilience. We then describe an indicator analysis with a case study and present the design of our proposed framework "Digital Crow's Nest".

BACKGROUND AND RELATED WORK

We have two focus areas in the related work for this research: community resilience and open source data.

Community resilience has a comprehensive coverage in terms of the range of areas it is connected to and those required to understand it holistically (Patel et al., 2017; Comes and Van de Walle, 2014), including public communication and risk monitoring, local knowledge, community networks and relationships. While there is no common, agreed upon definition for resilience across the world and the different practitioner and research areas, it is ".. a highly sought after by disaster-response professionals, government officials, and academics. .." (Patel et al. 2017). The key goal of community resilience identified across the different definitions focuses on increasing local capacity, social support and resources, and decreasing risks, miscommunication, and trauma. The common characteristics identified across the different definitions for resilience include a proactive approach to policy, governance, community management and lastly, the information and communication technologies. Although there is a gap in understanding the design of such ICT technologies and how the state-of-the-art methods for data sourcing and analytics can support such design. It is essential to understand the technology design requirements that would serve the key characteristics and goals of community resilience.

Open-source data has recently become a state-of-the art resource to discover hidden patterns and exploit intelligence that can help address the technology design needs for resilience. Particularly, Open-source Intelligence (OSINT) is a national security term whereby OSINT is relevant information collected from "overt collection." (Lowenthal, 2003) That is, any publicly available source collected and used in an intelligence context. For the purpose of this study, we refer only to data that may be collected via the World Wide Web. Sources range from traditional news media and their websites, social media, commercial data, professional and academic publications, government reports, or any verifiable source identified publicly or online.

Information from online data can be extracted and assessed with regards to any intelligence question. Despite certain inherent risks such as issues of trust and credibility of sources, the vetting process of most sources aside from social media is routinely accomplished in a more objective ways in various intelligence-driven processes. Thus, we argue that the open-source data analytics can be leveraged for timely informing or at least partially meet the needs of the technologies for community resilience.

Table 1. Analytical summary of the dataset collected from ISCRAM digital library for the period of 2004 to 2017.

	Counts
Number of library records with abstract metadata	1323
Number of nodes and edges in the concept network	250 concepts, 13956 relations
Number of modular communities in the concept network	5
Illustrative top-ranked concepts per community (ranked by PageRank score; colored in consistence with figure 1)	c1: {*ict, city, preparedness, hazard, power, earthquake, natural disaster, threat, communicate, resilience*}, c2: {*disaster management, gis, geographic, behavior, humanitarian, automatic, twitter, situational awareness, volunteer, technological*}, c3: {*cis, emergency, environment, crisis management, emergency management, simulation, fire, awareness, architecture, adapt*}, c4: {*efficiently, casualty, casualty incident, organisational, mass casualty, mci*}, c5: {*public, responder, mobile, sensor, phone, alert, timely, deployment, internet, video*}

DATA AND METHODS

We take a mixed-method approach in this paper to address our research questions on the role of technology for designing resilient communities. First, we present the co-occurrence network analysis of concepts in the ISCRAM publications. Second, we describe an indicator analysis via case study of Santa Rosa wildfires to discover the patterns of information needs and available indicators in the open data.

Scholar Data Analysis: Concept Co-occurrence Network

The ISCRAM library is a premiere avenue for disseminating research on information systems for crisis management. So, we collected all the publications from its digital library. Table 1 provides a summary of the collected dataset. We extracted all the abstracts from the collected publications and then, constructed a concept set of interest by removing all the stopwords, extracting both unigrams and bigrams with minimum frequency 3, and ranking terms by the popular *tf-idf* measure of term importance in a document corpus. We then created a co-occurrence based network for the nodes as the top ranked 250 concepts (for computational tractability, given the large number of edges) and used Gephi open-source tool for network analysis.

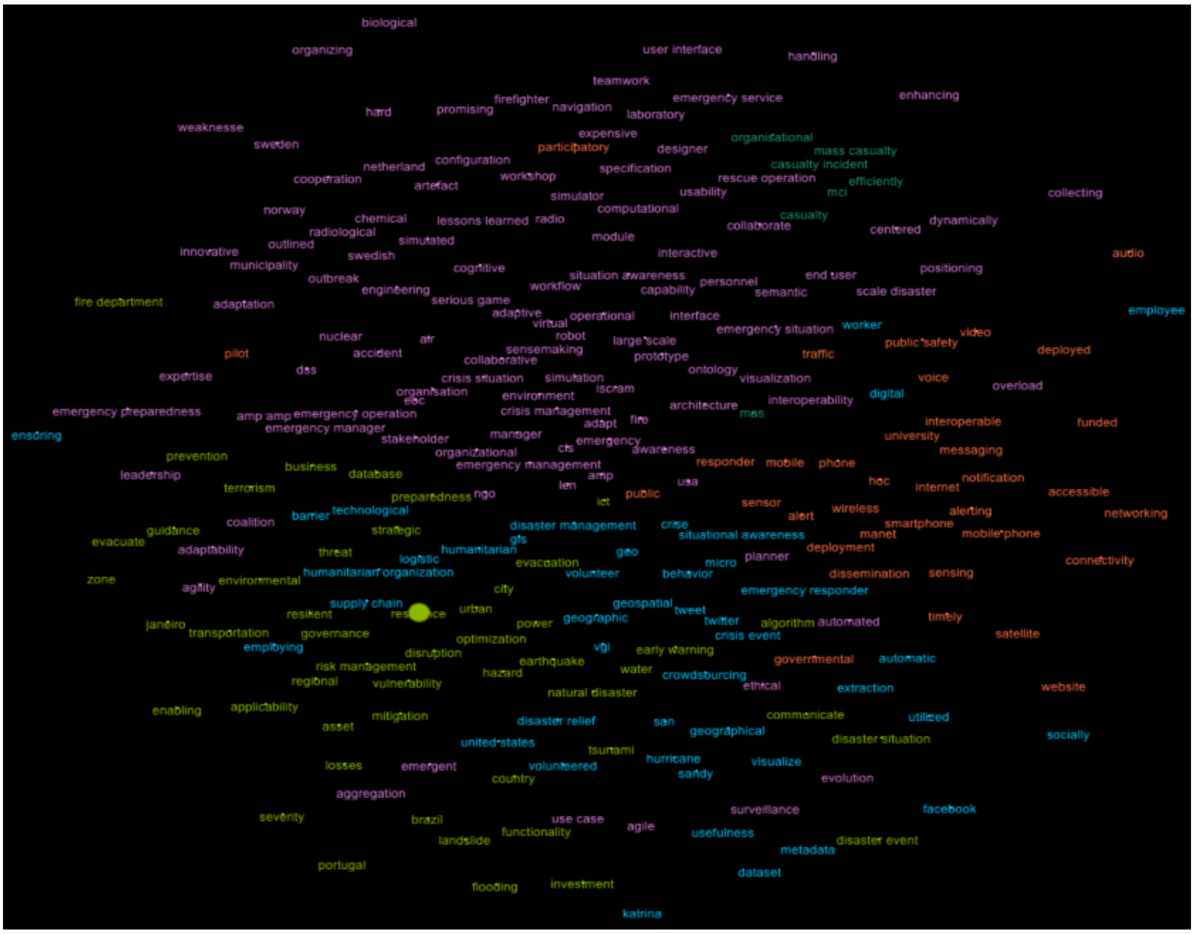

Figure 1. Concept communities detected from the co-occurrence network extracted from the ISCRAM publications. Green colored community contains the resilience related concept and depicts a lack of focus on discussing concepts of technology design and development for resilience.
[color view recommended]

Measures:
We adopt the following network analysis metrics (Newman, 2010) for this study: a.) Modularity of network for community detection, b.) PageRank of a node for concept importance. Modularity measures the strength of dividing a network into modules or clusters, which implies that high Modularity networks will have dense communities separated by sparse connections across the communities. PageRank is a variant of eigenvector centrality of a node that computes the relative importance of a concept node in the network, implying such high centrality nodes will have a critical role in communication within a community. We used these two measures to generate communities of concepts and rank concepts within the communities by importance as shown in figure 1 and table 1.

Observations:
We can observe a number of patterns in the co-occurrence network (see figure 1 and table 1). First, a visualization of detected communities shows that for the ‘resilience’ concept (member of the green colored community c1), there is a lack of concepts related to technology factors in its community c1, while all other communities represented by other colors have some aspect of technology either as a solution or a barrier. Second, the identified top concepts connected to the resilience include ‘preparedness’, ‘threat’, ‘power’ and ‘city’ as well as ‘risk management’, ‘investment’, and ‘vulnerability’, which as anticipated, forms the foundation for the discussion of resilience in the existing literature. However, these concepts primarily relate to

the management, policy, and governance domain than actually the technology design and thus, support our argument for the need to understand technology factors associated with the resilience. Next, we conduct an indicator analysis in the context of a recent disaster.

Indicator Analysis

Indicator Analysis (IA) is a structured analytical technique used in Intelligence analysis by US national security agencies (Heuer & Pherson, 2015). The method tracks and maps pertinent historical and current data in the effort to expose patterns and trends that indicate a significant shift in an area of interest. When employed successfully, the technique reduces biases and provides documentation for forecasting events.

IA develops a matrix for analysis that includes scenarios, categories, factors, and indicators (explained next). The matrix is dynamic and fluid; while scenarios and categories may not often change, the factors and indicators are persistently evolving and therefore, require persistent monitoring and revision. This means that factors for analysis are unique by location, type of possible event/scenario, and may change according to the time of year.

A *scenario* is a customized estimate of possible specific outcomes that could result from a category for improvement or destabilization. Usually these scenarios are based on the current events of the factors involved in that category. Consideration of various types of scenarios to encounter are expected by an emergency manager that helps determine the broad categories of events used for consideration. A *category*, in essence, is the broad aspect of the potential scenario that merit individual scrutiny in order to understand the entirety of a situation. A *factor* is a subset or granular events occurring within a category. It is understood that factors and categories are interconnected, meaning that individual events can have cascading results affecting other categories. Factors are gleaned by the information extracted from online, publicly available sources. An *indicator* is a trigger event and can be assessed at geographically and temporally varied levels.

With regards to crisis management research, in the US, emergencies are managed locally, regionally, and also at a state or federal level. As such, indicators can be categorized according to their respective pertinence to a given level: local (micro), regional/state (meso), or federal (macro) level. Further, indicators can be assessed by strategic, operational, and tactical areas. Strategic indicators are those that cover large geographic expanse (national, global) and occur over long periods of time. Operational indicators are more limited to state and regional geographies and occur within weeks and months. Tactical indicators occur in immediate areas such as counties, cities, and towns, and are immediate - within hours down to minutes. Tactical indicators typically serve as triggers, meaning their mere presence can begin a series of events leading to an acute phase of a crisis.

Lastly, is the application of indicators. Indicators can be single events or actions within a factor that signify a major shift, affecting conditions in the rest of the category or other categories. Indicators can also be a combination of events that serve a similar function in conjunction with each other. IA is most successful when indicators are not only identified, but when a pattern of activity is also determined. Much of indicator analysis is not only looking for the specific indicators that will signal a potential upheaval, but tracking how factors change over time resulting in more useful trend analysis.

It is important to note that IA pre-supposes a crisis event. That is, IA is a proactive activity to monitor a current status in any context. At such time indicators show a pattern that a current state of something is changing, for example, a pending natural disaster, then the state shifts from proactive to reactive as the prodromal stage of a crisis evolves, thus requiring a different type of monitoring activity and response.

Case Study: Santa Rosa, California

We analyze the Northern California wildfire event using our IA method. An accepted assumption in the disaster management community is that no two crises are ever the same. The unique conditions of time, space, people, institutions, weather, and other factors associated with an event implies that each event requires its own set of unique considerations that inform the response. Because of this, events such as the wildfires that occurred in Northern California during October of 2017 would have required a radically different response from the wildfires that occurred in Southern California during December of the same year.

However, risk may be a factor that the events could conceivably share. When we consider the worst-case scenario prior to an event, it better informs prevention, preparation, response, and ultimately, resiliency of a community. We present the indicator analysis matrix in table 2 for the case of Santa Rosa and present the details of in-depth context of the indicators and activities happened during this event in the following.

Under normal conditions, California has a history of being well-prepared for fire events, however, evolving weather, climate, social, economic, and government conditions created an underlying risk that was not considered and resulted in the death of 42 residents, and the destruction of over 8400 structures. The cost of over

USD 1 billion in damages made it one of the worst natural disasters in California history (Winton and Grad, 2017). The town of Santa Rosa alone lost 32 residents and over 3000 homes.

Weather conditions. After experiencing severe drought for over four years, California received a respite during the winter of 2017 with significant amounts of snow and rainfall (Rogers, 2017b). Despite increasing reservoir levels throughout the state that alleviated much of the drought (United States Geological Survey, 2017), the period of a wet winter and dry summer, resulted in an abundance of dried-out, low-lying vegetation alongside 80 million dead trees. The dead trees had perished during the previous four years, creating a large amount of dormant fuel. During the early fall, wildfire season began as expected with several small fires occurring throughout the northern portion of the state (Sorci *et al.*, 2017). However, also as expected, the Diablo Winds, a hot, dry, offshore wind from the Northeast, began to sweep through the San Francisco Bay area (Shepherd, 2017). Above-average temperatures with extremely low humidity (Accuweather, 2017), combined with steady and persistent dry wind as well as the abundance of dried vegetation created ideal conditions for large-scale wildfires.

Climate conditions. During the last 25-year period, the effects of climate change began to show in the area. Parts of the wine country that did not traditionally experience wildfires began to see an increase, as winters became wetter and summers longer and drier. This change in climate shifted the fire danger zones throughout the area, placing Santa Rosa within one such zone. However, construction ordinances failed to address this shift, so new construction did not mandate fire-resistance building practices (Payne, 2016).

Social demographic conditions. Santa Rosa, California is a mid-sized city centered in California's wine country. Since the 1990s, the population of the city grew from 120 thousand to over 170 thousand by 2015. The population segment most increased was an older, upper-middle class to wealthy demographic (Payne, 2017). In the deaths that followed, the majority of the deceased in Santa Rosa were older persons who likely experienced a normal decrease in hearing and smell thus not likely alerted to or sensing the danger, and in the end, lacking the speed and mobility with which to escape their homes (Jaffe, 2017).

Infrastructure and governance conditions. The socio-economic conditions of the area led to a building boom during the early 2000s in both commercial and residential real estate. This also led to more residential houses being constructed on previously unoccupied land increasing the Wildlife-Urban Interface (WUI) significantly. Within and outside the city limits, this urban sprawl led to overdevelopment of the area and drove increases in real estate prices. The final result was a persistent affordable housing shortage for lower to middle class residents (Hart, 2017).

Economic conditions. A slow recovery of state finances from the Great Recession of 2008 resulted in budget cuts. Combatting ever-increasing incidents of wildfires increased the need for money (Gorte, 2013) to support prevention activities, just as state and local municipalities gutted prevention budgets (Board, 2017). Additionally, wage stagnation affected the profession of wildfire fighters as wages topped out, on average, at slightly above state minimum wage standards (Calfas, 2017). This happened while also reducing the funding for volunteer fire departments, which were established to help lower costs of firefighting.

Government conditions. Further exacerbating all of this, murky cooperation agreements between federal and state agencies, and local union infighting, resulted in large-scale disagreements over who is responsible for combatting which fire and at whose expense (Gabbert, 2017; United States Department of Agriculture, 2013 & 2015). However, when disaster strikes, and all grievances are temporarily placed on hold, there is still the reality that due to a high level of WUI, the different types of firefighting converge, and yet it became clear that wildfire specialists are not trained at urban firefighting and vice versa (Rogers, 2017a). And city firefighters are certainly not trained, staffed, and resourced at a level capable of managing multiple structures burning at once. Lastly, because of the systemic issues across the state at a time of numerous wildfires occurring at once, traditional resource sharing is impossible because resources are spread too thin (Calfas, 2017).

Taken into context all the factors prior to the wildfire event, Santa Rosa was already at a heightened level of risk simply requiring one or two triggering events to create an immediate, full-scale emergency. Over time, these same conditions also mark the city as incredibly non-resilient.

Observations

Considered temporally, Santa Rosa possessed different levels of concerns over strategic, operational, and tactical time frames. Strategically, or over the long-term, climate change, infrastructure, demographics, and economics all contributed to the level of loss and destruction, as shown in table 2. Operationally, or in the near-term, weather patterns and lack of resources both human and material contributed to a less-effective response. Tactically, the series of small wildfires converging due to a normal wind event created the trigger for the disaster to occur.

Nearly every indicator for risk and triggering events, were discoverable through open source data analytics methods with the potential for extracting relevant information for analysis with some uncertainty. The only indicator not meeting this criteria in this case study were the cross-training issues between urban and rural firefighters. However, now known, this is an indicator that could be incorporated into future risk assessment scenarios.

Table 2. Santa Rosa case study - Indicator Analysis. *[color view recommended]*

Category	Type	Level	Indicators	Risk Score	Source
Strategic	Climate	Macro	Climate Change	3	NOAA, NWS
	Government	Meso	State/Federal turf wars	3	News
	Government	Meso	Murky Cooperation agreements	3	USDA, NFS
	Economic	Meso/Micro	Rising Costs of Wildfire Protection	2	News
	Economic	Meso	Decreased volunteer fire fighter budget	4	News, State & Local
	Economic	Meso	Drained prevention budgets	4	News, State record
	Government	Macro	Interstate union fighting	3	News
	Government	Micro	Lax regulation on fire proof housing	4	Local Record
	Government	Meso	Overdevelopment - Wildland Urban Interface	4	NFS, CalFire, News
	Government	Meso	Interface issues with firefighter training	2	
	Infrastructure	Macro	Evolving fire zones due to climate change	3	NOAA, NWS, State
	Social	Micro	Aging Demographic	1	Census Data
	Economic	Meso	Lack of Affordable Hosing	1	News
	Economic	Meso/Macro	Professional Jobs - Minimum wage	2	Labor Statistics
Operational	Government	Meso/Macro	Capability - Resources spread thin	5	News
	Climate	Meso/Macro	Resevoir Conditions	1	USGS
	Weather	Meso/Macro	Drought	5	USGS, NOAA
	Weather	Meso/Macro	Temperature	4	NWS
			Risk Score	*54*	
Presense of Triggering Mechanism					
Tactical	Event	Meso	Multiple wildfires in the region	Y	CalFire
	Weather	Meso/Macro	Weather Event: Diablo Winds	Y	NOAA, NWS

5	Serious Concern
4	Substantial Concern
3	Moderate Concern
2	Low Concern
1	Negligible Concern

On the micro level, at the individual sites, the fires arrived unexpectedly in the middle of the night. The victims who perished were mostly aged and elderly, and lacking the ability to identify the risk or escape, thus it would be unfair to attribute hubris or optimism bias on their behalf. However, the reality of an aging demographic does require a strategic and operational level risk assessment on behalf of local and regional emergency managers.

The meso-level experiences most of the level of responsibility for risk assessment with regards to the Santa Rosa disaster. This is due to the fact that there are local and regional governments to consider and the majority of the risk indicators apply here. Issues in training, wages, agreements, housing, and budgets are all problems than can be remedied. In not only recognizing, but solving these issues, this risk level possesses the greatest chance at increasing resiliency. At the macro level also, state and federal governments, climate change, and weather conditions are also factors beyond control, thus, when it comes to resiliency, this level can only be recognized and have proper corresponding actions to mitigate the indicator.

Sadly, even after destruction from these fires, the onset of steady rain, and the process of rebuilding has begun. The town still conceivably exists in a state of high-risk should the underlying conditions that exacerbated the loss of life and property not be mitigated.

It is interesting to note here that social media did not appear as an early indicator data source. This may be attributed to the fact that social media possibly only becomes active when a known event will occur but is not yet occurred. It implies that active social media streaming may itself be an indicator for an event being no longer just theoretical and the volume itself becomes an indicator that a crisis may be in its prodromal stage.

Next, we propose a framework (see figure 2) as a key lesson based on the main observations of the two types of analyses — lack of research on linking technologies to community resilience and the need for proactively tapping open-source data for indicators of predictive intelligence for disaster informatics.

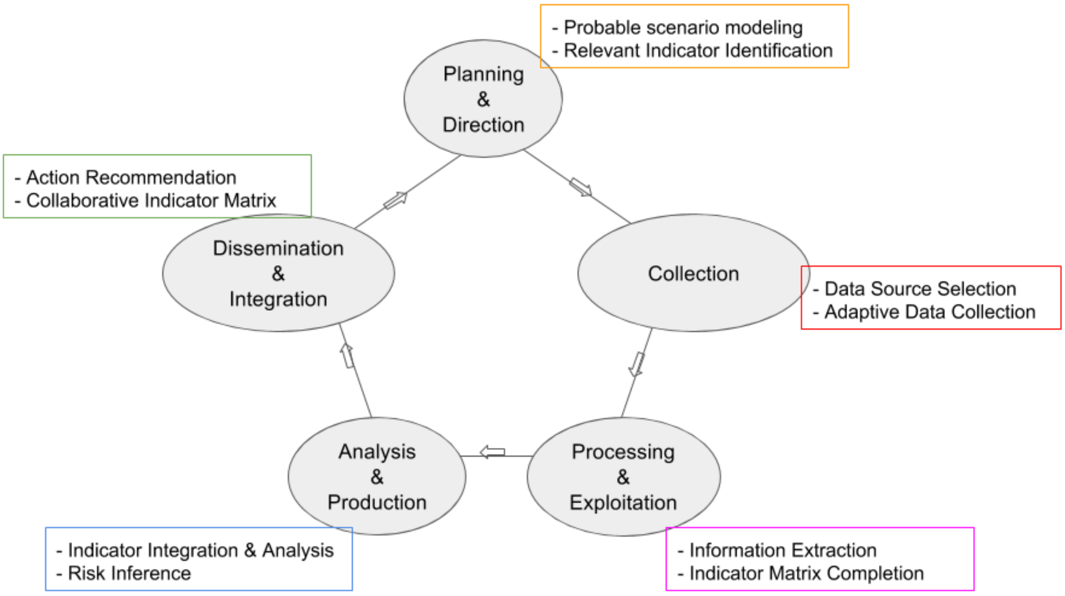

Figure 2. Summary of the proposed framework to inform technology design for community resilience.

LESSONS LEARNED: *DIGITAL CROW'S NEST* FRAMEWORK

The proposed framework for the *Digital Crow's Nest* seeks to assess a status of risk at any given time with or without the presence of an impending crisis. This allows emergency managers to proactively monitor and prepare for crisis scenarios in hopes of mitigating the effects of an emergency when it occurs. The framework proposes five areas of activity: Planning and Direction, Collection, Processing and Exploitation, Analysis and Production, and Dissemination and Integration.

Planning and Direction: This phase begins with analysts developing conceivable scenarios that a given area may experience. By considering past and probably future scenarios, this allows analysts to develop a list of activities to monitor. If there are arguments or biases over an issue, the indicators may help to depersonalize the argument by referring to a list of objective criteria.

Collection: Once indicators are established, analysts then identify appropriate sources for data and information. Digital collection methods of data is determined by the form of the data. The regularity of collection may be automated and the frequency determined by analysts. Given the growing open-source data sources, this component requires an adaptive design towards data collection technologies.

Processing and Exploitation: Within the indicator matrix, several steps must be accomplished before analysis. The data and information gleaned must then be categorized. Analysts must assign temporal aspect: strategic (long term), operational (near term), tactical (immediate). A short description of the type of data is also assigned (i.e. Government data, news report, crowdsourced/ social media, etc.). The level of data (micro, meso, or macro) refers to whether this is an issue within local, state/regional, or federal control. A short description of the indicator may assign or refer the title of the data report or news item. A risk score is then assigned on a scale of 1 (negligible) to 5 (Serious). Also, the source of the data will also be listed. Lastly, an analyst should determine which indicators serve as a triggering mechanism - an indicator, whose mere presence, serves as a main alert for trend analysis. Normally, a tactical level activity serves as this mechanism.

Analysis and Production: Analysis may be performed by the presentation of each indicator for manual assessment, or by an automated method where rudimentary risk is assigned and either confirmed or reevaluated by the analyst. The culmination of the risk factors should be constantly maintained, and a threshold risk score established. Any score above the threshold will indicate high exposure to the state of risk independent of any triggering mechanism. Presence of a triggering mechanism, regardless of the aggregated risk score, may also determine risk exposure.

Dissemination and Integration: Ideally, the indicator matrix should be maintained and shared across all levels of concern (micro, meso, macro) in a preferred form that is mutually agreed upon, however, a data-driven alert technique may be optimal as written reports lack the ability of online semantic integration and collaboration across systems. As scores of information pertinent to a given level are presented, they may also be revised if a more nuanced understanding of the information is available. Collaboration in the maintenance of this matrix also enhances consistent communication across levels.

The proposed framework is an easy technological solution for analyzing resilience related information from open-source data and can be implemented in an offline or online interface of a software.

DISCUSSION

When events from the Santa Rosa fires are deconstructed (see Table 2), what we see is a systemic failure to identify risk from a meso and macro level - the levels occupied by governments. Local, regional, state, and federal concerns have top-down and bottom-up effects. No one level only affects their own sphere, thus a uniform and comprehensive approach is required when performing risk assessment. When the perception of risk remains only within one sphere of concern, and other spheres are not considered, it is easy to see how risk can become normalized and the proper level not assessed.

Using the same technological approach as the Santa Rosa fires, we could observe similar indicators in Puerto Rico as discussed in the introduction, where conceivably, an earlier state of emergency might have been declared allowing the state and federal governments to mobilize resources for mitigation.

There are a few limitations to this research. The proposed framework is dependent on a given geographical area having no legal restrictions that may hinder collaboration and cooperation between stakeholders. Further, the implemented framework must be designed in such a way as to accommodate the technical systems of all stakeholders, highlighting the interoperability challenge. We plan to address these concerns in our future work.

CONCLUSION

This paper presented an analysis on the lack of research in linking technology design to community resilience aspects of crisis management, given the major focus of prior works in disaster informatics on the response phase only. We described a novel framework Digital Crow's Nest based on open source intelligence as a solution towards the design of technologies with a proactive disaster informatics approach for resilient communities.

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