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# AREA: A Mobile Application for Rapid Epidemiology Assessment

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**Abstract**

Health crises are challenging because the normal channels of communication and ways of reporting have often broken down under novel and unexpected circumstances. The most critical need in such situations is accurate, timely, and relevant information. AREA is a mobile application designed specifically for bio surveillance and health crisis resiliency. The app helps health workers identify and obtain the most critical information to assess and mitigate health risks; distribute these data in a secure and curated way, and optimize cross-organizational resource allocation. AREA provides situation awareness, comprehension, and projection of relevant on-the-ground information. In short, AREA meets the most pressing need in health crisis management. The Area app combines state-of-the-art social networking technology with advanced, proven algorithms for assessing risk and managing distributed resources. Intuitive user experience design ensures that the Area app is easy to understand and to use, even for non-technical personnel. The Area app is designed for application in all phases of public health or humanitarian crisis management, from Early Detection/Onset to Response/Relief and Recovery/Transition.

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## 1. Introduction

Disasters, public health emergencies and humanitarian crises are generally characterized by a high-level of uncertainty. Uncertainty is not only a problem during the onset and immediate aftermath of a crisis, but often lingers well into the recovery phase, making it difficult to formulate courses of actions and track efficacy of response efforts. Informational uncertainty often stems from delays in information flows, frequent contradictions in information, and the untrustworthy of information sources coupled with fast paced change in the facts on the ground. All too often this uncertainty hinders the effectiveness of relief efforts by negatively affecting decision

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making, which can result in critical resources not being allocated where most needed.

Increasingly, ubiquitous mobile computing platforms, including smart phones and tablets, can serve two important purposes in managing uncertainty and developing effective and timely actions in response to public health emergencies and humanitarian crises. First, smart phones and tablets can provide personal situation awareness tools, to which one can quickly refer in order to obtain information that supports decision making. Second, mobile computing platforms are rich with sensors, including GPS and cameras, and so can form a distributed sensor network not only for passive collection of information but also for active collection through targeted requests from users via social media, text messaging and email. The key to fully leveraging the benefits that mobile devices offer in addressing the uncertainty challenges is an "app" specifically designed to support group coordination and information sharing from the various entities involved in responding to a disaster or humanitarian crisis, which may include NGOs, first response organizations, military units as well as the general population (see Figure 1). Such an app is described in this paper.

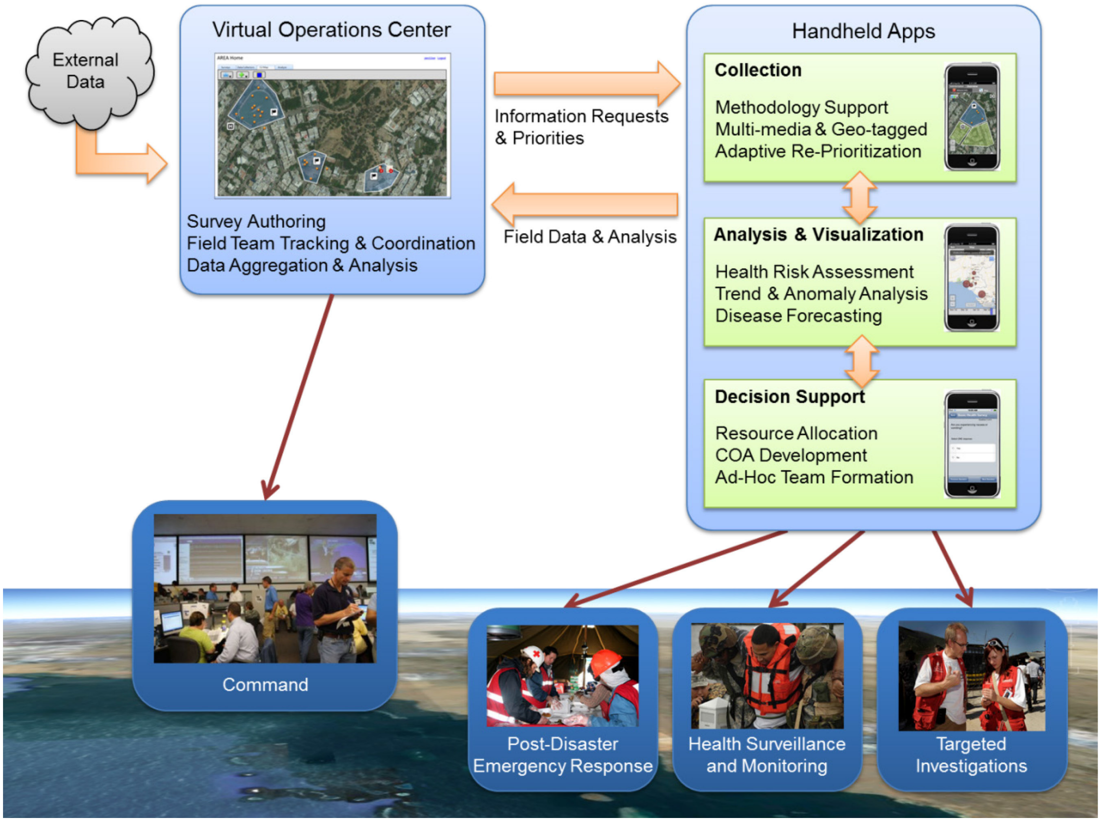


Figure 1. Area Solution Footprint.

## 2. The AREA Solution

The AREA mobile app that Perceptronics Solutions is developing for Apple iPhone/iPad and Android mobile devices provides novel capabilities and visualization tools for maintaining situational awareness, collecting vital information to support decision making and formulating rapid courses of action. In addition, AREA integrates with Perceptronics Solutions' OssaLab Social Media Analysis platform to support multimodal biosurveillance and fusion of information from social media with data reported from the app. Figure 2 illustrates the AREA solution footprint. AREA is designed to support use and deliver value even when there is only intermittent or limited network connectivity which may be the case in natural disaster or crisis in a remote location.

A key element of the AREA solution is the AREA Virtual Operations Center (VOC) for monitoring and managing the data collected using the Toolkit. The data flows supported by the AREA and the AREA VOC are shown in Figure 2. The AREA coupled with the AREA VOC provides a complete solution for biosurveillance and crisis response management.

AREA puts powerful computational analysis capabilities in the hands of field users for the first time, greatly enhancing situational awareness and enabling faster identification of health risks and crises. This paper describes the various algorithms and technologies used by the AREA system.

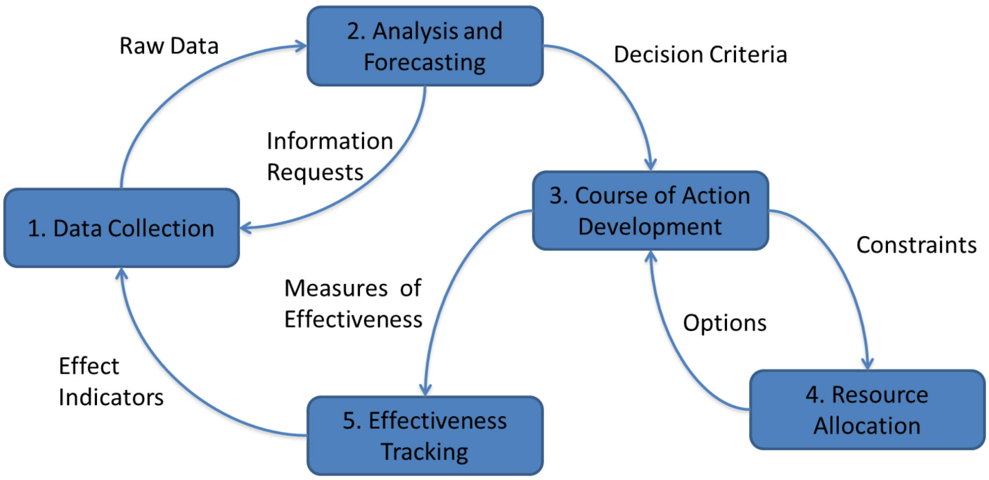


Figure 2. Area process data flow.

## 3. AREA mobile app functions

Health care workers and responders can use the AREA mobile application for detailed, directed, and highly visible crowd-sourced incident reporting. The user can efficiently create, request, and manage task allocations; privately share and segment information sharing; and collect targeted survey data collection (see Figure 3).

### *3.1. Incident reporting*

The application provides users the ability to quickly generate reports of a wide variety of incidence. Users can either search for a specific report type or select a type from an option menu. The report types have been derived from standard disaster response taxonomies. Users can begin a report by clicking on the map which opens a library of potential indidence types. Users can fill in detailed attribute information (e.g. symptoms, detailed observations about an incident, medicines available, hospital bed avaiaility) or may opt to provide merely a name and location that a specific incident occurs. This structure offers a wide range of use flexibility; especially pertinent in high stress, high mobility environments where this platform will be leveraged.

### *3.2. Task allocation*

To properly manage the flow of incident report information, a tasking structure has been built to view and prioritize response focus to a specific series of tasks or response actions that have been generated by users of the application and the virtual operations center. The task allocation extension of the application leverages a complex set of algorithms to determine which AREA users can be allocated to a specific task. These algorithms take into account principals of locality, responder availability based on other task allocations, responder skills and resources, and a variety of deterministic characteristics to properly respond to tasks as they're being generated.

### *3.3. Data sharing & groups*

As a method of handling sensitive or private information, a simple to use yet powerful data sharing procedure has been built into the framework of AREA. Users of organizations or private users may create private groupings to share and view content visible only to those with access to the group. The user has the ability to create groups that are only visible to users if an invitation has been provided; public access groups may also be created as an additional layer to incident reporting. With these groups, users will also have the ability to effectively change the visibility of incident report data to affecting only their group members; this provides a more closed distribution of incident reports and a more managed task response loop to a group or organization.

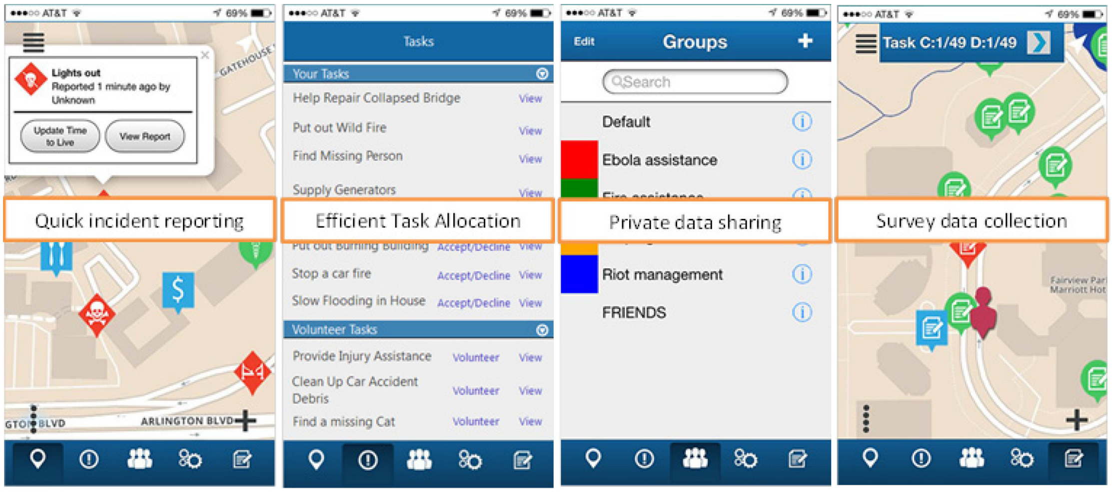


Figure 3. Area mobile app functions.

### *3.4. Survey data collection*

The AREA application provides functionality specific to mobile survey data collection efforts. Collectors will be provided map based visibility of the locations and specific surveys that are within their collection effort task; this has been broken down in the application to include the survey target and the survey or surveys they are to receive as a part of the collection effort. Survey authoring and analysis efforts will be managed as an extension of the Virtual Operations Center.

### *3.5. Virtual operations center control*

The Virtual Operations Center (VOC) is the web application extension of the AREA mobile platform. This desktop based environment is intended to be used by administrative or process management personnel to view, manage, and direct users within their organization. Much of the functionality seen within the mobile application can be seen in the VOC however, the VOC contains a much more robust series of functions to appropriate control over on-the-ground, mobile data collectors and responders. From this platform, an operator has the ability to view the locations of their organizational responders, manage the information they receive, communicate with them, and moderate the tasks they engage in.

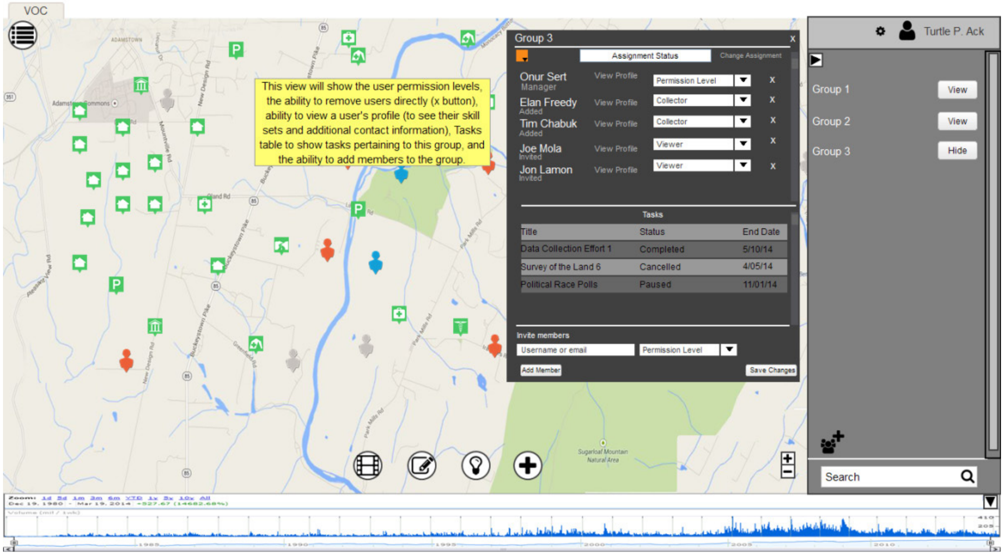


Figure 4. AREA Virtual Operations Center.

## 4. AREA analysis and forecasting

### *4.1. Social mapping based reporting with active information acquisition and risk assessment*

The ability to quickly identify critical risks is essential for quickly mitigating those risks through action by field users. As information is collected, the AREA app will process and reprocess available information and produce a consolidated risk analysis of the area in which field users are operating. In epidemiological terms, risk is defined as being a product of hazards, vulnerabilities, exposure, and response (HVER). For example, in a measles outbreak (hazard), a particular neighborhood may have poor sanitation (vulnerability) yet good health resources (response).

AREA leverages the communities of users such as NGOs, first responders, and military personnel, as a distributed sensor network to obtain timely information about illnesses and symptoms, injuries, environmental and public safety hazards as well as locations of assistance and shelters. Within the communities of users, customizable privacy settings based on data types enable data to be shared within defined groups or publically. The app incorporates algorithms, based on Bayesian models for uncertainty reduction, which capture and quantify how various epidemiological or environmental indicators may be early evidence of a problem, or causally linked to public health risks. These models identify areas where reduction in uncertainty would provide the highest payoff for effective decision making, and so drive information requests.

The AREA system is pre-loaded with a library of expert-crafted Bayesian models, such as the one pictured in Figure 5 below. Each of these models relates the various HVER factors to their relevant health risk, and also to the relevant input variables, such as field unit observations, populace answers to questions, and external intelligence reports. Each connection between HVER factors and other nodes has an associated weight that describes the causal strength of that relation. Causal Bayesian networks such as these have been shown in numerous domains to be: 1) highly effective at producing useful assessment; and 2) very amenable to specification by domain experts because causal knowledge is a natural part of human cognition. Bayesian networks are also a natural fit for this domain because they do not require complete information in order to operate. Available information (in the form of known variable values) may be set in the model prior to performing Bayesian inference, and any unknown variables may be left unspecified. The Bayesian inference will produce a probability estimation of all remaining variables in the network, given the specified values. This is an ideal fit for post-disaster and stability operations, in which assessments must be made even with incomplete information.

Figure 5 is a simple example of a Bayesian model to support active information collection where environmental conditions either directly impact pathology (such as a contaminant in the environment) or are increasing the risk of contagion among a population via water, insects or other disease vectors. The arrows show the causal links between several variables in the model from the Environmental Conditions to Pathologies and the Symptoms that would manifest among the population. Through use of the model, we can compute *Value of Information* such that when users report symptoms or environmental conditions, the app can quickly identify the additional information (other environmental factors, population information, or symptoms) that would be most value in determining the nature of the threat and its overall risk.

Consider a situation where members of a population in a given area exhibit symptoms of gastroenteritis. Based on the symptoms reported the app will generate a risk profile of the possible pathologies; these may include norovirus infection (relatively low-risk) or potentially the onset of a cholera epidemic (very high risk). The app will act to reduce uncertainty by automatically prompting for the additional information that will provide a better understanding of the risks. For example: '*Has there been recent flooding?',* which could suggest that water supply is contaminated by fecal matter and can put the population at risk for cholera. The app can also automatically alert the user community in a given area to be more vigilant about specific environmental observations or symptoms.

Another form of uncertainty reduction is the AREA app's capability to maintain timeliness of its data by associating a "*time-to-live"* with the various data types. As reports near expiration time, the app will automatically alert users in the vicinity of the report and request that they confirm if the report is still valid. In this manner, the app not only allows users to report issues, but actively attempts to maintain correctness on data that has previously been reported. Similarly, if data reported to the app by different users is deemed to be in conflict, and thus contributing to uncertainty, the app may request more information from the users who generated the reports to help resolve conflict. It may also request a third party in the vicinity to provide information that may reduce uncertainty.

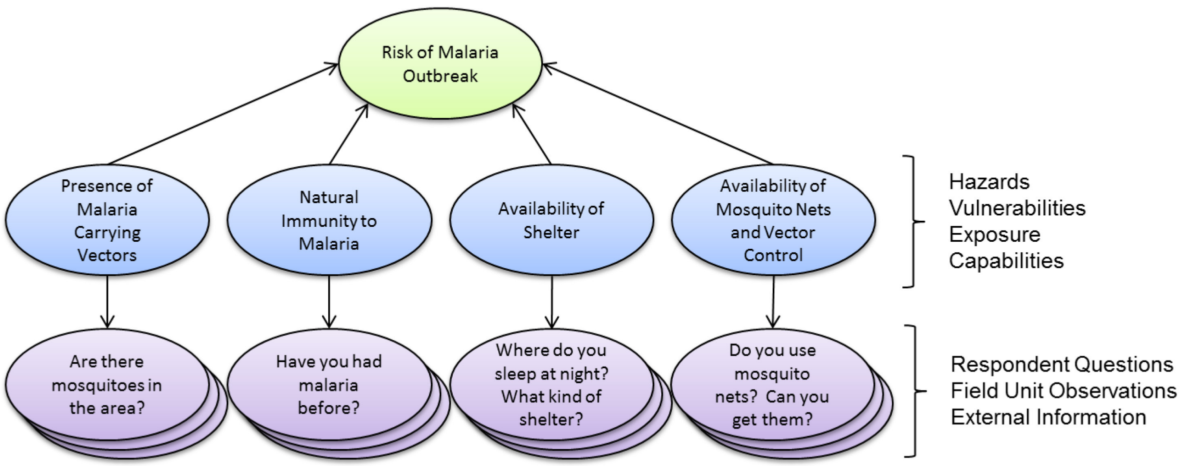


*Figure 5.* Example Risk Health Model that maps HVER factors to input variables and health risk.

### *4.2. Surveys and targeted investigations for disease forecasting*

A key instrument of epidemiological study is surveys. For survey data to be useful it must be collected according to a protocol and as part of a principled overall collection effort. The AREA VOC provides comprehensive tools for survey authoring and data collection management, while AREA provides integrated support for executing collection methodologies in the field. AREA survey capabilities can be used in a variety of scenarios, including:

- Part of a formal data collection effort where app users are assigned areas to enumerate for purposes of collecting baseline data, or investigating an issue
- In response to a specific report generated by a user that requires the user provide more information about illnesses or other notable events or reports

The AREA app includes sophisticated social-science based methods for forecasting disease progression and for predicting the impact of hypothetical interventions aimed at stopping the spread of the contagion. This enables the user to more accurately understand disease outbreaks and more effectively halts its spread.

It is well established that epidemic spread depends on the configuration of the contact network as well as on the individuals' personal health characteristics and the mode of disease transmission. However, because most health care responders do not know the host population's contact network, they perform disease forecast analysis under the assumption that the contact network is random or some form of lattice. Unfortunately, such assumptions render the application of their forecasting models both theoretically and practically incomplete as well as badly flawed.

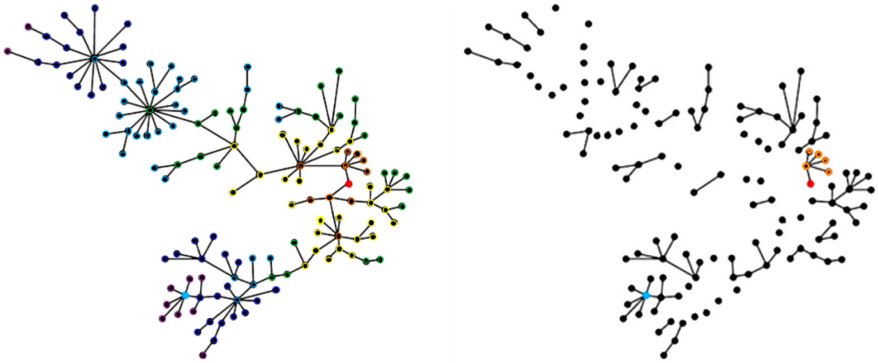

Figure 6. A network of individuals connected by a highly skewed distribution of contact interactions (left) and the same network (right) with eight central nodes (5%) immunized.

In contrast, the AREA system uses the state-of-the-art social network sampling methodology, i.e., Respondent Driven Sampling (RDS), which is integrated into the handheld app and is readily accessible to untrained users to gather information relevant to pathogen transmission. Our use of RDS tools embedded in handheld devices provides a unique and unprecedented opportunity to determine the contact network which guides and constrains the contagion.

Given information about the contact network, knowledge about who currently is infected, who is currently susceptible, who is recovered but may become susceptible, individuals' health characteristics, and the probability of disease transmission between any two individuals, simulation-based approaches will be used to forecast the spread of the pathogen across the network [1-4]. We can use a similar model to forecast the spread of pathogens between towns and villages in that they as well are interconnected by contact networks (although much more probabilistic involving the likelihood of interaction between members of any two particular towns / villages.

This forecasting capability can in turn be used to perform targeting analysis. A potential host population for a pathogenic contagion proves to have "herd immunity" if we can protect most members by immunizing only a small fraction of them. Ignoring such a protocol, when it is readily available, wastes time and effort and endangers countless individuals. For example, Figure 6 illustrates a network with a highly skewed distribution in which immunizing a few select targets (those with the greatest network-wide multi-step exposure and retransmission probabilities) can quickly immunize the entire population.

### *4.3. Visualization of uncertainty*

As part of AREA, we are integrating a novel multidimensional visualization of uncertainty in situational data and reports from users. The graphic visualization concept is shown in Figure 7.

Our graphic visualization concept captures uncertainty in terms of four key dimensions: (1) Support for relevant claim, 2) Conflict in evidence or reports, 3) Lack of resolution, 4) Incompleteness of information. Consider a situation where there exists a particular environmental hazard such as raw sewage leakage in a particular region. Conventional map based visualizations would show the number of reported incidents in the areas and locations the reports are being generated. These may be visualized as either pin points on the map or in a heat map. While these types of visualization are valuable situational awareness tools, they may not accurately portray the whole picture. In some cases there may be conflicting reports, where some are reporting there in raw sewage in the area and other reports are refuting it. There might not sufficient information to form a clear understanding on the extent of the problem. Using our uncertainty visualization the complexity around the various dimensions of uncertainty can be displayed as shown in Figure 7. Using this information can help determine the information to seek most urgently to inform an effective response decision.

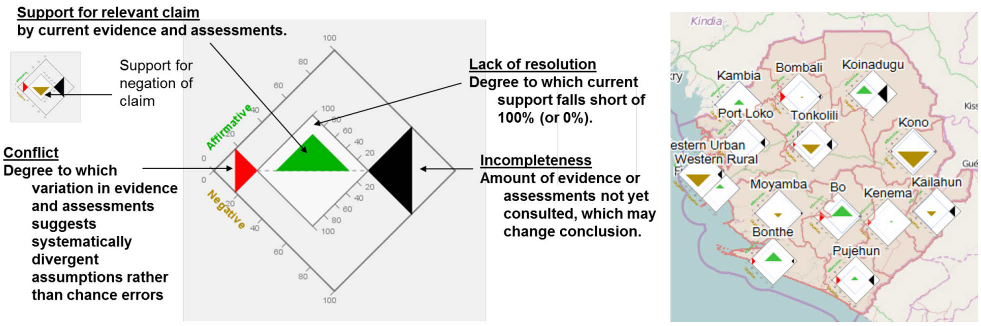


*Figure 7.* Uncertainty visualization using a decision information icon (DICON).

### *4.4. Rapid course of action development and resource coordination*

Cross leveraging resources available from different organizations is a key challenge in coordinating relief efforts for humanitarian crises where there are diverse organizations involved in the response efforts, including NGOs, local authorities, military organizations and others. Often requests for resources get stuck in chain-of-command decision making processes, which can cause time delays that impact effectiveness of a timely response, particularly when the needed resources are not locally available.

AREA supports algorithms that can assist in coordinating resources across organizations based on the principle of locality. Individual organizations share information with the broader user community on their resources that are available for coordination with others and on their capabilities -- including specialized skills and expertise. Tasks or urgent needs for resources can be requested through the app and the AREA will generate possible options for addressing the resource requirements. This is accomplished by emphasizing coordination among users located near each other who can provide assistance for the task or resource requests. Thus, the AREA helps facilitate more localized decision making about resource sharing and potentially bypassing the lengthy requisition processes to support more rapid and effective response.

## 5. Conclusions

The AREA facilitates the creation of a novel app-based social computing network for supporting situational awareness, risk reduction decision making, and effective resource allocation in public health and humanitarian crises. Functionality currently under development focuses on supporting information sharing in a structured manner with the goal of uncertainty reduction to support effective response. Future work will extend these capabilities with more advanced decision support tools, including data fusion from diverse data streams, measures of effectiveness tracking for continuous course of action optimization and other algorithmic enhancements.

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