Architecture for an Automatic Customized Warning System

Mirko Montanari, Sharad Mehrotra and Nalini Venkatasubramanian
Donald Bren School of Information and Computer Sciences
University of California, Irvine
{mirko, sharad, nalini}@ics.uci.edu

***Abstract*—Public communication during natural and man-made disasters is a key issue that must be addressed to protect lives and properties. The choice of the best protective actions to take depends on a global situation-awareness that is not available to the general public. Emergency personnel and public authorities have the duty to inform the population before, during and after catastrophic events to support the disaster response.**

In this paper we describe the design and the implementation of PWS (Policy-driven Warning System), a system for public warning dissemination. PWS is not intended to replace existing systems or procedures, but to serve on top of them in order to leverage the current emergency response knowledge.

I. Introduction

During an emergency the population takes protective actions to reduce injuries and deaths. Major emergencies require local officials to issue warning messages to the population, informing people about the situation and providing support in choosing the best protective actions to take.

Communications of this type take place during every emergency, going from warnings about the weather - floods, wild fires or tornadoes - to information about local events, such as hazardous chemical spills or terrorist attacks. The goal of the communication component of an emergency warning system is to disseminate clear and useful information that enables a proper response of the population at risk.

In the case of a natural disaster, it is possible to have forecasting models that can issue a warning even before the actual event. Such systems are called *Early Warning Systems* (EWS) and they are an important part of the emergency communication. The objective of an EWS is to empower individuals and communities threatened by a hazard to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury; loss of life, damage to property and to the environment, and loss of livelihoods [1]. Warning systems are currently in use to protect people from different types of natural disasters, such as hurricanes, volcanoes, tsunamis and earthquakes and they have proved effective in several occasions. The earthquake early warning system in place in Mexico City was able to detect a magnitude 7.3 earthquake (Sept. 14, 1995) that was going to hit the city, allowing to broadcast a notification 72 seconds before the arrival of a strong ground motion [2]. The *West Coast and Alaska Tsunami Center* is continuously monitoring earthquakes in order to issue a tsunami warning if needed [3]. Instead, in case of man-made disasters, no forecasting models are available: emergency personnel acts as live sensors and send updated information about the situation.

Warnings are needed not just before the event, but even during and after it. Information about the situation has to be disseminated continuously to inform the population about the evolving situation: areas that were safe before could become dangerous, therefore the protective actions to take may need to be changed continuously.

The choice of the best protective action to take also depends on a variety of factors, such as the location of the recipients, their distance from the crisis area and the type of event; hence, different people should receive different type of notifications. For example, schools in an area slightly affected by a chemical spill can receive a notification that says to close the windows and stay inside, while organizations in an area that is going to be affected soon by the same event can be notified to start an evacuation.

In this paper we describe PWS (Policy-driven Warning System), a system for public warning dissemination. PWS is not intended to replace existing systems or procedures, but to serve on top of them in order to leverage the current emergency response knowledge. In fact, awareness to natural and man-made disasters has created a rich know-how about crisis response: public authorities know what kind of protective actions are adequate in case of a certain disaster and certain conditions, and organizations have in place procedures to implement them. Leveraging this knowledge means being able to improve the current response without changing the way people are trained to react. PWS formalizes the response knowledge of the emergency personnel defining a policy language that enables an assisted or automated creation of warning messages, customized according to the characteristic of the crisis, type and location of the recipients, local conditions such as weather or hospital availability. Also, it takes into account the organization emergency plans by sending the right information directly to the key decision makers, helping them in organizing protective actions. Moreover, the architecture is able to integrate different communication technologies, such as phones, text messages and Internet, to adapt the use of the infrastructure to the crisis characteristics. Such multi-modal dissemination enables the recipients to receive the warning in the way they prefer and allows the notification to be delivered even if part of the infrastructure is not available.

II. Related Works

Emergency warning communication is treated in the current literature under sociological and technological aspects.

For the technological aspect, infrastructures such as the NOAA Weather Radio All Hazards (NWR) [4] and the Emergency Alert System (EAS) [5], with standards like SAME and CAP provide the basic mechanisms for the dissemination of the warnings over dedicated radio frequencies and public media. Early Warning Systems, like the Local Tsunami Warning in the Pacific Coastal United States [6], are currently using this infrastructure for the dissemination of warnings. Our work is built on top of this communication infrastructure.

The sociological part of early warning system is treated in different works. In particular, the work of McGinley et al [7] determined a set of design criteria that must be considered in the creation of a public emergency warning system. This work takes into account those criteria, but we propose to leverage the current emergency response of organizations and we provide a system for the automatic creation and customization of messages.

III. Policy-based Warning System

Considering the case of early warning systems, the current literature describe them as composed by four different parts. First, the community has to know which hazards it is exposed to and which are the vulnerabilities of the community. Second, a continuous monitoring and a sound scientific forecast model have to be put in place to identify when one of the hazards becomes a real threat. Then a dissemination and communication system has to be available to allow the dissemination of warning notifications to the people at risk. Last, the members of the community must respect the warning service and know how to react to warnings. All those phases are necessary for an effective dissemination of the warning.

In this scenario PWS (Policy-driven Warning System) assists the communication and dissemination part of a public emergency dissemination system. This system is based on an architecture that clearly separates different phases of the warning communication, from the creation of the notification to its public dissemination. Each component has a clear input and output that enables the definition of an open architecture on the top of which complex systems can be created by the interconnection of multiple subsystems, developed by third-party companies. Communication between components is possible by the use of standard protocols, like the Common Alerting Protocol (CAP).

The architecture is composed by four layers, as shown in Fig. 1. Each part of the architecture leverages a piece of the response knowledge. The system supports the complete process of warning dissemination: from the creation of the warning notifications to their dissemination to the public. Below we describe each layer in detail.

A. Content Generator

The first layer supports the automatic and assisted creation of messages: it receives a warning signal from sensors, external systems or directly from the operators, and defines a set of *actions* to perform, such as the dissemination of a warning notification or the activation of specific alarms.

An important part of warning messages is created at the local level in the *Emergency Operation Centers* (EOCs). The short time available and the stressful situation don't allow for the creation of a clear and concise message from scratch; emergency personnel rely on templates to be filled with the current disaster information. Usually these templates are few and generic to allow the emergency operator to choice easily and to direct the communication to a broad audience [8].

The choice of the best protective actions to take, and consequentially of the notifications to send, is not an easy process: it depends on the location and type of the recipients in addition to other local conditions such as weather, availability of transportation and hospitals. Consequentially, different parts of the population should take different actions: people living in areas heavily affected by a disaster can be required to evacuate, while people in safer areas can shelter in place and wait for further instructions. Hospitals have specialized procedures for dealing with emergencies, and the protective actions they must take can be different from the one taken by schools. For this reason, targeted notifications are needed to improve the warning response. A warning system should be able to send information suited for each particular subset of population. Performing this process manually is a big burden for the emergency personnel.

To overcome this problem, this process can be partially automated by leveraging the response knowledge of emergency organizations. A part of the emergency management is the definition of response plans to use in case of a disaster: in the early warning system literature this phase is called *risk knowledge* [1], in other response management models it is called *preparedness* [9]. In all cases, the hazards and the vulnerabilities of a community are identified to guide preparation for response and disaster prevention. Part of this knowledge can be formalized into a set of rules - *Crisis Policies*, created by the emergency personnel according to the procedures that they have currently in place for each type of disaster. These rules specify which message template should be used for each specific event, how it has to be adapted to the current situation and what kind of information should be provided to the recipients of the warning. Through the application of these rules, a set of message template is automatically selected and filled with information about the current disaster, enabling the emergency personnel to easily create customized messages for different subsets of the population.

The set of rules can be represented through a logic-based language, as shown in Fig. 7. Each rule associates a triggering event to a generic *action*. Example of possible actions are the activation of a specific alarm or radio signal; the dissemination of a specific message to a set of recipient or the delivery of a signal to stop dangerous processes in specific facilities. Multiple rules can be triggered by the same event to enable the creation of multiple notifications, each one targeted to a subset of the population. In order to simplify the process of

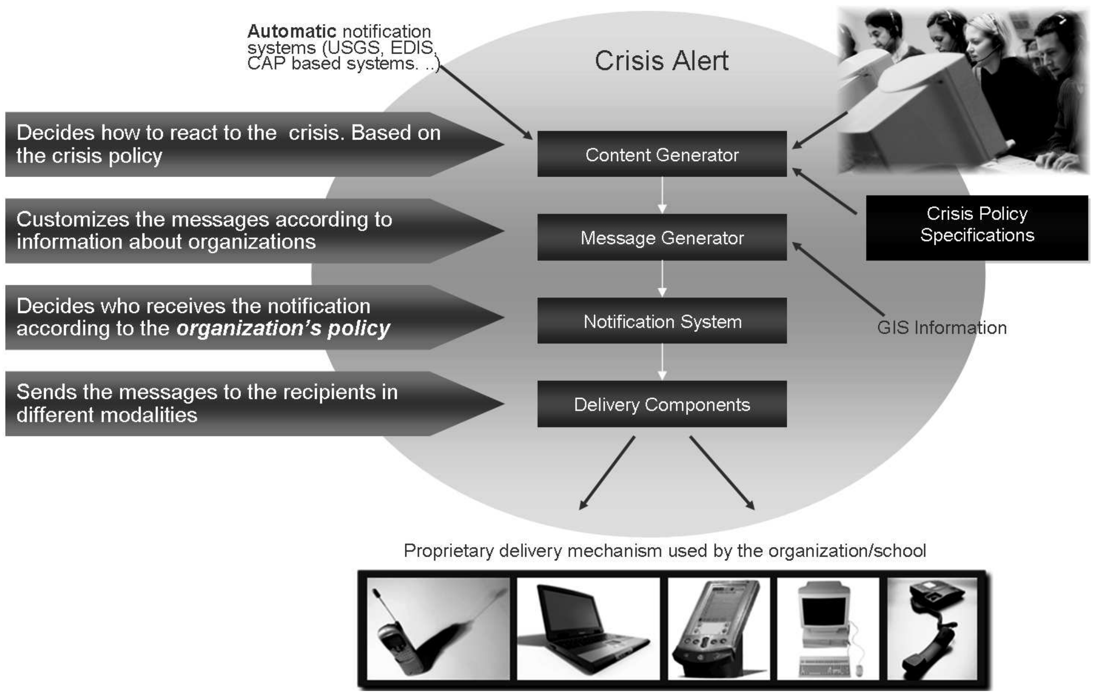

Fig. 1. High level architecture of PWS

rule creation, a wizard-style interface has been developed to guide the user through the specification of the different parts of the rule. By using this interface rules can be created without the need of knowledge about their underlying representation.

The structure of each rule follows a IF-THEN structure and it can be represented in logic as shown in Eq. 1.

$$action(event, action) : -conditions. \quad (1)$$

Eq. 1 can be read as "if $conditions$ about the event $event$ are met, then perform the action $action$". A set of such rules represents a logic theory. Each time a notification has to be created, this theory is enriched with a representation of the event, created by describing the its main features as a set of ground facts (see Fig 2). Also, additional information, such as the current weather and road conditions, can be represented as ground facts and integrated in the theory. These facts can be used to verify the conditions of rule activation.

When the system wants to determinate the action to perform in response to a particular event, it queries the logic theory with the predicate in Eq. 2.

$$? - action(eventid, A). \quad (2)$$

The set of actions that can be associated to the variable A represents the action to perform for this event. Each action is a predicate, that in case of public message notification is a triple:

$$< T, O, F > \quad (3)$$

In Eq. 3, T is the message template to use, O is the organization predicate that selects the targets of the notification and F is the merging function to use to customize the content

$event(shake2314, earthquake).$
$magnitude(shake2314, 6.5).$
$epicenter(shake2314, 36.456133, -118.691700).$
$shakemap(shake2314,' shake2314data.ddd').$

Fig. 2. Example of event representation

sendmessage(shelterinplace,
(organization(Y),orgType(Y, school),
inredregion(event213, Y)), $nearbyshelters$).
sendmessage(shelterinplace-chemical,
(organization(Y), orgType(Y, school),
within(5, chemicalplant, Y)), $chemicalnearby$).
sendmessage($safe$,
(organization(Y), orgType(Y , school),
inredregion(event321, Y)), $nearbyhospitals$).

Fig. 3. Actions output of the Content Generator

for each recipient. Each triple represents a notification that is passed to the next layer to continue the dissemination process.

B. Message Generator

The message generator layer (figure 5) uses the local knowledge about the geography of the area to identify the organizations targeted by the notifications. The knowledge is contained in a GIS database that keeps the locations and characteristics of the possible recipients. Also, this database contains other local information: location and availability of

(organization(Y),orgType(Y, school),
inredregion(event213, Y))
(organization(Y), orgType(Y, school),
within(5, chemicalplant, Y)), $chemicalnearby$).
(organization(Y), orgType(Y , school),
inredregion(event321, Y)), $nearbyhospitals$).

Fig. 4. Organization predicate

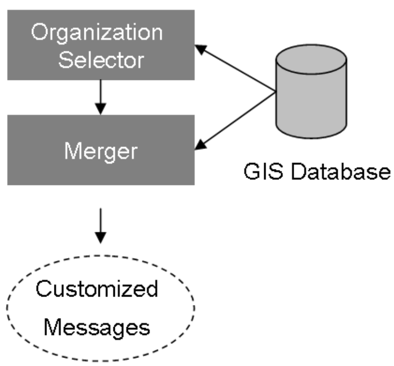

Fig. 5. Message Generator Component Architecture

hospitals and shelters, location of hazardous chemical facilities, etc. This database is expected to be maintained at the local Emergency Operation Center and kept up to date by the local personnel.

Each warning notification is associated to a specific organization predicate that describes message recipients, as shown in Fig. 4. To identify the actual targets, this predicate is matched against the list of organizations in the GIS database: the organizations that satisfy it are the recipients for the notification. For a specific warning notification, each target receives just one message: if a target satisfies multiple predicates, then the conflict is resolved through the use of a priority associated with each rule.

The expressivity of the organization predicate allows us to identify a target based on the location and the type of the recipient, in addition to its relationship with other organizations: for example, it is possible to identify organizations that are near chemical facilities or school districts that have at least one school in the affected area.

Once the targets are identified, local information can be used to transform the message template into the actual message by the application of a *merging function*. A merging function modifies the template according to location and type of the recipient: this customization doesn't change the form of the message, but it adds additional information such as the location of the nearest shelters or hospitals; information about chemical facilities near the recipient's location, providing procedures to protect from eventual chemical spills that can happen as a consequence of the crisis.

After this phase, each triple has been transformed into a set of messages ready for dissemination. Each message has a content and a set of target organizations. The notification doesn't contain the actual recipient yet, but just the list of organizations that are going to receive the notification.

If one of the target organization has an internal system that can handle the message dissemination, then the message is passed directly to it. Automatic dialers are available on the market and they are deployed within big organizations to handle such dissemination. Exploiting such systems has the advantage to reduce the contact information that must be kept up to date.

C. Notification System

Schools, universities and public places like malls or public offices are more exposed to risks during natural or man-made catastrophes: the high number of people to coordinate in order to provide protective actions and the special needs of some of them - like children - complicate the response; for this reason *emergency plans* have to be in place to organize a response. Examples of these plans are the schools' safety plans: for each possible thread a plan prescribes a set of activities to perform before, during and after a crisis. Also, it determinates who are the *decision makers* for each of those activities [10]: these people have the duty to organize the protective actions within the organization.

The existing organizational plans are valuable for the creation of a warning system: they educate the population to react to crises and they keep this knowledge current through regular drills. A warning system should integrate these plans, leveraging their connection with the population. Leveraging this process is possible by sending information directly to the decision makers to increase their situation-awareness, helping them in choosing and organizing the best protective actions for their organizations.

This layer associates each of the messages to a set of recipients that, accoding to the organization emergency plan, are the decision makers for that particular type of disaster. Moreover, each decision maker can define which modalities should be used to notify her of the emergency.

The output of this phase is an association between each message and a set of contact information.

D. Delivery Component

The delivery component realizes the interface with the communication channels. According to the indication obtained by the previous component, it converts the message into the correct modalities and deliveries it to the different channels.

This component is composed of a set of modules, each of them dedicated to the interaction with a specific communication channel. Each modules has two parts, one that adapts the message content to the modality compatible with the communication channel, for example by converting images and text to the right format, and one that interacts with specific gateways to perform the message delivery, as shown in figure 6. Currently, PWS is able to disseminate the notifications through two channels: Internet, by using a flash P2P protocol, and mobile phones via SMS. We are working toward expanding this list by creating gateways to other communication channels, such as standard phones.

The Internet-based dissemination relies on CREW, a Gossip-based P2P protocol designed for the *flash dissemination* of information: dissemination of fixed, rich information from one source, to a large number of receivers, as fast as possible, and over a heterogeneous and potentially unstable network. The CREW dissemination algorithm is based on gossip theory and random networks; experiments show that it significantly outperforms both traditional gossip and current large content dissemination systems while sustaining its performance in the presence of network errors [11]. Such qualities makes this protocol the best candidate for the dissemination of rich warning information.

Using Internet as dissemination modalities has many advantages. Internet, due to the redundancy built in it, provides resilience to failures. This characteristic make it survive in case of disaster, when more centralized communication infrastructures can fail. Also, portable devices that are connected to the Internet are becoming popular, allowing Internet-based notifications to reach their targets even when the recipients are not in front of the computer. Moreover, Internet enables the dissemination of rich notifications: the messages that can be sent are not limited to only text or audio, but they can contain maps of the area, procedures to follow, contact information, links to verify that the information are accurate and videos.

The decision makers of each organization can join the P2P network by installing a small Java client on their computers. A username and a password, obtained after a registration process, are the user's credential in the system. When the client starts, it verifies the user's credential on a authentication server and, if successful, it transmits the client's IP to the PWS delivery layer and joins the P2P network. Then the client stands by, waiting for notifications; when a warning message is received, a window pops up showing the content of the notification.

In addition to the Internet-based dissemination, we are working to connect the system to the standard and mobile phone lines. Currently, the system is able to deliver SMS notifications through the use of gateways available on the Internet [1]. To improve the reliability of this process and integrate phones, we are working with an external company for creating a gateway to the phone infrastructure. When the deployment is completed, the system will be able to delivery the notifications through standard phones and SMS in a reliable and efficient way. The specific target of this integration is the dissemination of warning notifications to school officials and children's parents, allowing PWS to completely cover the warning dissemination process in the case of schools: from the EOC to schools, and from schools to the the parents.

[1]see http://vsmsgateway.com/ and http://www.accutracking.com/sms-email.html

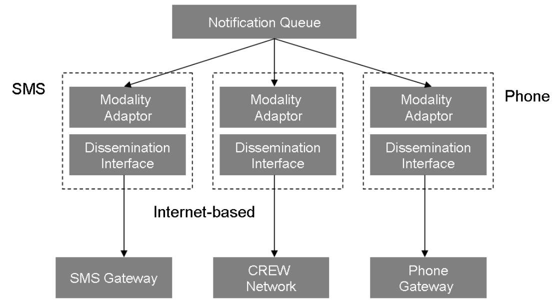

Fig. 6. Delivery Component

E. *Fast Dissemination*

Some messages have to be disseminated within few seconds from the identification of the event; this is the case of an Earthquake Early Warning notification.

In the case of Earthquake Early Warning, the warning doesn't come from a forecast. Instead, these systems detect actual quakes near their sources and issue warnings several miles away, exploiting the fact that electronic communication travels faster than seismic waves. Also, it takes advantage of the two types of waves that are generated in a fault rupture: P waves and S waves. S waves, that carry most of the energy of the quake and cause the most of the damage, travel slower than P waves. The latter can be received and used to predict the strength of the earthquake the arrival of the S waves. [12] A Earthquake Early Warning system can issue a warning before the arrival of the S waves. A specific algorithm is used to make the prediction and the actual amount of time available depends on the distance between the fault rupture and the region to notify, but it is in the order of tens of seconds. In this scenario, it is important that the process of dissemination, from sensors to the public, is completely automated to eliminate the delay-prone human interaction.

The Crisis Policies can be used to automate this process: the set of actions to perform can be pre-defined and inserted into a special Fast Crisis Policy, kept simple to immediately process the event as fast as possible. Then the information can be disseminated through emergency radio and through the activation of special alarms in schools and public buildings, along with a flash dissemination of the warning through Internet.

IV. Implementation and Testing

The PWS system has been implemented as a Java application of about ten thousand lines of code. The system is composed by two parts: the server and the client. The client part has to be used if the user wants to take advantage of the Internet-based notification, otherwise is not necessary. The system provides a web interface for defining rules, notifications and for managing the organizations' policies. Also, it defines an API that can be used to interact with other systems. The logic engine has been implemented through the use of the library tuProlog [13], a Java-based light-weight Prolog implementation that has the advantage of being easily extendible with java code. The database system used to store policies and GIS information is MySql [2].

For testing the system we created an heterogeneous environment composed of a real part and an emulated part. In the real part we installed the server and the client applications on a set of machines connected through a LAN network and it serves as a test for the application usability. The emulated part uses the ModelNet network emulator [3] to simulate the dissemination of the messages in a realistic situation.

During our tests we simulated a couple of scenarios that can demonstrate the system's capabilities. Considering such scenarios allows us to describe the interfaces and the interactions between the system and the users: EOC personnel, organization manager and decision makers. In this section, first we describe the deployment phase of the system, and then the two scenarios that we created.

A. System Deployment

The phase of deployment of the system requires the interaction of all the types of users of the system. The EOC personnel defines the crisis policies; the organization managers registers the organizations in the system and defines the organization policy; the decision makers choose the channels to use for the delivery of the notification to them. All the interactions are performed through a web interface offered by PWS

A wizard-style interface is used to specify the crisis policies. The first pages of the wizard specify the event that triggers the rule, along with other local conditions that can conditionate the activation of the action. The following pages defines the action to perform and, when we consider the delivery of a message, the type of notification, choosed from a set of predefined templates, and its recipients. This interactions create a rule as shown in Fig. 7. Example 1 shows a simple rule: in case of an event X, if it is an earthquake with magnitude over 6.5 then perform the action $sendmessage$, sending the message of type $evacuate$ to every organization Y that satisfies the predicate $inredregion$: this predicate is satisfied by the organization in the red region determinated by the ShakeMap. The customization of the message is done by using the merging function $nearbyshelters$.

The interfaces for organization managers and decision makers allow them to log into the web site and edit their preferences. The organization managers define the organization policy by registering the decision makers and assigning them to each crisis; the decision makers specify the modalities through which they prefer to be notified, providing phone numbers or other contact information.

B. Usage Scenario 1: Earthquake

The first scenario that we consider is the dissemination of an earthquake early warning message to the schools in the city of Ontario, CA. We populated the database with information of about fifty schools in the area: each school has emergency policies defined for about ten different types of disasters and contact information of the decision makers. The warning notifications have been disseminated through an emulated environment which has been created with the ModelNet network emulater.

Earthquake early warning systems are able to issue a notification before the earthquake hit a populated area. For simulating the scenario, we manually issued an earthquake early warning. The information about the event are converted into a simple logical representation and inserted into the Fast Crisis Policies engine. Then, the logic theory is queried and the actions to take, the types of notifications and their recipients are determinated.

Different actions can be performed in this scenario. For example, it could be possible to send a signal to factories in order to stop their operation, meanwhile we could disseminating a warning notification, through Internet and emergency radios, to advise the population to "duck and cover" and wait for the shake. This notification allows people to have the time to move away from shelves or scafolds that can pose a threat during the shaking; doctors in operating rooms can stop working to limit the damage to the patient.

After the first shake, more information about the earthquake can be automatically collected by the warning system. USGS issues *ShakeMaps* within minutes from the event. This bulletins describe the impact of the earthquake in the region and determinates the areas which have been heavily affected by the quake and the ones that have been less damaged. This information can be used to issue customized notifications. The information about the new event is converted into a logical representation - as shown in Fig 2 - and integrated into the set of Crisis Policies. A query on the logic theory determinates the actions to perform: the more time available allows the creation of a set of notifications richer that the one created before: organizations in the most affected area can are notified to evacuate or shelter in place, depending on the strength of the earthquake, meanwhile organizations near chemical facilities are notified to shelter in place in order to give time to the first responder to verify the presence of dangerous spills. Each set of notifications created in the previous sections are passed to the Message Generator layer. The actual recipients of the messages are identified by matching each organization predicate in the GIS database. If a merging function has been specified, additional information are added to the template: organizations in the most affected area receive the locations of hospitals and shelters in safe areas; organizations near a chemical facility receive standard information about the type of chemical contained in the facility and how to protect from it; organizations in safe areas can receive a list of the nearest hospitals.

In this scenario, the recipients of the notifications are schools. Usually, the decision makers are the principal and other school officials. Through the client running on their machine they receive rich notifications that contain maps, routes and addresses of hospitals and shelters. Then, relying

[2]http://www.mysql.com

[3]http://issg.cs.duke.edu/modelnet.html

action($event$, $action$) :- $conditions$

The response of the system at the event $event$ is $action$, when $conditions$ are met.

Example 1

action(X,
    sendmessage(evacuate,
        (organization(Y),orgType(Y, school), inredregion(R, Y)), $nearbyshelters$)
:- event(X, earthquake), magnitude(X, M),$M > 6.5$, shakemap(X, R).)

If the event is an earthquake and it has a magnitude greater than 6.5 then send the message represented by the template $evacuation$ to the organizations of type school that are in the red region of the USGS $shakemap$.

Example 2

action(X,
  sendmessage(evacuationprogess,
    organization(Y), orgType(Y, schooldistrict),
      organization(S), orgType(S, school),
        inredregion(X, S), partOf(S, Y)), schoollist)) :-
  event(X, earthquake), hasMagnitude(X, M), $M > 6.5$.

If the event is an earthquake and it has a magnitude greater than 6.5 then send the message represented by the template $evacuationinprogress$ to the school districts for which at least one of their schools is in the red region of the USGS $shakemap$.

Fig. 7. Examples of crisis policies.

[t]

on this information, they are able to plan the protective actions to take; in case of evacuation they know where to move the children; in case somebody needs medical attention they can contact the nearest hospital. As the situation evolves, the decision makers are updated with the latest information and are able to immediately adapt the response to the new conditions.

An example of how a notification appears on the computer screen is shown in Fig. 8.

C. Usage Scenario 2: Chemical Spill

In the second scenario we consider a man-made disasters; in particular a chemical spill that happens in Irvine, CA. As for the previous scenario, we loaded information about fifty schools in the Irvine area, defining an organization policy and a set of decision makers for each of them.

In the case of a chemical spill, the information about the event is provided by first responder on the field: they contact the EOC providing details such as the type of chemical and the quantity that has been spilled. The EOC can start a public notification by manually inserting this information in PWS through the web interface.

Manually issuing a notification is a two phases process. In the first phase the crisis policies are queries to determinate the notifications to prepare. In the second phase, these notifications are shown to an EOC operator that can check the content of the messages and their recipients. If the operator is satisfied by the proposal, then she can confirm the actions and continue the dissemination as the previous scenario.

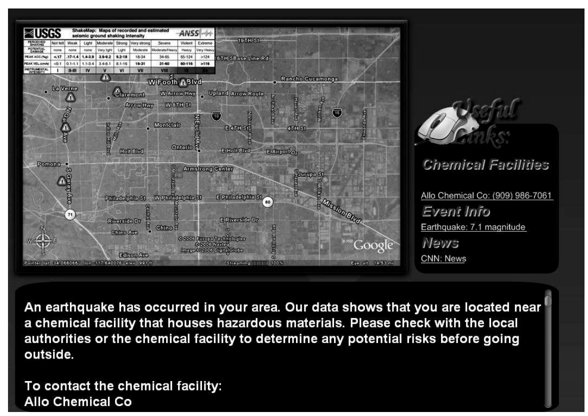

Fig. 8. Example of notification to organizations near a chemical facility

V. Conclusions and Future Work

In this paper, we have presented PWS, a dissemination component for a public emergency warning system. This system is able to cover the whole process of warning notification, from the creation of the warning to its dissemination to the public. PWS leverages the current knowledge end experience in emergency response to create customized and personalized notifications. It is built on top of already-in-place plans and communication infrastructure in order to leverage what is already available in the emergency response community: its open architecture enables the interaction with third-part systems to achieve its goals. This system has been created and it has been tested in an emulated scenario.

We are further investigating different parts of the PWS system. For what regards the warning creation, we are investigating how to integrate uncertainity in the Crisis Policies. Uncertainity is intrinsic in the information that comes from the field and from the forecasts of natural events: we are going to integrate this information in the expression of the rules and on the ground facts that trigger it.

Also, another issue in this type of system is keeping the contact information updated: office phone number, mobile phone numbers, etc associated to each person change over time. Though, keeping this information current is fundamental for the efficacy of the system. We are going to investigate on how it is possible to check this contanct information and assure that it is updated.

REFERENCES

[1] UN, "Global survey of early warning system," United Nation, Tech. Rep., March 2005.

[2] F. Wenzel, M. Baur, F. Fiedrich, C. Ionescu, and M. C. Ionescu, "Potential of earthquake early warning systems," *Natural Hazards*, vol. 23, no. 2-3, pp. 407–416, March 2001.

[3] M. Darienzo, A. Aya, G. L. Crawford, D. Gibbs, P. M. Whitmore, T. Wilde, and B. S. Yanagi, "Local tsunami warning in the pacific coastal united states," *Natural Hazards*, vol. 35, no. 1, pp. 111–119, 2005.

[4] N. O. . A. Administration, "National weather service instruction 10-1712," http://www.nws.noaa.gov/directives, February 2006.

[5] L. K.Moore, "Emergency communications: The emergency alert system (eas) and all-hazard warnings," CRS Report for the Congress - Received through the CRS Web, July 2006.

[6] G. L. Crawford, "Noaa weather radio (nwr) - a costal solution to tsunami alert and notification," *Natural Hazards*, vol. 35, no. 1, pp. 163–171, May 2005.

[7] M. McGinley, D. Bennet, and A. Turk, "Design criteria for public emergency warning systems," Proceedings of the 3td Interational ISCRAM Conference, Newark, NK (USA), May 2006.

[8] M. L. Vanderford, "Breaking new ground in wmd risk communication: The pre-event message development project," *Biosecurity and Bioterrorism: Biodefence Strategy, Practice, and Science*, vol. 2, pp. 193–194, 2004.

[9] D. McLoughlin, "A framework for integrated emergency management," *Public Administration Review*, vol. 45, no. 1-3, pp. 165–172, Jan 1985.

[10] A. D. of Education, "Arizona school site emergency response plan template," 2005 September.

[11] M. Deshpande, B. Xing, I. Lazardis, B. Hore, N. Venkatasubramanian, and S. Mehrotra, "Crew: A gossip-based flash-dissemination system," *icdcs*, vol. 0, p. 45, 2006.

[12] R. M. Allen and H. Kanamori, "The potential for earthquake early warning in southern california," *Science*, vol. 300, no. 1-3, pp. 786–789, May 2003.

[13] E. Denti, A. Omicini, and A. Ricci, "Multi-paradigm java-prolog integration in tuprolog," *Sci. Comput. Program.*, vol. 57, no. 2, pp. 217–250, 2005.

[14] J. H. Sorensen, "Hazard warning systems: Review of 20 years of progress," *Natural Hazard Review*, vol. 1, no. 2, pp. 119 – 125, May 2000.

[15] D. S. Mileti and J. H. Sorensen, "Communication of emergency public warning - a social science perspective and state-of-the-art assessment," Oak Ridge National Laboratory, Tech. Rep., August 1990.