Increasing the Effectiveness of Early Warning via Context-aware Alerting

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ABSTRACT

The effective implementation of early warning is one of the best investments for disaster prevention and mitigation. In the last decade, we have witnessed strong efforts and progress towards better risk detection, monitoring and prediction. However, the best warnings are ineffective if they cannot be distributed in a timely way and targeted to people at risk. With the evolvement of new Information and Communication Technologies, we have new opportunities and face new challenges for improving classical warning processes. Based on our experience and research results from two user-centered hydro-meteorological Early Warning Systems (EWS) we present an approach for context-aware alerting that can increase considerably the effectiveness of warning. Furthermore, we introduce an applied evaluation model for the effectiveness of an EWS.

Keywords

Early warning systems, disaster alert systems, context-awareness.

1. INTRODUCTION

With increasing damage caused by natural disasters in last decade, the implementation of effective Early Warning Systems (EWS) has become a major issue on the agenda of international, national, and local authorities. In the past years several EWS have been introduced (such as the Global Disaster Alert and Coordination System GDACS [6]), existing systems have been improved (such as the Emergency Alert System EAS in the United States), or about to be interconnected (such as the Tsunami Early Warning Systems in the Pacific Region). Despite this progress, we are still far from being able to distribute timely and effective warnings to at least a portion of the world population, especially in less developed countries. Even existing national EWS in developed countries – which mainly use broadcast dissemination – are often ineffective when it comes to targeted warnings for specific areas or user groups. On the other hand, we already find an increasing number of heterogeneous alerting systems, operated by local authorities, non-governmental or private organizations that are mainly isolated solutions for specific areas and user groups where synergy potentials with national or international systems are not yet applied.

The approach presented in this paper builds on context-aware alerting in Early Warning Systems that can provide this enhanced target orientation of warnings to individuals, systems, and user groups and are complementary to global and national EWS. The overall challenge is to find interoperable and flexible models and architectures for a new layer of local alerting systems that provide an effective dissemination of warnings on a local level in terms of coverage and adaptation to the needs of the receiver and its local environment. This layer should provide a significant contribution to the target-orientation, reliability, accuracy, and cost-effectiveness of early warning infrastructures in the future.

Our approach is based on our experience of the development and operation of the EWS WIND [21], a meteorological Early Warning System in Germany, Austria, and Switzerland with 350,000 subscribed users, operated as a commercial service provided by the insurance sector. The results of our research are currently implemented in the EWS SAFE [14], where we developed and applied a cost-benefit model that serves as an evaluation of the presented approach for context-aware alerting in EWS. This model consists of general performance parameters for EWS that should be applicable for the effectiveness evaluation of other Early Warning Systems.

The paper is organized as follows. Section 2 describes the foundations and the focus of our approach based on the recent developments and challenges in EWS. Section 3 presents an approach for context-aware alert strategies and warning adaption, an architecture for the integration within existing EWS infrastructures, and a cost-benefit evaluation model for the implementation in SAFE. Finally, Section 4 draws our conclusions.

2. DEVELOPMENTS AND CHALLENGES IN EARLY WARNING SYSTEMS

This section first gives some definitions before presenting the main challenges in designing efficient EWS.

2.1 Definitions and Classification

A first problem that arises for someone working in the field of EWS is the existence of different notions of what constitutes an Early Warning System. The formal UN definition describes the term Early Warning as follows: "The provision of timely and effective information, through identifying institutions, that allow individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response" [6]. Despite this quite common definition the views and the understanding of Early Warning in detail are often considerably different and depend on the domain of a user or developer which is partly due to the fact that the components of an EWS are complying very heterogeneous and interdisciplinary tasks. In its effort to support a common understanding of Early Warning the UN Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR) has defined four key elements of an EWS: Risk Knowledge, Monitoring and Warning Service, Dissemination and Communication, and Response Capability [20]. Looking at existing EWS we can see that the focus is often set on one or two of these elements only, and rarely on the complete set. Usually, we still speak of an EWS, even though by this formal definition it is often not complete. Thus researchers developing a system with a focus on risk knowledge and others with a focus on dissemination and communication might both call their solution an EWS, however, they still deal with completely different tasks and challenges. It is therefore important to define the specific field and aim of one's contributions to EWS research.

In order to categorize developments and solutions in EWS, let us consider several views. A set of criteria is given by the overall task and system boundaries of an EWS: Criteria as the hazard type (natural: hydro-meteorological, volcanic, earthquake, tsunamis, landslides, etc., human-caused: wars, terrorist attacks, etc.; technological: infrastructure failures, etc.; biological: diseases, etc.; and multi-hazard), the time scale (long-term, short-term and real-time), the geographical or political scale (global, international, regional, national, or local), or the organizational scale (operated by governmental, non-governmental, or private sector). Another interesting criterion distinguishes by the maturity state of an EWS: pre-science, ad-hoc science-based, systematic end-to-end, and integrated [1]. We can identify these stages often as improvement stages of existing EWS, and yet rarely the final stage has been reached. The UN/ISDR has generated a compendium of existing EWS [20]. This collection is by far incomplete (missing mainly local and private sector EWS), however, it is one of the best common overviews.

Other model views can be applied to structure an EWS: Task and functional view (as above), process views, and architectural views. Structural and process views are proposed in [6]. From a systems engineering point of view we propose an additional architectural view that consists of four layers: *monitoring and data collection layer*, *information processing layer*, *warning generation layer*, *alert dissemination layer (CF.* Figure 1). It is important to note that this view is strongly system oriented and leaves out organizational aspects.

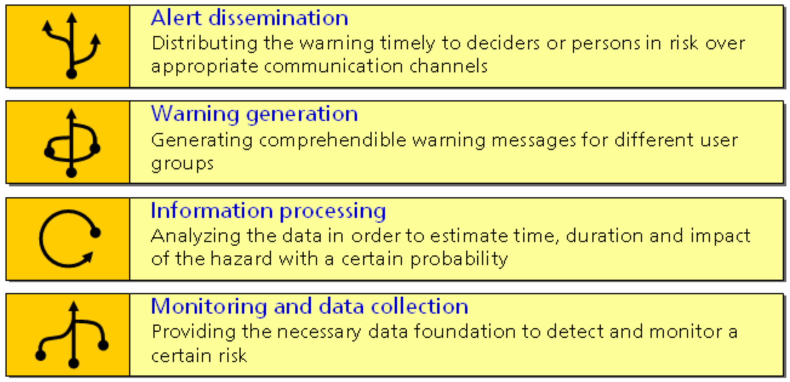

Figure 1. Layers of an EWS

In our work we focus on the two layers of *warning generation* and *alert dissemination* for user-centric, short-term multi-hazard and multi-channel EWS. This sub-system of an EWS can also be referred to as a Disaster Alert System (DAS).

2.2 Challenges

For most of existing EWS, the efforts in the implementation mainly focus on the detection, monitoring, and prediction of risks. Warnings produced by these systems are usually available for governmental authorities who are responsible for the dissemination of alerts to the public. Often, we witness major problems in the effective dissemination of these warnings to people at risk. In less developed countries, this is due mainly to missing infrastructures. However, even in developed countries this task has been underestimated. Several projects have been initiated to implement better alerting mechanisms for the public (e.g., improvement of EAS in the US, Cell-Broadcast-Alerting in the Netherlands [17], SATWAS in Germany [3], MyRescue in Japan [8], IPAS in Canada [16], among others). In this context new available information and communication technologies are offering new potentials as well as new challenges to effective warning. As classical public warning until the nineties was transported via sirens, loud speakers, mass media and partly radio-based receiver-specific solutions, new channels are now used such as digital broadcast technologies (Digital Radio and TV), mobile network technologies (GSM, UMTS, TETRA), fixed networks (Internet, Telephone, Cable TV), Satellite Technologies (VSAT or the new promising EGNOS-ALIVE approach [10]) and others (pager and proprietary radio-based solutions such as DCF77, EFR). Aside from this existing potential, new challenges occur in providing systems that make full use of these heterogeneous channels in an intelligent, sustainable, and cost-effective way:

(1) Regarding the intelligent use of alerting channels, different aspects need to be considered. First, as it is stated by the UN/ISDR [20], warning messages are often not sufficiently targeted to the users and therefore inefficient. Second, a problem may arise with the possible - and in the case of disasters most likely - failure of communication infrastructures (physical, congestion, failure of supporting infrastructure) [18].

(2) In terms of sustainability, it should be stated that a major part of the afore-mentioned new communication channels complies the integration of private stakeholders. This fact makes public-private partnership models inevitable and can be strongly beneficial for the sustainability of EWS, especially in terms of long-term operational and maintenance costs that are often underestimated in this area.

(3) In terms of cost-effectiveness, the necessary infrastructure should be interoperable with existing warning systems and the synergy of using the same dissemination infrastructure among EWS should be exploited. A major milestone towards this direction has been reached through the development of the Common Alerting Protocol (CAP) [4] which offers a sound basis for interoperability and is now adopted by several EWS. Now the task is to identify synergies and realize interoperability between isolated EWS solutions in the area of alert dissemination (note that the US alone count eight different warning systems on the federal level [13]). Furthermore, the cost-benefit relationship for the realization and maintenance of an alerting infrastructure has to be estimated.

3. INCREASING THE EFFECTIVENESS OF ALERTING

In this section, we present an approach for context-aware interoperable alerting components in a user-centered multi-hazard and multi-channel early warning environment.

3.1 User-centered Situation-based Approach

The UN/ISDR recommendations for EWS [19] as well as other sources [9;11;13;16] stress the importance of people-centered approaches for Early Warning. It is now common sense that the public should not anymore be seen as one homogeneous group of people with the same information demand but should be distinguished by their individual demands. The reason why this aspect has often been neglected in existing EWS has different causes. One cause might be sought in the strong focus on risk detection, monitoring, and prediction in the development of EWS in the recent years. Given the classical broadcast-based alert mechanisms, it was also technically not feasible to distinguish user groups or even individuals in the alert dissemination processes. Even with the new available ICT that enable individual addressing of users, people-centered systems strongly rely on the knowledge about their users, which require sophisticated profiling via subscription or context-aware systems.

The EWS WIND was developed with a strong user-centered focus. Based on a subscription component, the system collects profile information of users and uses these to adapt warnings to the estimated information demand. From the beginning of 2001 the system already provided a component for location-based service provision, however, with the availability of affordable handhelds and mobile phones with GPS-functionality, the component became operational only last year. The dynamic aspect of location addresses an important issue for target-orientation of EWS in the future. As target orientation is now mainly realized by static profiles via subscription systems such as in GDACS, these systems cannot adapt to dynamic profiles or context rapidly changing over time. For these context parameters, location is just one example. Other relevant parameters can be reachability (mobile phone, internet, etc.), environment (building, outside, forest, etc.) or activity (sleeping, driving, etc.). Similar to the evolvement of location-based systems (e.g., navigation systems), of which we are currently witnessing a fast pervasion in our daily environment we expect a similar pervasion of intelligent context-aware services in the next decade. This evolution will have a significant impact for alerting in EWS (first in developed countries). As EWS have to be developed with a long-term operational perspective and with the potential of context-awareness for increasing effectiveness of alerting, future EWS solutions should be designed openly for future device abilities.

3.1.1 Context Model

Our approach for context-aware alerting in EWS uses a general context model applicable in different fields. This model introduces the notion of the situation of a user, which is a set of characteristics (context parameters) that hold during a time interval. A situation is defined as a triple

$$s = (t_b, t_e, C)$$

where t_b and t_e are respectively the begin and the end time of the interval and C a set of context parameters. Different types of context parameters such as location, environment, or activity, are distinguished as dimensions. Possible hierarchical relations of parameters within a context type, ontologies, are modeled as taxonomies (dimension structures). Figure 2 describes excerpts of ontologies used in SAFE.

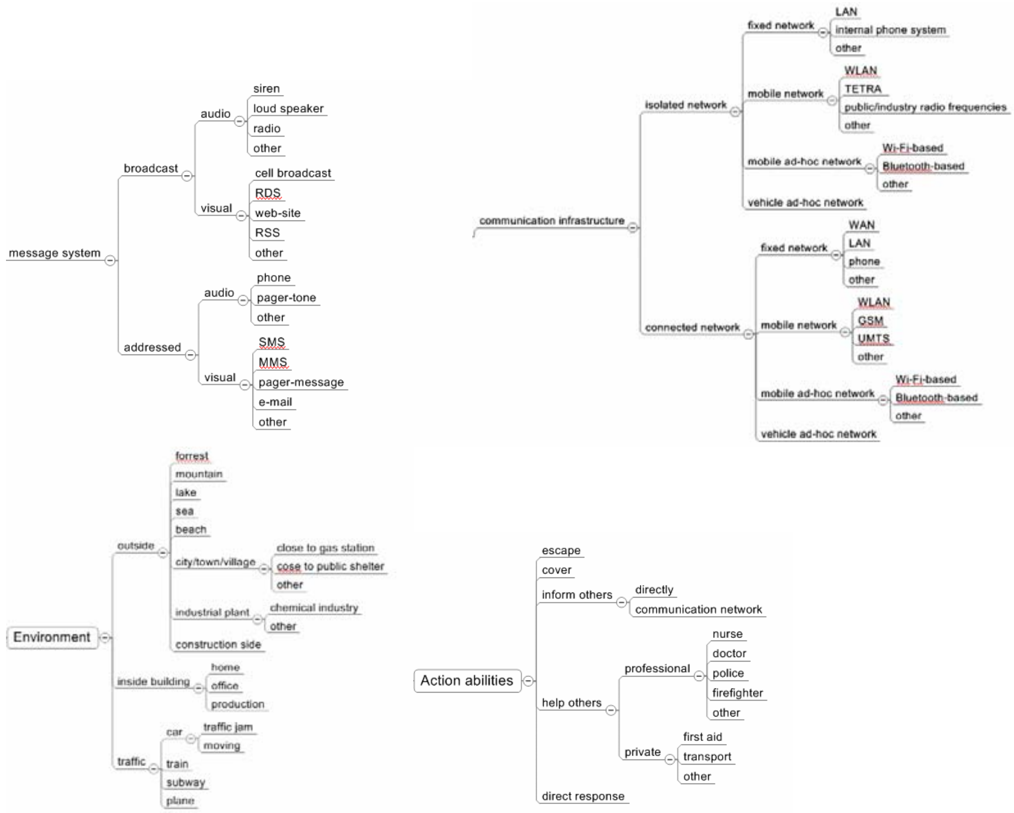

Figure 2. Excerpts from the dimensions reachability, environment and action ability

An example for my actual situation writing this paper would be

s(12-27-2008-18:30;now;"Berlin","office","writing","internet" AND "fixed phone")

Furthermore, situation sequences are defined as well-ordered, not-overlapping set of situations:

$$S_r = (s_1 \succ \ldots \succ s_n)$$

We use these situation sequences for modeling the context change of users, user groups, and even systems (for the reason of the integration of systems in our EWS approaches we also talk more generally of receivers and actuators)

This model has the following advantages:

(1) it offers different aggregation levels for describing the context user groups. This feature is inevitable for certain performance strategies in alerting as we will see later in this paper.

(2) it offers a simple implementation and is open to integrate simple ontologies from different domains, such as existing ontologies from disaster management.

(3) its focus on time intervals aligns well with the usual phase models in disaster management.

In the following, we describe two integrated approaches that use this context model for increasing the effectiveness of alerting.

3.1.2 Effective Alerting Strategies

Implementing effective alerting strategies is concerned with three main challenges in disaster alerting. The first one is to reach only the appropriate recipients, as efficiently as possible [14]. The second one is to reach recipients geographically and by user profile [11]. The third one is ensuring optimal use of available infrastructure even and especially when failures occur or are to be expected.

The problem of scarce communication infrastructure can already be observed even when the infrastructure is not physically affected by a disaster. As an example, with the increasing user numbers in WIND we already face the problem that the GSM communication infrastructure is reaching capacity limits in certain cells during warnings. Other influences can be the cascading communication needs as soon as first alerts are out to the public, which leads to further congestions. The effect worsens when the communication infrastructure is physically disrupted or supporting infrastructures (such as electricity supply) fails.

In our example (see [12] for more details), receiver or receiver groups are represented by their situation sequences in a database (Cf. Figure 3). The relevant dimensions for our alerting strategies are *Location, Reachability, Environment*, and *Action Ability*. Stable profile information can also be incorporated in the situation model as we can describe action ability ("first aid") as something that does not change over time. For selecting the right user groups to be alerted we define situation patterns. An example for a situation pattern would be

s_p= (01-25-2008-18-00,01-25-2008-18-30,"Zip-Code:10435;Germany","outside")

These patterns express a search pattern for situations along the defined dimensions: e.g., a polygon for location and a specific ability or reachability of receivers. In our system alerting strategies can be easily implemented as a predefined set of prioritized selection patterns for certain alert and infrastructure constellations. For the example pattern the system would return all receivers with situations estimated to be in the ZIP-Code area, outside, and in the given time period to be alerted. Thus the system can prioritize certain receiver groups such as multiplicators or first responders, which is especially important when the communication infrastructure is scarce and when not all receivers can be informed within the given amount of time.

The system can also prioritize certain channels with limits due to an expected failure, e.g., informing all receivers reachable via SMS before GSM-Infrastructure will fail and informing all receivers with alternative communication channels through other available channels in order to reduce the number of SMS alerts. Other strategies can prioritize receiver groups who, due to their current environment, are more exposed to the risk (e.g., "in building", "chemical plant" or "in forest"). Several other alerting strategies can be easily implemented through the configuration of such predefined alerting plans. The system ensures automatic adaptivity through dynamic context information of its receivers.

3.1.3 Targeted Warning Adaptation

In our approach, the context knowledge described above is used to adapt general warning information to the profile and context of the receivers. After having selected a certain user group (by the above described alerting strategies) the situation parameters of single users or of sub-groups are used to adapt the general alerting content to the estimated information demand of the receiver. This can imply the modality adaptation to the formats of the alerting channel (e.g., e-mail, SMS, MMS, voice, signal systems). In addition, response advice can be selected according to the environment (e.g., "outside", "building"). In the current version of the WIND system these different types of advice consists of lists with up to 20 entries that due to their length can only be transmitted via e-mail and fax. Due to the number of advice messages and inapplicability to the actual situation (e.g., "If you are in a forest you should …") these advice messages are usually ignored by the users. In our context-aware approach, the advice messages can be reduced to one or two of those most fitting. We expect that the users more likely will react according to the advice if the message is adapted to their situation. Besides, these specific advice messages can now be added to length-restricted media such as SMS. Furthermore, messages can be adapted to the preferred language or specific audio/visual requirements of user with disabilities or in disturbing environments.

3.1.4 General Architecture and Implementation

Figure 3 depicts the general architecture for context-aware alerting in EWS. The core of our context-aware EWS is the general Warning and Alerting System. This central part is mainly designed as domain independent and should be reusable for any EWS application. It offers a standardized interface to hazard warning systems which complies the CAP standard. When the system receives a CAP message, the *Strategy Controller* activates a specific alerting strategy. The *Receiver Selection* and *Warning Generation* components provide the realization of the alerting strategy based on receiver situation sequences as described in the previous sections. The *Situation Broker* provides the general management of situation sequences. It provides operations for storing, selecting, monitoring, and optimizing (for search) situation sequences of receiver or receiver groups. All domain-specific knowledge (e.g., warning advice content, geo-topologies) and services (for planning and subscribing) are kept in the control system that has to be adapted to the specific application field of the EWS (e.g., for a city, a community, or a chemical plant).

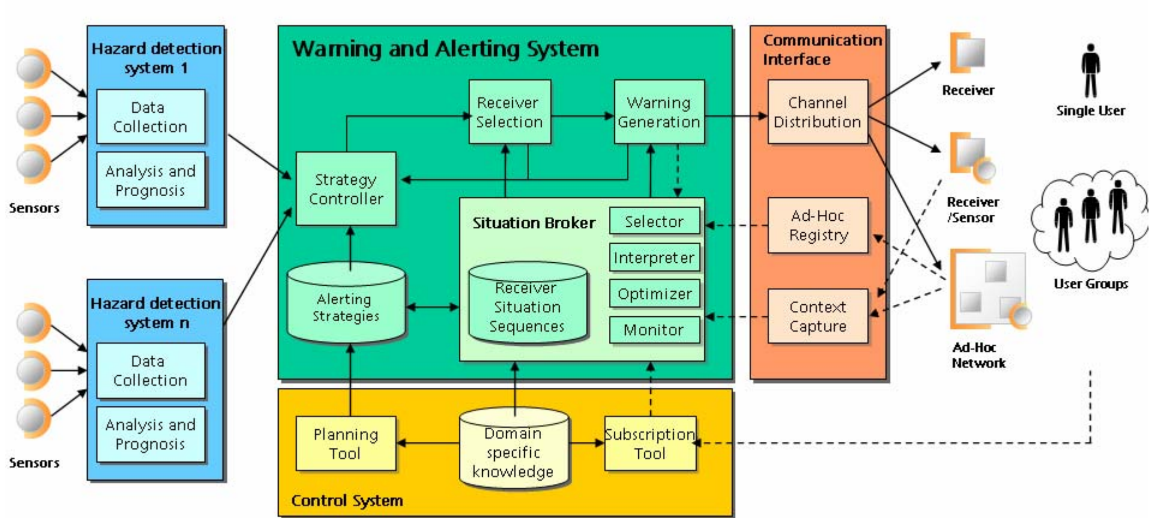

Figure 3. Architecture for context-aware alerting

Once the receivers have been selected and the warning messages have been adapted, CAP messages with individualized warning content and receiver addresses are produced and disseminated by the *Communication Interface* for the specific infrastructure connected to the EWS. In an optional extension, these CAP-messages can be augmented with situation patterns for controlled broadcast dissemination where client applications on the devices filter out the relevant CAP message based on their context.

The core part of this architecture is currently implemented in the SAFE project [14]. The warning dissemination in SAFE supplies adapted context-aware alerts for users and systems over several channels. Context monitoring is based on classical profiling over a subscription system, on thin client-applications on mobile devices (with GPS-integration), sensors in buildings and production plants, electronic calendars and enterprise resource planning systems. Context parameters are either directly measured, derived or – if not available – estimated (e.g., through population statistics of home, sleep, and work times). The adaptation of warnings is implemented through a JSP-based content component that indexes layout and content building blocks via a given set of context parameter and alert relationships.

3.2 Evaluating the Effectiveness

One important challenge in the successful implementation or improvement of an EWS is evaluating and monitoring its efficiency. Yet there is no common proven evaluation approach and one of open research identified by the UN/ISDR platform is the elaboration of cost-benefit-models for EWS. Especially with the integration of private stake-holders, this issue is becoming more and more important, but also authorities need to have decision support (e.g., for the question whether a budget of 1 mil. Euro is better invested in improving monitoring or alerting technologies). We should keep in mind that not everything desirable is necessarily efficient.

Several criteria for evaluating the performance of EWS are already proposed by different authors. However, to our knowledge, a common framework has not yet been established. [5;2] propose parameters for measuring the performance with a stronger focus on the monitoring and system performance such as accuracy, response time, availability or up-time, and reliability. A stronger focus on alerting performance is set in [17], which considers aspects such as coverage and reachability of the population.

For evaluating the performance of SAFE, we developed a hierarchical set of parameters which enables us to measure the overall performance but also to identify the performance of single aspects of the system. First, we defined the overall goals with the stake-holders. In this case we defined – together with communities, industries and the insurance industry – the overall goals towards better response and damage mitigation and detailed them to single-use case scenarios. From our experience in WIND we identified the following five main parameters (that aggregate several sub-parameters) and integrated them in a cost-benefit-model:

(1) Frequency: Describes the average frequency of the occurrence of the specific disaster for a certain location. We derived this parameter for severe meteorological events (storms, thunderstorms, heavy rain, etc.) and their severity (orange, red, violet) from ex-post analysis of the meteorological data and user-feedback in the WIND-system over the last 7 years for single ZIP-Codes of south Bavaria with adding major disasters of the last 20 years.

(2) Accuracy: Describes the accuracy (as a probability) of correctly predicting a certain disaster in given response time corridors, incorporating false-positives. These parameters were again derived from WIND statistics.

(3) Response: Is a highly aggregated function that expresses the probability of the end users to correctly and efficiently respond to the given disaster. This parameter is derived from several sub-parameters (a collection of parameters stated above, and other aspects): availability of the system (derived from NAGIOS-System-Monitoring data of WIND); probability of the alert reaching the receivers (a time-sensitive function for each channel based on general population and communication use statistics as well as availability parameters given by the telecommunication providers); probability that messages are understood and response actions have been taken (based on user surveys in WIND).

(4) Prevention: An aggregated parameter that expresses the probability that a certain preventable damage occurs during a disaster. In our case we used as a basis risk statistics and estimations from insurance companies. E.g., the average number of flooded cellars claimed after a severe thunderstorm where the damage could have been prevented by the action of the house owner.

(5) Damage cost: An average cost unit describing the mitigation potential for each single disaster - response action use-case of a single receiver. These numbers are derived from damage statistics of insurance companies: e.g., the average claimed costs for cars damaged by hail in southern Bavaria in the last decade. For non-disclosure reasons these numbers are simplified in Figure 4.

Figure 4 shows an excerpt of the benefit calculation for storm events and response actions for a single receiver. The benefit is calculated as a product of the parameters described above. In order to extend it to a cost-benefit model we calculated the average costs of the EWS-System for a single user, including single costs for development and installation divided over five years, as well as yearly operation and communication costs for several scenarios (including scalability aspects: installation for communities, industries, states, or nation).

Risk Scenarios	Frequency	Response action	Accuracy	Response	Prevent prob.	Damage cost	Benefit
Storm							
Risk level red	2	Fix loose items	87 %	37 %	0,1000000%	500,00 €	0,32 €
Risk level violett	0,25	Fix loose items	93 %	39 %	0,5000000%	500,00 €	0,23 €
	0,25	Car in garage	93 %	30 %	0,0100000%	10.000,00 €	0,07 €
	0,25	Stay in buildings	93 %	42 %	0,0000005%	500.000,00 €	0,00 €
Thunderstorm							
Risk level red	15	Fix loose items	92 %	37 %	0,1000000%	500,00 €	2,55 €
	15	Close windows	92 %	37 %	0,0100000%	1.000,00 €	0,51 €
	15	Unplug electronic devices	92 %	25 %	0,0100000%	1.000,00 €	0,35 €
	15	Car in garage	92 %	30 %	0,0010000%	5.000,00 €	0,21 €
	15	Stay in buildings	92 %	45 %	0,0000005%	100.000,00 €	0,00 €
	15	Close valvets in cellar	92 %	37 %	0,0010000%	20.000,00 €	1,02 €
Risk level violet	1,5	Fix loose items	94%	39 %	0,1000000%	500,00 €	0,27 €
	1,5	Close windows	94%	39 %	0,0100000%	1.000,00 €	0,05 €
	1,5	Unplug electronic devices	94%	30 %	0,0100000%	1.000,00 €	0,04 €
	1,5	Car in garage	94%	35 %	0,1000000%	2.500,00 €	1,23 €
	1,5	Stay in buildings	94%	50 %	0,0000005%	100.000,00 €	0,00 €
	1,5	Close valvets in cellar	94%	42 %	0,0050000%	20.000,00 €	0,59 €
Local flooding							
Risk level red	0,5	Close valvets in cellar	82 %	37 %	0,0050000%	20.000,00 €	0,15 €
Risk level violet	0,2	Close valvets in cellar	88 %	39 %	0,0100000%	20.000,00 €	0,14 €
	0,2	Install barriers	88 %	10 %	0,0050000%	20.000,00 €	0,02 €
	0,2	Secure oil and gas	88 %	15 %	0,0050000%	250.000,00 €	0,33 €
Sum:							8,09 €

Figure 4. SAFE – Excerpt from current evaluation based on surveys and statistics (preliminary and simplified)

Our focus in SAFE is to increase the parameters accuracy from an estimated 80%-90% and the response from estimated 20%-30% currently reached by the WIND-System. The goal should be reached by enhancing accuracy over 90% with the new sensor networks and enhancing response in average over 40% with the new context-aware alerting approach. Initial findings show that our alerting approach is able to significantly increase the correct response of the receivers.

4. CONCLUSION

This paper presented an approach for context-aware alerting in EWS that can significantly increase the warning efficiency. The proposed solution is based on long-term experience with user-centered meteorological EWS WIND and is currently implemented in the SAFE project.

One of the major goals of SAFE is to test the feasibility of innovative technologies in the area of local, user-centered early warning. The project is accompanied with user surveys, acceptance test, and cost-benefit studies. The described context-aware alerting approach is ambitious and might not be feasible to all extents, but our initial findings prove that with the evolvement of mobile devices, building automation, and pervasive sensors, the presented solution is not far from becoming an integral part of modern alerting solutions for EWS. It is already decided by the insurance industry to implement parts of the described context-aware alerting system in the existing WIND EWS in order to provide innovative warning services for mobile devices (with integrated GPS), navigation systems, and building automation.

Even though the evaluation model presented here has been developed with the specific focus on a hydro-meteorological EWS, it can be applicable for other warning systems. Especially based on the increasing activities in enhancing risk knowledge as it is currently carried out by several organizations, we believe that this approach in combination with further metrics might be adoptable to other EWS fields.

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