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Early Warning Systems : Analytical Approach to False and Missed Alarms

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ABSTRACT
Early Warning is represented by the measures that can be carried out from the moment in which an event is triggered, with sufficient reliability, and the moment in which a disaster occurs in a certain place of interest. Early warning systems (EWS) represent innovative and promising technologies for natural (i.e. earthquakes, volcanic, epidemics, tsunami, flood, drought, etc.) and man (i.e. fires, chemical accidents, etc.) made disasters mitigation.

The more timely and accurately the alert is issued, the more likely an EWS is able to manage and prevent natural disasters. However, timeliness and reliability are contradictory requirements. EWS decision making processes must solve the trade-off between them. Here is presented a decision procedure based on real-time monitoring of expected consequence of taking action, such as probabilities of false and missed alarm. An analytical expression is presented for evaluating these probabilities. The threshold at which mitigating actions should be taken is then quantified based on a cost-benefit analysis.

Categories and Subject Descriptors
I. Computing Methodologies; I.6 Simulation and Modeling; I.6.5 Model Development.

General Terms
Algorithms, Management, Reliability, Theory.

Keywords
Early Warning, accuracy, decision making, false and missed alarms analytical theory.

1. INTRODUCTION
The main goal of Early Warning Systems (EWS) is the reduction of losses of human lives and mitigation of social and economic damage. EWS performance and application is strictly dependent on its timeliness, reliability and existence of a decision support system.

2. BENEFITS AND LIMITATIONS OF EWS
Timely alerts allow mitigation measures to be carried out, such as evacuation of potentially endangered areas, emergency operations, secondary effects mitigation, management of humanitarian response and others. The benefit from EWS depends on the existence of decision support systems that take into account the incremental information due to additional data becoming available with time. An EWS should be reliable, convey uncertainty to users, take into account user perspectives and be integrated with a decision model [3].

On the contrary, limitations of EWS depend on the amount of warning time and accuracy of the prediction on which a decision is based. Reduction of the uncertainty of the prediction, due to a partial knowledge of the phenomenon, is a key aspect for optimization of the decision making process.

3. REAL-TIME DECISION MAKING
Up-to-date decision making procedure in early warning has been based on predicted severity of the event, $\hat{S}$, and decision has been based on the exceedance of a critical severity level, *a*. Here is proposed a shift in paradigm of decision making process in early warning. For an improved performance of EWS, a performance-based decision making procedure is proposed, based on expected consequences of taking action, in terms of probability of false and missed alarm. The threshold in this innovative approach is chosen to be the acceptable probability of false (missed) alarms, from a cost-benefit analysis.

3.1 Probability of wrong decisions
Consider the case of a EWS decision making strategy based on raising the alarm if a critical severity level, *a*, is predicted to be exceeded at a site. The decision of whether to activate the alarm or not is based on the predicted severity of the event. Since

prediction is uncertain in making this decision two kinds of errors may occur [4]. M*issed alarm* occurs when the alarm is not activated when it should have been, while a *false alarm* is when the alarm is activated when it should not have been.

The probability of missed alarm, P_{ma}, can be then defined as the probability of having critical threshold exceedance but no alarm activation and the probability of false alarm, P_{fa}, is defined as the probability of having no threshold exceedance but alarm activation.

A decision model that takes into account the uncertainty of the prediction and the consequences of taking action will be capable of controlling and reducing false and missed alerts incidence. The proposed decision making procedure intends to fill this gap.

3.2 Analytical approach to probabilities of wrong decisions

The EWS will provide to the user a real-time prediction of the severity of the event, $\hat{S}(t)$, and its error, $\varepsilon_{tot}(t)$. During the course of the event, the increase of data available will produce an improvement of the prediction accuracy. The prediction and its uncertainty are updated as more data come in. The actual severity of the event, S, is unknown and may be defined by adding the prediction error, ε_{tot} to the predicted value, $\hat{S}$.

The potential probability of false (missed) alarm is given by the probability of S being less (greater) than the critical threshold, it becomes an actual probability of false (missed) alarm if the alarm is (not) raised:

$$P_{fa}(t) = P\left[S \leq \mathrm{a} \middle| I\hat{M}(\mathrm{t})\right] \tag{1}$$

$$P_{ma}(t) = P\left[S > \mathrm{a} \middle| I\hat{M}(\mathrm{t})\right] \tag{2}$$

Referring to the principle of maximum entropy [2], the prediction error is being modeled by Gaussian distribution, representing the most uninformative distribution possible due to lack of information. Hence, at time *t*, the actual severity of the event, S, may be modeled with a Gaussian distribution, having mean equal to the prediction $\hat{S}(t)$ and uncertainty equal to $\sigma_{tot}(t)$, that is the standard deviation of the prediction error $\varepsilon_{tot}(t)$. Eq. (1) and (2) may be written as [1]:

$$P_{fa} = \int_{-\infty}^{a} \frac{1}{\sigma_{tot}(t)\sqrt{2\pi}} \exp\left[\frac{-\left(S - \hat{S}(t)\right)^2}{2\sigma_{tot}(t)^2}\right] dS = \Phi\left(\frac{a - \hat{S}(t)}{\sigma_{tot}(t)}\right) \tag{3}$$

$$P_{ma}(t) = \int_{a}^{\infty} \frac{1}{\sigma_{tot}(t)\sqrt{2\pi}} \exp\left[\frac{-\left(S - \hat{S}(t)\right)^2}{2\sigma_{tot}(t)^2}\right] dS = 1 - \Phi\left(\frac{a - \hat{S}(t)}{\sigma_{tot}(t)}\right) \tag{4}$$

where Φ represents the Gaussian cumulative distribution function. Eqs. (3) and (4) confirm that the probabilities of wrong decisions sum to one being the two conditions, threshold exceedance or not, mutually exclusive.

3.3 Decision making procedure

The proposed decision making strategy is tailored on user needs and requirements, for an improved performance of the overall system. User needs are included in the decision process in terms of warning time required for taking action and alert accuracy. The system will notify the user about the lead time available for taking action. On the other hand user requirements concerning alert accuracy are quantified as tolerable level of probabilities of wrong decisions. The tolerable level at which mitigation action should be taken can be determined from a cost-benefit analysis [1].

The tolerable levels of P_{fa} and P_{ma} are obtained by minimizing the cost of taking action:

$$P_{fa} \leq \beta = \frac{C_{save}}{C_{fa} + C_{save}}; \quad P_{ma} < \alpha = \frac{C_{fa}}{C_{fa} + C_{save}} \tag{5}$$

where C_{save} are the savings due to mitigation actions and C_{fa} is the cost of false alert. Note that the tolerable levels α and β sum up to one which directly exhibits the trade-off between the threshold probabilities that are tolerable for false and missed alarms.

4. CONCLUSIONS

Here is presented an innovative approach to EWS decision making based on probabilistic representation of expected consequences of taking action. The methodology offers an effective approach for decision making under uncertainty focusing on user requirements in terms of timeliness and reliability. The threshold at which mitigating actions have to be taken is determined from a cost-benefit analysis.

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