Towards an Economic Assessment Approach for Early Warning Systems: Improving Cost-Avoidance Calculations with Regard to Private Households

Simone Wurster
TU Berlin
simone.wurster@tu-berlin.de

Ulrich Meissen
Fraunhofer FOKUS
ulrich.meissen@fokus.fraunhofer.de

ABSTRACT

In recent years, Early Warning Systems (EWS) have proven their value by saving many lives. However, most investments into EWS were motivated directly by experienced disaster events and rarely pro-actively by possible upcoming threats. In order to change that we think that besides ethical and humanitarian reasons also the positive economic effects should be analyzed. EWS also help to protect property, but their contribution is not as obvious in that field due to the lack of quantitative models. This paper presents a disaster-independent formula that shows the benefits of EWS. Additional value to existing approaches is based on its advanced focus on behavioral aspects and the benefits of EWS in comparison to warnings issued via social media. We consider this work as an important contribution for future investments into warning technologies. However, yet this model just provides a theoretical framework for necessary empirical studies that are subject of further research.

Keywords

Early warning systems, investment decisions, quantitative assessment model.

INTRODUCTION

Modern societies are increasingly threatened by a wide range of natural and man-made hazards. One way to enable populations to cope with all these risks is the use of advanced EWS which can warn a large number of users within a very short time frame with specifically targeted localized or personalized alerts. However, implementing such advanced systems requires quite significant investments, which creates a need for cost-benefit analyses. According to Graymen and Males (2002) and the United Nations (2006) there is a lack of formulas for assessing and justifying the economics of EWS. In addition, the United Nations (2012) describe the contribution of volunteerism to disaster risk reduction. In this context EWS can also be used not only to warn the affected population in time but to motivate appropriate response and activate volunteers for the important first hours where response forces cannot reach the affected areas. This paper proposes an approach to assessing the benefits of EWS. A disaster-independent formula that highlights the benefits of EWS which consists of three parts is currently being developed. It considers the protection of a) private assets and b) corporate assets by those affected as well as c) by volunteers and highlights first results for part a). Additional value is based on its advanced focus on behavioral aspects and the benefits of EWS in comparison to warnings issued via social media. This paper builds on Klafft and Meissen (2011).

EXISTING APPROACHES TO ASSESSING THE VALUE OF EARLY WARNING SYSTEMS

The cost avoidance approach offers a principal foundation for the assessment of EWS. In principle, this method uses statistical analyses and cost estimations to determine the amount of damage that can be prevented if a warning system is in place, and compares these benefits with the investments needed to build and operate the system (see

Klafft and Meissen, 2011). A few cost-avoidance models for the assessment of EWS are already available. They include models that focus on one type of disaster as well as models which work independent of specific disaster types. Wenzel, Baur, Fiedrich et al. (2001) present an early model which is specifically focused on earthquake warnings and does not include human aspects of system use. Meissen and Voisard (2008) developed a complex model which was used to calculate the benefits of a meteorological warning system in practice, but it lacks the consideration of behavioural and psychological effects on system use, too. Currently, one of the most advanced approaches is the EU FHRC Model (FLOODsite, 2009). It helps to assess flood warnings but social and behavioural aspects are not analysed. Based on survey data, Parker et al. (2007) showed the validity of the model and found that people who had been warned could save £821 more than those who hadn't. Many people in the survey received warnings via telephone. By stressing contextual changes due to new warning technologies, the authors unveil a research gap. Another advanced model is proposed by Klafft and Meissen (2011). Similar to Meissen and Voisard (2008), its advantage is that its use is not limited to one type of disaster. However, personal influences such as the situational assessment of a warning, panic, the physical and situational ability to implement a recommended action and the contribution of volunteers are not considered. An extended overview of additional models is given by both authors. However, no existing model includes an in-depth consideration of human behaviour after receiving a warning or unveils the additional benefits offered by volunteers who use EWS. In addition, a need to compare EWS with social media has emerged recently (see Ridler-Ueno, 2013). This paper helps to close all of these gaps.

FACTORS INFLUENCING THE EFFECTIVENESS OF EARLY WARNING SYSTEMS

The effectiveness of an EWS can be described by four groups of factors.

1.) Personal factors influence how a warning is processed by the recipients and if and how it is then translated into protective actions. In private households, these actions may include, for example for meteorological threats, closing windows, securing loose items outside and driving the car into a garage. The actions largely depend on how the underlying risk is perceived (see Klafft and Meissen, 2011). Based on our research four factors are relevant:

Situational Likelihood of willingness to respond: The state of research offers the variable 'likelihood that a recipient is willing to perform a certain protective action' (Klafft and Meissen, 2011). In addition, Thieken, Kreibich, Mueller and Merz (2007) show the relevance of situational responsiveness. Therefore, we define the variable *'situational likelihood that the relevant person is willing to perform a specific protective action in case of a warning for the specific disaster'*. Bubeck, te Linde and Aerts (2013) provide a meta-analysis of factors that influence private flood mitigation behavior and, therefore, help to specify this variable. These factors include: flood experience, feeling of worry or fear, damage suffered, perceived probability and perceived risk of property damage.

Physical and mental ability to perform the action: An important issue to assess possible reactions to an alert is whether at least one person who is physically able to perform the relevant measure belongs to the household. The relevant measures are often simple like e.g. securing loose items and closing doors. Exceptions exist i.e. when transporting furniture or installing water pumps is necessary. The latter also requires good technical understanding. This is reflected by the component 'mental capacity'. Therefore we define the meta-variable '*likelihood that one person is physically and intellectually able to perform the relevant protective action'.* Bubeck et al. (2013) show the influence of both abilities by introducing four variables: age, gender, education and flood experience.

Psychic ability to perform the action: Severe situations lead to three typical behaviors. Unlike normal reactions, hyperactivity and apathy reduce the likelihood of efficient behavior (ANZ, 2000). Therefore, we define the variable *'probability that at least one person who is present is mentally capable of performing the specific action'*.

Spatial distance: Consistent with Parker et al. (2007) who found it significant whether or not at least one person is at home, we define the variable *'probability that at least one person is available in time to take appropriate action'*.

2.) Prediction-related factors comprise five variables. The first one, ***prediction accuracy,*** is crucial in every early warning process. Two kinds of errors have to be avoided: missing alerts ('false-negatives') and false alerts ('false-positives') (see Jacks and Ferree, 2007). The factor ***lead time of the EWS*** describes the time gap between issuing a warning and the appearance of the disaster. It determines the scope and complexity of protective actions that can be taken by warning recipients. Its relevance is, for example, shown by Day (1970). Klafft and Meissen (2011) outline the lead times for different disaster types. Natural disasters like storms, thunderstorms and local flooding enable EWS based loss prevention. In addition, calculating the benefits of EWS has to take into account that the target groups can receive alerts in alternative ways. ***Lead time$_{human}$*** refers to the fact that they might have taken the same protective action even without an EWS (e.g., because they notice an upcoming thunderstorm visually). In addition, ***lead times based on the use of other media*** needs consideration. The key advantage of advanced EWS is the fast information transmission which is specified through the geographical defined areas and connected with specific recommendations for action. Television and radio cannot issue warnings when switched off at night. This applies also to receiving messages on a PC. Advantages of smartphone warning apps compared to social media include the opportunity to offer personalized warnings and specified information at the city or regional level (see Ridler-Ueno, 2013). The information is frequently structured; easily machine readable and pictures are often automatically geo-tagged (see Meier, 2013). Furthermore, Chatfield and Brajawidagda (2012) describe disadvantages of EWS based on social media regarding speed of communication and information quality. Based on the three lead time-related variables, the variable '***increased likelihood that a protective action will be completed due to an EWS-generated warning'*** shows their additional contribution compared to noticing one's self or through other media.

3.) Dissemination-related factors influence the likelihood of recipients of early warnings being correctly notified and actually taking notice of the warning in time. We will describe three factors in detail. Numbers of subscribers are highly important for evaluating EWS. Like Parker et al. (2007) we model the variable ***'proportion of households that subscribe to the service***'. The notification of a warning is an important prerequisite for carrying out the intended activities. Klafft (2013) shows that the time-lag of noticing an alert is subject to strong fluctuations. On this basis, we model the variable ***'probability of notification in due time'***. According to Rechenbach (2012), the effectiveness of EWS is increased by ***multiplier effects*** (e.g., recipients pass the warning to neighbours). Since we focus on systems, which offer volunteers the opportunity to register as a multiplier, this effect is especially important. The variable shows how many additional households are warned on average by one multiplier.

4.) General factors include, e.g., ***the probability of the occurrence of a specific disaster per time unit in the warning area*** and the ***average monetary benefit of the protective actions***. In addition, possible bottlenecks affect the probability of damage reduction. Measures for flood protection, for example, can be hindered by living in a one-story house or a lack of storage space. Therefore, the variable ***'absence of bottlenecks'*** (AoB) is created.

ASSESSING THE BENEFITS OF EARLY WARNING SYSTEMS

In this section, a formula for assessing the benefit of EWS is proposed. It builds on the following variables:

D_i	: disaster of type i
$P(D_i)$	: projected number of type i disaster per time unit in the warning area
H	: number of private households in the warning area
S_i	: share of households in the area under consideration typically struck by a disaster of type i, with $0 < S_i \leq 1$
h	: private household
k	: protective response action of type k
$R_{i,k,h}$	: Relevance of protective action k to protect private households in case of a disaster of type i, with $R_{i,k,h} \in [0;1]$
$AoB_{k,h}$	: Absence of bottlenecks with regard to protective action of type k and household h with $AoB_{k,h} \in [0;1]$
$bfit_{prot,k}$	: average monetary benefit of one protective action of type k
bfit	: total system benefit caused by additional successful protective actions
t	: time span of economic assessment (EWS life cycle time)
m	: communication channel m
$LHood_{able,k}$	: likelihood that a household member is able to perform protective action k, product of $LHood_{able,k,l}$, $LHood_{able,k,ph\&i}$ and $LHood_{able,k,ps}$
$LHood_{able,k,l}$	: likelihood that the relevant person is able to be at the location in due time
$LHood_{able,k,ph\&i}$	: likelihood that the relevant person is physically and intellectually able to perform protective action k
$LHood_{able,k,ps}$	: likelihood that the relevant person is psychically able to perform protective action k
$sLHood_{willing,k,i}$	: situational likelihood that the relevant person is willing to perform protective action k in case of a warning for disaster i
$P_{Pred}(D_i)$	: probability that a disaster of type i is (correctly) predicted
$LHood_{subscr,m}$	: likelihood that a household member uses communication channel m
$LHood_{notice,m}$	: likelihood that a household member notices an incoming warning message via communication channel m in due time
$LHood_{outage,m,i}$	: likelihood that communication channel m is inoperational (e.g., due to adverse effects of the disaster of type i)
M	: multiplication factor for volunteers who disseminate warning information
$T_{Lead,EWS}(D_i)$	: typical lead time for an EWS warning for a disaster of type i
$T_{Lead,human}(D_i)$	: typical lead time in which humans can detect upcoming disasters of type i themselves
$T_{Lead,othermedia}(D_i)$	: average maximal lead time for disasters of type i based on warnings by other media (social media, TV and radio) in addition to $T_{Lead,human(Di)}$
$inc_{prot,m,k,i}$	: increased likelihood that protective actions k will be completed in case of a disaster of type i due to an EWS-generated warning via communication channel m in due time, depends on $T_{Lead,EWS}(D_i)$, $T_{Lead,human}(D_i)$ and $T_{Lead,othermedia}(D_i)$.

In a first step of the calculation, the likelihood that a warning is received and translated into a protective action of type k in case of a disaster of type i in a private household ($LHood_{action,m,k,i,h}$) can then be described as:

$$LHood_{action,m,k,i,h} = LHood_{subscr,m} \cdot (1 - LHood_{outage,m,i}) \cdot LHood_{notice,m} \cdot R_{i,k,h} \cdot sLHood_{willing,k,i} \cdot LHood_{able,k} \cdot AoB_{k,h}$$

The equation above includes factors like the reachability ($LHood_{subscr,m}$), possible communication loss ($LHood_{outage,m,i}$), attention ($LHood_{notice,m}$), as well as the situational willingness ($sLHood_{willing,k,i}$) and ability ($LHood_{able,k}$) of the household members to take relevant protective actions in case of an early warning. Benefits resulting from protective actions depend to a large extent on the alert accuracy and the disaster frequency. Considering the life cycle time t of a multi-channel multi-hazard EWS, the benefit ($bfit_H$) for private households created by additional protective actions initiated by an EWS can be calculated as:

$$bfit_H = \sum_i \left[t \cdot P(D_i) \cdot P_{Pred}(D_i) \cdot M \cdot \sum_k \sum_m LHood_{action,m,k,i,h} \cdot bfit_{prot,k,i,h} \cdot H \cdot S_i \cdot inc_{prot,m,k,i,h} \right]$$

The equation above summarizes the benefits ($bfit_{prot,k,i,h}$) of all types of additional ($inc_{prot,m,k,i}$) protective actions k taken by private households in the considered area to protect private property ($LHood_{action,m,k,i,h,}$ H) as a result of warnings distributed over different communication channels m. Of course, benefits only materialize for those households that have actually been struck by a disaster (S_i), and in case of disasters that have been correctly predicted ($P(D_i)$, $P(P_{Pred}(D_i))$) over the EWS life cycle time t. After calculating the overall positive impact bfit of the EWS, this impact needs to be set into relation to system-induced costs. Klafft and Meissen (2011) give detailed instructions on how to calculate them. By determining the system benefit for companies and the additional benefit created by the volunteers and subtracting the cost of the EWS, its economic value becomes visible.

EXAMPLE

In this example we take a closer look at heavy precipitation events. Although most of them go unnoticed, some cause severe damage and illustrate the importance of timely alerts, just like the one in the German city of Hamburg on June 6th 2011: up to 81.3 l/m² of rain teemed down within 70 minutes, flooding basements, underground parking lots and many other buildings (see Fein, 2011), causing an estimated overall damage of €27M to €46M including a damage of €9M to €28M in private households (damaged cars not included). This amount is based on damages in 1.000 cellars with average losses between €9,000 and €28,000 ($12,200 and $38,000) (see Ecologic and HWWI, 2012). East-Hamburg was hit particularly hard with 50 to 100 mm of rain within six hours (see de Paus, Riecke, Rosenhagen and Tinz, 2011). The following calculation is based on the aforementioned event and examines the benefit of an app and SMS based EWS. With regard to $LHood_{subscr,m}$ there is potential that 10% of the population are subscribed to such a service in Germany (see Rechenbach, 2012). The number of households with at least one subscriber can be estimated higher as an average German household consists of two persons. In addition Rechenbach's number refers to the population in general which also includes children. Therefore the share of subscribers among adults and households is higher. We estimate that more than 20% of German households may subscribe to the service. Breakdowns of complete mobile phone networks which are relevant for $LHood_{outage,m,i}$ can be estimated at less than 5%. $LHood_{notice,m}$ is calculated as follows: per day (2/3 of 24h): 93%, at night (1/3 of 24h): 25%, total: 70%. With regard to $sLHood_{willing,k,i}$, Klafft and Meissen (2011) show that the willingness to respond to appeals for protective actions in case of meteorological alerts is very high in Germany (Ø: 73%). The likelihood that at least one household member is at home in due time and is able to perform protective actions is set around 65%. As described earlier, Parker et al. (2007) found that alerted households in Great Britain could save £821 more than those which hadn't been notified in 2004 and 2005 (≈ $1,620 in 2013, adjusted for inflation and purchasing power) during several flood events. We explained earlier, that advanced EWS are more capable than the channels analysed in Parker et al.'s (2007) survey. Therefore, we use this amount to define the minimum level of the potential benefits of modern EWS. According to the following table, the total benefit of an EWS that induces households to protect property can be estimated at (at least) $100,338 (≈ 0.3 to 0.8% of their total damage) for an event similar to the one of June 6th 2011 and the presumptions above. It was mentioned above, that the event affected many parking lots. Protecting one car alone can save several thousand dollars (see Scawthorn, Flores, Blais et al., 2006).

$LHood_{subscr,m}$	20%	**$sLHood_{willing,k,i}$**	73%	**$P_{Pred}(D_i)$**	89%	**$bfit_{prot,k,i,h}$ [in $]**	1,620
$LHood_{outage,m,i}$	3%	**$R_{i,k,h}$**	1	**M**	1.8	**$inc_{prot,m,k,i}$**	60%
$LHood_{notice,m}$	70%	**$AoB_{k,h}$**	1	**$H \cdot S_i$**	1.000	(conservative estimation)	
$LHood_{able,k}$	65%	**$P(D_i)$**	1	**t**	1	**$bfit_H$ [in $]**	**100,338**

The average potential benefit in an event like that one of June 6th 2011 will be specified based on a survey.

SUMMARY AND OUTLOOK

This paper presented a formula to assess the economic benefits of EWS with regard to the property of private households. The relevance of key variables is stressed by Parker et al. (2007). Additional validation activities in accordance to Merz et al. (2010) will be an important part of future activities. Thieken, Ackermann, Elmer et al. (2008) provide guidelines for loss data collection procedures. Collecting information on the asset value of the (avoided) property loss, the reaction time and the measures for damage prevention is planned. In addition, the present formula only includes the additional benefit realized by the dissemination of information by volunteers. Formulas for the benefits of EWS for companies and the practical help of volunteers will be developed in the project

ENSURE and accompanied with the yet missing empirical studies. One major task for further research is to elaborate common methods for a robust and feasible measurement or estimation of the parameters used in the formula.

ACKNOWLEDGEMENTS

This research has been funded by the BMBF (project ENSURE, project number 13N12813).

REFERENCES

1. ANZ (2000) Psychologie des Verhaltens der Bevoelkerung in extremen Situationen. Workshop report. http://ec.europa.eu/echo/civil_protection/civil/act_prog_rep/psych_aspects_inf_pub_de.pdf.
2. Bubeck, P., te Linde, A., Aerts, J. (2013) Assessment of upstream flood risk in the Rhine Basin. *KfC,* 100/2013.
3. Chatfield, A. T., Brajawidagda, U. (2012) Twitter tsunami early warning network: a social network analysis of Twitter information flows. *Proceedings of the 23rd ACIS Conference*, 1-10.
4. Day, H. J. (1970) Flood warning benefit evaluation-Susquehanna River Basin (urban residences) ESSA Technical Memorandum WBTM Hydro-10, National Weather Service, Silver Spring, Md.
5. de Paus, T., Riecke, W., Rosenhagen, G., Tinz, B. (2011) Meteorologische Referenzdaten fuer die Metropolregion Hamburg, http://klimzug-nord.de/index.php/page/2011-08-01-Projekt-des-Monats-August-2011.
6. Ecologic, HWWI (2012) Gutachten zu den oekonomischen Folgen des Klimawandels und Kosten der Anpassung fuer Hamburg, http://www.hamburg.de/contentblob/3815154/data/.
7. Fein, J. (2011) Niederschlagsrekord fuer Hamburg, http://www.wetterspiegel.de/de/nachrichten/.
8. FLOODsite (2009) Developing models to estimate the benefits from flood warnings. Project report. http://www.floodsite.net/html/publications2.asp?by=documentTitle.
9. Grayman, W. M., Males, R. M. (2002) Risk-based modeling of early warning systems for pollution accidents, *Water Science and Technology,* 46, 3, 41-49.
10. Jacks, E., Ferree, J. (2007) Socio-Economic Impacts of Storm-based Warnings. *AMS Second Symposium on Policy and Socio-economic Research*. http://ams.confex.com/ams/pdfpapers/120849.pdf.
11. Klafft, M. (2013) Diffusion of Emergency Warnings via Multi-Channel Communication Systems - An Empirical Analysis. *Proceedings of the 11th Internat. Symposium on Autonomous Decentralized Systems,* 295-299.
12. Klafft, M., Meissen, U. (2011) Assessing the Economic Value of Early Warning Systems. *Proceedings of the 8th Internat. ISCRAM Conference*, Lisbon, 2011.
13. Meier, P. (2013) Can Official Disaster Response Apps Compete with Twitter?. http://irevolution.net/2013/08/13/can-official-disaster-response-apps-compete-with-twitter/.
14. Meissen, U., Voisard, A. (2008) Increasing the Effectiveness of Early Warning via Context-aware Alerting. In: Fiedrich, F., Van de Walle, B. *Proceedings of the 5th Internat. ISCRAM Conference*, Washington, 2008, 431-440.
15. Merz, B., Kreibich, H., Schwarze, R., Thieken, A. (2010) Review article "Assessment of economic flood damage", *Nat. Hazards Earth Syst. Sci.,* 10, 1697-1724.
16. Parker, D., Tunstall, S., McCarthy, S. (2007) New insights into the benefits of flood warnings: Results from a household survey in England and Wales. *Environmental Hazards,* 7, 2007, 193–210.
17. Penning-Rowsell, E.C., Green, C. (2000) New Insights into the Appraisal of Flood-Alleviation Benefits: (1) Flood Damage and Flood Loss Information. *Water and Environment Journal,* 14, 5, 347–353.
18. Rechenbach, P. (2012) Warnung der Bevoelkerung – Erfahrungen mit KATWARN in Hamburg. Ergaenzendes Informationssystem fuer Großschadenslagen und Katastrophen. *Brandschutz*, 2012, 10, 772-775.
19. Ridler-Ueno, S. (2013) An ‘App’ for everything; But can Apps for Disaster save lives? Presented at the TIEMS Berlin Conference, Berlin, 2013.
20. Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., Mifflin, E. et al. (2006) HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment, *Nat. Hazards Rev.,* 7, 2, 72–81.
21. Thieken, A. H., Ackermann, V., Elmer, F., Kreibich, H. et al. (2008) Methods for the evaluation of direct and indirect flood losses. *Proceedings of the 4th International Symposium on Flood Defence*, Toronto, 2008.
22. Thieken, A. H., Kreibich, H., Mueller, M., Merz, B. (2010) Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002. *Hydrological Sciences Journal*, 52, 5, 1016-1037.
23. United Nations (2006) Global Survey of Early Warning Systems. Prepared at the request of the UN.
24. United Nations (2012) Contribution of Volunteerism to Disaster Risk Reduction. UN Volunteers.
25. Wenzel, F., Baur, M., Fiedrich, F., Ionescu, C., Oncescu, M. (2001) Potential of Earthquake Early Warning Systems. *Nat. Hazards,* 23, 407-416.