A Tool for the Simulation of Alert Message Propagation in the General Population

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ABSTRACT

Informing and alerting the population in disaster situations is a challenging task. Numerous situational factors have to be considered, as well as the impact of a plethora of communication channels, and multiplication effects in the population. In order to optimize the alerting strategies and enhance alert planning, it would be beneficial to model the dissemination of alerts. In this paper, we present a general overview of an alert dissemination model as well as its prototypical implementation in a simulation software. The software takes situational parameters such as time of day and location into account and can even infer characteristics of the alerting infrastructure from geospatial information.

Keywords

Alert simulation, message propagation, multipliers, crisis preparation, warning channel, alert modeling

INTRODUCTION

In the event of a hazardous situation, citizens in the affected area have to be warned and – often – evacuated. Especially in case of rapidly emerging acute disasters such as fires or flash floods all people concerned must be notified quickly. A key step in this process is the alert dissemination from the operation room to the population (Meissen and Voisard, 2008). This step should be well prepared in advance to make sure that everybody receives the relevant information and nobody is left behind. However, due to an emerging plethora of new alerting channels like smartphone apps or notification services, it is increasingly difficult to model the dissemination of alert messages within an area and its population. Therefore it is important for alert system operators to regularly access statistics about how many people can be reached by which alert channel in a given alert area. This information is valuable during planning but also helps to make better decisions during an acute crisis.

Often, general statistical information is not sufficient for alert modeling since hazards are often regional and concern only small parts of an area. Furthermore, alert efficiency depends on the time of day, as this determines how many people are situated in the warning area and how attentive they are. To simulate the number of people getting a warning message, a lot of parameters thus have to be considered. Every available warning channel has a different efficiency, which can change over time. At the same time, not every warning channel is available in every area. Therefore it is fundamental to analyze how well a region is equipped with warning channels and how effective they are.

For Germany a study was conducted that investigates the technical options for an early warning of the population (Held, 2001). The author analyzes the available channels (in 2001!) and their efficiency. The goal of this study was to get an overview about the over all situation and to define new concepts for a more efficient warning. Held analyzes the alert efficiency as a result of channels used and the time of the day, but does not take into account regional differences in the alerting infrastructure. Furthermore, he does not include the effect of "unofficial" warnings.

Unofficial warnings are warnings disseminated by people who have received the warning and then tell others (Rogers and Sorensen, 1991). In the following this phenomenon is also called multiplication. Various studies have been done to investigate the influence of multipliers like neighbors (Nagarajan, Duncan and Albores, 2012; Parker and Handmer, 1998; Parker, Priest and Tapsell, 2009).

All the studies consider factors that influence the dissemination to the public, that are necessary for the simulation of the message propagation while none of them combines all to an analytic tool that can respond dynamically to a region and point in time. This paper presents a simulation tool that could be used to estimate the delivery and perception of warning messages to the public. It thereby helps in the planning and preparation of regional disaster operations. The experience of an operator can be supported by up-to-date statistics and therefore improves decision-making. New channels can be easily connected and extended. Thus, the simulator works with up-to-date values and also includes the distribution via new technologies such as SMS, Email or smart phone apps.

AN ALGORITHM FOR THE DISSEMINATION OF WARNING MESSAGES

To figure out how many people can be reached in a warning area, a simulation algorithm is used which is presented in the following. The simulation algorithm is designed in a general way. It could be used for every channel and depends on statistical and dynamic data. The warning channels are not predefined; they have to be entered for each region. Each channel has a different alerting efficiency. An interesting question is therefore how efficient the different systems can be and on what factors they depend. The general efficiency for each channel is based on two steps. First, how many people can be reached by official warning, which means through a siren, personal message or other notification from an official organization. Second, how many people are reached by unofficial warning through multipliers that distribute the message. Thereby each step is influenced by individual factors like technical properties or situational circumstances that are presented in the following. As last part the distribution over the time is analyzed.

Official warning channels

Official warning channels are all communication ways that are triggered by an official authority and try to warn the public or registered users. In the following this group of people is also called "directly informed", because these are the persons warned first and directly from the officials. The number of people that could be alarmed depends on the **maximum number of people** a channel can reach and the number of **people listening** depending on situational factors like the time of day and their location.

The maximum number alarmed depends on the device used because every one has a different reach. Three categories of devices can be discerned:

- Devices issuing **point alerts**, that is, alerts for one specific place, like a building. One example for this type of alert channels is the personal announcement system in a school, which allows the headmaster to talk to all persons who are currently in the school.
- Devices that alert people within a certain **range**, such as sirens. Sirens can alert almost everybody in the area around (except people with a hearing disability). Depending on the siren model used, a typical alerting range is between 600 m and 1000 m.
- The last type of alerting devices are **personal devices that are not fixed to a certain location,** such as mobile phones or smartphones which receive alerts via SMS or apps. Such alerting devices typically require prior registration of the recipients (due to data protection law issues).

The theoretical maximum number of people who are reachable (the "**reach**") depends on the availability and the technical characteristics of a device, but not everyone who could be reached really receives and listens to the alarm. The number of people listening depends on human characteristics. For example if the recipient is inside or outside a building or if he or she looks immediately at the phone or has it switched of. Unlike machines, people change their status several times a day. They sleep, are at work, at home or on the go. To take these uncertain factors into consideration, statistics about the behavior of people at certain daytime are used. For some types of buildings (e.g., schools), it can be derived how many persons are situated in them depending on the time. At midnight, for example, no one is at a school, and in the late afternoon a large part of the persons who frequent the school are already at home. Another factor that influences the number of people listening is the so-called wake-up effect. This means if the device that is transmitting the message has an alarm function to wake up the people that cannot be turned of. A siren, for example, has a strong wake-up effect since it is very loud and it is not possible for the recipient to turn the siren off. On the contrary, phones, televisions or computers either have a weak wake-up effect or none at all. These devices can be turned of or made silent so that it is not guaranteed that the message reaches the audience in time. In (Klafft, 2013) a study was made to evaluate the distribution of text messages over time and a formula for the distribution was developed which is used in the simulation algorithm.

Combining all the mentioned parameters, it is possible to determine the share of people in the alert area who are alarmed directly from an official warning channel ($informed_{directly}$). Formula (1) represents the factors that influence the amount of directly informed people. Thereby it is possible for some devices that parameters are 100%. For example, the registration for a public siren is 100% since it is not possible to be unregistered, it is just possible to be inattentive.

$$\mathbf{informed}_{directly} = \mathbf{reach} * \mathbf{registration} * \mathbf{attention} * \mathbf{wake\_up} \quad (1)$$

Explanations (all values in %):

Reach: Share of people in the alert zone who could in theory be reached by the channel in the most optimal conditions.

Registration: Share of the reachable people who registered to the alert channel (set to 100% if deregistration is impossible).

Attention: Share of the reachable and registered people who would pay attention to an alert (if noticed).

Wake Up: Share of the reachable, registered and attentive people who will actually notice the incoming alert.

Unofficial warning channels: the effect of multipliers

Initial feedback obtained from an online survey on personalized alerting indicates that a majority of respondents would inform their family and friends about an alert, thus creating a substantial multiplication effect. These multipliers are unofficial warning channels that distribute the alert message to others. The number of newly informed persons depends on the number of people who have received the official information and **would distribute it** but also the amount of still **uninformed people**.

Whether people would distribute the warning they have received depends on their willingness to do so and their location. The location is important because there are different ways of multiplication. There is a difference if the people are at home or outside on the way. So from the daytime it is possible to determine where the people are and whom they can additionally warn. The willingness of informed people to warn others is already analyzed by other works (Nagarajan, 2012 or Parker, 2007) and the found parameters are used in the calculation. The other works show that the willingness to inform strangers is low in contrast to the notification of household members, neighbors or friends. The number of possibly warned people depends on the average number of people around the multipliers who may be in the warning area. It can be assumed that multipliers would first warn the people in their immediate environment. For example household members are very likely to be also affected by the potential disaster for which an alert has been issued. In addition the warning messages are also distributed to people in the neighborhood and to friends and relatives who may also be affected by the disaster. To assess the number of people contacted, regional statistics are used, such as population numbers and household sizes. The number of neighbors to be informed is estimated based upon settlement patterns (rural settlement, major city) and population density. Based upon the directly informed people and the just mentioned parameters it is possible to calculate the number of people informed by multiplication effects. Formula 2 sums the multiplication effect for different types of multipliers (household members, neighbors, friends).

$$\mathbf{informed}_{indirectly} = \sum_{MultiplierGroup}(\mathbf{informed}_{directly} * \mathbf{location}_{Multiplier} * \mathbf{willingness}_{Multiplier} * \mathbf{people}_{uninformed,MultiplierGroup}) \quad (2)$$

Explanations:

$\mathbf{location}_{Multiplier}$: the share of the directly informed people which is in a location where they can quickly inform the people from the multiplier group. Household members, for example, can easily be informed at times when the person receiving the direct alert and the household member are typically at home (e.g., in the evening or at night).

$\mathbf{Willingness}_{Multiplier}$: the share of the directly informed people who is willing to inform people from the multiplier group.

$\mathbf{People}_{uninformed,MultiplierGroup}$: the average number of indirectly informed people in the multiplier group. For household members, this number is household size – 1 in many situations, because one person has been directly alerted.

Share of population noticing the alert over time

For modeling purposes, it is assumed that the multiplication patterns are similar for all channels once the recipient has noticed the alert. There will not be multiple notifications and each channel is considered separately. It is assumed that after informing a first group of people, the message spreads so that saturation approaches 100% over time. Previous research indicates that alert message diffusion follows an S-shaped pattern (Rogers and Sorensen, 1991), due to the fact that only few people notice the alert initially, but soon after dissemination gains speed due to multiplication effects before approaching alert saturation. This exponential growth pattern with saturation can be represented by a logistic function of type

$$f(x) = \frac{1}{1+ e^{k(a-x)}}$$ (3., a Verhulst-type function)

with x being the time elapsed since the alert, and k and a being constants (> 0) which have to be determined through a calibration process. Calibration of the Verhulst function is done as follows:

- Channels with strong wake-up effect: the first calibration point is the number of people who have been alerted instantaneously and directly (minute one). The second calibration point is after 10 minutes, when all of those initially warned are assumed to have completed their multiplication task.
- Channels with weak wake-up effect work less quickly, so that direct alerting is assumed to have taken place after 10 minutes with the first round of multiplication completed after 20 minutes.

Since the alert message dissemination for two points in time has been estimated, it is now possible to set up equations to determine the two unknown coefficients k and a. The result are formulae that can be used to determine as a function of time the ratio of the population which has been warned through a certain channel.

TECHNICAL IMPLEMENTATION OF PROTOTYPE

A prototype that uses the presented algorithm was developed and implemented. The simulator can flexibly react to different situations and can process dynamic data. A client-server-architecture is used to implement the prototype, where the location of the warning area can be defined over a web interface and then sent to the server. On the server, there is a database with all the statistical data about the area, population density and whereabouts of persons, but also facts about the connected warning channels. The modular architecture applied makes it easy to change and add warning channels or get more detailed information about the location. It's also possible to have different client systems using the simulator at the same time. For the communication a standardized CAP object is used and the calculated results are sent back within an SVG file so that they can be displayed to the operator. In Figure 1 the output of the simulator is shown for a flooding alert in the German city of Hamburg. The graph on the left shows the distribution of the warning message over 60 minutes. In the chosen area three channels were available and for each one the ratio of successfully alerted people is shown. The curve for "public sirens" already starts approaching saturation after one hour, showing the S-shaped dissemination pattern. On the right, input data is shown like the size of the warning area, the number of inhabitants or the time of the day.

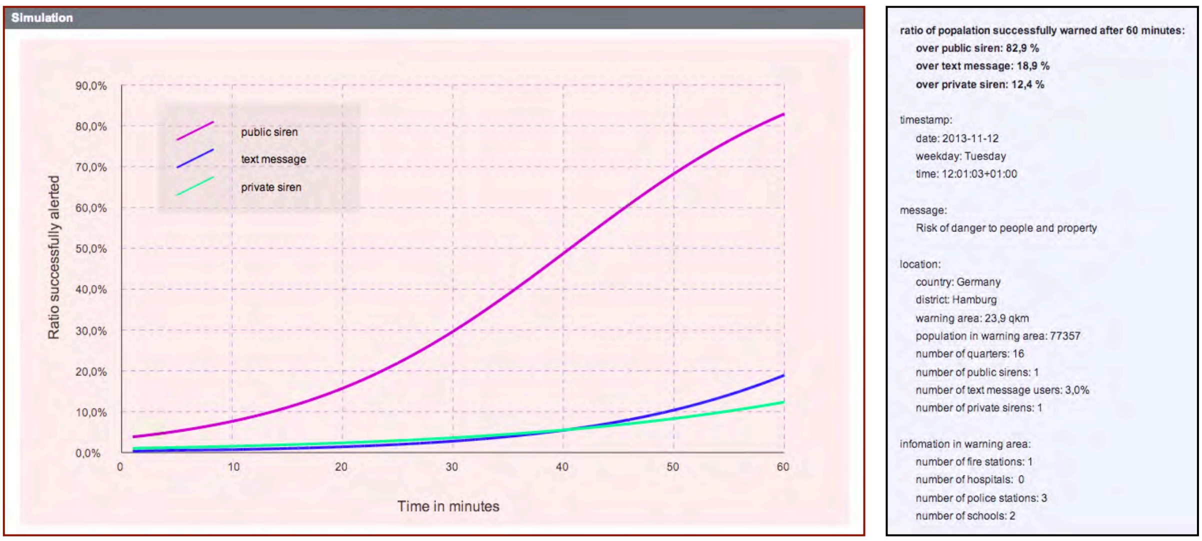

Figure 1. Output of the simulator (left) the graph and (right) additional information

DATA

As already said the simulator works with dynamic and static data. Dynamic data comprises the exact daytime and therefore also the day of the week, the geo-coordinates of the warning area and optionally a description of the warning. The statistic data in the database contain information about areas and all possible information linked to them like population data. Further, information about multipliers is saved in the database, for example the average number of household members in the area. The statistics for the behavior of the people depending on the daytime can be found in the database as well. The data about the warning channels contains the available warning channel with location, reach or registration as well as the possible multiplication ways for each channel with corresponding parameters. The biggest problem for the simulator is to find suitable data. To overcome the problem for a new region that should be evaluated, the simulator comprises an inference engine for a rule-based derivation of available alert channels. Examples for these rules are that schools have a personal announcement system, or that fire stations are required to have a siren. Thus, information on schools and fire stations in the warning area is retrieved from Open Street Maps and the alerting devices connected to these locations are automatically included in the simulation. Data on the registration to different types of alert systems are based on the experiences from operating alerting systems in 15 counties and 6 cities in Germany.

LIMITATIONS

The simulator has some simplifying assumptions. One of these simplifying assumptions is that during the first round of multiplications, none of the persons being contacted is counted twice (because he or she has received the alert from two directly informed people). This effect is not very likely to occur during the calibration phase because the overall number of people who have been warned is still low. Nevertheless, this may lead to a slight overestimation of the alerting success. On the other side, the alerting success is to some extent underestimated because we assumed that, during the first moments of dissemination, indirectly informed people are busy verifying the alert and thus do not immediately start to inform other people themselves.

CONCLUSION

In this paper, we presented a model for the dissemination of emergency alerts in the general population. This alert model takes into consideration situational factors. It was implemented in a simulation tool that can be easily integrated with different front-ends. It could be demonstrated that the simulator is working as expected, and that it is possible to infer information on the local / regional alerting infrastructure from Open Street Maps. However, additional field tests are needed to gather more precise information on the alerting efficiency of some channels, as well as on multiplication effects. Such tests are currently planned until mid-2014.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 261699.

REFERENCES

1. Meissen, Ulrich, and Agnès Voisard. (2008) - Increasing the Effectiveness of Early Warning via Context-aware Alerting, In Proceedings of the 5th International Conference, on Information Systems for Crisis Response and Management (ISCRAM), 431–440.
2. Held, Volkmar. (2001) - Technologische Möglichkeiten einer möglichst frühzeitigen Warnung der Bevölkerung: Kurzfassung. Bundesverwaltungsamt-Zentralstelle für Zivilschutz.
3. Rogers, George O., and John H. Sorensen. (1991) - Diffusion of Emergency Warning: Comparing Empirical and Simulation Results. ADVANCES IN RISK ANALYSIS 8 117–134.
4. Klafft, Michael. (2013) - Diffusion of Emergency Warnings via Multi-channel Communication Systems an Empirical Analysis. In Proceedings of the 2013 IEEE Eleventh International Symposium On Autonomous Decentralized Systems (ISADS), 295–299.
5. Nagarajan, Magesh, Duncan Shaw, and Pavel Albores. (2012) - Disseminating a Warning Message to Evacuate: A Simulation Study of the Behaviour of Neighbours. European Journal of Operational Research 220, no. 3, 810–819
6. Parker, Dennis J., Sally J. Priest, and Sue M. Tapsell. (2009) - Understanding and Enhancing the Public's Behavioural Response to Flood Warning Information. Meteorological Applications 16, no. 1, 103–114
7. Parker, Dennis J., and John W. Handmer. (1998) - The Role of Unofficial Flood Warning Systems. Journal of Contingencies and Crisis Management 6, no. 1, 45–60