Beyond Saving Lives: Assessing the Economic Benefits of Early Warning Apps for Companies in the Context of Hydrological Hazards

Simone Wurster
Technische Universität Berlin, simone.wurster @tu-berlin.de

Michael Klafft
Fraunhofer FOKUS & Jade University of Applied Sciences
michael.klafft@fokus.fraunhofer.de

Marcel Kühn
Technische Universität Berlin, kuehn.marcel @freenet.de

ABSTRACT

Natural and man-made hazards are increasingly threatening modern societies. Therefore Turoff, Hiltz, Bañuls and Van Den Eede (2013) highlight the need for boosting efforts in planning for emergencies. Advanced early warning systems (EWS) provide opportunities to increase the resilience of societies. Warning via mobile phones is considered to be the best way of alerting but few public authorities already use this warning channel. EWS also help to protect property but their implementation requires significant investments. Cost-benefit estimations are needed for public authorities, insurance companies and the users, particularly private households and enterprises. This paper contributes a disaster-independent formula to disaster research with specific applications for hydrological hazards. Illustrated by a heavy rain scenario, it shows, in particular, the benefits of EWS for companies. A specific focus is put on lead time aspects.

Keywords

Early warning systems, cost-benefit analysis, warning apps. natural disasters

INTRODUCTION

Turoff, Hiltz, Bañuls and Van Den Eede (2013) show that emergency preparedness and management and resulting activities like investments in infrastructure are not functioning as they should in modern societies. 'Given the large number of threats that are possible in the next decade', they show the need for 'far more efforts at planning for emergencies'. The threats consist of natural and man-made hazards and impose risks on populations and property as well. Natural disasters include, for example, floods, heavy rain, thunderstorms, tornados and tsunamis and each country has its specific threat profile. In Germany, for example, an increase of intense rainfall is predicted within the next 30 years (see Kutschker, 2014). Even today's heavy rain events like the 2013 record floods have already caused extensive damage. According to Kutschker (2014), Germany's public authorities have to prepare new emergency strategies and the general public has to enhance its resilience. One way to enable people to cope with natural and man-made risks is provided by advanced early warning systems (EWS) which can warn a large number of users immediately with specifically targeted localized or personalized alerts via mobile devices, text messages and smartphone apps.

According to a recent study in selected European countries by Dressel and Pfeil (2014), mobile phones are considered to be the best way of alerting people in all participating countries, but only Dutch authorities already use an EWS. Implementing advanced EWS requires significant investments. Therefore, cost-benefit analyses are needed. Although several formulas have been developed in recent years to close this gap, applications for companies are missing. Disaster research also requires the consideration of the political context (see Wisner, Blaikie, Cannon and Davis, 2003). As Dressel and Pfeil's (2014) example shows, this context is also relevant for the investments into EWS, which are often a political issue (see e.g. Klafft and Meissen, 2011). Policy makers require a justification of costs, and some may be opposed to such a system because it constantly highlights existing threats by natural hazards in the area and may have a negative impact on industries like tourism. Therefore, it is essential to provide decision-makers with a comprehensive set of data to support their investment decisions. Our paper addresses this problem by providing a cost benefit assessment model including simulations and exemplary data for the case of hydrogeological hazards. Building on Klafft and Meissen (2011) and Wurster and Meissen (2014), it proposes a disaster-independent approach to assessing the benefits of EWS for companies. Specific value is based on its advanced focus of lead time aspects, human behaviour and financial estimations. Based on the work of Wurster and Meissen (2014) who defined the financial EWS-specific variable multiplier effect, this paper is also the first to use simulator data on the dissemination of EWS warning information to the public. The data optimize financial EWS assessments because they provide a more realistic view of the potential benefit of EWS. They allow for advanced assessments of such systems.[1]

EXISTING APPROACHES TO ASSESSING THE VALUE OF EARLY WARNING SYSTEMS

The methodological environment of economic EWS assessments consists of return on security investment (ROSI) calculations (ENISA, 2012) as well as cost avoidance analyses (see Klafft and Meissen, 2011) and cost-benefit analyses in the context of natural phenomena (see Grahn, 2014).

Early cost avoidance approaches to assess EWS include a) models which focus on one type of disaster only (see e.g. Wenzel et al., 2001) as well as b) models which work independent of specific disaster types (e.g. Meissen and Voisard, 2008; see Klafft and Meissen, 2011 for a detailed overview). A relative advanced approach is the EU FHRC Model (Parker, Tunstall, and McCarthy, 2007, FLOODsite, 2009) but it lacks the consideration of behavioural effects on system use although the resulting actions largely depend on how the underlying risk is perceived (see Klafft and Meissen, 2011). Modern communication devices and services were almost not analyzed. Therefore Parker et al. (2007) formulated a research gap in their article. Another advanced model is proposed by Klafft and Meissen (2011) themselves. It is disaster-independent and its strength is the consideration of human behaviour but further research is needed in this regard (see Wurster and Meissen, 2014). Certain progress has been achieved by Scholte and Rothkrantz (2014) and Meissen and Voisard (2014) who show that the responses on EWS warnings depend on the degree of their personalization and the existence of information on how to react. Specific financial benefit estimations are not only missing in their papers. In addition, no approach to calculate EWS benefits makes use of advanced, dynamic investment calculation principles. Wurster and Meissen (2014) propose an advanced model for the economic assessment of EWS for private households but the benefit for companies has not been analyzed so far.

FACTORS INFLUENCING THE EFFECTIVENESS OF EARLY WARNING SYSTEMS AT COMPANIES

Dressel and Pfeil (2014) formulated three general rules for early warning services, which form the basis of this study: the alerting strategy should correlate with the respective 'national trust context', the age of the recipients, and with the area of residence. In line with these assumptions, Klafft and Meissen (2011) and Wurster and Meissen (2014) calculate the economic benefit of EWS for private households based on four groups of factors: personal, prediction-related, dissemination-related and general factors. This paper shows an application of these factors for the disaster loss prevention of companies. Most modifications are related to personal factors. With regard to the protection of property, 'general factors' were replaced by the categories 'company-related factors' and 'disaster-specific factors'.

Company-related factors comprise variables related to the asset value of the relevant companies. We focus on ***fixed assets*** and ***inventories***. Specific financial figures and additional factors allow for the calculation of the ***potential amount of loss*** which forms the basis of the potential damage reduction. Its realisation through the use of EWS can be affected by bottlenecks. Measures for flood protection, for example, can be hindered by a lack of storage space. Therefore, Wurster and Meissen (2014) created the variable ***absence of bottlenecks***.

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Disaster-specific factors include ***the probability of the occurrence of a specific disaster per time unit in the warning area*** as well as ***specific disaster-related variables*** like the inundation depth in the contexts of flood events and heavy rain.

Personal factors influence how a warning is processed by the recipients and if and how it is then translated into protective actions. A principle concept for the description and prediction of behaviour is Bourdieu's (1970) habitus theory. The habitus describes structured propensities of a society to think, feel and act (see Navarro, 2006, p. 16). It ensures the active and unconscious presence of previous experiences and is composed of perception, thought and action schemas, which determine how a player perceives his/her environment as well as his/her individual and collective practices (Bourdieu, 1970, p. 40). There are, for example, different behaviour types, based on parameters such as age, gender and area of residence (see e.g. Ghersetti and Oden, 2014). In particular two factors are relevant in the EWS context: ***situational likelihood of willingness to respond*** and ***situational ability to perform the relevant actions***. At companies, these actions may include for meteorological threats, for example: moving goods in secure areas, switching off electricity, interrupting the supply of flammable liquids, filling and piling up sandbags, installing protective barriers; fixing outdoor storage and protect machines against condensation (see CHE, 2006).

***Situational likelihood of willingness to respond*:** Modifying the work of Klafft and Meissen (2011) by integrating the findings of Thieken, Kreibich, Mueller and Merz (2007), Wurster and Meissen (2014) created the variable 'likelihood that a recipients is willing to perform a certain protective action', if necessary, by using additional help from family and friends. In private households, the people who receive a warning and those who perform the protective actions are often identical. In corporate contexts, specific interrelations between both aspects exist. Combined activities of different persons are more likely. People involved in such activities include a) persons who receive a warning message, decide to initiate protective actions ('willingness') and give instructions and b) additional staff members who have to follow the relevant orders and instructions. The willingness to respond to disaster threats in a work context is also strongly influenced by the scope of disaster, in particular if relatives of the responders are also threatened and in need of help.

Situational ability to perform the relevant actions: With regard to private households, Wurster and Meissen (2014) distinguish three variables: Physical and mental ability to perform the action, Psychic ability to perform the action and Spatial distance. In corporate contexts the ability to perform relevant actions is mainly influenced by the availability of employees with the relevant skills. Disasters occur regardless of working days or holidays. They may happen during the day or at night and bear specific challenges in this regard. The relevant prevention measures can include the support of specialized service companies.

Warning-related factors comprise five variables. The first one, the ***probability that a disaster is correctly predicted,*** measures the absence of missing alerts and false alerts (see Jacks and Ferree, 2007). The potential benefit of an EWS is also related to the provided reaction time which affects the potential measures of the companies and persons concerned (see e.g. Klafft and Meissen, 2011). By issuing rapid warnings, EWS provide more time to initiate reaction measures. This additional time is labelled as the ***lead time or warning time of the EWS*** whose relevance is, for example, shown by Day (1970). Consequently, the financial benefit of an EWS equals the prevented damage. 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. According to an expert from the German Weather Service (DWD), heavy rain events usually have lead times of at least 12 hours and storms of 24 hours.

The benefit of an EWS also depends on the possible receipt of alternative warnings. ***Lead time$_{human}$*** considers that the alert recipients might have taken the same protective action even without an EWS (e.g. after noticing 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[2]. 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, additional benefits of personalized SMS-based warnings from public authorities are shown by Dressel and Pfeil, 2014). Wurster and Meissen (2014) describe the advantage of EWS compared with other media in detail. Based on the three lead time-related variables, the variable '***EWS-based increased likelihood that appropriate protective actions will be***

2 Based on the wish of the public, sirens are not used any more for public warning in Germany.

completed' was created. The lead time of the EWS also determines the resulting ***reaction time of the relevant persons***.

Dissemination-related factors influence the likelihood of recipients of early warnings being correctly notified and actually taking notice of the warning in time. Like Parker et al. (2007) in the context of private households, we model the variable ***'likelihood that an appropriate number of responsible persons per company subscribe to the EWS***'. Noticing 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. The dissemination issue also highlights questions related to the technical capability of an EWS. Hofmann, Handtke and Tondryk (2014) provide a concept to overcome this problem. Another potential problem is ***the likelihood that the communication channel would be nonoperational***. According to Klafft and Meissen (2011), this danger is very low on a national level in Germany. However, local outages of communication channels did occur in the past (Klafft, Kräntzer, Meissen and Voisard, 2009), and as long as point to point communication is concerned, network congestion might be an issue.

Further insights into dissemination-related factors can be gained from Hellriegel and Klafft's (2014) model, which simulates several communication channels and their respective reach (although for private users only). On this basis, we model the variable ***'likelihood that an appropriate number of EWS subscribers per company notice a specific warning in due time'***. According to Wurster and Meissen (2014), the preliminary work by Rechenbach (2012) and additional findings from Hellriegel and Klafft (2014), the financial benefit of EWS is increased by ***multiplier effects*** (e.g., recipients pass the warning to others). The following list summarizes the relevant factors in this paper:

t	: time span of economic assessment
$P(Di)$	: projected number of disasters of type i per time unit in the warning area
$P_{Pred}(D_i)$	: probability that a disaster of type i is correctly predicted
FA	: value fixed assets of the companies in the warning area
IN	: value inventory assets of the companies in the warning area
d_{FA+IN}	: potential damage fixed assets and inventory of the companies in the warning area[3]
$LHood_{action,i,C}$	: likelihood that companies concerned perform relevant protective actions in case of a disaster of type i due to EWS-based warnings
$Lhood_{subscr,C}$	: likelihood that an appropriate number of responsible persons per company subscribe to the EWS
$LHood_{outage,i}$	: likelihood that the EWS is nonoperational
$LHood_{notice,i,C}$	: likelihood that an appropriate number of employees per company and/or specialized service companies are alerted via the EWS in due time[4]
$sLHood_{willing,i,C}$	: situational likelihood that the companies decide to perform protective actions in case of a warning of disaster i
$sLhood_{able,i,C}$	: situational likelihood that the companies are able to perform protective actions to react on disaster i, if necessary with the help of specialized service companies
$R_{i,C}$	: relevance of the protective actions to protect the companies in case of a disaster of type i
$AoB_{i,C}$	: absence of bottlenecks to perform protective actions to react on disaster i in the companies in per cent
$T_{Lead,EWS}(D_i)$	: 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 $T_{Lead,human}(Di)$
$T_{lead,EWS(Di)PLUS}$	: additional reaction time based the use of a specific EWS, depends on $T_{Lead,EWS}(D_i)$, $T_{Lead,human}(D_i)$ and $T_{Lead,othermedia}(D_i)$

[3] In addition to tangible assets, intangible assets often have significant importance for companies. Intangible assets, which can be damaged by a disaster, are in particular related to data stored in IT systems. This will be subject of further research.

[4] The effects of a typical two-stage warning process within a company including noticing warning messages and submitting subsequent instructions are considered by $LHood_{notice,i,C0}$ * $LHood_{notice,i,C1}$ with $LHood_{notice,i,C0}$ for responsible persons and $LHood_{notice,i,C1}$ for staff members.

$T_{react,EWS(Di)}$	: reaction time on average
M	: multiplier effect
ind	: inundation depth
$bfit_{prot,i,C}$	: potential monetary benefit of protective actions at all companies concerned for disaster type i (depends on additional formulas and parameters)
$inc_{prot,i,C}$	: increased likelihood that appropriate protective actions will be completed due to the EWS-based warning in case of a disaster of type i in due time
$bfit_C$	: total EWS-based benefit for companies caused by additional successful protective actions

The following sections show the impact of the EWS-based lead time on the damage prevention of companies by using a heavy rain scenario of the German city of Hamburg.

ASSESSING THE BENEFITS OF EARLY WARNING SYSTEMS

Formulas to calculate the potential financial loss

The calculation of the potential benefit of an EWS depends on the financial damage caused by the relevant disaster(s). These damage calculations often prove to be difficult due to the wide spread damage and the decentralized determination of the amount of loss. Based on radar data of precipitation, Grahn (2014) found a significant relationship between the amount of precipitation and insured damages. To assess the amount of loss caused by flood events, Emschergenossenschaft and Hydrotec (2004) provide formulas for sectors with different types of industrial activity. They calculate the percentage of assets[5] of a company that is damaged as a function of the water level (inundation depth) X in meters. They differentiate between industry, trade and mixed usage (sectors 1 and 2 in Tab. 1, formula, $y = 27*\sqrt{x}$), facilities with functional usage (sector 3, $y = 30*\sqrt{x}$), mining facilities (sector 4, $y = 4.47*\sqrt{x}$) and facilities for energy- and water supply (sector 5, $y = 6*\sqrt{x}$). The formulas were used by HWWI and Ecologic (2012) to calculate the damage caused by heavy rain in Hamburg. Based on their analyses, the authors show a holistic approach to calculate the damage based on heavy rain but also the need for further research efforts to develop specific formulas for such kinds of events.

Calculation of the amount of loss

This section provides a description of the calculation of the assets owned by companies in Hamburg potentially affected by the fictitious flood event with the aid of statistics and the resulting amount of loss. Hamburg is the center of a metropolitan area and around 105,820 companies are located in the city itself (see SLBW, 2014a). To assess their potential amount of loss, data for the fixed assets for all German companies was taken from the National Accounts for 2012 (Statistisches Bundesamt, 2013a). With the employee numbers provided by the same source, the fixed assets per employee for all economic sectors were calculated. This quotient was multiplied with the numbers of employees in each sector (source: Statistikamt Nord, 2014; SLBW, 2014b; which yielded an approximation for the assets of companies based in Hamburg (see Tab. 1).

Since no detailed statistics were available (see Statistisches Bundesamt, 2013b, p. 4), the inventory assets were estimated to be 30% of the capital assets (according to Hirschhäuser, n.d.) and added to the previously calculated sum. Regarding the amount of loss, HWWI and Ecologic (2012) analyzed heavy rain in Hamburg in June 2011. Hamburg's city center was affected in particular, which consists mostly of shops, department stores, restaurants and offices. It was estimated that 1% of all commercial enterprises as well as 1% of the hotel and restaurant industry were affected. Peperhove (2014) developed a heavy rain scenario which affects a whole city but causes particular damage in specific areas. Likewise, we estimate that 10% of the city are particularly affected by the disaster. Our example considers companies in five sectors. Based on this specification, our scenario builds on the assumption that 1% of their assets in the given area are affected by the event. (For simplicity's sake, we refer to 1% of the assets and not to the companies themselves). Furthermore, we use formulas of Emschergenossenschaft and Hydrotec (2004) for an inundation depth (ind) of 0.2m.

[5] The result '12' shows, for example, that 12% of the assets are damaged.

Sector	(1a): $FA_{,Ger*}$	(1b): $IN_{,Ger}$	(2): $employees_{Ger}$	(3): [(1a) + (1b)] / (2)	(4): 10% $employees_{HH}$	(5): (3) * (4)	(6): (5) * specific formula $d_{FA+IN}(0.2)$ * 1%
1	6,373.1 bn	1912.0 bn	24,212,000	342,189	84,350	28.86 bn	34,854,000
2	146.8 bn	44.1 bn	324,000	589,197	240	0.14 bn	171,000
3	1,258.2 bn	377.5 bn	8,948,000	182,800	32,600	6.00 bn	7,995,000
4	13.5 bn	4.0 bn	73,000	239,726	50	0.01 bn	2,000
5	441.9 bn	132.6 bn	481,000	1.194,386	620	0.74 bn	197,000
						sum (EUR):	43,219,000
*without financial assets, real estate						exchange rate (5 May, 2014):	1.3874
Ger = Germany, HH = Hamburg						rounded sum (USD):	59,962,000

Tab. 1: Calculation of the amount of loss in Hamburg based on the heavy rain scenario

Estimating that 1% of the firm assets in our scenario's area are affected takes into account that offices in lower floors are more affected than for example those in offices towers. Based on the given data and assumptions, the total damage of fixed assets and inventories (d_{FA+IN}) was assumed to be €43.2M ($59.96M, basis: ECB exchange rate of 05 May, 2014: EUR 1 = USD 1.3874).

Formulas to calculate the damage reduction

Regarding the potential flood damage reduction at companies, two formulas based on the additional time for damage mitigation measures exist. The formula y = 0.023*x + 0.189 for the percentage damage reduction as a function of the lead time in the industry sectors comes from Schröter, Ostrowski, Velasco, Torres et al. (2008). It consists of a fixed part of just below 19% damage reduction that can be achieved with no lead time at all. This damage reduction eventuates e.g. from actions taken by persons concerned observing the event happening and reacting accordingly with safety measures. Per additional hour of warning time, the formula suggests that a damage reduction of 2.3% can be achieved. This variable part is of particular interest when observing the contribution of an EWS to reduce the financial impact of a flood event. Due to this, the fixed part of the formula needs to be excluded to reflect the benefit of an EWS correctly. Another approach to calculate the flood damage reduction is based on the Day curve (Day, 1970) which also describes a connection of the percentage damage reduction and the additional lead time for flood events. It will be described later in more detail.

Based on Schröter et al. (2008), Klafft and Meissen (2011) and Wurster and Meissen (2014), the following formula to calculate $bfit_C$ represents the benefit of an EWS for the entirety of the companies concerned:

$$bfit_C = \sum_i \left[t \cdot P(D_i) \cdot P_{Pred}(D_i) \cdot M \cdot LHood_{action,i,C} \cdot bfit_{prot,i,C} \cdot inc_{prot,i,C} \right]$$

$Bfit_{prot,i,C}$ is determined by the disaster-specific variable 'ind'. It states the preventable damage according to the formula by Schröter et al. (2008) and depends on the damage d_{FA+IN}, which was calculated as described before. It is also influenced by the chosen additional lead time $T_{lead,EWS(Di)PLUS}$ and hereby sets an upper bound for $bfit_C$.

According to the following formula, $LHood_{action,i,C}$ comprises a number of behaviour variables:

$$LHood_{action,i,C} = LHood_{subscr,C} \cdot (1 - LHood_{outage,i}) \cdot LHood_{notice,i,C} \cdot Ri_{,C} \cdot sLHood_{willing,i,C} \cdot sLHood_{able,i,C} \cdot AoB_{i,C}$$

The formula builds on the work of Klafft and Meissen (2011) and overcomes its specific weaknesses: the need to conduct numerous separate calculations for every single protection measure, which is nearly impossible and its specific and narrowed emphasis on cultural aspects regarding $LHood_{willing}$, which made considerations of multicultural companies very difficult. In addition, it does considers neither a) the *relevance* of the chosen protective measures, nor b) possible *barriers* which reduce the measures' prospects of success.

An alternative to calculating the potential damage reduction $bfit_{prot,i,C}$ as a function of the lead time according to Schröter et al. (2008) is provided by the Day curve. It sets an upper maximum of 35% damage reduction ($bfit_{prot} \leq 0,35*d_{FA+IN}$), which is approached with an increasing lead time. The formula was approximated to be y = 35 – 5040/(23*x +144).

Calculation of the damage reduction

This section shows the potential damage reduction of Hamburg's companies. Sources to determine the value of the variables include Klafft and Meissen (2011), Rechenbach (2012), Wurster and Meissen (2014) who provide estimations for private households and own calculations. This paper assumes a lead time of three hours. In accordance with Rechenbach's (2012) projection that at least 10% of the population will subscribe to the service, it estimates that 10% of all companies in the affected area are subscribed.

The likelihood of warning the users of an app-based Early Warning service successfully is determined by two variables: (a) the likeliness to have a charged up and ready for reception mobile phone on one's person and (b) the likeliness to notice the transmitted message within the given time frame. Based on an empirical study by Hader and Hader (2009), variable (a) was estimated to be 70.89% after three hours for short messages. On the other hand, Dinardo (2014), amongst others, suggests that 95% are read within the first 5 minutes. Based on this rapid increase, it is most likely that almost all transmitted messages are read within a 3-hour lead time. Combining both and determining the average yields a value of 70.73% for $LHood_{notice,i,C0}$ for *short messages*. The *app-based warning service* in our example includes a specific warning sound. This feature facilitates the notification of the alert significantly. The minimum of $LHood_{notice,i,C1}$ is also 71% but in most cases this likelihood is higher because the realization does not require noticing by a specific person but can refer to different staff members. Furthermore, regarding small and medium-sized companies (SME's), we assume that the receiver of the warning message also conducts protective actions him/herself. 99.6% of all German companies are SME's and 50% are micro enterprises. Therefore $LHood_{notice,i,C1}$ is set 100% for 50 % of all companies and 71% for the remaining cases. In total, $LHood_{notice,i,C}$ is 60% on average.

Based on a survey, Klafft and Meissen (2011) analysed the willingness to respond to a warning and to conduct specific protective actions. The willingness to close windows, to secure loose items outside and to drive cars into garages reached the highest results of between 93 and 100%. As shown before, there are many kinds of potential protective actions. Warnings may also allow for conducting several activities. For the purpose of this study the willingness to respond in general is set at 95%, which is also supported by the fact that employees are acting in a context that usually contractually binds them to execute their employer's instructions. Considering the findings of Fielding et al. (2007) and incorporating the assumption that companies are more capable of acting than private households, $sLhood_{able,i,C}$ is estimated to be 85%.

As for the multiplier effect, a simulation of the dissemination of warnings via mobile phones at Fraunhofer Fokus, showed that after three hours 98.7% of the people concerned received a warning, which is 9.87 times the initial 10% that subscribed to the service. The simulation assumes that the warning is triggered during ordinary working hours (more precisely, shortly before noon). It also reveals that the average reaction time of warning recipients is around 1.5 hours. Depending on the size of the company, activities in this period vary. Unlike large companies, many sole proprietors cannot delegate activities but this means they also save time for emergency planning. On the other hand, large companies can mobilize a high number of employees which also increases the likelihood of an appropriate number of fast responses. For simplicities sake, our calculation does not include additional assumptions for the reaction time.

Assessing $inc_{prot,i,C}$ is far more complex and dependent on a variety of external factors, although mainly the media use and the considered importance of the received warnings are of particular significance. The use of different types of media varies throughout the day. Especially at work, most employees do not watch any TV and only a few listen to the radio, which, combined with the periodicity and lag in distribution, makes it quite unlikely to receive a warning via these channels within a short lead time during work. Nevertheless, many office jobs include regular internet usage, which lags the disadvantages mentioned above. One of the biggest benefits of an EWS is its personalization. Additionally, the warnings are distributed quickly. In terms of conversion rate, many sources (e.g. Johnson, 2012) suggest that marketing via SMS has an exceptional high one compared to other marketing channels. Considering the unwanted nature of marketing messages, it can be assumed that recipients of EWS messages have a vastly higher conversion rate. Figure 1 shows the results of the calculations.

The possible damage reduction $bfit_{prot,i,C}$ based on the Day curve is almost twice as high as in the calculation based on Schröter et al. Simultaneously, this results in an analog increase of $bfit_c$. In particular, there are two explanations for these differences. According to Nicholas, Holt and Proverbs (2001) the potential damage depends on 'the building's characteristics.' In addition, Kreibich, Seifert, Merz and Thieken (2010) stress the importance of precaution measures and distinguish several groups of companies based on these measures. The nature of the precautionary measures influences the potential contribution of additional ad-hoc measures. Furthermore, the Day curve shows a reduction of a maximum of 35% and that this is mainly for protecting movable property (Subbiah, Bildan and Narasimhan, 2008, p. 50). Therefore, it does not consider that fixed assets can also be protected by ad-hoc measures, e.g. by the construction of sandbag walls. Depending on the object of study, both approaches have to be distinguished and selected accordingly.

$Lhood_{subscr,C}$	10%	$R_{i,C}$	1	d_{FA+IN} [$]**	59,962,000
$Lhood_{outage,i}$	3%	$AoB_{i,C}$	1	t	1
$Lhood_{notice,i,C}$	60%	$P(D_i)$	1	$TLead,EWS(Di)_{PLUS}$ [h]	3
$sLhood_{able,i,C}$	85%	$P_{pred}(D_i)$	89%	Treact,EWS(Di) [h]	1.5
$sLHood_{willing,i,C}$	95%	M	9.87	$bfit_{prot,i,C,Schröter}$ [$]	2,068,689
		ind* [m]	0.2	$bfit_{prot,i,C,Day}$ [$]	4,056,253
*max. inundation [m], **assumption: 10% of the city are affected as well as 1% of the companies in five sectors in the relevant area				$inc_{prot,i,C}$	95%
				$bfit_{C,Schröter}$ [$]	810,908
				$bfit_{C,Day}$ [$]	1,590,015

Figure 1: Potential benefits of an app-based EWS for companies in Hamburg in the heavy rain scenario

After calculating $bfit_C$, this positive impact needs to be set into relation to system-induced costs. Klafft and Meissen (2011) gave detailed instructions on how to calculate them based on a static approach. This paper suggests an approach based on dynamic investment calculation principles which requires five additional steps: a) extrapolation of the present results on the life-cycle of the EWS, b) determination of the total EWS-based loss avoidance for all relevant target groups, disaster types and regions, c) estimating the initial EWS cost and the EWS cost per year, d) calculating and discounting all annual surpluses 'EWS-based loss avoidance minus EWS costs' and e) determination of the EWS-based benefit by subtracting the initial investment cost from the sum of all discounted annual surpluses.

SUMMARY AND OUTLOOK

This paper presented a formula to assess the economic benefits of EWS for companies in the context of flooding events and heavy rain. Building on Wurster and Meissen (2014) who showed the benefits of EWS for private households with fixed disaster prevention data, this paper allowed for specific calculations based on lead time aspects. In addition, it gave advice on how to calculate the total EWS-based benefit based on dynamic calculation methods. As a foundation of the benefit analyses, it showed how to calculate asset data of companies for concrete regions. The concept made also use of specific damage-avoidance formulas. An innovative simulator tool and advanced dissemination data of warning messages created additional benefits.

The relevance of key variables is confirmed by Parker et al. (2007) but need for further research remains. The present version of the formula does not consider specific time lags of mobilizing staff. Therefore, its application is currently most appropriate for small companies including restaurants and small shops. Further research is necessary to specify the multiplier effect among EWS subscribers in specific business contexts. Additional validation activities in accordance to Merz, Kreibich, Schwarze and Thieken (2010) will be an important part of future activities. Based on forecasting techniques, weather data for specific regions can be modelled. ‘Powerful computers now allow approximate numerical methods based on space/time discretization to be developed for quantitative modelling and simulation of complex phenomena’ (Iovine, Sheridan, Di Gregorio, 2006). Nevertheless the authors stress the need for further research ‘to analyze complex natural phenomena through modelling techniques, and on evaluating the associated hazards‘.

Our formula offers additional opportunities to estimate the total EWS-based benefit with regard to heavy rain for a whole region, e.g. a German federal state, or even a country. Its key variable is potential damage based on statistical data, and such country-level data is, for example, available for Germany. Based on this data similar, calculations can be conducted for the whole country.

The development of applications for additional disaster types is planned and will require specific research efforts. In contrast to flooding and heavy rain, no lead time-based formula for the economic assessment of storms could be derived so far. Therefore alternative concepts have to be taken into account, e.g. combinations of existing formulas for past events and new data based on EWS use. An appropriate foundation might be, for example, Schmidt, Kemfert, and Hoeppe (2008) who found a statistical relationship between wind speed and the damage caused by cyclones.

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