An analysis of Modern Early Warning Systems: How might Risk-Terrain Modeling contribute to the development of an optimal system?

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Early warning systems have long existed for many types of threats and hazards, and in various different shapes and at different levels of sophistication. Gas canaries, for instance, were used in coalmines for many years in order to detect gas leaks, so as to give the miners some time in which to execute an evacuation procedure. Likewise, weather forecasts continue to provide people with some degree of early warning regarding inclement weather conditions, enabling them to make some level of preparations for future events. However, such early warning systems are often sub-optimal in several ways. Warnings may not be provided in adequate time to allow sufficient preparations to occur, or may not even occur until the threat in question has materialized. Gas canaries were only able to provide a warning that a gas leak had already occurred, rather than that one was imminent. Furthermore, warning systems often do not adequately highlight vulnerability to a given threat. For instance, weather reports which warned of Hurricane Katrina provided little clue that a humanitarian catastrophe was imminent. The differential abilities of people in New Orleans to deal with the disaster were certainly not considered in the response of the authorities[i].

The purpose of this paper is to examine how early warning systems might be improved so as to take into account the likelihood of an impending humanitarian, financial, or environmental disaster. Specifically, it will ask “what are the requirements of optimal modern early warning systems? What successes have modern systems had in reaching this archetype?" Finally, it will also ask "how can Risk Terrain Modelling (RTM) be used to improve on current early warning systems?" I will argue that in order for early warning to be most effectively utilized, several concepts need to be implemented. Early warning systems themselves need to approach the hazards which they are designed to warn against from an integrated perspective, in order to provide accurate and effective warning. Furthermore, they must take into account the differential abilities of people to respond to the same hazard, i.e. they must be adapted to consider vulnerability to a particular threat, rather than simply warning about the imminence of that threat's occurrence. I argue that RTM allows for the presence of variables which could help provide more accurate and reliable warnings, and which would be crucial to indicating the differential vulnerabilities of people in a given area to a particular threat: "the advantage of RTM is that it provides a picture of a landscape in terms of factors that contribute to negative events…that are more enduring than just the characteristics of the people who frequent these places"[ii]. I also state that RTM can be used to help adapt existing early warning systems to take more integrated approaches to risk and threat assessment. As such, I contend that RTM can provide a valuable addition to present early warning systems, and will prove to be extremely useful in the development of an optimal system.

Components of an optimal early warning system

An analysis of the literature available on the subject of risk balance and risk assessment clearly displays the importance of information regarding early warnings in adequately dealing with threats in the modern world. Early warning is a vital component in the risk assessment phase of risk management. As Kennedy et. al. point out, during this phase, it is vital to ensure that as much information as possible is gathered in order to ensure that in the subsequent decision-making phase, adequate and appropriate steps to mitigate the threat in question are being taken and the correct decisions are being made[iii]. Likewise, in talking about warning systems that target violent conflicts, Davies and Gurr argue that the earlier a warning can be given regarding the imminence of the eruption of hostilities, the more likely it will be that effective preventive measures will be taken[iv]. As such, early warning is crucial to ensure that accurate information is provided in a timely fashion.

By the same token, it is equally important that an effective warning system provides an absolute minimum of either ‘false positive’ results (where an alarm is raised, but the feared threat never emerges or materializes) or ‘false negatives’ (where an event occurs in the absence of any alarm being raised). Any warning system whose warnings cannot be trusted, or who fails to provide sufficient warning, is therefore doomed to obsolescence. On this note, however, there is a little bit more debate. While it is patently clear that any effective warning system should ideally have no ‘false negative’ results, for some there is more room for ‘false positives’. Wyatt, for instance, claims that the reasons people give for seeking to eliminate incorrect warnings from any system is because of the unnecessary panic it would create: however, he points to the World War II air raid alarms which occasionally sounded without being followed by an attack as being evidence that people are willing to tolerate such false alarms if the system is otherwise reliable and provides adequate warning when a hazardous event is imminent[v]. With that being said, it must be remembered that although the occasional occurrence of false warnings would not necessarily result in disaster, continuous occurrences of this would dilute the significance and noteworthiness of the warning being provided.

On the basis of these fundamental requirements, there seems to be several necessities for the provision of adequate early warning. Of those, the most obvious one is the need for an integrated approach to threats and hazards. This is true of all types of warning system, from those designed to deal with financial and currency crises, to those that warn of impending food shortages, famines and droughts. Indeed, a major international conference hosted by the Government of Germany in 2006 in co-operation with the UN International Strategy for Disaster Reduction (UNISDR) advocated multi-hazard, integrated warning systems as being more economical, sustainable and efficient, and capable of providing more complex conceptualizations of the range of threats and risks that people face[vi]. The National Drought Mitigation Center at the University of Nebraska-Lincoln also identified warning systems which adopted integrated, multi-disciplinary approaches to threats as being more desirable, as they allowed for a comprehensive assessment of conditions at ground-level, rather than those that focused purely on one field[vii]. Specifically, they gave the example of traditional drought early warning systems paying too much attention to precipitation levels in order to predict drought severity, without looking at other vital sources of information such as soil moisture, ground water levels, and so on[viii].

Similarly to this, great attention must be also paid to the range and types of data sources used. Effective systems need to draw their data from a vast range of sources. This is a requirement that seems to be universal to all types of warning systems: certainly, the approaches of a variety of systems (prospective or otherwise) would point to this. For instance, in their proposal for the development of a warning system designed to warn against impending financial crises, Goldstein et. al. state that any effective system would necessarily have to use as large a sample of previous crises as possible in order to find correlates to watch for, and would require data updates on a monthly rather than a yearly basis[ix]. Bakker shows that regular monitoring of information derived from a variety of open sources has been identified as crucial to the development of a working conflict warning system[x], a point repeated by Davies and Gurr, who state that open sourced data from a variety of sources is necessary for functional Early Warning[xi]. However, of equal importance are the types of data being collected. While a strong quantitative element based on accurate and reliable statistics is vital, practical human analysis[xii], grassroots information and local knowledge[xiii], and a strong theoretical understanding of the causes of various disasters and/or conflicts[xiv] must all be included to ensure that data is relevant and will be able to help provide accurate warnings.

Additionally, the issue of resources is of great importance. As Kennedy et. al. note, ideal risk assessment processes are often disrupted because countries lack the resources to continually analyze threats and vulnerabilities[xv]. Likewise, Bakker points out that governments are often preoccupied with current crises, and do not have the will or the resources necessary to deal with tomorrow's problems today[xvi]. Dorn adds to this, stating that financial and managerial considerations have previously constrained the United Nations in their attempts to develop effective systems[xvii]. In this sense, the immediate financial and economic predicament of a state that is faced with a particular risk might outweigh the potential benefits of implementing and maintaining advanced early warning systems, a point heightened by the fact that in many cases, the countries in most dire need of reliable early warning systems are those with the least abundance of resources. As such, in order to remain relevant to those countries that are most in need of them, warning systems should be relatively cheap and cost-efficient.

Finally, as we move forward into the 21st Century, early warning systems should be capable of taking into account the differential levels of risk that people face. In other words, warning systems should be able to warn not just about the likelihood of an event occurring, but also about what sort of effects an event might have on the region where it occurs. Traditionally, early warning systems have provided a uniform warning to all those that are likely to be affected by a particular threat: a smoke alarm might alert all members of a household that the house is on fire, but it will not specify which rooms are currently on fire, or which people are in most imminent danger of smoke inhalation. In the context of a house fire, it is not necessary to take into account these differential levels of risk, as there is going to be very little difference in the relative vulnerabilities of each person that is affected by the threat in question. However, the need to consider vulnerability becomes more prescient when one focuses on more macro-level disasters such as conflicts and wars, hurricanes, earthquakes, droughts and famines, and so on. In these instances, those who have more or less access to resources will be affected to a greater or lesser degree by the hazard in question[xviii]. The need for such predictive capabilities has been thrown sharply into focus by disasters such as Hurricane Katrina and the Haiti Earthquake disaster. In both cases, it is quite clear from the resulting catastrophes that, while the authorities may have had some foreshadowing that an event was to imminently transpire (admittedly, in the case of the Haiti Earthquake, given the difficulties of predicting earthquakes, the authorities would likely have had no more than a couple of minutes warning that an event was about to occur[xix]), they were completely unprepared for, and unable to deal with, the humanitarian situation which was to emerge in the wake of the event. It is necessary that if early warning systems are to play a full role in the risk management process, they need to pay at least some attention to the differentiated risk levels different people face. This is to ensure that aid and resources are sent to areas that are most vulnerable and in need of help. This would then help mitigate the effects or likelihoods of humanitarian situations in the region in question.

Examples from the field

With this in mind, we must look at how various early warning systems have fared in their attempts to provide reliable warnings. Indeed, several relatively high-profile Systems have come unstuck because of their inability to offer useful services. There are a variety of reasons for these failures. Data issues have certainly played a part. One primary example of this is the Humanitarian Early Warning System of the UN Office for the Coordination of Humanitarian Affairs (OCHA). Dorn identifies this system as being "one of the earliest and most ambitious" systems devised to date[xx]. He states that this system incorporated a variety of indicators and statistical sources aimed at keeping tabs on humanitarian situations in over a hundred countries, but failed to provide warning of even a single armed outbreak. Dorn identifies the paucity of the data being analyzed, rather than any insufficiencies in the amount of data being examined, as being the reason for this failure, and states that too much attention was paid to statistical analysis rather than to practical human knowledge[xxi]. Similarly, Wulf and Debiel highlight two other conflict warning systems, the Forum on Early Warning and Early Response (FEWER) and the Early Recognition and Analysis of Tensions (FAST) systems as having failed due to an inability to incorporate relevant field information into their analyses[xxii]. They also note that in both of these cases, the Systems in question did not provide adaptive or flexible services, and thus found that as methodologies improved, "their niche [had] waned"[xxiii]. An examination of the FEWER website also highlights several other issues with the system. Warnings and reports were not presented in a particularly clear and straightforward manner: for instance, the graph in Figure 1 was intended to provide analysis of conflict and co-operation trends in the region under study for a group of two-month periods, however it is not readily clear what the graph is indicating.

Furthermore, this method of warning provides little or no information regarding the vulnerabilities of the affected populations.

By contrast, Wulf and Debiel cite the International Crisis Group's Crisis Watch database as being more successful and relevant, incorporating easy-to-access open source data and effective field research into their warnings[xxiv]. Another success story is the US Agency for International Development's Famine Early Warning System Network (FEWSNET). Indeed, in its field, the FEWSNET system is considered to be the most effective program in existence, and it has been identified as being crucial in the prevention of several disasters related to food shortages since its inception[xxv]. FEWSNET draws its information from a wide variety of sources: while it uses remote sensing data and satellite imagery, it also incorporates grassroots information, such as market price levels, information on livelihoods in the region being examined, the institutional context within which the region being studied is operating, and various other forms of field research[xxvi]. Furthermore, it incorporates the concept of vulnerability into its analyses, thus ensuring that resources are targeted towards those in most desperate need of assistance[xxvii]. FEWSNET also displays its results online in a clear fashion, using raster maps and Geographic Information Systems (GIS) maps (see figure 2). In this sense, FEWSNET can be viewed as being the closest thing that exists to an optimal Early Warning System currently in existence.

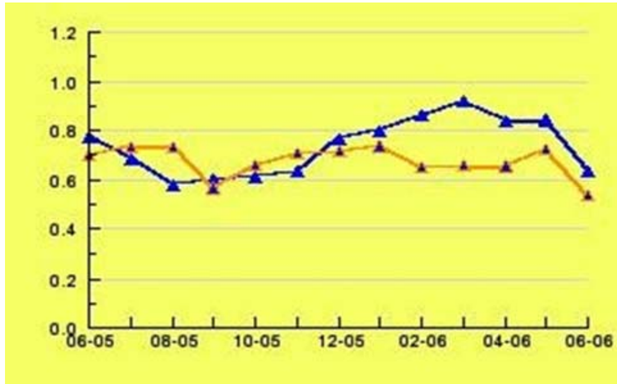

Fig. 1: FEWER Eurasia IDEA graph, depicting conflict and co-operation trends over two-month periods (FEWER International (2010) 'Monitoring', *FEWER Eurasia* [online], available: http://www.fewer-international.org/pages/eurasia/monitoring_27.html (accessed on 11/5/2010))

However, even with this, FEWSNET has room for improvement. For instance, while it has begun since 2007 to include the presence of a conflict as a causal variable for famines, it does not seem to offer any predictions as to the likelihood of the emergence of conflicts resulting from famines. Such an oversight ignores several important issues such as the interconnectivity of risk, and the ways in which the emergence and/or occurrence of a specific threat can give rise to other threats. Furthermore, it undermines the message of FEWSNET, as it can interfere with the subsequent steps in the risk management process. The imminent outbreak of a conflict (or indeed, ongoing hostilities) could hypothetically interfere with decision-making and lead to drastic changes in the situation on the ground which could scupper relief efforts. As a result, even in spite of the comparative effectiveness of the FEWSNET system, it is still lacking somewhat in terms of its appreciation of the interconnectivity of risks and the necessity of an integrated approach.

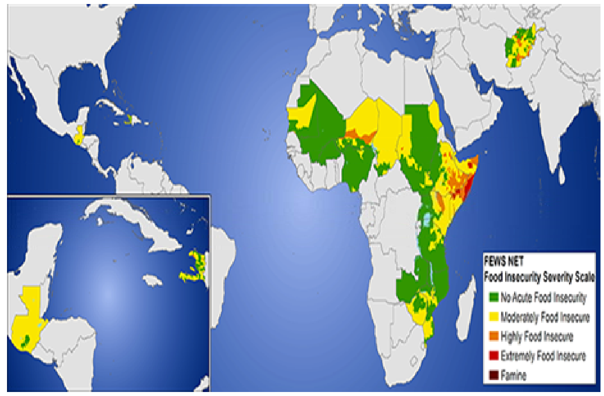

Fig. 2: Sample FEWSNET Food Insecurity Map for Fourth Quarter 2010 (October-December) (USAID (2010) 'FEWSNET Food Insecurity Severity Scale', *Famine Early Warning System Network* [online], available: http://www.fews.net/ml/en/info/pages/scale.aspx (accessed on 11/4/2010)

Towards an optimal Early Warning System: the role of Risk Terrain Modeling

At this stage, we have established that in order for effective early warning systems to be able to provide reliable and timely warnings regarding the risk not only of a particular event occurring, but also about the possibility of a related humanitarian disaster, several criteria need to be satisfied. Early warning systems need to adopt integrated approaches to the threats which they are warning against: as such they need to look at a variety of causes and risks. In concert with this, information needs to be drawn from a wide variety of sources, in order to ensure that all known causal variables, based on a strong theoretical background, are incorporated into the system. Early warning systems also need to exert a low demand on resources, so as to make them more easily accessible. And finally, it should ideally include an analysis of the relative vulnerabilities of those people who are most likely to be affected by the event in question, so as to assist in effective risk-management processes and to ensure that aid is provided to those people and places in most urgent need of help. The FEWSNET system developed by the US Agency for International Development has come closest to meeting all these requirements; it should come as no surprise, then, that despite it not taking a fully integrated view of all risks associated with famine and food insecurity, it is viewed by many experts as being the most effective Early Warning System of its type in the world.

However, it is quite clear from world events that these requirements are still not being met, and that early warning, risk assessment, and risk management is not being approached in an integrated fashion. An obvious example here is the recent Japanese earthquake. In terms of providing an alert that an earthquake was imminent, the system worked almost flawlessly, undoubtedly saving lives[xxviii]. Likewise, the steps taken to mitigate the damage done to buildings by an earthquake achieved their intended goals; even tall, high-rise buildings wavered, but failed to collapse (although some buildings were not fully prepared for an earthquake as powerful as the one that occurred)[xxix]. However, the threats associated with an earthquake were not approached in an integrated fashion, with consideration being given regarding vulnerability to all related risks. As a result, preparation for the subsequent tsunami which hit the country was relatively inadequate. For instance, in the case of the Fukushima Nuclear Power Plant, backup power generators failed when the plant was hit by the tsunami, as they had not been prepared to deal with such an event; additionally, cooling systems which relied upon the backup power were not adequately prepared for the generator's failure[xxx]. The failure of the authorities to prepare the plant for all eventualities indicates that an integrated approach to the risks and threats associated with earthquakes was not undertaken, while also highlighting the necessity of integrated approaches.

With this in mind, we must now consider how such procedures may be incorporated into exiting early warning systems. From this perspective, we should look to the possible input of RTM, and how this might be able to consolidate the above factors in order to make existing early warning systems optimally effective, in a similar manner to the FEWSNET system. It must be noted that RTM is not, in itself, an Early Warning System, and as such not be viewed as a replacement for such Systems; rather, it is an instrument which can be used to enhance the capabilities of other Systems through a variety of means:

1) it can help solve certain resourcing issues, due to the lack of expensive specialist software/hardware required for it to function;

2) it can enable early warning systems to generate easily accessed and easily understood warnings through the use of GIS maps;

3) it can improve risk assessment capabilities by increasing flexibility and facilitating integrated threat analyses, and by allowing for the inclusion of various different correlates and sources of information;

4) most importantly, it can be easily re-tooled to explain not only what threats are likely to occur in a certain area, but also to elaborate on the differential vulnerabilities of people within the area being studied.

These improvements can be incorporated into a wide variety of warning systems, and are not necessarily specific to any single issue: I will now expand on these points.

1) Resourcing issues: In terms of resourcing issues, the usefulness of RTM comes partially from the added value it can provide for a relatively insignificant cost. RTM does not require specialized or expensive software or hardware: while specific GIS software packages can be used to generate risk terrains, free-to-access online tools such as Google maps may also be used[xxxi]. In terms of hardware, all that is needed to generate these models is a computer with internet access. RTM might also potentially reduce certain costs related to the analysis of threats, as it only requires one person to load the data into the analysis package and thus generate the desired risk terrain maps.

2) Easily accessed and understood warnings: As noted above, an issue that some early warning systems have had is that the warnings they provided were neither easily understood, nor easily accessed. As Wulf and Debiel argue, public accessibility is an important ingredient in an ideal Early Warning System[xxxii]. RTM can help solve this issue through its use of GIS mapping systems. Risks are explained on a 'hotspot' map, which clearly enumerates where threats are more likely to occur within a geographic space. These maps can then be posted online (or elsewhere) in such a way as to make the warning as publically accessible as possible.

3) Improved flexibility and inclusion of varied information sources: RTM is a very flexible tool which can easily be used to provide risk assessment in a wide range of fields. Indeed, RTM has previously been used to predict the risk gang-based violence and criminality and shootings in American cities: the same processes that allow RTM to predict these incidents can thus be used for various different issues. However, the flexibility of RTM goes further than this. RTM can use as many correlates associated with a particular threat as have been identified through "…meta-analysis or other empirical methods, literature review, professional experience, and practitioner knowledge…"[xxxiii]. As such, it can be easily amalgamated into an existing early warning system. Indeed, due to its requirement of several different indicator in order to provide differentiated maps, RTM can encourage warning systems to adopt integrated, multi-threat approaches to the hazard they intend to warn against.

4) Vulnerability prediction: The most significant addition RTM can provide to any early warning system is its capacity for highlighting risk levels and predicting the differential vulnerabilities experienced within population groups. It has already been used to provide a somewhat similar service, in predicting the risk levels of gun shooting incidents in Irvington, New Jersey[xxxiv]. In this case, RTM has been used to assist police units allocate resources, not just to areas with current high crimes levels, but also to areas which are most likely to become hotspots again in the future[xxxv]. Maps that are subsequently produced give a clear idea of which areas are more likely to be vulnerable to the emergence of criminality in the future.

This focus on future threat mitigation could be of crucial benefit to early warning systems in different spheres. Similarly to what was noted earlier, the same processes that allow RTM to predict where crime hotspots are most likely to develop can also be used to predict where conflicts may emerge, or to say where post-event humanitarian disasters might happen. What would be required to do this would be a complex understanding of what causes these issues, based on a strong appreciation of the various theoretical explanations. This would then provide a varied set of correlates, whose occurrence would then be monitored throughout the territory in question. Such an approach would thenceforth allow for the most cost-effective risk management procedures: if we accept Davies and Gurr's argument, that early warning of conflicts can make its prevention more likely and the chances of extreme costs being incurred less likely[xxxvi], then the form of assistance RTM can provide (essentially pre-early warning services) would be extremely beneficial in ensuring early warning systems are optimally effective.

Again, using the example of the 2011 Japanese earthquake and tsunami disaster, the application of RTM to existing warning systems would most likely have been able to contribute significantly to the country's preparedness. RTM would have been able to give a detailed analysis of the vulnerability to earthquake-related risks (such as tsunamis) faced by the Japanese authorities, while also allowing for the possibility of it being tailored to specific locations (such as the vulnerability of the various nuclear power plants to tsunamis). Based on a combination of factors such as e.g. economic profiles of the areas studied, relief, coastline, average elevation of land and property in a given region and so on, one would have been able to provide a useful picture of vulnerabilities in an area to earthquakes and related phenomena; this picture would not only have encourage systemic thinking and integrated conceptualizations of all the risks associated with earthquakes, but would have allowed the Japanese authorities to understand at a glance where resources would need to be targeted in advance of any disaster. This information would then have allowed authorities to understand which risks were greatest (and where), which issues should have received priority treatment, where resources would be most effectively allocated, and so on. While RTM was not taken up in time to help prevent this particular calamity, its future implementation could help mitigate the effects of disasters further on down the line.

Conclusion

Based on the events of recent months and years, it is clear that quite a bit of work is required to make various forms of early warning systems optimally effective. Even foremost systems, such as the FEWSNET warning system, do not approach the concept of risk in a completely unified manner and overlook certain areas (in the case of FEWSNET, this is the lack of focus on famine and food insecurity as being possible causes of conflict). Likewise, in countries where warning systems and action plans for specific risks are virtually at the highest possible standard (Japan, in this case), risks have been dealt with in a singular approach, with insufficient attention being paid to the interconnectivity of risk. From this perspective, RTM can be extremely useful in helping develop the capabilities of early warning systems and encourage integrated conceptualizations of risk. RTM can add great value to existing early warning systems, without requiring a major outlay of expense. It can provide warnings and threat analyses in a simple and clear manner. However, its biggest benefits are in its flexibility and its ability to integrate a wide variety of data sources and correlates, and its capacity to provide analyses of differential risk and vulnerability levels, and where risks are most likely to be raised to their highest levels. These benefits can allow decision-makers and authorities to generate accurate predictive maps of where given threats may cause the greatest damage to property and life, and can thus allow for optimal resource allocation and the application of preventive measures to mitigate the effects of any future event. This would be a major addition to various different early warning systems, and would go a long way towards the creation of an optimal system. It must be noted that while RTM can be a great addition to the risk-assessment phase of risk management, it is not sufficient on its own to prevent catastrophes; there needs to be political will among decision makers to allocate resources to vulnerable areas, and mitigation processes must be efficiently designed and executed in order to take advantage of the improved information. However, the complexity of the questions and issues these decision makers face can be greatly simplified by implementation of RTM into early warning systems, to create an optimally effective system.

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