

A Unified Localizable Emergency Events Scale

ABSTRACT

Managers of emergencies face challenges of complexity, uncertainty, and unpredictability. Triadic constraints imply requisite parsimony in describing the essence of the emergency, its magnitude and direction of development. Linguistic separation increases as the crisis management organization is more complex and made up of diverse constituents. Therefore, a standard objective emergency scale is vital to quantify and unambiguously communicate the nature of any emergency. Previous work laid the foundations for an objective measurable emergency event scale. This paper proposes a unified emergency scale based on a mathematical model, accompanied by several examples spanning local to national events.

SIDEBAR

Problem the paper addresses: emergency is a complex situation. No emergency event scale exists to objectively quantify an emergency event.

Purpose of the research: propose a mathematical model for emergency events scale which can be used at all levels of organizations and geographical scope as they prepare or respond to an event. The model is applicable to managing developing events as well as predicting if the event may result in an emergency or not.

Methods employed: identification of underlying dimensions that exist in all emergency events, and formulate those into a mathematical model.

Results and conclusions: the model's soundness, robustness, and completeness, is demonstrated using several recent events in the USA and the Middle East.

Takeaway for practice: deployed and used correctly, the model can provide means of assessing and communicating existing emergency situations. The model can provide predictions on the direction and magnitude of a situation, including assessing whether or not a situation may result in an emergency.

Keywords: emergency scale, emergency management, emergence, complexity, dynamical systems

A Unified Localizable Emergency Events Scale

INTRODUCTION

The American Heritage College Dictionary defines emergency as “a serious situation or occurrence that happens unexpectedly and demands immediate action” (American Heritage Dictionary 2000). There are numerous scales that attempt to define degrees of emergencies. These scales tend to describe the characteristics of the event itself rather than the consequences. Such scales are ill-suited to describe emergencies in a way that is meaningful for response. People assume there is a positive relationship between the magnitude of an event and the magnitude of the emergency it causes, but this is not always the case. For example, a strong earthquake in a deserted area may create a smaller emergency compared to a moderate earthquake in a densely populated area. A useful emergency scale should accurately describe the nature and magnitude of the crisis.

The need for a unified, emergency scale is vital to facilitate clear communication and mutual understanding of the nature of the emergency, by the public, government agencies, and responding organizations. It has been stated that “50% of the problems with communication are due to individuals using the same words with different meanings. The remaining 50% are due to individuals using different words with the same meanings” (Appleby, Forlin et al. 2003). They further discuss how legislation still has not provided definitions of “disaster” or “emergency”, as well as the difference in impact and immediacy of response. An objectively calculable emergency scale should therefore quantify and clearly communicate the notion of “emergency”. This paper proposes such an emergency scale that could be understood and used at different scopes and by various clientele – internationally, nationally, regionally, at the municipality level, as well as by

global companies through local organizations. Further, the proposed model satisfied all five roles of system science (Warfield 2003): it describes the physical world and portrays the results of interactions among a few of its components; it proposes a generic design; it is a constituent of “science of complexity” as it enlarges the domain of demonstrable results in the service of humanity; and, it is actionable, as it has linguistic clarity and a model that suggests clear direction of actions essential to resolve emergency. Our model addresses several of Warfield’s Twenty Laws of Complexity (Warfield 2002). It does not require humans to process more than three components at a time (triadic constraint). The model’s renders a parsimonious description of any emergency. It addresses the challenge of vertical incoherence as it can show the right aggregated level to decision makers at different organizational levels. Similar to the CRISSI project (Asproth and Håkansson 2007) we consider all relevant factors of emergencies in a balanced fashion. However, while CRISSI limits itself to flooding, our abstract model can be applied to any emergency.

Related Work

Scales relating to natural phenomena that may result in an emergency are numerous. This section provides a review of emergency related scales. We concentrate mainly on weather and environmental scales that provide a common understanding and lexicon with which to understand the level of intensity and impact of a crisis. Some scales are used before and/or during a crisis to predict the potential intensity and impact of an event and provide an understanding that is useful for preventative and recovery measures. Other scales are used for post-event classification. Most of these scales are descriptive rather than quantitative, which makes them subjective and ambiguous.

1805: The Beaufort Wind Scale

One of the oldest weather related scales still in use is the Beaufort Wind Scale. It was created in 1805 by British Rear-Admiral, Sir Francis Beaufort and classifies wind based upon both its speed and the observed effects the wind has on the sea and land. This ranked scale, with 12 levels, goes from calm (Beaufort number 0) to Hurricane (Beaufort number 12) and thus is used in all conditions, not just emergencies. Each level has an observed effect associated with it together with a wind speed and wave height. Therefore, one can estimate the wind speed by visual inspection (NOAA 2006). This scale is used as a dimension within other emergency scales.

Beaufort scale number	Descriptive term	Units in km/h	Units in knots	Description on Land	Description at Sea
0	Calm	0	0	Smoke rises vertically	Sea like a mirror.
1 - 3	Light winds	<=19	<=10	Wind felt on face; leaves rustle; ordinary vanes moved by wind.	Small wavelets, ripples formed but do not break: A glassy appearance maintained.
5	Fresh winds	30 - 39	17-21	Small trees in leaf begin to sway; crested wavelets form on inland waters	Moderate waves, taking a more pronounced long form; many white horses are formed - a chance of some spray

Figure 1: Beaufort Scale (excerpt)

1931: Modified Mercalli Intensity Scale

The Modified Mercalli Intensity (MMI) scale is used to describe the intensity of visible damage by comparing the damage recorded after the event to a set scale of possibilities. The set scale of possibilities has twelve possible categories which all events must fall under. For example – “light”, “moderate”, “violent” (State of California 2003). The scale has no mathematical basis and therefore can vary greatly depending on the individual who is interpreting the damage (Bolt 1993).

MMI Value	Shaking Severity	Summary Damage	Full Description
V	Light	Pictures Move	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VII	Strong	Nonstructural Damage	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles. Some cracks in masonry C

Figure 2: Modified Mercalli Scale (excerpt)

1935: Richter Scales

The Richter Magnitude Scale developed by Charles F. Richter in 1935 (USGS 2006) is used to measure the magnitude of earthquakes. The United States Geological Survey takes great care to clearly define the differences between *intensity* and *magnitude* as there are two different scales used to determine each.

“Intensity is based on the observed effects of ground shaking on people, buildings, and natural features. It varies from place to place within the disturbed region depending on the location of the observer with respect to the earthquake epicenter” (USGS 2006).

The Intensity, as we can see above is based on observable effects, which are not calculated by the Richter scale. This differs greatly from magnitude which is based on the overall measured amplitude of the waves originating from the epicenter of the earthquake.

“Magnitude is related to the amount of seismic energy released at the hypocenter of the earthquake. It is based on the amplitude of the earthquake waves recorded on instruments which have a common calibration. The magnitude of an earthquake is thus represented by a single, instrumentally determined value (USGS 2006).

The magnitude is expressed in decimals and whole numbers. Each whole number represents a magnitude increase of 31 fold. This means that for each level of magnitude,

1, 2, 3, etc., the overall energy being released in the earthquake increases by 31 times. The magnitude of the Richter scale is calculated as follows:

$$\text{Magnitude} = \log_{10}A + (\text{Distance correction factor})$$

where “A” is the amplitude of the seismic wave measured in millimeters. The distance correction factor is included in the magnitude formula to compensate for the variation in the distance between individual seismographs and the epicenter of the earthquakes.

1969: Saffir-Simpson Hurricane Scale

The severity of a hurricane is further described by the Saffir-Simpson Hurricane Scale. The scale was initially developed by Herbert Saffir in 1969 and was based entirely on wind speed. Saffir gave the scale to the National Hurricane Center and Bob Simpson, then director of the center, added the effects of storm surge and flooding. The five category scale is defined by wind speed and describes the expected damage from the wind and storm surges. For example, a Category One hurricane has winds from 74-95mph and may cause some coastal road flooding with damage primarily limited to mobile homes and trees. A Category Five hurricane, on the other hand, is a hurricane with winds of over 155 mph and can be expected to cause complete roof failure on many residences and industrial buildings or even complete building failures (FEMA 2006).

1971: The Fujita Tornado Scale

The Saffir-Simpson Hurricane scale assignment of category is based upon current hurricane conditions. In contrast, tornados are assigned scale ratings after the fact. The Fujita scale infers tornado intensity (wind speeds) by analyzing wind damage after the tornado passed through an area (NOAA 2005). Surveyors measure the approximate path width and length of the tornado’s funnel and from that assign a rank of F0 (weak) to F5 (violent). Each category in the scale has a descriptive phrase and is associated with a

range of wind speed and probable damage descriptions. A weakness of this scale is that the rating is subjective and the characteristics of the tornado are inferred indirectly from the damage it left behind.

1999: Air-Quality Index

The Air Quality Index (AQI), (formerly known as the Pollutant Standards Index) was issued on July 23, 1999 by the U.S. Environmental Protection Agency (EPA) for daily air quality reporting to the public (USEPA 2008). This new index reflects revisions to the primary health-based national ambient air quality standards for ground-level ozone and particulate matter issued by the EPA in 1997. The EPA calculates the AQI and issues a daily report for five major air pollutants regulated by the Clean Air Act. The pollutants are: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide (STAPPA and ALAPCO 2006). The scale aggregates measures of those five pollutants giving a range from 0 to 500 clustered into six categories, ranging from “Good” (0 to 50) to “Hazardous” (300 and above). Each category corresponds to a different level of health concern. The AQI is also used to trigger health alerts (category 5). AQI values over 300 trigger health warnings of emergency conditions as the entire population is more likely to be affected.

2001: US Homeland Security Terror Alert Scale

Subsequent to the 9/11 Jihadists’ terrorist attack, the United States Department of Homeland Security created a color-coded taxonomy of five terror alertness levels, ranging from *Low (green)* to *Severe (red)*. Each level has a short written description associated with it. The scale is nominal, even though every level is also identified by a number (DHS 2001).

2006: Emergency Scales Survey

Gomez, Rohn et. al. used a computer-mediated modified Delphi process and a survey to elicit emergency scale ideas from subjects who were knowledgeable in emergencies, yet no one was an emergency expert or a full-time first responder by training or vocation. The researchers identified three leading ordinal emergency scales (Gomez, Plotnick et al. 2007). Rohn's independent analysis of those scales revealed underlying basic dimensions that define emergency events. Those underlying basic dimensions are: Scope, Topographical Change (or lack thereof), and Rate of Change. The rest of this article articulates each dimension, proposes a unified localizable emergency scale, and discusses the characteristics and usage of the proposed scale.

Proposed Unified Emergency Scale

Any emergency can be defined using three orthogonal dimensions: (a) scope (b) topographical change (or lack thereof) and (c) speed of change. The intersection of the three dimensions provides a detailed scale for defining emergencies. Figure 3 illustrates the three dimensions and the values they may assume. The scale provides a 3D surface for professional and advanced usage, which is convertible to an equidistance numeric scale for public communications. Using an equidistance numeric scale is universally usable: it does not require meaning preservation in translation from one natural language to another as is the case with nominal scales; it eliminates misinterpretation by laic audience, as is the case with logarithmic scales, such as the Richter scale.

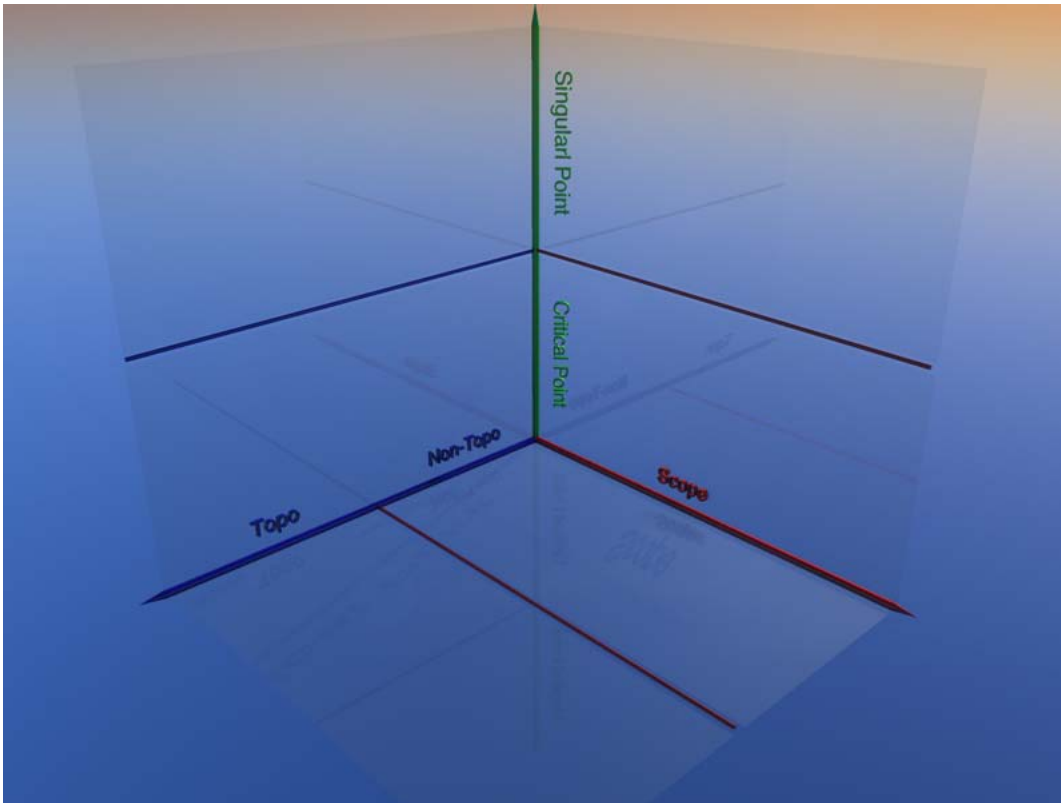


Figure 3: Emergency Dimensions

Scope

Scope of change varies from small to humongous. For the purposes of this proposed scale it is a continuous variable with a lower limit of zero and a theoretical calculable upper limit. For the purposes of this scale we use only two parameters that form the scope: percent of affected humans out of the entire population, and damages, or loss, as a percentile of a given Gross National Product (GNP), which is a country's yearly output of goods and services. When used locally this could be represented by a Gross State Product (GSP) or Gross Regional Product appropriate to the entity under emergency.

The model, and specifically the scope, does not incorporate geographical size because we believe that size is not independent of the number of people affected, and should therefore not constitute an additional coordinate for scale measurements. If the

phenomena happened in an isolated location its size would be rather meaningless as it has little effect on humans.

Many natural and man-made phenomena have a power law distribution. Examples are city size, income, country (state) size, word usage in corpora, ecological systems, and more (Li 1999). Other natural phenomena have logarithmic characteristics. Case in point: human hearing of sound and earthquake magnitude. Intuitively, *scope* makes a good candidate for such a power distribution. Additionally, emergencies are self-similar (Koehler 1995), where the main difference is the perception of the “size” of the emergency and the granular details. Therefore, we define scope as follows:

$$RawScope = \left(\frac{Victims}{Population} + \frac{Monetary Losses}{GNP} \right)^{\left(\frac{\ln(victims)}{\ln(losses)} \right)^{[\beta]}} \quad (1.1)$$

β is a coefficient which we calculated to be 1.26 ± 0.03 using sample data of US emergencies and statistics from the 2006 attack of the Hizballah on Israel, as reported by the Israeli government.

$$MaxScope = \left(\frac{0.7 * Population}{Population} + \frac{0.5 * GNP * \delta}{GNP} \right)^{\frac{\ln(victims)}{\ln(losses)}} \quad (1.2)$$

We loosely assume that a society whose majority of the population (70% in our model) is affected and half of its GNP is drained as a result of a calamity reaches a breaking point of disintegration. Sociologists and economists may shed light as to what a better estimate could be. δ is a financial resilience coefficient. We estimate it to be 1000 for the US, using sample data of US emergencies. We estimate it to be 600 for a country like Israel, using statistics from the 2006 attack of the Hizballah on Israel, as reported by the Israeli government.

$$Scope = \left(\frac{RawScope}{MaxScope} \right) * \frac{1}{\alpha} \quad (1.3)$$

Where α is the normalized scale to be used. We opted for $\alpha = 5$, which yields a scope between zero and five.

Figure 4 shows a few examples based on real events using $\alpha = 5$, $\alpha = 1.26$, $\alpha = 700$ for Israel and $\alpha = 1000$ for the United States. Note that US GNP and population are rounded estimates.

Location	Year	GNP	Population	Description	Affected Population	Losses + Rescue costs	1-5 scope	Data Source
US	1995	8.61E+12	260,000,000	Oklahoma City Bombing	759			NHI
US	2002	9.41E+12	275,000,000	Mississippi Nov. Storms	1,226	\$ 8,296,200.00	0.01	FEMA
US	2003	1.015E+13	269,000,000	Ohio Storm	7,189	\$ 752,516,100.00	0.08	FEMA
US	2005	1.241E+13	295,000,000	Hurricane Katrina	1,200,000	\$ 40,000,000,000.00	0.33	FEMA
Nowhere	2006	1.241E+13	300,000,000	Hypothetical Pandemic	75,000,000.00	\$ 1,500,000,000,000.00	4.08	
Israel	2006	2.72E+11	6,000,000	Wwar	1,750,000	\$ 7,000,000,000.00	1.72	MFA.GOV.IL

Figure 4: Scope calculations based on events

Topographical Change

This dimension indicates if the emergency has to do with some kind of a topographical change or is non-topographical. A topographical change means a measurable and noticeable change in land characteristics, in terms of elevation, slope, orientation and land coverage. The latter can be either natural (e.g., trees) or artificial (e.g., houses).

Topographical changes have a direct impact on the accessibility to an emergency site. Compare the 1929 stock market collapse (a form of an emergency) to that of 9/11/2001. They both happened in the same geographical area – down town Manhattan. Both claimed lives and great financial losses. One involved a major topographical change, at least on a local scale, which made the response physically more dangerous and more difficult.

For the purpose of our proposed emergency scale, topographical change is treated as a continuum ranging between 0 and 1 that gives the estimated visual fractional change in the environment. The fraction is the ratio between the geographical volume occupied

before the disaster and the volume occupied after the disaster, all in relation to sea level in order to anchor the measure to a uniform constant. For example, if the volume of man-made structures, farming and natural vegetation and inanimate natural structures occupied three cubic mile before a disaster, and only two cubic miles after a disaster occurred, then the size of the topographical change is $1-(2:3) = 1/3$. Measuring deformations by means of differential Synthetic Aperture Radar (SAR) interferometry could be a practical means to get such information quickly and reliably (Dixon 1994; Vettore, Ponte et al. 2003).

Rate of Change

An emergency is typified by a departure from normal state of affairs. We can use some mathematics to define and analyze a “departure”, or Change Magnitude:

Let us define a dynamic process $P = \Delta x / \Delta t = X(x, t, a, b, c, \dots)$ where x measures an environment, t is time and a, b, c , etc. are external parameters representing factors affecting the environment. Such factors can be degree of autonomy, energy supply, food supply, water supply; “acceptable” level of political corruption, etc. $\Delta x / \Delta t$ denotes the change of the environment over time. (“ Δ ” is the Greek letter Delta - short for “change”)

Local maximum, minimum and inflexion points occur where the graph of a function P has a horizontal tangent. Such points are called *critical points*. Some critical points can be more than that – they can be in a place where the curve has an irregular behavior such as a cusp or a point of self-intersection. Such a point is termed a singular point. (Anton 1988). We can view a critical point as a relatively small magnitude departure from a given state, where continuity and connectedness still exist. In contrast, a

singular point is a large and sharp departure from a given state, where continuity and connectedness are not assured.

We are interested in calculating $\Delta(\text{victims})/\Delta(\text{time})$ and $\Delta(\text{losses})/\Delta(\text{time})$. Figure 5 illustrates a linear (1.25X/hour) growth in victims during the first five hours of an emergency, followed by an exponential growth ($x^{1.03}$ /hour) in the next four hours and then zero change in the tenth hour. The change rates represent a critical point and a singular point respectively. These rates of change would typically be made for Δt small in comparison to the time increments at which the measurements are made. More precisely, if the rate of change is measured at time t_m , and the average increment between measurements is Δ_{av} , then the increments for measuring the rate of change are taken around t_m , with $\Delta t \ll \Delta_{av}$.

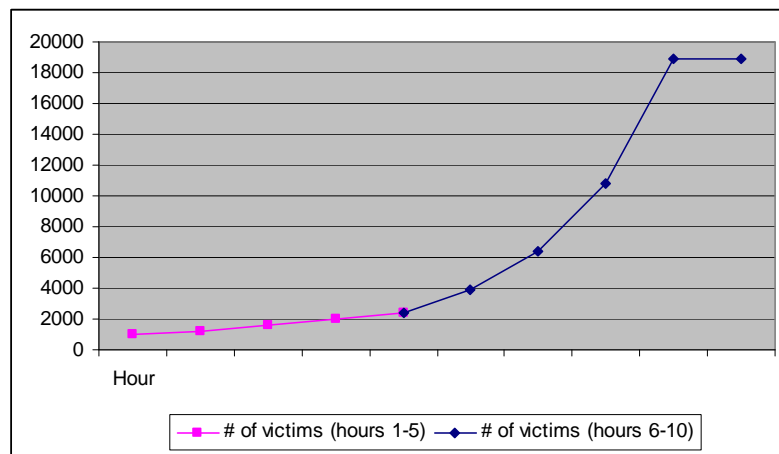


Figure 5 Hypothetical rate of change in number of victims showing two critical points

THE EMERGENCY SCALE MODEL

The scale is a normalized function whose variables are *Scope* (S), *Topography* (T), and *Rate of Change* (D), which may be determined by using certain clientele specific parameter values, whose relations determine the magnitude of the emergency. If one is

seeking a single number to gauge the scale of an emergency (which is probably clientele specific), it should be a function of the coordinates in the proposed scale space; that is, it should be expressible in the form

$$E = \textit{Emergency} = f(S, T, D), \quad (1.4)$$

where the function f , which is likely to depend on the particular scope involved, needs to be specified. A reasonably good general choice would be a weighted average – with weights determined by the clientele – that can be expressed as

$$E = \textit{Emergency} = f(S, T, D) = w_S S + w_T T + w_D D, \quad (1.5)$$

where $0 \leq w_S, w_T, w_D$ and $w_S + w_T + w_D = 1$. There are, of course, other simple choices for the function that can further heighten the effects of one or more of the coordinates; for example, if along with taking the last coefficient above to be significantly larger than the other two, we want to enhance the importance of the rate of change (which seems to be an appropriate approach for many applications), we could modify (1.5) as follows:

$$E = \textit{Emergency} = f(S, T, D) = w_S S + w_T T + w_D D^2, \quad (1.6)$$

or use an even larger power of D . This by no means exhausts the plausible choices: perhaps a particular clientele might hit upon the right choice for them by doing a bit of data analysis mixed with some intuition based upon experience.

Simplified Scale for Public Communications

In some instances, it may be preferable to have an integral scale to more simply and dramatically convey the extent of an emergency, with a range say from 1 to 10, and 10 representing the direst emergency. This can be obtained from the function E above in any number of ways. The following approach is as good as or better than most others: Depending on the clients perceptions, minimum values for each of the variables S, T, D

that constitute the direst emergency can be specified and denoted as S_m , T_m , and D_m .

Then we define

$$E_m := \min \{w_S S_m, w_T T_m, w_D D_m\}, \quad (1.7)$$

which corresponds to an emergency of 10 on the integral scale that we are developing.

Accordingly a reasonable approach to the proposed integral value scale, which we denote as E_* , is to define it as

$$E_* := \left\lceil \frac{10E}{E_m} \right\rceil_{10}, \quad (1.8)$$

where $\lceil x \rceil_{10}$ is a variation of the ceiling function defined as the smallest integer greater than or equal to the real number x , except it assumes the value 10 for all x greater or equal to 10.

The integral scale, and therefore the ceiling function, need not be confined to “10”. We suggest that clientele designate ceiling values to correspond with the size of their oversight responsibility. For example, towns and cities may want to use “10”, counties may want to use “30”, States or their equivalent may want to use “50” while large socio-political entities such as the European Union or the United States may find it most appropriate to use “100” for their ceiling value.

DISCUSSION

A simplistic emergency scale can be expressed as a coordinate in the *STD*-space. A more simplistic approach which might be easier to communicate to non-experts such as the public at large would be a single number. In this section we use a single real world example, hurricane Katrina, to demonstrate the usage and utility of our scale using coordinates and a single number. The next section hints at additional utility that experts may derive from the proposed mathematical model.

Hurricane Katrina

We collected the following data about hurricane Katrina from several sources, primarily from FEMA (FEMA 2006; FEMA 2007) and NASA (NASA 2005). The hurricane affected the states of Alabama, Florida, Louisiana, and Mississippi.

Data

Number of people killed: 1800. Number of people directly affected: over 5.5 million. Estimated 400,000 jobs were lost as a result of the hurricane. About 89,000 square miles (slightly larger than the size of Great Britain) was flooded. Wind damages covered at least double that size, totaling in about 180,000 square miles. Monetary damages (as of Feb 28, 2007): individual assistance for housing and other needs: \$44.28 billion; public assistance for protective measures, debris removal, road & bridges, and public buildings: \$179.45 billion; national flood insurance program claims paid: \$15.65 billion. Total monetary damages as of February 2007: \$239.38 billion. The Gross State Product (GSP) for 2005 in billions of US dollars, as reported by (SSTI 2005) was as follows: Alabama \$132.213; Florida 595.846; Louisiana 135.362; Mississippi 69.672, totaling \$933.093 billion

Scope

Using the data we calculated the raw scope to be 0.87, the max scope 2.28 and the normalized scope 0.38.

Topographical Change

Due to lack of access to volumetric topographical change data we use the ratio of the affected area to the affected states yielding $180,000/222,409=0.80$; obviously this estimate could be improved greatly by the application of more sophisticated data collection techniques.

Rate of Change

Duration = $\Delta t = 13$ days. Victims = $\Delta v = 1800$ people killed. Losses – we split this up into loss of money and loss of jobs: $\Delta m = \$239.38$ billion dollars; $\Delta j = 400,000$ jobs lost.

We recognize that putting a comparative value on life is ethically impossible. However, various legal systems through their courts and insurance companies do so for practical reasons, and so do we. Reckoning that loss of lives is thrice as important as loss of money, which is twice as important as loss of jobs, and that loss of life should be considered on a scale of hundreds, loss of money should be regarded on a scale of billions, while loss of jobs should be on a scale of thousands, we take the following weighted average as a measure of the rate of change:

$$D := \frac{1}{9} \left(6 \frac{\Delta v}{\Delta t} + 2 \frac{\Delta m}{\Delta t} + \frac{\Delta j}{\Delta t} \right) = \frac{1}{9} [6(18) + 2(239.38) + (400)] = 109.64$$

We note here that our reckoning of the relative weights of lives, money and jobs lost – as are the scales on which they are based – has been chosen somewhat arbitrarily based upon what we deem plausible reasoning. Naturally, other clients or agencies might find very different weights and scales better suited to their purposes.

Katrina Emergency Size

Using equation 1.4 we obtain Emergency $= E = f(0.38, 0.80, 109.64)$. Using a cube that depicts all three orthogonal variables, the Katrina emergency would be graphed approximately at the location of the floating ball in Figure 6. In order to obtain a single value E to characterize the emergency, we would have to have the weights w_S , w_T , and w_D along with the preferred function – say (1.5), (1.6) or some alternative. For purposes of illustration, we choose $w_S = 0.5$, $w_T = 0.25$, and $w_D = 0.25$ and select the linear form (1.5).

With these choices, we compute that

$$E = (0.5)(0.38) + (0.25)(0.8) + (0.25)(109.64) = 27.80.$$

In order to compute E^* , we need to decide on a reasonable value of E_m in accordance with (1.7). The following values seem plausible as thresholds for an emergency at the local (city) level: $S_m = 1.0$; $T_m = 2.0$; and $D_m = 150$. With these values specified, we compute from (1.7) that

$$E_m = \min \{ (0.5)(1.0), (0.25)(2.0), (0.25)(150) \} = 0.5.$$

Whence from (1.8) we find that

$$E_* = \left\lceil \frac{10E}{E_m} \right\rceil_{10} = \left\lceil \frac{278}{0.5} \right\rceil_{10} = \lceil 556 \rceil_{10} = 10,$$

which is certainly consistent with our perception of the magnitude of the emergency caused by Katrina at the level of a city such as New Orleans. Applying a national ceiling value of 100, and thresholds for an emergency at the national level with $S_m = 80.0$; $T_m = 200.0$; and $D_m = 1000.0$ we find that for the US the emergency level for public communication on a national level would be:

$$E_* = \left\lceil \frac{100E}{E_m} \right\rceil_{100} = \left\lceil \frac{2780}{40} \right\rceil_{100} = \lceil 71.49 \rceil_{100} = 72,$$

which appears consistent with our perception of the magnitude of the emergency caused by Katrina at the US national level.

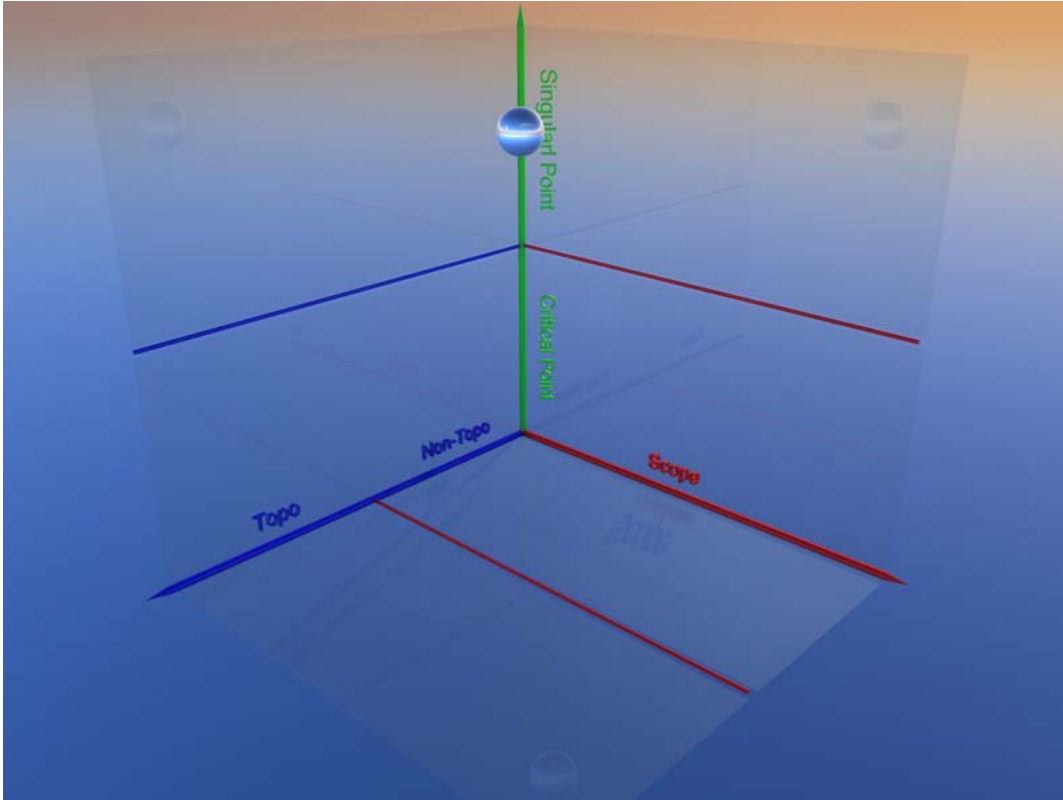


Figure 6: Large scope high rate of change topographical emergency

Additional Utility

If we had a more detailed timeline on all of these changes over the duration of the emergency, we could plot a graph of the losses against time (say on a daily basis) and investigate the derivative of an interpolated function as in Figure 5. This graph would then be plotted as the function

$$\Phi = \Phi(t) := \frac{1}{9} [6(\# \text{ lives lost}) + 2(\text{monetary losses in billions}) + (\# \text{ jobs lost in millions})].$$

Obviously, different weights could be assigned to the various components of the rate of change. The weights could be developed using a variety of techniques, one of which is reliance on data gathered from past events.

More utility may be drawn from the scale than we have covered here, which requires additional mathematical development, and will be explored in a paper that is in progress. As emergencies are probably too complex to be completely predicted by a single number, it is more likely that a particular clientele would postulate a *critical* or *emergency surface* based upon experience and some analysis. Such a surface in STD – space might take the form of the locus or solution set of an equation of type

$$\mathcal{S}_E : F(S, T, D) = 0. \quad (1.9)$$

The nature of these critical surfaces suggest that in practice they are likely to include singularities, and have projections (that would appear to play a significant role in emergency scaling) onto different coordinate planes that may exhibit standard catastrophes in the sense of Thom (Lu 1976).

If one had such a critical surface, it could be used for predicting emergencies before they happen. This might be done along the following lines. Points in the scale space would be plotted over time – using some interpolation method to join points taken at discrete times to comprise a curve (or trajectory) charting the evolution of events. Then if it is observed that a measured point is fairly close to the critical surface, one could use some standard extrapolation procedure to predict an intersection of the trajectory with S_e at some time in the near future, thereby indicating an imminent emergency and providing an opportunity to take certain necessary measures. This is better than simply noting that a point is now near the critical surface, since no matter how close the point is the nature of the evolutionary trajectory might still show that no emergency is on the horizon. For example, suppose the critical surface is just a plane, and the trajectory is close to but also parallel to this plane.

CONCLUSION

This paper proposes a unified emergency scale based on three orthogonal dimensions discovered in a previous research. The proposed scale is formulated using abstract concepts that transcend natural languages, understanding of logarithmic scales, individual organizations, counties or countries, but have the capability of integrating aspects that are sensitive to individual clientele. The response to any given emergency is a direct derivative of these three dimensions. The model addresses some of the challenges and concerns discussed in the Emergence and Complexity literature, a feature that is entirely absent in emergency scales we have identified in the related work section. The management of an emergency event is an exercise in adaptation of complex systems to a rapidly changing environment. The adaptation process can be greatly improved by utilizing an objective measurable event scale which serves as a well grounded scaffold supporting many organizational processes and interactions that occur in an emergency.

The emergency scale is computed as a 3D surface for professional use and a single number on a simple equidistance numeric scale for public consumption, indicating the magnitude of a particular emergency, in lieu of partial, ambiguous and subjective scales that exist to date. Future mathematical development and analysis of the scale may provide sophisticated methods for emergency prediction, and may force organizations adopting it to define their tolerance to surprise changes and thresholds for emergencies during the planning phase rather than after the fact.

REFERENCES

- American Heritage Dictionary (2000). *The American Heritage Dictionary of the English Language, Fourth Edition*. Houghton Mifflin Company.
- Anton, H. (1988). *Calculus with Analytic Geometry, Third Edition*. John Wiley and Sons, isbn 0-471-85045-4.
- Appleby, M., Forlin, G., et al. (2003). *The Law Relating to Emergencies and Disasters. Tolley's Handbook of Disaster and Emergency Management: Principles and Practice*. R. Lakha and T. Moore, Butterworth-Heinemann, isbn 0-406-97270-2.
- Asproth, V. and Håkansson, A. (2007). *Complexity Challenges of Critical Situations Caused by Flooding*. *Emergence: Complexity & Organization*, 9(1): 37-43, issn 1532-7000.
- Bolt, B. A. (1993). *Earthquakes: Newly Revised and Expanded*. W.H. Freeman, New York, NY
- DHS. (2001). *Citizen Guidance on the Homeland Security Advisory System*. Retrieved 24 August, 2006, from <http://www.dhs.gov/>.
- Dixon, T. H. (1994). *Sar Interferometry and Surface Change Detection*. Retrieved March 26, 2007, from <http://southport.jpl.nasa.gov/scienceapps/dixon/index.html>.
- FEMA. (2006). *Frequently Requested National Statistics Hurricane Katrina – One Year Later*. Retrieved March 26, 2007, from http://www.fema.gov/hazard/hurricane/2005katrina/anniversary_factsheet.shtm.
- FEMA. (2006, 09-Jun-2006). *Saffir-Simpson Hurricane Scale*. Retrieved December 12, 2006, from http://www.fema.gov/hazard/hurricane/hu_about.shtm.

- FEMA. (2007). *Hurricane Katrina Information*. Retrieved March 26, 2007, from <http://www.fema.gov/hazard/hurricane/2005katrina/index.shtm>.
- Gomez, E. A., Plotnick, L., et al. (2007). *Towards a Unified Public Safety Scale*. Hawaii International Conference on System Sciences (HICSS), Waikoloa, Hawaii.
- Koehler, G. A. (1995). *Fractals and Path Dependent Processes: A Theoretical Approach for Characterizing Emergency Medical Responses to Major Disasters*. What Disaster Response Management Can Learn From Chaos Theory California, USA, California Research Bureau.
- Li, W. (1999). *Zipf's Law*. Retrieved 24 august, 2006, from <http://myhome.hanafos.com/~philoint/phd-data/Zipf's-Law-2.htm>.
- NASA. (2005). *Hurricanes Katrina and Rita Storm Track Map and Animation*. Retrieved March 26, 2007, from http://www.nasa.gov/vision/earth/lookingatearth/h2005_katrina.html.
- NOAA. (2005). *The Fujita Scale*. Retrieved December 12, 2006, from <http://www.crh.noaa.gov/glossary.php?letter=fujita>.
- NOAA. (2006). *Beaufort Wind Scale*. Retrieved January, 2007, from <http://www.spc.noaa.gov/faq/tornado/beaufort.html>.
- SSTI. (2005). *Real Gross State Product by State, 2001-2005*. Retrieved March 2007, 2007, from <http://www.ssti.org/Digest/Tables/061206t.htm>.
- STAPPA and ALAPCO. (2006). *Air Quality Index (Aqi) - a Guide to Air Quality and Your Health*. Retrieved December 12, 2006, from <http://airnow.gov/index.cfm?action=static.aqi>.

- State of California. (2003). *Modified Mercalli Intensity Scale*. Retrieved January, 2007, from <http://www.abag.ca.gov/bayarea/eqmaps/doc/mmi.html>.
- USEPA. (2008, April 22, 2008). *Air Quality Index: A Guide to Air Quality and Your Health*. Retrieved 20 July, 2008, from <http://airnow.gov/index.cfm?action=aqibroch.index>.
- USGS. (2006). *The Richter Magnitude Scale*. Retrieved January, 2007, from <http://pubs.usgs.gov/gip/earthq4/severitygip.html>.
- Vettore, A., Ponte, S., et al. (2003). *Space-Based Surface Change Detection with Differential Synthetic-Aperture Radar (Sar) Interferometry: Potentialities and Preliminary Investigations*. *Geomatica*, 57(3): 326-334, issn 1195-1036
- Warfield, J. N. (2002). *Understanding Complexity: Thought and Behavior*. AJAR Publishing Company, Palm Harbor, Florida, isbn 0-971-6962-0-9.
- Warfield, J. N. (2003). *A Proposal for Systems Science*. *Systems Research and Behavioral Science*, 20(6): 507-520.