Furthering Development of a Unified Emergency Scale Using Thurstone's Law of Comparative Judgment: A Progress Report

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ABSTRACT

In disasters, local civilians on or near the scene, are often first to respond and give aid. Therefore, the public needs to be well-informed with accurate, time critical information. However, a primary information source is event-specific scales that are inconsistent in their categorization and measurement, adding confusion to public responsiveness. These scales are not extendable to new emergencies in a changing world. We argue for development of a unified emergency scale to facilitate communication and understanding. This scale will inform local communities with regional community-specific information, and will be extendable for further use by professional responders. Research in progress elicited 15 dimensions of an emergency using a Delphi-like process and then ranked the dimensions by importance utilizing Thurstone's Law of Comparative Judgment. Contributions of this paper are to highlight the need for an unequivocal, unified scale and further its development.

KEYWORDS

Public safety scales, emergency management, Thurstone's Law of Comparative Judgment, paired comparisons.

INTRODUCTION

The first people on the scene of an emergency are often not the trained first-responders but, rather members of the community (Palen, Hiltz, and Liu, 2007). Then, in the wake of an emergency, community organizations and individuals frequently rally to the aid of the victims. This was poignantly seen in the aftermaths of the terrorist attacks on September 11, and the massive flooding of the 2004 Indian Ocean tsunami and 2005 Hurricane Katrina . After Katrina, volunteers opened their homes to strangers, created web sites to help reconnect the refugees (Palen et al., 2007), and went to the devastated areas to rescue and evacuate the victims. It is a misconception to think that preparation and response is the sole domain of the professionals. The public must prepare and so must be fully cognizant of the level of threat and its possible consequences. Palen et al. (2007) note that, "in the wake of the U.S. government's failure to deal adequately with Katrina, Americans have even more reason to prepare as if they are 'on their own.'" After the events of September 11, the US Department of Homeland Security developed a website (http://www.ready.gov/america/index.html) in which citizens are instructed on how to prepare an emergency kit and a plan in case of disaster. In any major disaster, and its aftermath, it is important that accurate information be disseminated in a timely manner (Currion, DeSilva, and Van de Walle, 2007). The professional responders, the organizations that provide aid, and the individuals who become involved must be well-informed and understand the detailed extent of the disaster in order to respond most effectively and efficiently. In sum, then, the public prepares for, endures, and aids in the aftermath of emergencies and so must understand fully the extent of an emergency and its potential consequences at any phase of the event. Scales are used (e.g. the Richter scale) to provide information about an emergency, but each is specific to the type of emergency for which it was created. In this paper the need for the development of a unified scale that creates a common lexicon by which all emergencies can be described and understood is proposed. A unified public safety scale can aid community responders (citizens, volunteers) who play

an ad-hoc role in the formation of a crisis response team and for the duration of an emergency (Gomez, Passerini, Hare, 2006; Gomez and Passerini, 2006). It is argued that current emergency scales are inadequate for the public need of a comprehensive understanding for adequate response. We propose how a unified scale might ameliorate the problems associated with the plethora of scales now used. Then a process by which such a unified scale can be developed is described; a process that the researchers have undertaken in an ongoing study. We present results of a preliminary study to develop the dimensions indicating criteria of a ubiquitously used emergency scale. The implications of this research and plans for future research are then addressed.

THE NEED FOR A UNIFIED SCALE

Dimensions of public safety emergencies vary. Public safety, as known in the United States, encompasses the protection and well-being of citizens in a community. The use of scales to describe emergencies is common (e.g. hurricane, tornado, homeland security).

Geographic location-based emergencies challenge the residents in a community and especially challenge the traveler foreign to an area. Different communities are susceptible to different types of emergencies and although the indigenous know what to do, it may be unclear to the visitor. Florida gets hit by hurricanes, Israel is victim to acts of terrorism, and earthquakes are commonplace in California, Turkey and India. But, if an emergency's severity is expressed in a common lexicon, then, together with additional information about what to do, people can be more helpful to themselves and to others.

A public safety scale should accurately describe the nature and magnitude of the emergency, as well as indicate the potential or actual consequences for a particular region. Comprehension of the emergency communicated via an ideal scale is more likely to foster a proper response (Gomez, Plotnick, Morgan, Rohn, Turoff, 2007). The need to understand an emergency warning regardless of where you are (i.e. familiar vs. unfamiliar) is needed.

DEFINING EMERGENCIES

Emergencies are caused by the occurrence of an adverse event whose manifestation is unexpected. An emergency is defined as "a serious situation or occurrence that happens unexpectedly and demands immediate action" (American Heritage College Dictionary, 2004). Kaplan (2004) indicates that no one definition of an emergency or definition of the degrees of an emergency exists. Many of these are on the ordinal scale and not interval which would provide a more accurate reflection.

The presentation of current scales promotes a perception that the levels of the scale are equidistant which may or may not be appropriate for the conditions described. A simple example is based on a grading system. If you also consider using a +/- in the grading system vs. just the grade itself, {A, B, C, D, and F}, you easily see the information perceived between the difference in an A and B versus A- and B+. The latter is a more precise reflection of a student's effort which is further calculated into a numeric equivalence that over time can change.

Per Quarantelli (2000), terms such as emergency, disaster, and catastrophes are often regarded as being conceptually equivalent. Moreover, existing 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. Acting upon erroneous conclusions can cause panic and impact the use of responder resources. Quarantelli asserts (2000) that there is a clear distinction between everyday emergencies and disasters, that accident and disaster differ quantitatively and qualitatively. And the differences between disasters and catastrophes are clearly manifested "at the organizational, community and societal levels". The use of scales and dimensions depends on definitions with accurate criteria to determine the intensity and conditions for each level of the scale.

The importance of scales, such as those for public safety, introduces multiple dimensions as presented in this research. Most existing scales are tied to expert judgment. The premise for this research is to explore a scale that is more comprehensive and better understood by the general public and can extend to a scale used by professional responders.

Table 1 is a summary of some scales presently in use. Although impressive, none of these scales provides for the interpretation of emergencies in a unified manner as outlined in this work.

Scale Name	Scale Use
Richter	Measures the magnitude of earthquakes. Both measures of intensity and magnitude have either own scale (Richter, 2006).
Modified Mercalli Intensity	Describes the intensity of visible damage of earthquakes by comparing the damage recorded after the event to a set scale. The set scale has twelve possible categories which all events must fall under (Earthquake Hazards Program, 2006).
Wind and Storm	Quantifies the intensity of an event. Numerous wind and storm scales exist, but fails to provide information about the effects of the event. (FEMA, 2006)
Beaufort Wind	Measures speed and observed effects the wind has on the sea and land are ranked, with 12 levels, going from calm (Beaufort number 0) to Hurricane (Beaufort number 12) and thus is used in all conditions, not just emergencies (Beaufort, 2006).
Saffir-Simpson Hurricane	Measures wind speed with a five category scale and describes the expected damage from the wind and storm surges (FEMA, 2006).
Fujita	Assigns scale ratings based on current conditions (after the fact) to rate the intensity of a tornado after it has passed over man-made buildings and is based upon the extent of the damage to those buildings. (Fujita, 2006; Tornados, 2006)
Air Quality Index	Calculates five major air pollutants (man-made) are reported daily. The ratings, aggregates of the five measures, go from 5 to 500, the higher the rating the more deleterious the air quality to human health. The scale has six categories from Good (AQI of 0 to 50) to Hazardous (from 301 to 500) and can be used to indicate an air quality emergency (AQI, 2006).
US Homeland Security Terror Alert	Measures five color-coded terror alert levels. Subsequent to the 9/11 terrorists attack, the United States Department of Homeland Security (DHS, 2006).

Table 1 Emergency Scales

ADVANTAGES OF A UNIFIED SCALE

A unified, comprehensive scale would be based upon a morphological analysis of the crucial dimensions of an emergency and could describe any emergency in "universal language" (i.e. common lexicon) that can be understood by anyone, even when the emergency is unfamiliar. The scale can be publicized quickly, enabling better response from the community. Shneiderman and Preece (2007) propose that web-based communication can be used to disseminate information to local communities to inform and assist them in helping each other in the event of an emergency. A unified scale could be easily posted on a "911.gov" (Shneiderman and Preece, 2007) site with the levels of intensity for each dimension adjusted to reflect the current situations in different locales. Each community will best know how their own community is faring and what parts of their infrastructure might be more vulnerable and can have their unique local emergency situation described in a lexicon understood by all.

Another advantage of having a unified scale is that new types of emergencies for which there are no current scales, can be quickly described and the information rapidly disseminated to the public. The use of a common lexicon also means that information about emergencies that are uncommon in an area can be disseminated and understood if the area is suddenly faced with what is, in essence, a freak occurrence. A tornado in a region that does not usually get tornadoes is an example. With a unified scale, the expertise of one area could be more easily transferred to another. For example, the Israeli's know that in the aftermath of a terrorist attack, a second wave attack is likely. America was unprepared for that likelihood, and so the response to the first World Trade Tower attack on September 11, 2001 was inappropriate. After the first attack, the responders assumed the attack was over and sent people back into the second tower, resulting in more loss of life.

Ubiquitous adoption of such a scale will be a process that will need to involve the academic community,

government, and leaders of community response organizations. It is therefore important that the development of such a scale be done in the context of the research community so that the result is grounded in theory and sound research practices. Such an effort has been started with research, reported here, into the critical dimensions to be included in a unified scale.

A PROCESS TO DEVELOP A UNIFIED SCALE

This ongoing research explores a technique to identify critical dimension of an emergency in order to create a unified scale. A modified Delphi process was used to elicit dimensions for a morphological analysis of an emergency (Gomez et al, 2007). Here we report on an analysis of the ranking of the top fifteen identified dimensions of an emergency. Beginning with those dimensions, this paper discusses the use of Thurstone's Law of Comparative Judgment to extend the analysis on the rank order findings from the survey results. Previous research on rank order scales resulting from Delphi studies support the use of Thurstone's Law of Comparative Judgment (Li, Cheng, Wang, Hiltz, and Turoff, 2001; Turoff and Hiltz, 1995) for this research.

METHODOLOGY

Modified Delphi Process

The Delphi Technique (Dalkey, 1972; Linstone and Turoff, 1975) is a non face-to-face procedure for soliciting and aggregating group members' opinions. Delphi structures group communication so that participants can view and evaluate the opinions of the other participants (Quarantelli, 2000). We seek to obtain a more representative view from the general public on their understanding and the degree of importance when ranking dimensions of emergencies.

Thurstone's Law of Comparative Judgment

Thurstone's Law of Comparative Judgment has the attractive feature of taking in ordinal data and calculating a single interval scale which reflects a group's position (Thurstone, 1927). This is one-dimensional data where a judgment is made against two items at a time where one item is preferred over the other based on some stimulus. A special case of Thurstone's allows for rank ordered data to be transformed into paired comparison data.

Ten subjects ranked 15 dimensions from least to most important as it directly affected the welfare of the public. Thurstone's method can provide the underlying variables that can contribute to the end result that is the fundamental source behind the decision. This provides another means of analyzing the data. For example, from the 15 dimensions, many were considered an equal threat. The dimensions' proximity may have core variables in common which are not overly obvious. These could further be grouped together based on some insightful variable, like immediacy for example. These insights are derived based on other information common to the pairs close in proximity. The two could be related not by name (obvious) but by immediacy (not obvious) or some other underlying variable.

RANK ORDER RESULTS AND THURSTON'S COMPARISON

The results of applying Thurstone's method to the dimensions are provided in Table 2. The first column in the table indicates the numeric value that was derived by the analysis of the rank ordering of the dimensions; the second column gives the order of the dimensions based upon that analysis. For comparison, the last three columns of the table show the result of analyzing the means of the participants' rankings of the dimensions.

While a rough estimate of relative importance between the dimensions can be understood by ordering the means of the ranking of dimensions, applying the Law of Comparative Judgment can provide further insight into the underlying relationships between dimensions. This is from the added insight providing the clustering of dimensions that are perceived to be similar in importance based on some merit as well as those perceived as drastically differing in judgment.

Dimension	Thurstone's Interval Score	Interval Rank		Mean Rank	Mean	Standard Deviation
Casualties and Fatalities	**7.00**	**1**		**1**	**5.5**	**5.72**
Systems Impact (utilities, power)	**5.00**	**2**		**3**	**6.1**	**2.85**
Potential to Spread	**3.60**	**3**		**2**	**6.0**	**3.77**
Infrastructure Response Adequacy	**2.90**	**4**		**4**	**6.9**	**3.31**
Loss of Command and Control	**2.43**	**5**		**4**	**6.9**	**4.91**
Resources for Containment or Aid	**2.40**	**6**		**5**	**7.1**	**4.04**
Infrastructure Damage in Terms of Physical Damage	**2.40**	**6**		**5**	**7.1**	**2.92**
Time Implications for Response	**2.38**	**8**		**5**	**7.1**	**3.67**
Duration	**1.82**	**9**		**6**	**7.3**	**4.83**
Public Reaction	**0.09**	**10**		**7**	**8.0**	**3.13**
Geographic Impact	**-0.04**	**11**		**7**	**8.0**	**4.32**
Time to Return to Normal Conditions	**-2.93**	**12**		**8**	**9.0**	**3.33**
Chance of Imminent Reoccurrence	**-4.39**	**13**		**9**	**9.6**	**4.77**
Financial Loss	**-9.30**	**14**		**10**	**11.5**	**5.32**
Financial Recovery Loss	**-12.99**	**15**		**11**	**12.3**	**3.40**

Table 2: Morphological Dimensions Rankings – Means and Paired Comparison Analysis

A comparison of the means of the rankings and the interval scores derived by application of the Thurstone's Law of Comparative Judgment indicates that the ordering of dimensions is nearly the same for both (with the exception of the second and third items in the orderings being swapped by the two methods). However, Thurstone's Law of Comparative Judgment gives finer grained analysis, with only one tie while there were multiple ties in the means analysis. Thurstone's, as noted above in the discussion of the method, also gives a clearer picture of the proximity of the dimensions to each other in the rank order. This can be seen graphically below in Figure 1.

That Casualties and Fatalities is ranked as most important could be expected. It is also not surprising that financial loss comes near the bottom, in that the emphasis was on trying to develop the determination of how bad a disaster threat is going to be in terms of preparing a response and financial loss is really more relevant to the recovery period. Also ranked near the bottom of the queue was chance of imminent reoccurrence and time to return to normal conditions. Those dimensions, while of importance, are also not critical to the exigency of the emergency and are

more relevant to after the critical period has passed. The application of Thurstone's Law of Comparative Judgment (Figure 1) also revealed that respondents found as essentially equivalent in importance; Time Implications for Response, Loss of Command and Control, Resources for Containment or Aid, and Infrastructure Damage in Terms of Physical Damage. Results for both Infrastructure Response Adequacy and Duration were nearly equivalent to them as well. Further analysis is needed to understand the differences in results. Planned future research may give insight into this phenomenon.

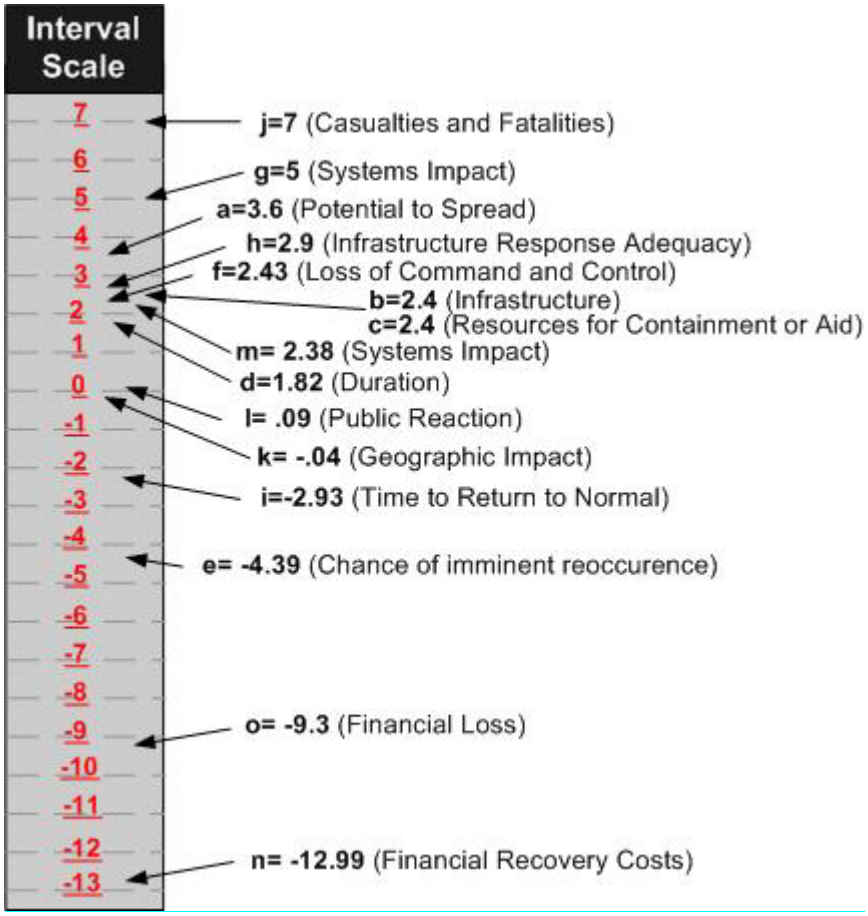

Figure 1. Thurstone's Paired Comparison n=10

CONTRIBUTION

The contribution of this work is to highlight the need for the development of a unified emergency scale that can be easily understood by the public, and to aid in the ongoing quest to develop such a scale.

CONCLUSION AND FUTURE OBJECTIVES

Although the relative means of the rankings of the emergency dimensions were not precisely what resulted from an application of Thurstone's Law of Comparative Judgment, the rank orders were similar in comparison. However, the actual rank order is clearer from Thurstone's analysis, which gives a degree of measurement adding beneficial insight into the dimensions giving strength of opinions derived through the differences calculated between each dimension on the interval judged. This provides much more information than a simple rank order would provide. Along with the development of the fifteen dimensions that should be used by professionals to measure the severity of a disaster we also developed through the Delphi three potential public scales (with point definitions) intended to be better understood by the general pubic (reference). One example of what a synthesis of those scales would look like is the following:

1. **Incident**
2. **Minor emergency**
3. **Major emergency**
4. **Disaster**
5. **Catastrophe**
6. **Extreme Event**

One objective of future work is to develop a system that would allow local professionals in Emergency Management to dynamically estimate each of the fifteen morphological dimensions for any approaching or ongoing emergency event. Estimates, such as the number of injured expected, could be made by local professionals that would reflect local conditions and the degree of preparedness. This would provide a more accurate local estimate. One could then utilize a separate Thurstone scale, giving the weights of each of the 15 dimensions, also based on local judgments, to map contributions of each of the 15 dimensions proportionally to single public scale such as the example above.

The above scale along a linear crisis thermometer would make a meaningful visualization on any future "911.gov" website for a local community and reflect the conditions in that local community in terms of the preparedness state, the scope the event, and response planned. Given that the professionals inputting the data could do this on a continuous basis from the earliest detection of the threat and on into the recover period this could become the appropriate measurement for a common understanding of what was happening based upon local community conditions. Such dynamic measurements can be based upon a subset of all the experts' opinions and the resulting uncertainties can be expressed as variations in the interval scale point (White, Turoff, Van de Walle, 2007).

We plan to continue the current Delphi process, but with professionals in Emergency Management to aid in designing the final scales and the system requirements for a software system that will allow automatic compilation of this type of scaling and the visualization of the results on an appropriate 911.gov type local website. Obtaining a local area willing to be the test bed for this type of system is a critical step in the process to gain acceptance of this approach. Working with professionals in a local area who are familiar with the conditions in that area and the prior experiences with relevant emergency situations for that area are what would be crucial for the evolution of this approach to a meaningful system that could be implemented on a national basis.

REFERENCES

1. "Air Quality Index (AQI)", (2006) *AirNow*. Online at http://airnow.gov/index.cfm?action=static.aqi
2. American Heritage Dictionary of the English Language (2004) Fourth Edition, Houghton Mifflin Company. Online at http://dictionary.reference.com/search?q=emergency
3. "Beaufort Wind Scale" (2006) *Stormfax Weather Almanc.* Online at http://www.stormfax.com/beaufort.htm
4. Currion, P., De Silva, C., and Van de Walle, B. (2007) Open Source Software for Disaster Management, *Communications of the ACM*, March 2007, Vol. 50, No. 3 pp. 61-65.
5. Dalkey, N. C. (1972) The Delphi method: an experimental application of group opinion. In N. C. Dalkey, Rourke, D.L, Lewis, R, and Snyder, D. (eds.) Studies in the quality of life. Lexington, MA: Lexington Books.
6. Department of Homeland Security (2001) http://www.DHS.gov 2006
7. "Earthquake Hazards Program" USGS online at http://earthquake.usgs.gov/learning/topics/mercalli.php
8. "Fujita-Pearson Tornado Scale" (FPP scale, 2006) *Stormfax Weather Almanac.* Online at http://stormfax.com/fujita.htm

9. Gomez, E.A., Passerini, K., and Hare, K. (2006) Public Health Crisis Management: Community Level Roles and Communication Options, *Proceedings of the 3rd Annual ISCRAM*, Newark, NJ.

10. Gomez, E.A., Passerini, K. (2006) Community Responders in a Public Health Emergency: Leveraging Their Role in the Crisis Response Teams with ICT Readiness. .http://www.iaem.com.sg/pdfs/May_200605bulletinonline.pdf, *International Association of Emergency Managers (IAEM).*

11. Gomez, E.A, Plotnick, L.S., Morgan, J.K., Rohn, E., Turoff, M. (2007). Towards a Unified Public Safety Scale. *Proceedings of HICSS*, Big Island, Hawaii. .

12. "Historical Tornadoes", NOAA Online. Online at http://www.spc.noaa.gov/faq/tornado

13. Kaplan, S. (2004) Tolley's Handbook of Disaster and Emergency Management: Principles and Best Practices; Disaster and Emergency Management Systems, Lexis Nexis UK

14. Linstone Harold A. and Turoff, Murray (1975) The Delphi Method: Techniques and Applications, Addison-Wesley

15. Li, Z., Cheng, K., Wang, Y., Hiltz, S. R. & Turoff, M. (2001) Thurston's Law of Comparative Judgment for Group Support, *Proceedings of AMCIS 2001*

16. Palen, L., Hiltz, S.R., and Liu, S. (2007) Online Forums Supporting Grassroots Participation in Emergency Preparedness and Response, *Communications of the ACM,* March 2007. Vol. 50, No. 3. pp. 54-58.

17. Quarantelli, E.L. – (2000) Emergencies, Disasters and Catastrophes Are Different Phenomena, Preliminary Paper #304. Newark (Del.): University of Delaware, Disaster Research Center.

18. "Richter Scale / Mercalli Scale", (2006) *USGS*, Online at: http://pubs.usgs.gov/gip/earthq4/severitygip.html ,

19. Shneiderman, B., and Preece, J. (2007) 911.gov*, Science*, 16 February 2007. Vol. 315 p.944.

20. The Fujita Scale of Tornado Intensity, Online at http://www.toradoproject.com/fscale/scale.htm.

21. Thurstone, L. L., (1927) A law of comparative judgment, *Psychological Review*, (34), 273-286.

22. "Saffir/Simpson Hurricane Scale. 'Hazards'", (2006) FEMA, Online at http://fema.gov/hazards/hurricanes/saffir.shtm.

23. Turoff, M. and Hiltz, S. R., (1995) Computer Based Delphi Processes. In: Adler, M. and Ziglio, E. (Eds), Gazing Into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health, London, Kingsley Publishers, 55-88.

24. White, C., Turroff, M, and Van de Walle, B. (2007) A Dynamic Delphi Process Utilizing a Modified Thurstone Scaling Method: Collaborative Judgment in Emergency Response. *Proceedings of the 4th Annual ISCRAM,* Delft, Netherlands.