HOW CONSISTENT ARE EMERGENCY AND DISASTER MEASUREMENTS AND SCALES?

by

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ABSTRACT

Measurements play major roles in our lives and in many fields including the natural sciences, social sciences, economics, and technology. Emergency managers utilize emergency and disaster scales and measurements in their planning for, mitigation of, preparedness for, response to and recovery from emergencies, disasters and other events. In order to explore the consistency of different emergency and disaster scales, this thesis measures thirteen (13) case studies representing a range of different emergencies in terms of type, size, location, and impact using at least three (3) different emergency scales from a total of seven (7) selected scales from practice and the literature. The scales are the Modified Mercalli Intensity, Richter, Saffir-Simpson Hurricane Wind Scale, Fujita Tornado, FEMA’s, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency scales. The selected emergency cases include natural disaster events such as earthquakes, hurricanes, and tornados in addition to technological events such as fires and explosions, terrorist attacks, and even car accidents. The selected emergencies also range from the 9/11 terrorist attacks and Hurricane to one person injury events. The thesis compares measurement results per emergency event showing very low consistency that could mislead emergency managers. The comparisons of measurement results per scale revealed important findings shared at the end of the thesis in addition future research suggestions.
Chapter 1

INTRODUCTION

Scales and agreed upon measurements are used to visualize and understand important things such as time, space, temperature, mass, currency, and many more attributes that we need or wish to quantify. We use scales and measurements for many purposes including better assessment, planning, and management. Further, they provide insights and support decision-making. They also play major roles in many major fields including the natural sciences, social sciences, economics, and technology. The field of emergency and disaster management also utilizes many metrics including measurements of specific phenomena such as the Richter scale for earthquakes and the Saffir-Simpson scale for hurricanes. Furthermore, some scholars have proposed Unified Emergency (Rohn and Blackmore, 2009) and disaster (Fischer, 2003) scales with different focuses including economics and social disruption. However, this topic has not received a great deal of attention in related literature.

Motivation and Background

The complexity of emergency and disaster management means that emergency managers, politicians, the media and researcher seek new ways to communicate information about the event. Measurements and scales can help
provide better clarity using numbers, figures, and descriptions to inform emergency and disaster management in matters related to planning, mitigation, preparedness, response, and recovery and hopefully allow for making more informed decisions (Buckle, 2005). They can also facilitate clear communication and mutual understanding of the nature of the emergency by emergency managers, responding organizations, government agencies, and the public (Rohn and Blackmore, 2009). Such enhancement of communication, which has been one of the main emergency management challenges (Manoj and Baker, 2007), is vital especially when we know about half of the problems with communication is due to individuals using the same words with different meanings while the other half is due to individuals using different words with the same meanings (Appleby et al, 2003). Moreover, a clear distinction among emergency and disaster scales and levels is critical to policy and program development and implementation, and to affected people to whom the difference between “disaster” and “emergency” are legal terms indicating eligibility for governmental assistance or not (Buckle, 2005).

The maxim, attributed to several brilliant minds such as Peter Drucker, Tom Peters, Edwards Deming, and Lord Kelvin, stating “what gets measured, gets managed” supports the importance of measurement. So when we measure emergencies, we get to understand them more. Increased mutual understanding
among and within organizations can help also enhance communication and the effectiveness of coordination, and the enhancement of communication and coordination effectiveness may very well enhance emergency management. Because of the importance of emergency measurement to its management, this thesis explores a different range of emergency and disaster measurements and scales. The research uses mixed methods. Specifically, quantitative and qualitative comparative case studies methods are used to see how consistent the emergency and disaster scales and measurements are with each other given the same emergency and the same reference, before making observations and recommendations for improvement and enhancement.

**Research Question, Objectives and Approach**

The research question addressed in this research is “How consistent are emergency and disaster measurements and scales?” To answer this research question, the following specific objectives will be addressed to explore this subject:

- To explore the concept of emergency measurement.
- To review different emergency and disaster measurements and scales to understand what they measure and how or their measurement methods.
- To apply the selected scales by measuring different applicable real emergency cases by each scale.
To adjust all measurement results into a percentage format to allow for direct comparisons.

To compare the measurements of the different applicable scales for each real emergency case to test the scales consistency using United States of America as the reference for the scope of the event.

To compare and analyze all applicable measurement results for each scale while considering its measurement method to capture strengths and areas of improvements.

To share observations, recommendations and improvement ideas for a more useful scale/measurement, and suggestions for future researches.

Using a mixed quantitative and qualitative comparative case studies method, this thesis explores some of the different emergency and disaster measurements and scales. The thesis presents and discusses related literature to the subject, the selection of the methodology, data collection, and the analysis design for answering the research question “How consistent are emergencies and disasters scales?” All observations and recommendations that are made are shared along with suggested future research.

**Scope and Limitations**

This thesis has several limitations including the review and testing of limited number of scales and measurements tools. Another limitation is the review of limited and purposively selected real emergency scenarios or cases.
The limited and purposive selection is made because there is no previous similar comparison study to build on and to help identify a clearer scope. The exploratory nature of the research also recognizes the limited time and resources available. Another important limitation is adjusting all scale results to a percentage without giving attention to data and calculations relations such as discrete and/or continuous linear or logarithmic. Therefore, the thesis research investigates a very specific matter with very generic yet clear scope.

Having said that, the selected scales include most officially used and publicly known scales for measuring different types of emergencies, such as earthquakes, tornadoes, and hurricanes, in addition to recently developed scales identified from the literature that aim to measure the impact, repercussions or resources required to respond to emergencies independent of the type. The purposive selection of real emergency cases includes different types of emergencies, such as earthquakes, tornadoes, hurricanes, terrorisms, industrial fires and explosions, mudslides, home fires, and motor vehicle accidents. The other reason was to include emergencies with different scales or sizes starting from car accidents and home fires to the 9/11 terrorist attacks and Hurricane Katrina. Moreover, the selection of cases was limited to those that took place in the United States of America. The United States is also used as the country that serves as the reference for losses and damages.
**Thesis Organization**

The thesis is organized as follows. Chapter 2 next presents the literature review including the measurement concept, the selected measurements and scales, and an overview of employed methodologies. Then, chapter 3 explains this thesis research methodology including the case study selection, data collection, and analysis plan. After that, chapter 4 presents the collected data that includes the descriptions of each case study and their measurement steps and results using the applicable scales from those selected from the literature. Finally, chapter 5 presents the analysis method and observation before sharing the recommendations and conclusions in chapter 6. References are at the end of the thesis.
Chapter 2

LITERATURE REVIEW

This literature review is divided into three parts. In the first part, the concept of emergency and disaster measurement is reviewed. The second part discusses the seven (7) selected common and recently proposed emergency scales including their method and application. The third part reviews the employed methodologies and why.

The Concept of Emergency Measurement

The utilization of quantifications, measurements, and scales is not new in emergency management. During emergencies, measurements such as distance, time, temperature, and the numbers of victims, responders, resources are very common for several reasons. These quantities support effective communication, mutual understanding, and more informed decision-making. Despite that, we cannot describe these measures as attempts at comprehensive measurements of emergencies. However, there are several emergency measurements that are known and utilized in emergency management. For example, we have the emergency scales that capture a single type of natural phenomena, such as the Richter scale for earthquakes, the Fujita scale for tornados, and the Saffir-Simpson scale for hurricanes. In addition, there are also other type of scales that are in used or recently proposed in the literature to
measure emergencies independent of their type or size. All of these scales are discussed in detail in the second part of the literature review.

Philosophically, “numerical identity requires absolute, or total, qualitative identity, and can only hold between a thing and itself.” (Noonan, Curtis, 2014). In other words, in order for any two things to be placed in a numerical or quantitative scale, they need to be totally qualitatively identical or share the same characteristics and qualities. For example, seconds, years, and centuries have a shared quality of duration and time and that why can be placed on a time scale using their quantitative difference in this particular quality of time. However, seconds, years, and centuries cannot be put in, for example, a distance scale like millimeters, centimeters, and kilometers because seconds, years, and centuries do not share the quality of distance. Measurements can also be more complicated that a single shared quality. For example, different forces are put in a force scale by considering multiple shared qualities such as mass and gravity or acceleration (speed over time or distance over time squared), and putting them in a correlated equation that properly links and weighs each of these shared qualities to each other for the accurate and meaningful measurements.

This means that in order for emergencies with different types and sizes to be measured and put on a scale, they need to be qualitatively identical so that
the scale can be built on the shared qualities. However, due to the complexities of emergencies and the difficulty to capture all shared qualities among them, we could identify critical shared qualities and use the quantitative differences of each to build a scale with proper scaling, correlations and adequate weightings for these shared qualities for meaningful measurements. A discussion of the mechanics of building a scale is presented in Davidson (1997). Therefore, in order to see whether emergencies, disasters, and catastrophes are qualitatively identical or not, we review the literature that presents the definitions and descriptions of these events for a better understanding, and to identify and discuss their similarities and differences. We also review and discuss literature related to specific qualitative differences among these events.

**Definitions and Specific Descriptions**

Emergencies or incidents despite their different types are categorized into three main terms; emergencies, disasters, and catastrophes within the literature and by the United State Federal Emergency Management Agency (FEMA). In this section, we only review a few common definitions and descriptions of emergencies, disasters, and catastrophes for better understanding and to explore similarities and differences.

Starting with emergencies, Drabek and Hoetmer (1991) define them as routine adverse events that do not have community-wide impact or do not
require extraordinary use of resources or procedures to bring conditions back to normal. Emergencies can be natural, such as minor earthquakes, floods, hurricanes, and tornados, or technological such as minor motor accidents, fires, and explosions. Emergencies are also seen as well understood and clearly defined classical incidents that require a limited number of emergency response providers familiar with these types of events and with clear-cut roles and responsibilities under a present authoritative structure (Lagadec, 1993). Therefore, as Lagadec (1993) observes, they are manageable and the condition is brought quickly under control. Because emergencies are routine and predictable, governments can plan accordingly and manage them. Although there might be some major emergencies that occasionally require outside help from the neighboring emergency response organizations, for anyone not directly involved in such emergencies, life goes on (Phillips; Neal; Webb, 2012).

Fritz (1961) defines disasters as “actual or threatened accidental or uncontrollable events that are concentrated in time and space, in which a society, or a relatively self-sufficient subdivision of society undergoes severe danger, and incurs such losses to its members and physical appurtenances that the social structure is disrupted and fulfillment of all or some of the essential functions of the society, or its subdivision, is prevented”. Disasters are also
non-routine events exceeding the capacity of the affected area to respond to save lives; to preserve property; and to maintain the social, ecological, economic, and political stability (Pearce, 2000, Chapter 2, 5). As a result, emergency organizations work to expand and extend themselves and ask at the same time for additional support from nearby communities to cope with the event (Quarantelli, 1987). Just like emergencies, disasters can also be natural, such as earthquakes, tornados, hurricanes, and floods, or technological, such as huge fires, large explosions, and destructive terrorist attacks (Phillips; Neal; Webb, 2012). Moreover, social science researchers have argued that disasters are social constructions and that an event occurring where there is no population does not usually rise to the level of a disaster unless it produces cascading effects that have an impact on society (Canton, 2007). In short, everyday life as we know it ceases during a disaster and the priorities change to focus on the event at hand with the need for extensive outside help (Phillips; Neal; Webb, 2012).

As for catastrophes, Hoetmer (1991) defines a catastrophic disaster as an adverse event that affects the entire nation and requires extraordinary resources and skills for recovery. Rotanz (2007) defines “catastrophic incident” as any natural or manmade incident, including terrorism that results in extraordinary levels of mass casualties, damage, or disruption, severely
affecting the population, infrastructure, environment, economy, national morale, and or government functions. He continues by saying that catastrophic events disturb government operations and emergency services and could have long term nation-wide impacts. Moreover, Bissell (2013) defines a catastrophe as an event that directly or indirectly affects an entire country, requires national or international response, and threatens the welfare of a substantial number of people for an extended period of time.

FEMA, in the National Response Framework (NRF) (NRF, 2013), looks at emergencies, disasters, and catastrophes as levels or scales of incidents defined in the context of response readiness and resources. For example, emergencies, such as transport crashes, small fires, local floods, and building collapses, are those incidents with local effects and are usually managed with local resources. Disasters are those with local or regional effects and are managed with local or regional resources (national resources may also be used, but damaging effects are not national and the surrounding societal infrastructure remains intact). Catastrophes, however, have national implications as local and regional response become impossible or inadequate. In catastrophes, many governmental and societal systems are affected and they may involve multiple countries.
Specific Qualitative Differences

So far, we have reviewed and discussed many differences between emergencies, disasters, and catastrophes, which seem to be quantitative differences. The differences, such as frequency, predictability, controllability, need for more resources, physical and social impact and cost, and time for recovery, are clear in the definitions and descriptions of emergencies, disasters, and catastrophes. They can also be directly noticed and rationally recognized. There are also at least four (4) identified qualitative differences in terms of behavior of organizations that appear in disasters but not in everyday emergencies (Quarantelli, 2000). It is important to note here that these qualitative differences are not related directly to the phenomena but in terms of organizational behavior and management and the social impact and adjustment. The differences, in brief, are as follows:

- Disasters quickly involve more and unfamiliar groups (or “massive convergence”) but not in everyday emergencies or accidents.

- Those impacted by disasters adjust to losing part of their autonomy and freedom of action (or “loss of relative independence”).

- Emergency personnel apply different performance standards or shifting from non-emergency duties to emergency-duties and standards.
• Emergency management organizations operate within “closer than usual public and private sector interfaces” or the “collapse of the private-public sector lines”.

Quarantelli (2006) has also identified six (6) characteristics of catastrophes that distinguish them from disasters and Wachtendorf et al. (2013) added a seventh (7th) characteristic. In brief:

• Most or all of the built structure in the community is heavily impacted and the facilities and operational bases of most emergency organizations are themselves usually impacted.
• Local officials are unable to undertake their usual work role.
• Help from nearby communities cannot be provided.
• Most, if not all of the everyday community functions are sharply and concurrently interrupted.
• The mass media constructs catastrophes even more than they do disasters.
• Because of the previous five processes, the political arena becomes even more important.
• Mass and extended out-migration of people occurs.

These distinctions between everyday emergencies, disasters, and catastrophes are made to advise emergency managers to consider these differences in their emergency planning and management (Quarantelli, 2000, 2006).
Literature Review Summary and Observations

The review of the literature reveals that in order to put two things on a scale, they must have important shared qualities on which to build the scale. The literature review also shows that emergencies, disasters, and catastrophes are all adverse or undesired events that can be natural or/and technological with some sort of a physical and social impact and cost. These qualitative similarities are very important as they provide the overall picture of each event including its description, cause, and impact. These important similarities can also be strengthened when knowing that emergencies, disasters, and catastrophes are managed by the same concepts and phases represented by the 4-phase emergency management cycle (mitigation, preparedness, response, and recovery).

Moreover, the reviewed literature highlights several differences among emergencies, disasters, and catastrophes such as the incident’s routineness or frequency, predictability, controllability, need for more resources, physical, social, and cost impacts, and time for recovery. However, these differences seem to be quantitative rather than qualitative differences since frequency, predictability, and controllability are generally decreasing as we move from emergencies to catastrophes. And the need for more resources or shortage of
resources, the physical, social, and cost impacts, and the recovery time or
duration are generally increasing as we move from emergencies to catastrophes.

The qualitative differences between everyday emergencies, disasters,
and catastrophes, discussed earlier, may also quantitatively differentiate among
the events because “it appears that the differences are more likely to appear
going up the social scale from the individual to the societal level” (Quarantelli,
2006). For example, the convergence of individuals does occur in everyday
emergencies while the convergence of groups and organizations seem to be
more apparent as we move from everyday emergencies to catastrophes.
Furthermore, convergence of individuals, groups, and organizations, loss of
independence and autonomy, degraded performance standards, blurred public-
private interfaces, and greater physical and social impacts, media coverage,
political attention, and migration also seem to increase as we move from
emergencies to disasters to catastrophes.

Finally, since there are important shared qualities among emergencies,
disasters, and catastrophes, these qualities can be utilized to build a scale.
However, because emergencies, disasters, and catastrophes are complex
phenomena, it will be very difficult to capture all of their shared qualities.
Therefore, another way of building a scale could be to identify critical shared
qualities, assess these qualities, and weight them based on importance or impact build a scale.

Now, we review and discuss the seven (7) purposively selected scales along with the qualities and dimensions used within the scale measurement method.

**Selected Measurement Scales for Emergencies and Disasters**

There are many measurement scales used to measure a specific natural phenomena like earthquakes, hurricanes, and tornados. There are also recently proposed Unified Emergency and disasters scales designed to measure all types and sizes of emergencies. Some scales are used to measure or predict the potential intensity and impact of emergencies before and during these events while others are used for post-event classification (Rohn, Blackmore, 2009). Because of the scope and objective of this research, only seven (7) selected scales are discussed here before using these scales for our emergency scenarios measurements. The selected scales are: 1) Modified Mercalli Intensity, 2) Richter Scale, 3) Saffir-Simpson Hurricane Wind Scale, 4) Fujita Tornado Scale, 5) FEMA Scale, 6) Fischer’s Disaster Scale, and 7) Rohn and Blackmore’s Unified Emergency Scale. Let us now discuss each to see what and how they do the measurements.
Modified Mercalli Intensity Scale

The Mercalli Intensity (MMI) scale is used worldwide to estimate or measure the intensity of earthquakes. The MMI scale came as the result of several improvements and revisions made by European scientists before being published in English in 1931. The scale originated from a revision of the widely used ten-degree Rossi-Forel scale by an Italian volcanologist called Giuseppe Mercalli in 1884 and 1906 (Comerci, 2013).

The scale measures the intensity of the earth’s shaking along with lives lost, property damage, environmental effects, and human behaviors. It is composed of increasing levels of intensity ranging from imperceptible shaking to catastrophic destruction expressed in Roman numerals. The MMI scale does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects. This scale is selected in this thesis because it is used officially in the United States for earthquakes as per the United States Geological Survey (USGS) (USGS, 2009).

The MMI scale was also selected since it measures earthquake intensity while considering the social impact at the same time. Philips et al. (p103, 2012) state “in short, it considers the social dimension of earthquakes. For example, depending on how well a community may have taken mitigation measures and prepared for an earthquake, the social consequences of a 5.0 Richter scale event
may vary greatly. In communities with strong mitigation and preparedness programs, the social impacts may be minimal (level III or IV) while in areas lacking effective mitigation and preparedness programs, the MMI scale may be as high as VIII or IX. Although the Richter scale is more common in media after an earthquake, the MMI scale better gauges the social impacts and consequences (USGS 2009).” Assuming that there are 2 identical disasters hitting two identical cities where city A is way more resilient than city B in terms of effective planning, mitigation measures, preparedness, response, and recovery, the net impact of the disaster on city A will be less than city B. It might even called a major emergency at city A while the same disaster might be called major disaster in city B. Table 1 shows the abbreviated descriptions of the levels of Modified Mercalli Intensity (USGS, 2009).
Table 1  Levels of Modified Mercalli Intensity from the Severity of an Earthquake (USGS, 2009)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Shaking</th>
<th>Description/Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Not felt</td>
<td>Not felt except by a very few under especially favorable conditions.</td>
</tr>
<tr>
<td>II</td>
<td>Weak</td>
<td>Felt only by a few persons at rest, especially on upper floors of buildings.</td>
</tr>
<tr>
<td>III</td>
<td>Weak</td>
<td>Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.</td>
</tr>
<tr>
<td>IV</td>
<td>Light</td>
<td>Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.</td>
</tr>
<tr>
<td>V</td>
<td>Moderate</td>
<td>Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.</td>
</tr>
<tr>
<td>VI</td>
<td>Strong</td>
<td>Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.</td>
</tr>
<tr>
<td>VII</td>
<td>Very strong</td>
<td>Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.</td>
</tr>
<tr>
<td>VIII</td>
<td>Severe</td>
<td>Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.</td>
</tr>
<tr>
<td>IX</td>
<td>Violent</td>
<td>Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.</td>
</tr>
<tr>
<td>X</td>
<td>Extreme</td>
<td>Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent</td>
</tr>
</tbody>
</table>
Richter Scales

The Richter Magnitude scale is one of the most common and known scales as it is widely mentioned in media and that is why it is selected here. It was developed by Charles F. Richter in 1935 (USGS, 2006) to measure the magnitude of earthquakes. The USGS (USGS, 2006) distinguishes between the magnitude and intensity. “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” while “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). In other words, Richter scale calculates the magnitude or the overall measured amplitude of the waves generated by the earthquake, as shown in Figure 1, and it does not measure the intensity or the observable effects. The magnitude is determined from the logarithm of the amplitude of waves recorded by seismographs and is expressed in decimals and whole numbers. For the whole numbers or as we move up for each level of magnitude, 1, 2, 3, 4, etc. as shown in Table 2, the overall energy
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.

Figure 1 Simplified Richter Scale mechanism from [http://earthquake.usgs.gov](http://earthquake.usgs.gov)
Table 2  
Magnitude, Scale, Physical Effects, and Number of Occurrences Each Year from [www.srh.noaa.gov/jetstream/tsunami/plates.htm](http://www.srh.noaa.gov/jetstream/tsunami/plates.htm)

<table>
<thead>
<tr>
<th>Magnitude Class</th>
<th>Richter Scale</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great</td>
<td>≥8</td>
<td>Can cause serious damage in areas several hundred miles across.</td>
</tr>
<tr>
<td>Major</td>
<td>7.0-7.9</td>
<td>Can cause serious damage over larger areas.</td>
</tr>
<tr>
<td>Strong</td>
<td>6.0-6.9</td>
<td>Can be destructive in areas up to about 100 mi (160 km) across in populated areas.</td>
</tr>
<tr>
<td>Moderate</td>
<td>5.0-5.9</td>
<td>Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.</td>
</tr>
<tr>
<td>Light</td>
<td>4.0-4.9</td>
<td>Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.</td>
</tr>
<tr>
<td>Minor</td>
<td>3.0-3.9</td>
<td>Often felt, but rarely causes damage.</td>
</tr>
<tr>
<td>Micro</td>
<td>≤3.0</td>
<td>Generally not felt, but recorded.</td>
</tr>
</tbody>
</table>

Saffir-Simpson Hurricane Wind Scale

The Saffir-Simpson Hurricane Wind (SSHW) scale is the official scale to measure the severity of hurricanes within the United States. The scale was initially developed by Herbert Saffir in 1969 based entirely on wind speed before it was enhanced by Bob Simpson by adding 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 74-95 mph and may cause some coastal road
flooding with damage primarily limited to mobile homes and trees (NOAA, 2012). 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 according to the FEMA (FEMA, 2006). A rating of a hurricane on Saffir-Simpson Hurricane Wind Scale is based on the hurricane's sustained wind speed and the estimated potential property damage as shown in Table 3. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous and require preventative measures (NOAA, 2012).
Table 3  Saffir-Simpson Hurricane Wind Scale Categories as per [http://www.nhc.noaa.gov/aboutssshws.php](http://www.nhc.noaa.gov/aboutssshws.php)

<table>
<thead>
<tr>
<th>Category</th>
<th>Sustained Winds</th>
<th>Types of Damage Due to Hurricane Winds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74-95 mph</td>
<td>Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.</td>
</tr>
<tr>
<td>2</td>
<td>96-110 mph</td>
<td>Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.</td>
</tr>
<tr>
<td>3 (major)</td>
<td>111-129 mph</td>
<td>Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.</td>
</tr>
<tr>
<td>4 (major)</td>
<td>130-156 mph</td>
<td>Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.</td>
</tr>
<tr>
<td>5 (major)</td>
<td>157 mph or higher</td>
<td>Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months</td>
</tr>
</tbody>
</table>
The Fujita Tornado Scale

The Fujita Tornado (FT) scale was developed in 1971 by T. Theodore Fujita of the University of Chicago to measure tornados after the fact. It provides 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 (weakest) to F5 (strongest). Each of these 6 categories 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. It is very important to note that the Fujita Tornado scale had been the official scale for tornadoes within the United States till 2007 where it was replaced with an Enhanced Fujita Tornado scale to address some limitations identified by meteorologists and engineers since the introduction of the Fujita Scale (NOAA, 2007). Table 4 shows both scales; the old one to the left and the newly enhanced one to the right.
Table 4  The Original Fujita Tornado Scale and the Enhanced Fujita Scale (http://www.spc.noaa.gov/faq/tornado/ef-scale.html)

<table>
<thead>
<tr>
<th>Fujita Scale</th>
<th>Fastest 0.25 mile Wind Speeds in mph</th>
<th>3 sec. Gust Speed in mph</th>
<th>Enhanced Fujita Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>40 – 72</td>
<td>45 – 78</td>
<td>EF0 65 – 85</td>
</tr>
<tr>
<td>F1</td>
<td>73 – 112</td>
<td>79 – 117</td>
<td>EF1 86 - 109</td>
</tr>
<tr>
<td>F2</td>
<td>113 - 157</td>
<td>118 – 161</td>
<td>EF2 110 - 137</td>
</tr>
<tr>
<td>F3</td>
<td>158 - 207</td>
<td>162 – 209</td>
<td>EF3 138 - 167</td>
</tr>
<tr>
<td>F4</td>
<td>208 - 260</td>
<td>210 – 261</td>
<td>EF4 168 - 200</td>
</tr>
<tr>
<td>F5</td>
<td>261 - 318</td>
<td>262 – 317</td>
<td>EF5 &gt;200</td>
</tr>
</tbody>
</table>

The new enhanced scale identifies 28 different free standing structures most affected by tornadoes taking into account construction quality and maintenance (NOAA, 2007). More details about the Enhanced Fujita Tornado scale can be found at http://www.spc.noaa.gov/efscale/. However, we still used the Fujita Tornado scale for this research since selected cases took place prior to 2007 and were only measured by the old scale and due to the limited difference between the old and enhanced scale especially that the general scale categories stayed as is from F0 to F5 or EF0 to EF5.
FEMA Scale

There is not an official FEMA and practitioner scale. We use this term to mean to refer to the terminology use by FEMA and practitioners, inside and the United States, and maybe outside it, based on common concepts. These concepts define an emergency as “a dangerous event that normally can be managed at the local level”, a disaster as “a dangerous event that causes significant human and economic loss and demands a crisis response beyond the scope of local and state resources”, and a catastrophe as “any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions” and therefore require federal and sometimes international aids as per the National Response Framework (NRF, 2013).

The NRF is based on the concept of levels of response with an understanding that most incidents start at the local level, and as needs exceed resources and capabilities, additional local, state, and Federal assets are applied (NRF, 2013). In other words, the FEMA’s three (3) response levels are the local, state, and federal. FEMA level 1 is for incidents handled locally without a need for any state-wide or country-wide help. FEMA level 2 is when a State Governor declares an incident as “a state of emergency” to unite state efforts in
preparedness and response. FEMA level 3 is used when the US President declares an incident as “a major disaster” in that area after the President receives, reviews, and approves an official request from the Governor of the affected state for federal support.

The same concept is used by emergency management practitioners in most metropolitan areas in the United States have developed matrices based on the intensity of hazard events and the availability of required resources to manage each. Several levels of response (e.g., 1, 2, and 3) are developed by many emergency response organization depending on the severity and controllability of an event to plan and provide guidelines for planning for response including other agencies as needed (Rotanz, 2007). The first level or level 1 of this hierarchy represents fairly frequent emergencies that can be dealt with internally within the available resources and capabilities of the impacted community. The second level or level 2 represents major emergencies or disasters that exceed the impacted community’s resources and capabilities and require support from nearby communities. The third level or level 3 represents major disasters or catastrophes that not just exceed the impacted community’s resources and capabilities but could even paralyze the directly impacted community with its emergency management organizations and could even extend to nearby communities. Therefore, significant external help from the
nearby partially affected and unaffected communities will be needed. The concept is used at lower levels by some emergency management organizations and practitioners as 3 response-levels for a county, city, and by even local emergency organizations such as Fire and Police Departments. Since the reference for this thesis is the United States, then only FEMA’s scale will be used to measure the different applicable real emergency cases.

Fischer's Disaster Scale

This scale was proposed by Henry W. Fischer from Millersville University in Pennsylvania in 2003 as a conceptual, rather than a purely quantitative disaster scale. The scale differentiates between the disaster agent, or precipitating event, and the sociological focus, or social structure (and its adjustments). As shown in Table 5, scale (how severe is the destruction and distress?), scope (how widespread is the disruption within the community?), and time/duration (the greater the scope and scale of disruption, the more likely the time for recovery will be extended) are the three factors applied to create ten disaster categories forming a continuum ranging from disaster category DC-1 through DC-10 (Fischer, 2003).
Table 5  Disaster Scale Categories assessing the relationship between disruption and adjustment (Fischer, 2003):

<table>
<thead>
<tr>
<th>DC-1: Everyday Emergency</th>
<th>Minor in Scale, Scope, Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minor in Scope, Major in Scale and Duration</td>
</tr>
<tr>
<td></td>
<td>Partial in Scope, Minor in Scale and Duration</td>
</tr>
<tr>
<td>DC-2: Severe Emergency</td>
<td>Major in Scope, Minor in Scale and Duration</td>
</tr>
<tr>
<td></td>
<td>Major in Scale and Duration, Minor in Scope</td>
</tr>
<tr>
<td>DC-3: Partial Small Town</td>
<td>Major Scale and Duration, Partial Scope – Town</td>
</tr>
<tr>
<td>DC-4: Massive Small Town</td>
<td>Major Scale, Scope, Duration – Town</td>
</tr>
<tr>
<td>DC-5: Partial Small City</td>
<td>Major Scale, Duration, Partial Scope - Small City</td>
</tr>
<tr>
<td>DC-6: Massive Small City</td>
<td>Major Scale, Scope, Duration – Small City</td>
</tr>
<tr>
<td>DC-7: Partial Large City</td>
<td>Major Scale, Duration, Partial Scope - Large City</td>
</tr>
<tr>
<td>DC-8: Massive Large City</td>
<td>Major Scale, Scope, Duration – Large City</td>
</tr>
<tr>
<td>DC-9: Catastrophe</td>
<td>Major Scale, Scope, Duration – Several Pop. Areas</td>
</tr>
<tr>
<td>DC-10: Annihilation</td>
<td>Major Scale, Scope, Duration – Society</td>
</tr>
</tbody>
</table>

Rohn and Blackmore’s Unified Emergency Scale

The Unified Emergency (UE) scale was proposed by Rohn and Blackmore (2009). It is the first scale that quantifies any emergency situation of any type and size based on a mathematical model (Rohn and Blackmore, 2009). The main concept of the scale is that all emergencies can be described by three independent dimensions or attributes: 1) scope; 2) topographical change (or lack thereof); and 3) speed of change. The intersection of the three dimensions provides a detailed scale for defining any emergency. Let us explain each in brief.
First, the scope of an emergency in the Unified Emergency Scale is represented as a continuous variable with zero as a lower limit and a theoretical calculated upper limit. The scale uses two attributes that form the scope. These attributes are the percent of affected humans out of the entire population, and damages, or loss, as a percentile of a given Gross National Product (GNP) and when applied to regional or local scope, this attribute may be represented by a Gross State Product, Gross Regional Product, or any similar measure appropriate to the emergency being measured. Second, the topographical change is a measure of the observed change in land characteristics, in terms of elevation, slope, orientation, and land coverage. Such changes can be natural, like trees, or man-made, like houses. Third, speed of change measurement uses the change of the number of victims over time and the change in economic losses over time to calculate a rate of change that is of utmost importance to society.

The calculation of the Unified Emergency scale is a normalized function of scope (S), topography (T), and rate of change (D) variables as expressed below:

\[ E = Emergency = f (S, T, D) \]

Each attribute is now defined and calculated:
1. **The Scope (S):** For the purposes of this scale, only two attributes represent the scope. These are the 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. Equation 1 shows the calculation of S, and Equations 2 through 5 represent the measurement of the attributes and the determination of the parameters in the model.

\[
\text{Scope} = \left( \frac{\text{RawScope}}{\text{MaxScope}} \right) \times \frac{1}{\alpha} \quad \text{Equation 1}
\]

Where

\[
\text{RawScope} = \left( \frac{\text{Victims}}{\text{Population}} + \frac{\text{MonetaryLosses}}{\text{GNP}} \right)^W \quad \text{Equation 2}
\]

\[
W = \left( \frac{\ln(\text{Victims})}{\ln(\text{MonetaryLosses})} \right)^\beta \quad \text{Equation 3}
\]

\[
\beta \text{ is a coefficient, which the model’s developers calculated to be } 1.26 \pm 0.03,
\]

\[
\text{MaxScope} = \left( \frac{0.7 \times \text{Population}}{\text{Population}} + \frac{0.5 \times \text{GNP}}{\text{GNP}} \right)^V \quad \text{Equation 4}
\]

\[
V = \frac{\ln(\text{Victims})}{\ln(\text{MonetaryLosses})} \quad \text{Equation 5}
\]

\[\alpha \text{ is a parameter. When } \alpha = 5, \text{ scope is between zero and five (Rohn and Blackmore, 2009).}\]
It is important to note the model is not applicable to emergencies in which there are no victims, as Equation 5 requires the calculation of ln(Victims) and ln(0) is undefined. In the calculations this is reported as an “Error” but it could be more reported as “Not Applicable” in much the same as the Richter scale is not applicable to Hurricanes.

The model used for the Unified Emergency Scale loosely assumes that a society in which the majority of the population (70% in this model) is affected and half (50%) of its GNP is drained as a result of a calamity reaches a breaking point of disintegration.

2. **Topographical Change (T):** Topographical change is treated as a continuum ranging between 0 and 1 to provide an 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.

\[
T = \frac{Volume \ before \ the \ event}{Volume \ after \ the \ event} \quad \text{Equation 6}
\]

or \( T = 0 \) for non-topographical events.

3. **Rate of Change Calculation (D):** The rate of change is very important to society and therefore incorporated in the model. It can include the the
difference in the number victims and the value of losses per unit time as shown in Equations 6 and 7.

\[ D = \frac{d(Victims)}{d(Time)} \]  \[ \text{Equation 7} \]

and

\[ D = \frac{d(Losses)}{d(Time)} \]  \[ \text{Equation 8} \]

Once the three attributes (S, T and D) are calculated, we can measure the emergency scale using Equation 9:

\[ E = \text{Emergency} = f(S, T, D) = w_S * S + w_T * T + w_D * D \]  \[ \text{Equation 9} \]

Where \( w_S, w_T, w_D \) are weights, each with a value between 0 and 1 and such that \( w_S + w_T + w_D = 1 \).

**Overview of Methodologies**

Since the research is focused on how consistent the emergency measurements and scales are, the basic design of the research focusing on identifying different emergencies and measure them using different scales. The research question could then be answered by comparing the different scales and measurement results of each emergency to test the scales consistency. The selected real emergency cases were used as references for comparison. Then, we went further by analyzing the measurement results of each scale given its
method and uses to evaluate its usefulness to emergency managers. The analysis led to several observations and recommendations for future scales. It also allowed for making suggestions for future research.

Since the measurement include physical, economic, and social factors, a mixed, quantitative and qualitative, comparative case studies method and analysis was used to address the raised question. The comparative method, or multiple case studies (Yin, 2014) refers to the partially distinctive methodological issues that arise in the systematic analysis of a small number of cases, or a "small N" (Collier, 1993). This method and approach is used by a large body of cross-national research in many fields including health care (Castilla, 2004), employment careers (Blossfeld et al., 2006), demography and socio-economy (Hoffmeyer-Zlotnik and Wolf, 2003).

This approach is chosen because the case study method is very suitable for research questions starting with “how” and “why” and very useful to understand complex phenomena (Yin, 2014), such as emergencies and disasters where multiple variables, including the type of event, scope, size, duration, fatalities, damages, social effects, and cost, need to be considered in categorizing and measuring each. In addition, these complex events and phenomena involve multiple fields and disciplines, such as natural sciences, psychology, sociology, political science, business, social work, economics, and
planning, in which case studies are common and useful (Yin, 2014). This is very important because we are testing measurements and scales that use different physical and social factors in their methods. Furthermore, comparative case studies and analysis is ideal for studying and comparing a small number of case studies and helps provide meaningful description, concept formation, and hypothesis testing (Collier, 1993). Comparative case studies also provide flexibility and freedom for our comparisons of measurements and scales and explorations of multiple variables and maybe their effects during the analysis stage. Further, another key factor for selecting the case studies method is because of its usefulness when the context and object of observation are difficult to separate as it is the case with emergencies and this method and approach allow us to simultaneously look at both.

Seven (7) measurements and scales, discussed in the literature review in this chapter, were purposively selected to represent the state of the art in the measurement of emergencies and disasters. These scales include most officially used and publicly known scales for measuring different types of emergencies. In addition, recently proposed uniform scales, reported in the literature only and not in actual use, were selected as they also measure emergencies independent of the type.
As for the thirteen (13) purposively selected real incident cases, the selection was done in a way to include different types of emergencies such as earthquakes, tornadoes, hurricanes, terrorisms, industrial fires and explosions, mudslides, home fires, and motor vehicle accidents. Moreover, the selection was made to include emergencies with different scales or sizes starting from car accidents and home fires to 9/11 terrorist attacks and Hurricane Katrina. All selected cases are from the United States of America as the country is used as a reference for losses and damages.

The small number of cases is because the phenomena under study can be better understood through the close analysis of relatively few observations (Collier, 1993). Moreover, given inevitable scarcity of time, energy, and financial resources, the intensive analysis of a few cases may be more promising than the superficial statistical analysis of many cases” (Lijphart, 1971).
Chapter 3

RESEARCH METHODOLOGY

The comparative case studies, using a mix of qualitative and quantitative methods, are used to address the research question and research objectives. The basic design of the research was to measure or scale a number of real incident cases by different applicable measurements and scales. The real incident cases were used as references for comparison. This means that the results of the different applicable scales and measurements of each incident case were compared to each other to test their consistency. Then, the different results of each tested measurement and scale for different real incident cases were analyzed considering its method to understand and explain the reasons for any inconsistencies noticed. This allowed us to make several specific observations and recommendations to the tested emergency measurements and scales. It also allowed for making recommendations for new emergency scales and suggestions for future research. This chapter describes the methodology in more detail including guidelines for selection of the case studies, data collection and analysis plan.

Case Study Selection

Since each emergency and each disaster is unique (Turner, 1995; Alexander, 2005; Vanholder et al, 2007; Beamon and Balcik, 2008; Yates et al,
2011), this thesis tries to include a combination of different types, scales, locations, and within the past three (3) decades. It also tries to select common emergencies as possible to relate to. For instance, common natural events such as earthquakes, hurricanes, tornadoes, and mudslide emergency cases were selected. In addition, technological or man-made events such as terrorism, industrial explosion, home fires, and vehicle collision emergency cases. The selection also included emergencies from minor car accident to catastrophic emergencies. The selection was made to cover different geographical locations and population densities from the north east to the south to California to Minnesota within the United States of America.

Therefore, thirteen (13) real incident cases (size N=13) were purposively selected. Seven (7) cases are natural emergencies while six (6) are man-made or technological emergencies. The selected emergency cases contain two (2) earthquakes, (2) tornadoes, (2) hurricanes, one (1) mudslides, (2) terrorisms, one (1) industrial fires and explosions, one (1) multiple vehicle collision, two (2) home fires, and one (1) minor injury emergency cases. Moreover, the selection was made to include emergencies with different scales or sizes starting from minor injuries and home fires to 9/11 Terrorist Attacks and Hurricane Katrina. All selected cases are from the United States of America.
to provide a consistent reference base for the comparison of losses and damages. The availability of data was also a factor for the selection.

The seven (7) emergency measurements and scales, discussed in chapter 2 of this report, were purposively selected to include most officially used and publicly known scales for measuring different types of emergencies. The main unit of analysis is the measurement result of each real incident case study by each applicable emergency scale. The comparison of results per each scale should help us answer the research question. In addition, a comparison of each scale’s results will be done considering its considered dimensions and method of calculations as an attempt to capture and highlight any observations and recommendations. Next, we discuss the data collection and analysis plan.

**Data Collection**

Evidence, information and data for case studies comes from documents, archival records, interviews, direct observation, participant-observation, and physical artifacts (Yin, 2014). In this research, data was gathered from official government reports, literature, and media sources. After identifying the thirteen (13) case studies based on real incidents and events, the data needed to apply the applicable measurements and scales of the (seven) selected scales was assembled. Some measurements were readily available as raw data while others need to be calculated depending on the measurement or scale used. In
addition, although most of the data and measurements are quantitative, some measurements are qualitative, such as Fischer’s Disaster Scale of social adjustment. All needed data was collected, calculated, and adjusted to be in a percentage format from 0% to 100%. Data, sources, calculations, and results are shared, discussed, and analyzed in Chapter 4 for each case study.

**Analysis Design**

The analysis of measurement results, cases and scales is a design based on discovery to answer the research question “how consistent are emergency scales?” After getting all measurement results, the analysis starts by converting measurement results to a percentage format or to a scale from 0% to 100% with 0% representing the least severe and 100% representing the most severe events for standardization as shown in Table 6.

After that, the measurement results of each emergency case are compared to assess the consistency of the scales. Since the consistency is subjective, the design of analysis assumes two measurements to be consistent when their adjusted results in percentage format are within 15% of each other. In other words, when the large result is divided over the small result, we get 1.15 or lower for those two results to be considered consistent. For example, if the measurement results are 100 and 90, they are considered consistent. Dividing 100 by 90, we get 1.11, which is less than 1.15 and therefore
considered consistent. On the other hand, if we have 53 and 63, we will get 1.30 which is more than 1.15 and therefore inconsistent. While if we have 90 and 90, we get 1.00 which means total consistency.

The 15% difference, selected as the threshold for determining consistency, is higher than the threshold used in other applications, for example, in budgeting, because it allows to spot more consistency or inconsistency than a 5% threshold. This initial selection of the threshold is based on our assessment of the level of variability expressed in the measures. For example, on a ten point scale, measures can be easily assessed as a plus or minus one representing a more than 10% difference. For emergency management, in terms budgeting, planning, mitigation, preparedness, response, and recovery, figures and numbers serve as a base for allocating resources to affected people.

To explore the impact of setting the threshold for consistency at 15%, we also explore the impact of 10% and 20%, and an absolute difference of 5, 10, 15 and 20 points. To summarize the results we look at the percentage of pairwise comparisons of scales for each case that are consistent.

Finally in comparing scales for each case study we compute the maximum number of scales that are consistent (within 15%) irrespective of their accuracy.
Next, the measurement results of each scale for its applicable cases are compared to evaluate its usefulness for emergency managers before, during, and after emergencies. The analysis observations, recommendations, and future research suggestions are then shared.

Table 6 Adjusting and standardizing measurements for better comparisons.

<table>
<thead>
<tr>
<th>Measurement Scale</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Adjusted Score to %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score</td>
<td>Equivalent Value</td>
<td>Score</td>
</tr>
<tr>
<td>MMI</td>
<td>1</td>
<td>1</td>
<td>X</td>
</tr>
<tr>
<td>Richter</td>
<td>Micro</td>
<td>1</td>
<td>Great</td>
</tr>
<tr>
<td>SSHW</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>FT</td>
<td>F0</td>
<td>1</td>
<td>F5</td>
</tr>
<tr>
<td>FEMA</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Fischer</td>
<td>DC-1</td>
<td>1</td>
<td>DC-10</td>
</tr>
<tr>
<td>UE</td>
<td>1</td>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>
Chapter 4

CASE STUDIES: DESCRIPTIONS AND MEASUREMENTS

No previous comparisons of emergency scales could be found in the literature. Therefore, no existing criteria were found for case study selection. As a result, the thesis combines several criteria by which the thirteen (13) real incident cases were selected. The selection criteria are more about an exploration of a variety of incidents rather than a very specific investigation of particular attributes. The first criterion is to include different types of emergencies such as earthquakes, tornadoes, hurricanes, terrorism, industrial fires and explosions, mudslides, home fires, and motor vehicle accidents. The second is to include emergencies with different scales or sizes starting from car accidents and home fires to the Twin Tower Terrorist Attacks and Hurricane Katrina. Third, all selected cases are from the United States of America as the country is used as a reference for losses and damages. Fourth and last, the selection only includes cases that took place within the past three (3) decades to facilitate data availability, accuracy, and validity of the comparison to each other.

The selected cases are New York City Twin Tower terrorist attacks (2001), Hurricane Katrina (2005), Loma Prieta earthquake (1989), Oso mudslide in Washington State (2014), Hurricane Charley (2004), Texas City
Refinery explosion (2005), multiple vehicles collision on I-75 Gainesville, FL (2012), Boston Marathon bombings (2013), South Napa earthquake (2014), Granite Falls tornado (2000), fatal home fire in Chester, Delaware County, PA (2013), Westchester County tornado (2006), and finally any non-fatal everyday emergency like car accident or minor house fire with one injury and losses of less than $10,000. In this chapter, each of the thirteen (13) real incident case studies is described. In addition the gathered data required for measurements along with all used sources used for each case are documented. Then, the applicable scales of the seven (7) selected are measured for each case using the United States of America is used as the reference for all cases. Next, we will talk about each case in detail, starting from the one with the most fatalities and to the case with the lowest number of fatalities since we, as human beings, are the focus of these events. The exception to this order is that we start with Hurricane Katrina even though it comes second after the 9/11 Terrorist Attacks in terms of number of fatalities. Starting with Hurricane Katrina makes explaining the Rohn and Blackmore Unified Emergency Scale easier since it was the example used in Rohn and Blackmore’s paper. Now we will go through the description, gathered data and sources for each case before presenting the measurements for each applicable scale and sharing the results. Again, the order
of cases is from the one with most fatalities to the least except for 9/11 and Katrina which were switched for the abovementioned reason.

**Hurricane Katrina (2005)**

**Event Description and Gathered Data**

As per the National Oceanographic and Atmospheric Administration (NOAA) (2005 and 2011), the National Aeronautics and Space Administration (NASA) (2005), and the Federal Emergency Management Agency (FEMA) (2006, 2014), hurricane Katrina was a catastrophic Atlantic tropical cyclone. Katrina’s fatal and destructive impact extended to several states including Florida, Louisiana, Mississippi, Georgia, and Alabama. On August 25th, 2005, hurricane Katrina struck southern Florida first as a Category 1 hurricane on the Saffir-Simpson Hurricane Scale before intensifying over the central Gulf of Mexico reaching to Category 5. Then, it started weakening to Category 3 with which it hit Louisiana and Mississippi on August 29th, 2005 with significant impact extending into the Florida panhandle, Georgia, and Alabama. Hurricane Katrina left around 1833 fatalities. At the same day, a “Major Disaster Declaration” was declared by President George Bush. Response efforts to hurricane Katrina continued till the area was hit by hurricane Rita on September 24th, 2005. Therefore, the tentative duration of Katrina was counted as 31 days from August 25th to September 24th, 2005.
One year after the hurricane, the U.S. Department of State (2006) issued a report explaining the efforts taken. The report states that the storms had a massive physical impact on the land as it affected around 93,000 square miles which is about the size of United Kingdom or 2.5% of the total USA’s area (3.8 million square miles). The impact included flooding 80% of New Orleans city. There were more than 1.5 million people directly affected and more than 800,000 were forced to live outside of their homes. The Federal aid alone reached $110.6 billion while total damage/cost estimates suggest an excess of $150 billion (Kunreuther and Michel-Kerjan 2009). In addition, about 400,000 jobs according to the Congressional Budget Office were lost as a result of the hurricane (Gruber, 2005). Moreover, many towns like Pass Christian, Bay St. Louis, Waveland and the eastern parts of Biloxi were annihilated too (Giudici, 2008).

**Measurements and Results**

There are four (4) applicable scales out of the seven (7) selected for hurricane Katrina’s case in this thesis. The applicable scales are Saffir-Simpson Hurricane Wind, the FEMA scale, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Hurricane Katrina’s case measurement is presented below by scale:
• **Saffir-Simpson Hurricane Wind Scale:** according to NOAA’s National Climatic Data Center report (2005), hurricane Katrina had sustained winds during landfall of 125 mph making it a strong category 3 hurricane on the Saffir-Simpson scale. Therefore, this is equivalent to 60% after adjustment.

• **FEMA Scale:** since the incident was at the federal level after the declaration of a major disaster by the President; then, it is level 3 or equivalent to 100% after adjustment.

• **Fischer’s Disaster Scale:** according to Fischer’s Disaster Scale, DC-10 represents “Major Scale, Scope, Duration – Society” which very well fits hurricane Katrina especially when knowing that Fischer gave 9/11 terror attacks as an example for DC-9 while hurricane Katrina was considered of higher scale than 9/11 as per many scholars including (Quarantelli, 2006) who categorize 9/11 as a major disaster while hurricane Katrina as a catastrophe. In addition, Mississippi Gulf Coast towns like Pass Christian, Bay St. Louis, Waveland and the eastern parts of Biloxi, were annihilated as a result of hurricane Katrina (Giudici, 2008). As a result, hurricane Katrina is rated as DC-10 per Fischer’s Disaster Scale or 100% after adjustment.
Rohn and Blackmore’s Unified Emergency Scale: this scale requires population and Gross Domestic Product (GDP) of the United States as the reference for the year of the event for its calculations. Therefore, the country populations over the years are taken from the U.S. Census Bureau while the Gross Domestic Product (GDP) figures over years are taken from the World Bank (http://data.worldbank.org/) for all cases. Rohn and Blackmore (2009) presented their measurement of hurricane Katrina as an example in their article. They reported a measure of 72/100, which is consistent with the author’s perception of the magnitude of the emergency caused by Katrina at the US national level. However, when the calculations in their paper were reviewed and there were several mistakes in implementing their proposed method and procedure. For example, the rate of change was not divided by the duration or delta time. This variable was not well defined in the paper, and could be the duration of the hurricane actions or the duration taken to stabilize and control the situation by emergency responding organizations. In our calculation, the emergency duration or time is the time taken to stabilize the situation by the response teams. Moreover, Rohn and Blackmore (2009) used a bank list of wide ranges of local and international emergencies data for setting the lower and upper
boundaries to properly rate or measure Katrina against. In other words, once they finished the measurement of Hurricane Katrina in their paper, they translated the emergency measurement result into a percentage format using the data bank and where the emergency would fit.

Now, we start the calculations of $E$ by getting first the scope ($S$), topography ($T$), and rate of change ($D$) variables as expressed below:

$$E = Emergency = f(S, T, D)$$

Using Equation 2,

$$RawScope = \left(\frac{1833}{295,500,000} + \frac{150 \times 10^9}{1.31 \times 10^{13}}\right)^W$$

And using Equation 3 to calculate $W$:

$$W = \left(\frac{\ln(Victims)}{\ln(MonetaryLosses)}\right)^\beta = \left(\frac{\ln(1833)}{\ln(150 \times 10^9)}\right)^{1.26} = 0.212$$

$\beta$ is a coefficient which the model creator calculated to be $1.26 \pm 0.03$, And therefore, $RawScope = 0.392$

Then, using Equation 4,

$$MaxScope = \left(\frac{0.7 \times Population}{Population} + \frac{0.5 \times GNP \times \delta}{GNP}\right)^V$$

Where $\delta$ is the financial resilience coefficient for USA which is 1000 (Rohn and Blackmore, 2009). Now we calculate $V$ using Equation 5:
\[ V = \frac{\ln(Victims)}{\ln(Monetary\ Losses)} = \frac{\ln(1833)}{\ln(150 \times 10^9)} = 0.292 \]

Then and using Equation 1:

\[ MaxScope = (0.7 + 0.5 \times 1000)^{0.292} = 6.141 \]

As the model assumes that a society whose majority of the population (70% in this model) is affected and half (50%) of its GNP is drained as a result of a calamity reaches a breaking point of disintegration.

As the model assumes that a society whose majority of the population (70% in this model) is affected and half (50%) of its GNP is drained as a result of a calamity reaches a breaking point of disintegration.

And since MaxScope = 6.141; then, Scope (S) = 0.013

Moving to the topographical change (T) and using Equation 6:

\[ T = \frac{Volume \ before \ the \ event}{Volume \ after \ the \ event} = \frac{93,000}{3,800,000} = 0.024 \]

As for the Rate of Change or (D), it is:

\[ \frac{d(Victims)}{d(Time)} \quad \text{and} \quad \frac{d(Losses)}{d(Time)} \]

Duration = \( \Delta t \) = 31 days.

Victims = \( \Delta v \) = 1833 people killed.
Monetary Losses = $150 billion dollars.

$\Delta j = 400,000$ jobs lost.

The paper used a weight of 6 for victims in hundreds, 2 for monetary losses per billion and 1 for each 1000 jobs lost. At the end, we divide by the total weight which is in this case: $6+2+1=9$ as shown below

$$D = \left( \frac{6 \times \text{Victims} + 2 \times \text{Monetary Losses} + 1 \times \text{Jobs Lost}}{100 + 10^9 + 1000} \right) \times \frac{6 + 2 + 1}{9}$$

$$D = \left( \frac{6 \times 1833 + 2 \times 150 \times 10^9 + 1 \times 400,000}{100 + 10^9 + 1000} \right) \times \frac{31 \times 9}{9}$$

Therefore, $D = 2.903$

Since we have now the 3 attributes; $S = 0.013$, $T = 0.024$, and $D = 2.903$, we can measure the emergency scale using below equation:

$$E = \text{Emergency} = f(S, T, D) = w_S \times S + w_T \times T + w_D \times D$$

Where each of $w_S, w_T, w_D$ needs to be between 0 and 1 and that $w_S + w_T + w_D = 1$. Using the same weights used by Rohn and Blackmore (2009), $w_S = 0.5$, $w_T = 0.25$, and $w_D = 0.25$, then, $E = 0.605$. Since we do not have the author’s referenced data set of emergencies to identify the upper and lower boundaries to properly rate hurricane Katrina, the 0.7383 was adjusted to be 0.7200 or 72.00%, which is describe by Rohn and Blackmore (2009) as a very reasonable
rating for Katrina at the US national level. The same was done for other case study results by dividing the score by 0.7389 and multiplying by 0.7200. Therefore, hurricane Katrina is about 72% as per the Unified Emergency scale and given $w_S = 0.5$, $w_T = 0.25$, and $w_D = 0.25$. We refer to this as UE1 scale.

To explore the sensitivity of the Unified Emergency Scale to different weights, we also compute the measurement using $w_S$, $w_T$, and $w_D$ equal to 0.333. $E$ is computed to be 94.63% instead of 72.00%. We refer to the measurement using equal weights at the UE2 scale.

All of these steps were implemented in an excel sheet as shown in Table 7. The calculation of $E$ for other cases will be presented in similar tables following the same calculations done above.

Table 7  Hurricane Katrina Emergency Calculation using Rohn and Blackmore (2009).

| Scope or $S = \text{Raw Scope} / \text{Max Scope} / 5$ | 0.0126 |
| Topographical Change or $T = \text{Affected Area} / \text{Total USA Area}$ | 0.0244 |
| Rate of Change or $D = 6*\text{Fatalities} / 100 + 2*\text{Monetary Loss in billion} + 1*\text{Job Lost} / 1000) / \text{Duration of Emergency in Days} / 9$ or 8 if there is no job loss | 2.9031 |
| UE1 or Final Emergency Scale Result (using 0.5 for $S$, 0.25 for each of $T$ and $D$ as coefficients or weights) | 72.00% |
| UE2 or Final Emergency Scale Result (using 0.33 for each of $S$, $T$, and $D$ as coefficients or weights) | 94.62% |
**9/11 Terrorist Attacks (2001)**

**Event Description and Gathered Data**

On September 11\textsuperscript{th}, 2001, nineteen (19) terrorists related to Al-Qaeda terrorism group hijacked four airliners to carry out suicide attacks against targets in the United States as per 9/11 Memorial website (http://www.911memorial.org/rescue-recovery). Two planes were flown into the World Trade Center Twin Tours in New York City. The third plane hit the Pentagon just outside Washington, D.C. and the fourth plane crashed in a field in Pennsylvania. The attacks killed 2,996 people including members from emergency organizations. The incident shocked New York City and the shock extended to the entire United States and international stages. A major disaster was declared by the US President on the same day.

The Bureau of Labor Statistics (2003) states that about 145,000 jobs were lost as a direct result of the attacks. Kunreuther and Michel-Kerjan (2004) estimate the total damages and lost income from business disruptions is about $80 billion. According to 9/11 Memorial website (http://www.911memorial.org/rescue-recovery), the last federal rescue team left ground zero on October 6\textsuperscript{th}, 2001. Therefore, 25 days is used as the duration, while topography change was estimated to be about 33.8 square miles (the areas of Manhattan).
Measurements and Results

There are three (3) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale**: since the incident was declared as a major disaster, it is 100%.

- **Fischer’s Disaster Scale**: it is major scale, scope, duration in several populated areas and therefore it is DC-9 or 90%. In fact Fischer (2003) used this emergency as an example to illustrate the score DC-9.

- **Rohn and Blackmore’s Unified Emergency Scale**: the calculations gave results of about 52 to 70% as shown in Table 8.

<table>
<thead>
<tr>
<th>Table 8</th>
<th>E = Emergency = f (S,T,D) calculations of 9/11 Terrorist Attacks in 2001 per Rohn and Blackmore (2009).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope or S</strong> = Raw Scope / Max Scope / 5</td>
<td>0.0087</td>
</tr>
<tr>
<td><strong>Topographical Change or T</strong> = Affected Area/Total USA Area</td>
<td>8.895E-06</td>
</tr>
<tr>
<td><strong>Rate of Change or D</strong> = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>2.1494</td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong> (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td><strong>52.83%</strong></td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong> (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td><strong>69.45%</strong></td>
</tr>
</tbody>
</table>
Loma Prieta Earthquake (1989)

Event Description and Gathered Data

As per USGS (http://pubs.usgs.gov/fs/1999/fs151-99/), just before the start of the third game of the 1989 World Series in San Francisco, a magnitude 6.9, in Richter, earthquake hit the coast of California from Monterey to San Francisco. The earthquake’s center was near Loma Prieta peak in the mountains south of San Jose. The earthquake killed 63 people and caused an estimated $6 billion to $10 billion in property loss ($8 billion was used for the calculations). Millions felt the earthquake and more than 1 million people ended up without power as a result.

According to FEMA (https://www.fema.gov/disaster/845), the emergency took place from October 17th to December 18th, 1989 (62 days) and was declared as a major disaster on October 18th, 1989

Measurements and Results

There are five (5) applicable scales out of the seven (7) selected for this case too. They are MMI, Richter, FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **MMI**: it is IX or Violent which equals 90% after adjustment.
- **Richter**: it is of a magnitude of 6.9 in Richter or at the top of Strong and close to Major. Therefore, it is about 79% (5 to 6 or 5.5/7x100 for adjustment).
- **FEMA Scale**: it is 100% because of the major disaster declaration.
- **Fischer’s Disaster Scale**: it is of a major scale, scope, and duration in a large city and therefore equals to DC- 8 or 80%.
- **Rohn and Blackmore’s Unified Emergency Scale**: the calculations gave results of a little more than 2% as shown in Table 9.

### Table 9

<table>
<thead>
<tr>
<th>Description</th>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope or S</td>
<td>Raw Scope / Max Scope / 5</td>
<td>0.0301</td>
</tr>
<tr>
<td>Topographical Change or T</td>
<td>Affected Area / Total USA Area</td>
<td>5.2631E-06</td>
</tr>
<tr>
<td>Rate of Change or D</td>
<td>6 * Fatalities / 100 + 2 * Monetary Loss in billion + 1 * Job Lost / 1000 / Duration of Emergency in Days / 9 or 8 if there is no job loss</td>
<td>0.0354</td>
</tr>
<tr>
<td>UE1 or Final Emergency Scale Result</td>
<td>(using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>2.33%</td>
</tr>
<tr>
<td>UE2 or Final Emergency Scale Result</td>
<td>(using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>2.11%</td>
</tr>
</tbody>
</table>

**Oso Mudslide, Washington State (2014)**

**Event Description and Gathered Data**

As per Snohomish County Medical Examiner's Office (2014), a major landslide occurred about 4 miles east of Oso, Washington, United States
on March 22\textsuperscript{nd}, 2014, at 10:37 a.m. local time. The major landslide took place when a portion of an unstable hill collapsed pushing mud and debris across the North Fork of the Stillaguamish River, engulfing a rural neighborhood, and covering an area of about 1 square mile. Forty-three (43) people were killed. The small town and its small surrounding populated areas faced access problem going out and back to their homes within the area.

According to FEMA (https://www.fema.gov/disaster/4168), a state of emergency for was declared on the same emergency day for the affected country before a major Disaster Declaration declared on April 2\textsuperscript{nd}, 2014 and the emergency ended on April 29\textsuperscript{th}, 2014 (about 37 days). This emergency cost about $10 million (Ramsey, 2014). In addition, about 530 jobs were lost (North and Stevick, 2014).

**Measurements and Results**

There are three (3) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale:** since the incident was declared as a major incident, then it is equivalent to 100%.

- **Fischer’s Disaster Scale:** since the emergency of a major scale, scope, and duration in a town, then, it is DC-4 or 40%.
Rohn and Blackmore’s Unified Emergency Scale: the calculations gave a result around 0.5% as shown in Table 10.

Table 10  
<table>
<thead>
<tr>
<th>E = Emergency = f (S,T,D) calculations of Oso Mudslide in 2014 per Rohn and Blackmore (2009).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope or S = Raw Scope / Max Scope / 5</strong></td>
</tr>
<tr>
<td><strong>Topographical Change or T = Affected Area/Total USA Area</strong></td>
</tr>
<tr>
<td><strong>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</strong></td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong> (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong> (using 0.33 for each of S, T, and D as coefficients or weights)</td>
</tr>
</tbody>
</table>

**Hurricane Charley (2004)**

**Event Description and Gathered Data**

As per NOAA (2011) and FEMA (2009), hurricane Charley was a major hurricane of the 2004 Atlantic hurricane season. Charley started on August 9th, 2004 moving slowly though the Caribbean Sea and crossing Cuba as a Category 3 hurricane on the Saffir-Simpson Hurricane Scale. On August 13th, 2004, hurricane Charley strengthened rapidly just before striking the southwestern coast of Florida as a Category 4 hurricane on the Saffir-Simpson Hurricane Scale. Although Charley was small in size, it caused catastrophic...
wind damage in Charlotte County, Florida. Serious damage occurred well inland over the Florida peninsula before proceeding north to North and South Carolina. On August 15th, hurricane Charley weakened and left towards the ocean.

The estimated total loss of Charley within the United States was about $15 billion in damage/costs; at least 34 deaths (Lott and Ross, 2006; FEMA, 2009; NOAA, 2011). In Florida, Charley caused at least 27 deaths and resulted in the evacuation of more than 1 million people between residents and tourists. In addition, more than 2 million people were without power with some remaining for several weeks without power (FEMA, 2009; NOAA, 2011). As per FEMA (https://www.fema.gov/disaster/1539), the emergency lasted from: August 11th to 30th, 2004 (19 days) and it was declared as a major disaster on August 13th, 2004. Although the effect of Charley reduced over the Carolinas, there were about 104,000 people without power in addition to many reports of flooded roads and damaged homes in North Carolina. As for South Carolina, around 180,000 tourists and residents were evacuated and there were about 65,000 people without power. Around 28,000 square miles were actually flooded in Florida alone as a result of Hurricanes Charley, Frances, Ivan and Jeanne (FEMA, 2005).
Measurements and Results

There are four (4) applicable scales out of the seven (7) selected for hurricane Charley’s case in this thesis. The applicable scales for are Saffir-Simpson Hurricane Wind, the FEMA scale, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Hurricane Katrina’s case measurement is presented below by scale:

- **Saffir-Simpson Hurricane Wind Scale:** it is Category 4 or 80%.
- **FEMA Scale:** since the incident was at the federal level after the declaration of a major disaster by the President; then, it is level 3 or equivalent to 100% after adjustment.
- **Fischer’s Disaster Scale:** according to Fischer’s Disaster Scale, DC-9 represents “Major Scale, Scope, Duration – Several populated areas” which very well fits hurricane Charley and there 90%.
- **Rohn and Blackmore’s Unified Emergency Scale:** the calculations gave results between 7% and 8% as shown in Table 11.
Table 11  

<table>
<thead>
<tr>
<th>Scope or S = Raw Scope / Max Scope / 5</th>
<th>0.0457</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Change or T = Affected Area/Total USA Area</td>
<td>0.0074</td>
</tr>
<tr>
<td>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.1915</td>
</tr>
<tr>
<td>UE1 or Final Emergency Scale Result (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>7.08%</td>
</tr>
<tr>
<td>UE2 or Final Emergency Scale Result (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>7.87%</td>
</tr>
</tbody>
</table>

**Texas City Refinery Explosion (2005)**

**Event Description and Gathered Data**

According to (Holmstrom et al, 2006) and Greenhouse (2009), an explosion occurred at a British Petroleum (BP) refinery in Texas City, Texas on March 23rd, 2005. The refinery is a processing facility that usually receives crude oil as an input to refine it and get more specific and useful products like gasoline for example. This particular refinery processes 433,000 barrels of crude oil per day. The explosion resulted in 15 fatalities or victims and about 100 injuries. The total cost is estimated by $800 millions in addition to $1 billion for repair. The emergency was handled by several government and
private response organizations without any declaration. It was assumed that it took 2 days from emergency response organizations.

**Measurements and Results**

- **FEMA Scale:** since the incident was at local or level 1, then it is equivalent to 33%.

- **Fischer’s Disaster Scale:** it is rated as DC-5 or 50% since the case caused “partial disruption and adjustment in a small or medium city”.

  Fischer (2003) gave examples of this category by an airline crash in a small or medium sized city where a significant portion of the community may be severely damaged or destroyed.

- **Rohn and Blackmore’s Unified Emergency Scale:** the calculations gave results of about 6 to 7% as shown in Table 12.

**Table 12**

| E = Emergency = f (S,T,D) calculations of Texas City Refinery Explosion on March 23rd, 2005 per Rohn and Blackmore (2009). |
|---|---|
| **Scope or S** = Raw Scope / Max Scope / 5 | 0.0433 |
| **Topographical Change or T** = Affected Area/Total USA Area | 1.888E-09 |
| **Rate of Change or D** = 6*Fatalities/100+2*Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss | 0.1700 |
| **UE1 or Final Emergency Scale Result** (using 0.5 for S, 0.25 for each of T and D as coefficients or weights) | 6.26% |
| **UE2 or Final Emergency Scale Result** (using 0.33 for each of S, T, and D as coefficients or weights) | 6.87% |
Multiple Vehicles Collision, Gainesville, FL (2012)

Event Description and Gathered Data

According to WCTV [http://www.wctv.tv/news](http://www.wctv.tv/news), on January 29th, 2012, a multiple vehicle collision emergency took place at I-72 in Gainesville Florida. The massive crash involved 25 vehicles and killed 11 victims. Total cost was assumed to be $250,000 for all damages and expenses. The emergency was locally handled and there was no declaration.

Measurements and Results

There are three (3) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale**: since the incident was at local or level 1, then it is equivalent to 33%.
- **Fischer’s Disaster Scale**: it is major in scale and duration due to the number of cars and victims and with minor in scope as only those passing by other than the directly affected people would really feel it and therefore it is DC-2 or 20%.
- **Rohn’s and Blackmore’s Unified Emergency Scale**: the calculations gave results of about 2 to 3% as shown in Table 13.
Table 13  E = Emergency = f (S,T,D) calculations Multiple Vehicles Collision (2012) per Rohn and Blackmore (2009).

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope or S = Raw Scope / Max Scope / 5</td>
<td>0.0073</td>
</tr>
<tr>
<td>Topographical Change or T = Affected Area/Total USA Area</td>
<td>3.776E-10</td>
</tr>
<tr>
<td>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.0734</td>
</tr>
<tr>
<td>UE1 or Final Emergency Scale Result (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>2.14%</td>
</tr>
<tr>
<td>UE2 or Final Emergency Scale Result (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>2.60%</td>
</tr>
</tbody>
</table>

**Boston Marathon Bombings (2013)**

**Event Description and Gathered Data**

According to FEMA website and Hemingway and Ferguson (2014), the Boston Marathon bombings and its following shootings were a series of attacks that started on April 15, 2013. The explosion of the planted two pressure cooker bombs during the Boston Marathon resulted in 3 fatalities and more than 260 injuries. On April 22, the incident was fully under control with one of the attacker killed while the other is in custody. Duration is from April 15-22 or 7 days. A state of emergency was declared on April 17, 201. The approximate cost of the emergency is 333 million (Rinaldi, 2013).
Measurements and Results

There are three (3) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale**: since the incident was declared as a state of emergency, then, it is of level 2 equivalent to 67%.

- **Fischer’s Disaster Scale**: it is of a major scope and duration but with minor scope as DC-30 or 30%. Major Scale and Duration, Partial Scope– Town.

- **Rohn and Blackmore’s Unified Emergency Scale**: the calculations gave results of about 4 to 6% as shown in Table 14.

Table 14  
E = Emergency = f (S,T,D) calculations of Boston Marathon Bombings, 2013, per Rohn and Blackmore (2009).

<table>
<thead>
<tr>
<th>Scope or S = Raw Scope / Max Scope / 5</th>
<th>0.1060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Change or T = Affected Area/Total USA Area</td>
<td>2.632E-07</td>
</tr>
<tr>
<td>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.0134</td>
</tr>
<tr>
<td>UE1 or Final Emergency Scale Result (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>5.50%</td>
</tr>
<tr>
<td>UE2 or Final Emergency Scale Result (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>3.84%</td>
</tr>
</tbody>
</table>
South Napa Earthquake (2014)

Event Description and Gathered Data

As per Napa County official website (www.countyofnapa.org/SouthNapaQuake/Timeline), an earthquake occurred on the West Napa Fault zone with a magnitude of 6 in Richter and VII or Very Strong in MMI. Effects of the earthquake were widely observed across the Napa Valley region from Vallejo and Mare Island in the south to the north end of Napa Valley. According to FEMA (https://www.fema.gov/disaster/4193), the emergency took place from August 24th to September 7th, 2014 (14 days) while a major disaster was declared on September 11th, 2014 by the US President. About a million people felt the earthquake with one (1) fatality and several injuries with a total estimated cost of $1 billion (Lin, 2014).

Measurements and Results

There are five (5) applicable scales out of the seven (7) selected for this case too and they are MMI, Richter, FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **MMI**: it is VII or Very Strong or 70%.
- **Richter**: it is of a magnitude of 6 in Richter or Strong or 71% (or 5/7x100 for adjustment)
- **FEMA Scale**: it is 100% because of the major disaster declaration.
- Fischer’s Disaster Scale: it is of a major scale, scope, and duration in a small city and therefore equals to DC- 6 or 60%.

- Rohn and Blackmore’s Unified Emergency Scale: the calculations gave results of about 10 to 7% assuming that 10 square miles were affected by the earthquake from damages and topographical changes as shown in Table 15. It is important to note that because LN(1)=1 , only 1 fatality, this makes the Scope of S is highest and not reflective of the case. We also explored the impact of increasing the number of victims from 1 victim to 2. The calculations gave lower percentages as we increase the number of victim till reaching 8 victims where the trend changed to increases the emergency scale or percentage as the number of victims increased.

Table 15  \[ E = \text{Emergency} = f (S,T,D) \text{ calculations of South Napa Earthquake, 2014 per Rohn and Blackmore (2009).} \]

<table>
<thead>
<tr>
<th></th>
<th>0.2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope or S</strong></td>
<td>Raw Scope / Max Scope / 5</td>
</tr>
<tr>
<td><strong>Topographical Change or T</strong></td>
<td>Affected Area/Total USA Area</td>
</tr>
<tr>
<td><strong>Rate of Change or D</strong></td>
<td>6 * Fatalities/100 + 2 * Monetary Loss in billion + 1 * Job Lost/1000 / Duration of Emergency in Days / 9 or 8 if there is no job loss</td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong></td>
<td>(using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong></td>
<td>(using 0.33 for each of S, T, and D as coefficients or weights)</td>
</tr>
</tbody>
</table>
Granite Falls Tornado (2000)

Event Description and Gathered Data

As per the Department of Natural Resources of Minnesota (http://www.dnr.state.mn.us/climate/journal/tornado_000725.html), Granite Falls City and Yellow Medicine County were hit on July 25th, 2000, by a powerful F-4 tornado as per National Weather Service classified it as an F-4 storm. One (1) person was killed, 14 were injured, and the town and surrounding area suffered about $8 millions of dollars in property damage. The emergency was declared a major disaster on June 27th, 2000.

Measurements and Results

There are four (4) applicable scales out of the seven (7) selected for this case too and they are Fujita Tornado, FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **Fujita Tornado Scale:** it is F-4 or 83% (5/6x100).
- **FEMA:** since the emergency was declared as a major disaster, then it is equivalent to 100%.
- **Fischer’s Disaster Scale:** it is of a major scale and duration but with partial scope and in a small city, therefore, it is DC-5 or 50%.
- **Rohn and Blackmore’s Unified Emergency Scale:** the calculations gave results of between 6 to 10% assuming the affected area by 2 sq. mile
and the emergency duration to be 5 days as shown in Table 16. It is important to note that because LN(1)=1, only 1 fatality, this makes the Scope of S is highest and not reflective of the case.

Table 16  

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope or S</strong> = Raw Scope / Max Scope / 5</td>
<td>0.2000</td>
</tr>
<tr>
<td><strong>Topographical Change or T</strong> = Affected Area/Total USA Area</td>
<td>5.263E-07</td>
</tr>
<tr>
<td><strong>Rate of Change or D</strong> = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.0017</td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong> (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>9.79%</td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong> (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>6.49%</td>
</tr>
</tbody>
</table>

**Fatal Home Fire (2015)**

**Event Description and Gathered Data**

This case study is loosely modeled on an incident reported in Fairfax, Virginia. Although the data used for the case is not real, it provides some insights into the use of scales. Fires in residential houses are common. We assumed here one (1) fatality or victim and three (3) injuries in addition to estimated loss of $200,000. Such an emergency is common and handled locally
in most cases. An online page of Washington’s Top News or WTOP reported on March 19\textsuperscript{th}, 2015 a fatal home fire at Fairfax County, Virginia. The fire and rescue crews responded to a single-family house fire with heavy smoke and rescued all and extinguish the fire but one of the victims died later on that day at the hospital. (http://wtop.com/fairfax-county/2015/03/1-dead-in-springfield-house-fire/)

**Measurements and Results**

There are three (3) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale:** since the incident was at local or level 1, then it is equivalent to 33%.

- **Fischer’s Disaster Scale:** it is Minor in Scope, Major in Scale & Duration or 10%.

- **Rohn and Blackmore’s Unified Emergency Scale:** the calculations gave results of about 6 to 10% as shown in Table 17. The higher than usual result is because LN(1)=1 and this makes the Scope of S is highest and not reflective of the case.
Table 17  
E = Emergency = f (S,T,D) calculations of Fatal Home Fire per Rohn and Blackmore (2009).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope or S</strong> = Raw Scope / Max Scope / 5</td>
<td>0.2000</td>
</tr>
<tr>
<td><strong>Topographical Change or T</strong> = Affected Area/Total USA Area</td>
<td>0.0000</td>
</tr>
<tr>
<td><strong>Rate of Change or D</strong> = 6<em>Fatalities/100 + 2</em>Monetary Loss in billion + 1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.0067</td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong> (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>9.92%</td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong> (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>6.65%</td>
</tr>
</tbody>
</table>

Westchester County Tornado (2006)

**Event Description and Gathered Data**

According to the Storm Prediction Center (2007), the tornado passed through Rockland, Westchester, and Fairfield counties (New York), damaging thousands of trees and several structures, including significant structural damage to the California Closets warehouse. Six (6) minor injuries were also reported with no fatalities. The total cost was estimated to be $12.1 million. According to FEMA (http://www.fema.gov/disaster/1650?page=9), the emergency lasted from June 26th to July 10th, 2006 or about 14 days. The emergency was declared as a major disaster on July 1st, 2006.
Measurements and Results

There are three (3) applicable scales out of the seven (7) selected for this case too and they are Fujita Tornado, FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **Fujita:** it is F-2 or 50%.
- **FEMA Scale:** since it was declared as a major disaster, then it is equivalent to 100%.
- **Fischer’s Disaster Scale:** it is of a major scale and duration but with partial scope and in a small city, therefore, it is DC-5 or 50%.
- **Rohn and Blackmore’s Unified Emergency Scale:** the calculations gave an error because of zero victims (LN0) as shown in Table 18. As discussed earlier, this scale is not applicable when there are no fatalities.

Table 18  
E = Emergency = f (S,T,D) calculations of Westchester County Tornado, 2006, per Rohn and Blackmore (2009).

<table>
<thead>
<tr>
<th>Scope or S = Raw Scope / Max Scope / 5</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Change or T = Affected Area/Total USA Area</td>
<td>9.439E-10</td>
</tr>
<tr>
<td>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>0.0027</td>
</tr>
<tr>
<td>UE1 or Final Emergency Scale Result (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>UE2 or Final Emergency Scale Result (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>
Minor Car Accident or House Fire with One Injury and Loss of $10,000

Event Description and Gathered Data

Although this case is not real, very similar emergencies happen every day in almost all cities.

Measurements and Results

There are four (4) applicable scales out of the seven (7) selected for this case too and they are the FEMA, Fischer’s Disaster, and Rohn and Blackmore’s Unified Emergency Scales. Below are the measurement by scale:

- **FEMA Scale**: since the incident was at local or level 1, then it is equivalent to 33%.
- **Fischer’s Disaster Scale**: it is obviously 10%.
- **Rohn and Blackmore’s Unified Emergency Scale**: again, the calculations gave an error as shown in Table 19 and this scale is not applicable.

Table 19  
E = Emergency = f (S,T,D) calculations of Minor Injury Emergency with $10,000 Loss per Rohn and Blackmore (2009).

<table>
<thead>
<tr>
<th>Scope or S = Raw Scope / Max Scope / 5</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Change or T = Affected Area/Total USA Area</td>
<td>0.0000</td>
</tr>
<tr>
<td>Rate of Change or D = 6<em>Fatalities/100+2</em>Monetary Loss in billion +1*Job Lost/1000)/Duration of Emergency in Days /9 or 8 if there is no job loss</td>
<td>2.222E-06</td>
</tr>
<tr>
<td><strong>UE1 or Final Emergency Scale Result</strong> (using 0.5 for S, 0.25 for each of T and D as coefficients or weights)</td>
<td><strong>Not Applicable</strong></td>
</tr>
<tr>
<td><strong>UE2 or Final Emergency Scale Result</strong> (using 0.33 for each of S, T, and D as coefficients or weights)</td>
<td><strong>Not Applicable</strong></td>
</tr>
</tbody>
</table>
Summary of Analysis Results

Table 20 summarizes the measurement results for applicable cases using the single-phenomena scales, while Table 21 summarizes the measurement results of the thirteen (13) cases using the unified scales irrespective of the type of emergency. In all cases the scales have been converted to a common measurement scale of 0 to 100 using the methods shown in Table 6.

Table 20  Measurement Results of Applicable Emergency Cases by Single-Phenomena Scales and Adjusted in a Percentage Format (%)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Case Study</th>
<th>MMI</th>
<th>Richter</th>
<th>SSWH</th>
<th>Fujita</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Hurricane Katrina 2005</td>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Loma Prieta Earthquake 1989</td>
<td>90</td>
<td>79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hurricane Charley 2004</td>
<td></td>
<td></td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>South Napa Earthquake 2014</td>
<td>70</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Granite Falls Tornado 2000</td>
<td></td>
<td></td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>12</td>
<td>Westchester County Tornado 2006</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>
Table 21 Measurement Results of 13 Real Emergency Cases by Unified Emergency Scales and Adjusted in a Percentage Format (%)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Case Study</th>
<th>FEMA</th>
<th>Fischer</th>
<th>Unified Emergency Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>9/11 Terrorist Attacks 2001</td>
<td>100</td>
<td>90</td>
<td>53</td>
</tr>
<tr>
<td>2</td>
<td>Hurricane Katrina 2005</td>
<td>100</td>
<td>95</td>
<td>72</td>
</tr>
<tr>
<td>3</td>
<td>Loma Prieta Earthquake 1989</td>
<td>100</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Oso Mudslide 2014</td>
<td>100</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Hurricane Charley 2004</td>
<td>100</td>
<td>90</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Texas City Refinery explosion 2005</td>
<td>67</td>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>I-75 Multiple vehicles collision 2012</td>
<td>33</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Boston Bombings 2013</td>
<td>67</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>South Napa Earthquake 2014</td>
<td>100</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Granite Falls Tornado 2000</td>
<td>100</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>Fatal Home 2015</td>
<td>33</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>Westchester County Tornado 2006</td>
<td>100</td>
<td>50</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>13</td>
<td>Minor Emergency with 1 injury and loss of $10,000</td>
<td>33</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

In the next chapter, we compare the measurement results of each studied emergency case to assess emergency scales consistency. Then, we compare the measurement results of each scale to evaluate its uses for emergency managers before, during and after emergencies.
Chapter 5

ANALYSIS OF RESULTS

All the measurements are converted to a common scale (0-100) and formatted as a percentage for each emergency case as shown in Table 20 and 21. We now compare the measurement results of each case to test the consistency of the scales and to address the research question posed in Chapter 1. Then, the application and measurement results of each scale are compared and evaluated with several observations and findings presented for each scale.

An Analysis of Consistency

We define scales to be consistent for a case study if the results of two scales are within 15%. To explore the impact of this threshold of 15%, we assessed consistency using a threshold of 10%, 15% and 20%, and an absolute difference of 5, 10, 15 and 20 points. The consistency was determined for each pair of scales for any given case. For example, if four (4) scales are applicable then there are six (6) different pairs involved in determining consistency. The results are shown in Table 22. For example, using a threshold of 15%, five scales were measured for Hurricane Katrina. Based on the comparison of ten pairs (Saffir-Simpson with the four unified emergency scales – four pairs, FEMA with Fischer, UE1 and UE2 – three pairs, Fischer with UE1 and UE2 – two pairs, and UE1 with UE2 – one pair), three pairs (FEMA and Fischer, FEMA and UE2, and Fischer and UE2) provide
consistent results giving a percentage consistent of 20%. This means that given this particular emergency event, the consistency of this event’s measurement results by the different applicable scales is only 20% and this shows very low consistency and could miss lead emergency managers. The calculations within this table is explained in Appendix 1 at the end of this thesis.

The percentage of pairs of scales that are consistent using this measure is relatively low, but more importantly using the percentage change as a threshold, rather than the absolute change, is more robust and supports the argument for setting the threshold at 15% as presented in Chapter 4.
Table 22  Consistency Determined by the Number of Consistent Pairs of Scales over Total Pairs per Case and the Average of All Cases Using different Thresholds and Absolute Points.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Case Study</th>
<th>Percentage Difference</th>
<th>Absolute Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>1</td>
<td>9/11 Terrorist Attacks 2001</td>
<td>0.0%</td>
<td>33.3%</td>
</tr>
<tr>
<td>2</td>
<td>Hurricane Katrina 2005</td>
<td>20.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>3</td>
<td>Loma Prieta Earthquake 1989</td>
<td>13.3%</td>
<td>33.3%</td>
</tr>
<tr>
<td>4</td>
<td>Oso Mudslide 2014</td>
<td>16.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>5</td>
<td>Hurricane Charley 2004</td>
<td>0.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>6</td>
<td>Texas City Refinery explosion 2005</td>
<td>16.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>7</td>
<td>I—75 Multiple vehicles collision 2012</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>8</td>
<td>Boston Bombings 2013</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>9</td>
<td>South Napa Earthquake 2014</td>
<td>6.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>10</td>
<td>Granite Falls Tornado 2000</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>11</td>
<td>Fatal Home Fire 2015</td>
<td>16.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>12</td>
<td>Westchester County Tornado 2006</td>
<td>33.3%</td>
<td>33.3%</td>
</tr>
<tr>
<td>13</td>
<td>Minor Emergency with 1 injury and loss of $10,000</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Average of All Cases</td>
<td>9.5%</td>
<td>15.1%</td>
</tr>
</tbody>
</table>
Comparison of Measurement Results by Each Emergency

Following the sequence in which the case studies were presented in Chapter 4, we start with the 9/11 terrorist attacks, beginning with the emergency with the most number of fatalities and ending with the emergency with the least number of fatalities. For each case study we explore the similarities and differences among the measures to better understand the consistencies and inconsistencies among the measures.

9/11 Terrorist Attacks

This emergency was measured by three (3) applicable scales. These are FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 2 shows the results and below is a list of the observations and findings:

- The results of FEMA and Fischer scales are close to each other while the Unified Emergency result is almost half to two-thirds of these two.
- The only consistency in the results is found between the FEMA and Fischer scales.
- The results of the Rohn and Blackmore Unified Emergency scale using either weighting scheme are inconsistent with other scales.
- The two computations for the Rohn and Blackmore Unified Emergency scale are also inconsistent with each other.
- The rate of change (D) within the Rohn and Blackmore Unified Emergency scale is much higher than the other two factors of Scope (S) and the topographical change (T) and therefore dominating the final result.

- FEMA scale is at its maximum of 100.

- Fischer scale is very close to its maximum of 100.

Figure 2 Comparison of the measurement results of 9/11 Terrorist Attacks Emergency by Different Applicable Scales
Hurricane Katrina

Hurricane Katrina was measured by four (4) applicable scales, which are Saffir-Simpson, FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 3 shows the results and below is a list of the observations and findings:

- The results of FEMA, Fischer, and Rohn and Blackmore Unified Emergency UE2 scales show three scales to be consistent with each other for this case.

- The Fischer scale and the Unified Emergency scale UE2 have the same result indicating 100% consistency for this case. These scales are also consistent with the FEMA scale but with less consistency.

- The results of Saffir-Simpson is inconsistent with all scales for this case.

- The Rohn and Blackmore Unified Emergency UE1 scale is inconsistent with all other scales for this case.

- The two results of the Rohn and Blackmore Unified Emergency scale are also inconsistent with each other.

- The rate of change (D) within the Rohn and Blackmore Unified Emergency scale is much higher than the other two factors of Scope
(S) and the topographical change (T) and therefore dominating the final result.

- FEMA scale result is at its maximum of 100.
- Fischer scale result is very close to its maximum of 100.
- Rohn and Blackmore Unified Emergency scale 2 result is very close to its maximum of 100.

Figure 3  Comparison of the measurement results of “Hurricane Katrina” Emergency by Different Applicable Scales
Loma Prieta Earthquake

This earthquake emergency was measured by five (5) applicable scales, which are the MMI, Richter, FEMA, Fischer, and Rohn and Blackmore Unified Emergency. Figure 4 shows the results and below is a list of the observations and findings:

- The results of MMI and FEMA scales are found to be consistent with each other for this case.
- The MMI and Fischer scales, and the Richter, and Fischer scales are found to be consistent with each other for this case. Similarly, the MMI and Richter scales are consistent.
- The MMI result is also consistent with FEMA scales.
- However, the Richter and Fischer scales are inconsistent with FEMA scale.
- Both results of Rohn and Blackmore Unified Emergency are very inconsistent with other scales in this case.
- The two results of the Rohn and Blackmore Unified Emergency scale are consistent with each other but much smaller than other scale results.
- FEMA scale result is at its maximum of 100.
• MMI scale result is very close to its maximum of 100.

Figure 4  Comparison of the measurement results of “Loma Prieta Earthquake” Emergency by Different Applicable Scales

Oso Mudslide

The Oso mudslide emergency was measured by three (3) applicable scales, which are FEMA, Fischer, and Rohn and Blackmore Unified Emergency. Figure 5 shows the results and below is a list of the observations and findings:

• The three scales cover the complete range zero to one hundred.

• The results of FEMA, Fischer, and both Rohn and Blackmore Unified Emergency Scales are inconsistent with each other for this case.
- The two results of the Rohn and Blackmore Unified Emergency scale are consistent with each other but much smaller than other scale results.
- FEMA scale result is at its maximum of 100.
- Both results of Rohn and Blackmore Unified Emergency are very close to the minimum of zero.

Figure 5  Comparison of the measurement results of “Oso Mudslide” Emergency by Different Applicable Scales
**Hurricane Charley**

This hurricane emergency was measured by four (4) applicable scales, which are the Saffir-Simpson, FEMA, Fischer, and Rohn and Blackmore Unified Emergency. Figure 6 shows the results and below is a list of the observations and findings:

- The results of FEMA and Fischer scales are found consistent.
- The result of Saffir-Simpson and Fischer scales are found consistent. However, Saffir-Simpson result is not consistent with FEMA/Practitioner scale.
- Both Rohn and Blackmore Unified Emergency Scales are low and inconsistent with other scales in this case, although consistent with each other.
- The rate of change (D) within the Rohn and Blackmore Unified Emergency scale is much higher than the other two factors of Scope (S) and the topographical change (T) and therefore dominating the final result.
- FEMA scale result is at its maximum of 100.
- Fischer scale result is very close to its maximum of 100.
Figure 6  Comparison of the measurement results of “Hurricane Charley” Emergency by Different Applicable Scales

Texas Refinery Explosion

The Texas Refinery emergency was measured using three (3) applicable scales, which are FEMA, Fischer, and Rohn and Blackmore Unified Emergency.

Figure 7 shows the results and below is a list of the observations and findings:

- The results of FEMA and Fischer scales are similar, especially when compared with both results of Rohn and Blackmore Unified Emergency scale, but are not consistent based on our criteria.
• The results of FEMA, Fischer, and Rohn and Blackmore Unified Emergency scales are found inconsistent with each other for this case.

• The two results of the Rohn and Blackmore Unified Emergency Scale are inconsistent with each other using our criteria. Although only one point different, they are much smaller than other scale results.

• Both results of Rohn and Blackmore Unified Emergency are close to their minimum (zero) in this case.

• The rate of change (D) within the Rohn and Blackmore Unified Emergency scale is much higher than the other two factors of Scope (S) and the topographical change (T) and therefore dominating the final result.
I-75 Multiple Vehicle Collision

This multiple vehicle collision emergency was measured by three (3) applicable scales, which are the FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 8 shows the results and below is a list of the observations and findings:

- The results of FEMA and Fischer scales are closer to each other than to the results of Rohn and Blackmore Unified Emergency Scales.
• The results of FEMA, and the Fischer scales, are found to be inconsistent with each other, and with the Rohn and Blackmore Unified Emergency Scales, for this case.

• The two results of the Rohn and Blackmore Unified Emergency Scale are inconsistent with each other and much smaller than other scale results.

• Both results for the Rohn and Blackmore Unified Emergency Scales are close to their minimum (zero) in this case.

• The rate of change (D) within the Rohn and Blackmore Unified Emergency scale is much higher than the other two factors of Scope (S) and the topographical change (T) and therefore dominating the final result.
Boston Marathon Bombings

The Boston Marathon Bombings emergency was measured by three (3) applicable scales, which are FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 9 shows the results and below is a list of the observations and findings:

- The scales range from 67 to 4. The FEMA and Fischer scales are inconsistent with each other and Rohn and Blackmore Unified Emergency Scales.
The results of FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales are found inconsistent with each other in this case.

The two results using the Rohn and Blackmore Unified Emergency Scale are inconsistent with each other and much smaller than other scale results.

Both results of Rohn and Blackmore Unified Emergency are close to their minimum (zero) in this case.

Figure 9  Comparison of the measurement results of “Boston Marathon Bombings” Emergency by Different Applicable Scales
South Napa Earthquake

This earthquake emergency was measured by five (5) applicable scales, which are MMI, Richter, FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 10 shows the results and below is a list of the observations and findings:

- The MMI and Richter scales are found to be consistent for this case.
- The results using the MMI, Richter, FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales are found to be inconsistent with each other for this case.
- The results using the two Rohn and Blackmore Unified Emergency Scales are inconsistent with each other.
- FEMA scale result is at its maximum of 100.
- Both results using the Rohn and Blackmore Unified Emergency Scale are close to their minimum (zero) for this case.
Figure 10  Comparison of the measurement results of “South Napa Earthquake” Emergency by Different Applicable Scales

Granite Falls Tornado

The Granite Falls Tornado emergency was measured by four (4) applicable scales, which are the Fujita Tornado, FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 11 shows the results and below is a list of the observations and findings:

- The results of Fujita Tornado, FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales are found to be inconsistent with each other.
• The two results using the Rohn and Blackmore Unified Emergency Scale are inconsistent with each other and much smaller than the results using the other scales.

• FEMA scale result is at its maximum of 100.

• Both results using the Rohn and Blackmore Unified Emergency Scale are close to their minimum (zero) in this case.

Figure 11  Comparison of the measurement results of “Granite Tornado” Emergency by Different Applicable Scales
Fatal Home Fire

This fatal home fire emergency was measured by three (3) applicable scales, which are FEMA, Fischer, and Rohn and Blackmore Unified Emergency. Figure 12 shows the results and below is a list of the observations and findings:

- The results using the FEMA scale are inconsistent with the results using the Fischer scale and the Rohn and Blackmore Unified Emergency Scales in this case.

- The results of Fischer scale and the Rohn and Blackmore Unified Emergency Scale 1 have the same result with 100% consistency in this case.

- The two results using the Rohn and Blackmore Unified Emergency Scales are inconsistent with each other.
Figure 12  Comparison of the measurement results of “Fatal Home Fire” Emergency by Different Applicable Scales

Westchester County Tornado

The Westchester Tornado emergency was measured by four (4) applicable scales, which are Fujita Tornado, FEMA, Fischer, and Rohn and Blackmore Unified Emergency. Figure 11 shows the results and below is a list of the observations and findings:

- Only the results using the Fujita Tornado and Fischer scales are consistent for this case, sharing the same result.
- The result of FEMA scale is found to be inconsistent with all other scale results.
- The Rohn and Blackmore Unified Emergency Scale is not applicable because there are no fatalities in this case as per of the scale calculation method ends to error.
- FEMA scale result is at its maximum of 100.

Figure 13  Comparison of the measurement results of “Westchester County Tornado” Emergency by Different Applicable Scales
**Minor Emergency with 1 Injury and $10,000 Loss**

This minor emergency was measured by three (3) applicable scales, which are FEMA, Fischer, and Rohn and Blackmore Unified Emergency Scales. Figure 12 shows the results and below is a list of the observations and findings:

- The results of FEMA and Fischer scales are found to be inconsistent
- The Rohn and Blackmore Unified Emergency Scale is not applicable because there are no fatalities.

![Comparison of measurement results](Figure 14)
Summary of the Consistency Assessment

In summary, there was no case where all scale results came to be consistent. Furthermore, it was found that for some events, some scales are consistent with each other in cases and inconsistent in other cases. Given the assumption that scales are consistent if they are within 15% of each other, Table 23 shows the number of applicable scales for each case along with the maximum number of consistent scale results. For example, if we have 5 applicable scales for a given case and 2 of them are consistent within the 15% while others are not. Then, the ratio is 2 to 5 or 40%. However, if the other 3 were also consistent with each other within the 15% but not with the other 2 scales that are consistent with each other only. Then, the ratio will be 3 to 5 or 60% as we take the highest number of consistent scales within 15%. The last column shows the percentage of the maximum number of consistent scales to the total applicable scales before getting the overall percentage of consistency for the selected cases and scales. For example, for the Hurricane Katrina, five scales were used, and the FEMA, Fischer and UE 2 scales are all consistent with each other, so the maximum consistency for this case is 60%. The overall consistency percentage is about 25% which is very low in general and it is even worse for critical measurements of these events along with the complexity of emergency management. For example, for a given emergency case that can be measured by eight (8) applicable scales, only 2 scales on average will be consistent with each
other. This also means that for an emergency case that can be measured by four (4) applicable scale, there will be no scales within 15% of consistency among the four (4) scales. This could be a serious thing to be highlighted and considered by emergency managers as they also utilize these scales for their size-ups and assessments of the emergency and the same thing may apply to the media and public.

### Table 23
The Calculations of the Percentage of Consistent Scales Over Total Applicable Scales per Case and the Average of All Cases.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Case Study</th>
<th>No. of Applicable Scales</th>
<th>No. of Consistent Scales</th>
<th>Percentage of Consistent Scales Over Total Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9/11 Terrorist Attacks 2001</td>
<td>4</td>
<td>2</td>
<td>50.0%</td>
</tr>
<tr>
<td>2</td>
<td>Hurricane Katrina 2005</td>
<td>5</td>
<td>3</td>
<td>60.0%</td>
</tr>
<tr>
<td>3</td>
<td>Loma Prieta Earthquake 1989</td>
<td>6</td>
<td>3</td>
<td>50.0%</td>
</tr>
<tr>
<td>4</td>
<td>Oso Mudslide 2014</td>
<td>4</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>5</td>
<td>Hurricane Charley 2004</td>
<td>5</td>
<td>2</td>
<td>40.0%</td>
</tr>
<tr>
<td>6</td>
<td>Texas City Refinery explosion 2005</td>
<td>4</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>7</td>
<td>I-75 Multiple vehicles collision 2012</td>
<td>4</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>8</td>
<td>Boston Bombings 2013</td>
<td>4</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>9</td>
<td>South Napa Earthquake 2014</td>
<td>6</td>
<td>2</td>
<td>33.3%</td>
</tr>
<tr>
<td>10</td>
<td>Granite Falls Tornado 2000</td>
<td>5</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>11</td>
<td>Fatal Home Fire 2015</td>
<td>4</td>
<td>2</td>
<td>50.0%</td>
</tr>
<tr>
<td>12</td>
<td>Westchester County Tornado 2006</td>
<td>5</td>
<td>2</td>
<td>40.0%</td>
</tr>
<tr>
<td>13</td>
<td>Minor Emergency with 1 injury and loss of $10,000</td>
<td>2</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total Applicable and Consistent Scales and the Average Consistency Percentage</td>
<td>60</td>
<td>16</td>
<td>24.9%</td>
<td></td>
</tr>
</tbody>
</table>
Clearly, the answer to the research question posed in Chapter 1 is that the measurement results of each case by applicable scales from the selected scales reveal high inconsistent scores. As an attempt to understand the reasons (why) behind these inconsistencies, we next evaluate each scale by comparing its measurement results of the different applicable cases. This evaluation also sheds lights on the strengths and weaknesses of each scale for emergency managers before, during, and after emergencies.

**Evaluation of Scales**

Noting the general inconsistency of the selected scales to measure the selected cases studies, we compare all applicable measurement results for each scale to evaluate its use and application and highlight observations and findings accordingly. We start with both the MMI and Richter scales for our earthquake cases:

**Modified Mercalli Intensity (MMI) and Richter Scales**

As discussed earlier, MMI and Richter scales measure different things although both are scales for earthquakes. MMI scale measures the intensity of the earth’s shaking along with lives losses, property damages, environmental effects, and human behaviors. On the other hand, Richter scale measures the magnitude of earthquakes. The 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 with common calibration and has nothing to do with lives losses, property damages, environmental effects, and human behaviors.

In addition, the measurements of MMI scale are done during and/or after the event while Richter measurements are live and respond directly with the earthquake magnitude while Intensity is based on the observed effects of ground shaking on people, buildings, and natural features.

In the case of Loma Prieta earthquake, there were 63 fatalities with an approximate cost of $8 billion while South Napa earthquake resulted in 1 fatalities and about $1 billion loss. As shown in Figure 15, while the magnitude of the 2 earthquakes are similar as we can see from the Richter results, the MMI results gave a higher value for Loma Prieta earthquake since it considers lives losses, property damages, environmental effects, and human behaviors. However, the relatively small difference in MMI results of both earthquake emergencies when compared to the actual difference fatalities and loss.
Figure 15  Comparison of the measurement results of “Modified Mercalli Intensity and Richter” Scales by Different Applicable Emergency Cases

Saffir-Simpson Hurricane Wind Scale

Hurricane Katrina resulted in 1833 fatalities in addition to about $150 billion loss and 400,000 jobs lost while hurricane Charley resulted in only 29 fatalities in addition to about $15 billion loss and 1,000 jobs lost. However, the Saffir-Simpson Hurricane Wind scale rated hurricane Charley higher than Katrina as shown in Figure 16. This shows that the rating of this scale depending on the hurricane wind speeds does not reflect the actual impact of measured emergencies. Having said that,
the scale has an advantage of providing early warning prior to the emergency or hurricane landfall or strike on land.

Figure 16  Comparison of the measurement results of “Saffir-Simpson Hurricane Wind” Scale by Different Applicable Emergency Cases

**Fujita Tornado Scale**

Granite Falls tornado caused 1 fatality and cost about $8 million while Westchester tornado left no fatalities but cost about $12 million. Although the impact of both tornados does not differ much from each other, the Fujita Tornado scale rated Granite Falls tornado more than 1.5 times the Westchester rating as
shown in Figure 17. This shows that that wind speed alone may not be representative of the emergency impact and maybe that is why the scale was recently modified to address some limitations identified by meteorologists and engineers since the introduction of the Fujita Scale. The Enhanced Fujita scale is still a set of wind estimates, not measurements, based on damage using three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage to the 28 indicators. The estimates vary with height and exposure (NOAA, 2007). This scale could be a good tool to estimate damages or potential physical impact of the tornado in advance as an early warning which is an advantage.
FEMA Scale

As shown in Figure 18, eight (8) of the thirteen (13) emergency cases received a presidential declaration of Major Disaster. On the other hand, two (2) emergency cases received a State of Emergency declaration and three (3) were local. This means that about 77% of selected cases could not be managed locally and therefore received escalations and declarations. Further, more than 60% of selected cases received a presidential declaration of Major Disasters. This highlights the
overdependence on federal assistance instead of strengthening local resources with effective utilization including mutual aid agreements. It also highlights that three levels does not differentiate among emergencies of different scales within the context of the United States of America.

![Comparison of the measurement results of FEMA Scale by Different Applicable Emergency Cases](image)

**Figure 18** Comparison of the measurement results of FEMA Scale by Different Applicable Emergency Cases

**Fischer’s Disaster Scale**

The scale provided reasonable measurements of social disruption as shown in Figure 19. However, it does not account for fatalities, injuries, damages, costs etc. In addition, its measurement is done after the onset of the emergency and requires important information or estimation of scale, scope, and duration. This means that an accurate measurement is done after the emergency which reduces its importance.
to emergency managers. Moreover, the differences between levels seem to be increasing as we go up the levels. For example, Boston Bombings emergency is rated as DC-3 or 30% and 9/11 terrorist attacks emergency is rated as DC-9 while it is true to say that the social disruption 9/11 is 3 times that of Boston Bombings. Further, the upper scale of DC-10 was close to be reached by several emergency cases as shown in Figure 19 and this may show a need for additional ratings.

![Fischer Disaster Scale](image)

**Figure 19**  Comparison of the measurement results of “Fischer Disaster” Scale by Different Applicable Emergency Cases
Rohn and Blackmore’s Unified Emergency Scale

This scale considers several impact factors such as lives lost, damages and costs, job loss, affected topography, and the duration of the emergency to get the rate of change. However, the calculations needed for this scale have several issues as follows:

- The calculations for emergencies with 1 fatality lead to a maximum of 1/5 or 0.2 because LN(1) is zero which makes RawScope and MaxScope to be 1 as both are raised to the power of LN(1) or zero leading to maximum scope.

- The scale is not applicable to emergencies with no fatalities.

- Given constant Topographical change (T) and Rate of Change (D), the Scope (S) and both final results for Unified Emergency Scale 1 and 2 (UE1 and UE2) reduces as fatalities increase from 2 to 9 because of the effect of LN function again. Once the fatalities reach 10, the S and both UE1 and UE2 increases.

- In almost all cases, the Rate of Change (D) score is higher than the Scope (S) and Topographical Change (T) and therefore dominating the final results of UE1 and UE2.
• Minor emergencies with short duration of an hour (1/24 of a day), for example, have very high Rate of Change (D) as the change will be divided by 1/24 or in other words multiplied by 24.

• Large differences are noticed in some cases between Unified Emergency Scale 1 and 2 or UE1 and UE2, particularly for larger events, depending on the coefficients used as shown in Figure 20.

Moreover, the scale does not consider injuries, human behaviors and social disruptions. In addition, its calculations require figures that are only available with good accuracy after the emergency, and often only months or even years after the event. This means that it is most probably calculated retrospectively, long after the emergency.
Further, Figure 21 and Table 23 show the comparison and correlations between FEMA, Fischer Disaster, and Rohn and Blackmore Unified Emergency 1 and 2 scales. Below is a list of the observations and findings:

- The highest correlation was between Rohn and Blackmore Unified Emergency Scales 1 and 2 results. However, it seems that this strong correlation is because of the dominance of Rate of Change (D) on the final results as discussed previously.
The results of FEMA and Fischer Disaster scales have noticeable correlation.

The results of Fischer Disaster and Rohn and Blackmore Unified Emergency 1 and 2 have some sort of medium to low correlation.

The results of FEMA and Rohn and Blackmore Unified Emergency 1 and 2 scales have weak correlation.

Figure 21  Comparison the Measurement Results of FEMA, Fischer Disaster, and Rohn and Blackmore Unified Emergency 1 Scales.
Table 24  The Correlations Between FEMA, Fischer Disaster, and Rohn and Blackmore Unified Emergency 1 and 2 Scales

<table>
<thead>
<tr>
<th></th>
<th>Fischer</th>
<th>Rohn and Blackmore UE1</th>
<th>Rohn and Blackmore UE2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMA</td>
<td>0.8164</td>
<td>0.3184</td>
<td>0.3219</td>
</tr>
<tr>
<td>Fischer</td>
<td></td>
<td>0.5987</td>
<td>0.6164</td>
</tr>
<tr>
<td>Rohn and Blackmore UE1</td>
<td></td>
<td></td>
<td>0.9967</td>
</tr>
</tbody>
</table>

In summary, when all measurement results were adjusted into a percentage format, the comparison of measurement results of each case revealed inconsistency in general even though some scales were consistent for some cases. The overall average consistency calculated for all cases with applicable scales is about 25% which is very low. Then, the application and measurement results of each scale were compared and evaluated with several observations and findings on each scale. In the next chapter, the findings, recommendations, and suggestion for future researches are discussed.
Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, using a mixed quantitative and qualitative comparative case studies method, this thesis attempted to answer the research question “How consistent are emergency and disaster measurements and scales?” In order to answer this research question, the concept of emergency measurement was explored first. As a result, we learned that scales require shared qualities to be used for measurement reference to differentiate among different emergencies. However, selecting qualities that are not shared among emergencies, disasters, and catastrophes as measurement references cannot lead to a proper scale for comparing these events. It was also found that there are important shared qualities among emergencies, disasters, and catastrophes. These shared qualities can be utilized to build a scale. However, because emergencies, disasters, and catastrophes are complex phenomena, it was not possible to capture many of their shared qualities. Therefore, further research is proposed to study and identify critical shared qualities to be assessed and weighted to build a scale that could be used by emergency managers and/or the public.

Next, the seven (7) selected emergency scales were also reviewed to understand what they measure and how to apply the measurement methods. The
selected scales were applied to real emergencies using the United States of America as the geographical reference for each case. After getting the measurement results, they were adjusted into a percentage format to allow for direct comparisons.

Then, the comparison of measurement results of each case using the different applicable scales revealed high inconsistency in general in measuring the same event, even though some of the scales were consistent in few cases. In an answer to this research question of “how consistent are emergency and disaster measurements and scales?” The overall average consistency calculated for all cases with applicable scales is about 25%, which is very low. It is just like having in average only two (2) consistent scales within 15% out of a total of eight (8) applicable scales yet the selected scales were only seven (7). This answers the thesis question.

These measures of consistency are based on the assumption that the conversion of the original scales to a linear scale ranging from zero to one hundred captures the original intent of the scale. Furthermore, these results also assume that the measures have appropriately captured the time frame and extent of the event. In addition, the application and measurement results of each scale were compared and evaluated resulting in several observations and findings for each scale as summarized in Table 25 and 26 while the details are in Chapter 5.
Table 25  Comparison of Selected Scale in Terms of Users and What is Measured

<table>
<thead>
<tr>
<th>Scale</th>
<th>Who uses the Scale?</th>
<th>Does the Scale have a Reference?</th>
<th>What is the Base of Measurement?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emergency Managers</td>
<td>Public</td>
<td>Emergency itself</td>
</tr>
<tr>
<td>MMI</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Richter</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Saffir-Simpson</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fujita</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>FEMA</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fischer</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>Rohn and Blackmore</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 26  Comparison of Selected Scale in Terms of Use Time and Dimensions Considered

<table>
<thead>
<tr>
<th>Scale</th>
<th>When can the Scale be Useful?</th>
<th>What Dimensions does the Scale Consider?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>At onset or during response</td>
</tr>
<tr>
<td>MMI</td>
<td>No</td>
<td>Maybe</td>
</tr>
<tr>
<td>Richter</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Saffir-Simpson</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fujita</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>FEMA</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>Fischer</td>
<td>No</td>
<td>Maybe</td>
</tr>
<tr>
<td>Rohn and Blackmore</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

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The single type event scales have several limitations. They do not have a reference and have limited focus and reflection of faced emergencies at the ground. Looking at emergencies from their impact to lives and economy, some medium emergencies were rated higher than major ones as shown in the analysis discussions. On the other hand, some of them are great for early warnings that are very important to both emergency managers and the public.

While reviewing FEMA scale results we found that 77% of selected cases could not be managed locally and therefore received escalations and declarations. More than 60% of selected cases received a presidential declaration of Major Disasters. This may highlight the overdependence on federal assistance instead of strengthening local resources with effective utilization including mutual aid agreements. It may also underscore the concept that FEMA’s 3 levels are too coarsely differentiated to scale emergencies within the context of the United States of America and maybe more differentiation is needed. The uniqueness of the FEMA scale is that it measures the emergency impact by the emergency organizations’ ability in terms of resources and capabilities. This is important as it considers the resilience or vulnerability of the impacted location.

One of the most important notes is the importance of having official Unified Emergency scales such as the Fischer Disaster and Rohn and
Blackmore Unified Emergency Scales. Such unified scales simplify the message to emergency managers and the public especially for enhancing the effectiveness of communication and mutual understanding.

As for the Fischer Disaster scale, it provided reasonable measurements of social disruption but it does not account for fatalities, injuries, damages, costs etc. The scope, scale, and duration need to be better identified as they still have some ambiguity. In addition, its measurement is done after the onset of the emergency and requires important information or estimation of scale, scope, and duration. This means that an accurate measurement is done after the emergency which reduces its importance to emergency managers. In addition, the differences between levels seem to be increasing as we go up the levels and not linear. Further, the upper scale of DC-10 was close to being reached by several emergency cases as shown in Figure 19 and this may show a need for additional ratings.

When reviewing the recently developed Unified Emergency Scale by Rohn and Blackmore, it was found that it is unique as it considers several impact factors such as live loss, damages and costs, job loss, affected topography, and the duration of emergency to get the rate of change. However, the calculations needed for this scale have several issues as follows:

- The scale does not work well for minor emergencies with fewer than nine fatalities or short durations
- In almost all cases, the Rate of Change (D) score is always higher than the Scope (S) and Topographical Change (T) and therefore dominating the final results.

- The results are sensitive the assigned weighting as underscored by the noticeable differences between UE1 and UE2 results.

Moreover, the scale does not consider injuries, human behaviors and social disruptions. In addition, its calculations require data only available long after the emergency.

It seems that the complexity of emergency management is increased by the lack of consistent measurements and accurate reflection of what we need to manage. Therefore, it is very important to consider the development of an official Unified Emergency Scale especially with the “All-Hazard” approach to emergency management. The uniqueness of each emergency and the complexity of emergency management makes the development of a scale that can provide powerful insights for more informed decisions by emergency managers and public.

The scale needs to have a clear objective and targeted audience. Perhaps it is better to build one for the public as it could be utilized by both and makes the communication between emergency managers and public easier by raising their public awareness and hopefully preparedness. Of course, it is easy to say
than do. The scale should have a reference to be meaningful to people despite their geographical location. For example, it is the galaxy, planet, country, state, county, city, neighborhood, household, and individual. The scale needs to identify what to measure. It is the emergency itself as an event or phenomenon or it is about the impact of the event. Maybe, we end up using a combination of both.

If it is about the emergency as an event, then, the design of scale should start anyway by wide understanding of emergencies in different types and sizes in order to select the most important and reflective shared qualities or characteristics to build a scale on. Maybe a combination of qualities could better help especially when each is properly weighted.

If we seek to measure the impact of an event, then, the Unified Emergency Scale should include several dimensions such as human fatalities and injuries, physical damages and economic losses, social and environmental disruptions. It should also consider the affected area resources and capabilities in addition to the area’s resilient and/or vulnerability levels. In other words, it is actually the net impact as referred to in Table 25. It is the net impact because the “Actual Impact (zero management effort)” = “Net Impact “+ Absorbed Impact “Emergency Management” including planning, mitigation,
preparedness, response, and recovery. Therefore, the Net Impact = Actual Impact - Absorbed Impact.

The development of an accurate and consistent Unified Emergency Scale should also consider the time of measurement and communication to emergency management with reference to the emergency timeline. Emergency management require fast, simple, and reflective measures to build plans and actions on. Early warnings are great when possible while understanding that not all can be detected in advance at least nowadays. Other measurements happen on the onset of the emergency while others are done at the end of the emergency or after it for detailed impact reports. Maybe the involvement if experienced emergency managers is also important for the development of effective scale. The measurement needs to consider the quantity and quality of matters as emergency management at the end is driven primary by human safety and security. Humans are surely more complicated than just numbers.

It is also suggested to study and research the concept used by FEMA and the practitioner. The use of the readiness and capability to manage emergencies is unique because it considers the overall impact and by emergency experts. However, an increase in levels seem to be needed. For example, Local (1), City (2), County (3), State (4), Country (5), and International (6).
Finally, could a disaster be looked at as multiple minor and major emergencies that are happening and concentrated in time and space? When looking at earthquake, flood, hurricane, or terrorist disasters, the results may be seen at a number of multiple major and minor emergencies that are happening and concentrated in time and space and are beyond the available resources of that effected area. Another question is which has the higher priority, preparing for Katrina that left 1833 fatalities or the so many motor accidents and fires that kill about 30,000 people and cause a loss of $100 every year in the United States of America according to government reports. Final question, if the likelihood and severity of smaller emergencies at least in the annual number of fatalities is much greater than disasters and catastrophes, should the focus be more on these events first for academic, practitioners, and public?
REFERENCES


Retrieved on March 2015.


Emergency Medical Operations, And Special Operations To The Public


http://www1.ncdc.noaa.gov/pub/data/extremeevents/specialreports/Hurricane-Katrina.pdf


http://www.crh.noaa.gov/glossary.php?word=Fujita+Scale


http://www.spc.noaa.gov/faq/tornado/ef-scale.html


http://www.nhc.noaa.gov/aboutsshws.php

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Appendix

CALCULATION EXPLANATIONS

This appendix provides more details on the calculation of consistency for a specific event. Table 27 is a snapshot from Table 22 presenting the “Consistency Determined by the Number of Consistent Pairs of Scales over Total Pairs per Case and the Average of All Cases Using different Thresholds and Absolute Points”. Table 27 takes the case of the 9/11 Terrorist Attacks as an example for the calculation explanations. Table 28 provides the detailed measurement results for the 9/11 Terrorist Attacks by the applicable scales.

Table 27  Snapshot from Table 22 Focusing on 9/11 Terrorist Attacks Case Only for Explanation

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Percentage Difference</th>
<th>Absolute Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>9/11 Terrorist Attacks 2001</td>
<td>0.0%</td>
<td>33.3%</td>
</tr>
</tbody>
</table>

Table 28  9/11 Terrorist Attacks Measurement Results

<table>
<thead>
<tr>
<th>Case Study</th>
<th>MM</th>
<th>Richt</th>
<th>SSWS</th>
<th>Fujit</th>
<th>FEMA</th>
<th>Fisch</th>
<th>UE1</th>
<th>UE2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/11 Terrorist Attacks 2001</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>100.0%</td>
<td>90.0%</td>
<td>52.8%</td>
<td>69.5%</td>
</tr>
</tbody>
</table>
The plan here is to explain how the results in Table 27 are calculated. Since we have only four (4) applicable scales for the 9/11 Terrorist Attacks case, there are a total of six (pairs). Using Table 29 we show where the numbers in Table 27 came from for this case. Each column in Table 29 references a comparison between two scales. If the scales are within the threshold indicated for that row then a “1” is recorded, otherwise a “0” is recorded. For example, for the FEMA scale, the score is 100 and for the Fischer scale, the score is 90 as shown in Table 28. Column 1 indicates that the two scores are not within 10% or each other but are within both 15% and 20%.
Table 29  Consistency of 9/11 Terrorist Attacks Case Determined by the Number of Consistent Pairs of Scales over Total Pairs Using different Thresholds and Absolute Points (Note: “0” means inconsistent while “1” means consistent).

<table>
<thead>
<tr>
<th>Percent &amp; Absolute Difference</th>
<th>FEMA &amp; Fischer</th>
<th>FEMA &amp; UE1</th>
<th>FEMA &amp; UE2</th>
<th>Fischer &amp; UE1</th>
<th>Fischer &amp; UE2</th>
<th>UE1 &amp; UE2</th>
<th>No. of Total Pairs</th>
<th>No. of Consistent Pairs</th>
<th>Consistent Over Total Pairs %</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>00.0%</td>
</tr>
<tr>
<td>15%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>33.3%</td>
</tr>
<tr>
<td>20%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>33.3%</td>
</tr>
<tr>
<td>5 points</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>10 points</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>16.7%</td>
</tr>
<tr>
<td>15 points</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>16.7%</td>
</tr>
<tr>
<td>20 points</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>33.3%</td>
</tr>
</tbody>
</table>

To further provide more explanations on the calculation of each “0” and “1”, Table 30 documents the consistency calculation based on several percentage and point differences using the highlighted numbers in Table 29.
Table 30  Examples of Consistency Determination Using different Thresholds and Absolute Points (Note: “0” means inconsistent while “1” means consistent).

<table>
<thead>
<tr>
<th>Percentage &amp; Absolute Difference</th>
<th>FEMA / Fischer</th>
<th>Calculation Explanation Given that FEMA Result of 9/11 Case is 100% while Fischer is 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0</td>
<td>100/90 = 1.11 meaning that they are consistent about 11% and not within 10%. Therefore, the result is zero (0) meaning no consistency within 10%.</td>
</tr>
<tr>
<td>15%</td>
<td>1</td>
<td>100/90 = 1.11 meaning that they are consistent since 11% within the set 15%. Therefore, the result is one (1) meaning that there is consistency within 15%.</td>
</tr>
<tr>
<td>5 points</td>
<td>0</td>
<td>100 - 90 = 10 points which is not within the 5 points difference reference. Therefore, the result is zero (0) meaning no consistency within 10 points.</td>
</tr>
<tr>
<td>10 points</td>
<td>1</td>
<td>100 - 90 = 10 points which is within the 10 points difference reference. Therefore, the result is one (1) meaning that there is consistency within 15 points.</td>
</tr>
</tbody>
</table>

Finally, once we have the number of consistent pairs, we divide it by the total number of pairs times 100 to get the consistency percentage as previously shown in Table 29.