THE ROLE OF RISK PERCEPTION IN TRADEOFFS FOR EARTHQUAKES AND OTHER HAZARDS

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ABSTRACT:

It is the role of the professional risk engineer to help guide society in its investment to mitigate against the consequences of earthquakes and other hazards. Too often these trade-off decisions are made without a full quantification of the multiple sources of the risks involved. Risk assessment should take into account the manner in which the risk might be mitigated, and separately the frequency of occurrence and magnitude of consequence. This paper presents comparative results of many natural hazards in terms of their frequency of occurrence and economic cost, injury and loss of life. It then explores the subject of risk perception and the role it plays in investments against various hazards. Losses due to earthquakes are studied, using a recent 25-year period in the United States as an example. In addition, data are collected for a total of 18 different natural hazards. Then information from the social-psychology literature on perception of risk expands the concept of risk from the common engineering one of probability of occurrence multiplied by a quantitative measure of consequence, to a multi-attribute one. This expanded measure includes such items as dread, familiarity, degree of voluntariness and trust. Finally, graphical comparisons are made of the risk due to earthquakes and other natural hazards, and recommendations made regarding the perspectives of different players in deciding on mitigation investments. The interaction between engineering risk and societal risk are highlighted. The multi-attribute nature of societal risk factors advocates for multidisciplinary decision-making.

KEYWORDS: Earthquakes, investment, natural hazards, risk, risk perception, tradeoffs

1. FACTORS USED TO ASSESS RISK

It has become increasingly evident that risks need to be assessed more than just on occurrence of devastation but also society's reaction to such events. Traditional risk measures using a single risk metric and expected values cause loss of valuable information. By looking at natural hazards one can formulate a risk analysis tool that includes sociological risk measures such as dread, familiarity and voluntariness. We will set out to develop a new risk framework incorporating some of these issues.

In early assessment of risk, mortality was proposed as the sole factor to compute risk (Slovic 1984). Consideration was then expanded to include injury, and loss of economic production, creating a more complete risk representation. Although the three factors capture more information pertaining to a specific risk, they raise the issue of conversion.

1.1 The Value of Life

The value of human life has been discussed in three different manners. First, financial reward in court cases involving a non-fatal injury in alcohol related driving events. In one such study by Stan V. Smith (Smith 1998) found that the value of lost of life could be extrapolated to a range of 2.2 million to 4.8 million dollars. Second, life insurance company's estimates can be used to approximate the value of life. This value is a representation of the loss of financial earnings, which can vary widely across different age and social groups. Thirdly, is the use of society's 'willingness-to-pay.' This represents the monetary amount the society is willing to pay to make an activity or piece of infrastructure safer. One such study was conducted by Kahneman and Tversky (2000) where they concluded considering safety regulation that society was willing to pay $1.1 million to save a life in 2000 dollars. Averaging the three approaches gives a rough estimate of 2.3 million dollars per statistical life. A range of 2 million to 3 million dollars seems to be a usable range for consideration of statistical life lost.

1.1.1 Injury

When one thinks of injury we imagine the type of injury that result in down time from a routine; however, once the body is healed everything goes back to normal. Recovery is not always possible, however. Morbidity is usually assigned a percentage of the value of life. For an example later, this study uses 12%.

1.1.2 Economic

The third aspect of consequences is the direct economic losses due to an event. The economic losses due to a natural hazard in the United States are often computed in accordance with the Federal Emergency Management Act (FEMA 2007). Some claim that these values are under-estimated because when a business closes, it affects the local economy due to jobs and taxes lost, and the possible relocation of people causes devaluation in home prices. On a larger geographic scale, these businesses typically are replaced by others, so that aggregate effects are minimal (Tierney 2001, Boland et al 1988). The estimate of economic losses is very much one that requires significant research combined with expert judgment.

2. LOSS ESTIMATES

Each of the three risk measures just mentioned, mortality, morbidity, and economic are expected losses. However, there is also much interest in maximum probable losses. These values help to set a guide for the future. Some of these projected losses are shown in Table 2.1 for a major earthquake.

Table 2.2 Projected losses for the future

Location	Injuries	Deaths	Prop 2005	
San Francisco	18,000	8,000	$175,000,000,000	*
LA	20,000	8,000	$170,000,000,000	*
Los Vegas	10,000	400	$11,000,000,000	**

*Stanford (1996), **(Batt 2003)

3. SHORTCOMINGS OF THE CURRENT STATE OF RISK-BASED DECISION MAKING

3.1 *Single Risk Metrics*

In the United States seismic design criteria is usually for an earthquake with a 50 year mean recurrence interval. However, some areas have more frequent moderate size earthquakes than others. Because of differences in potential costs a more robust risk analysis must be developed using more than probability multiplied by consequence. This can be accomplished by use of social factors. Paul Slovic a leading social scientist says people assess risk using three primary factors voluntariness, dread, and familiarity. Each of these will be explained further as a multidisciplinary risk assessment is formulated.

By combining information into a single metric, information is lost. The standard risk analysis causes risk-based decision making to place a value on life, which is highly controversial and has a range of several orders of magnitude. The metric that is chosen also affects the potential risk, and different risk metrics weigh risks differently. For example, one hazard might have a large mortality rate while another has a lot of losses associated with property damage, and there can be a significant reordering in risks.

It is standard practice to rate risk with a single metric. In some cases a single measure maybe appropriate, but on the built environment and its interaction with the natural environment, a single metric does not convey enough information. In a tradeoff situation where one event has a high number of injuries and some number of deaths, and another event might have same number of deaths and no injuries, the latter event has less risk. But often the mix of consequences is not that well ordered.

3.2 Expected Values

Use of expected risk has two major drawbacks. First, it does not distinguish between high probability, low consequence events (HPLC) and low probability high consequence events (LPHC). Second, it does not include information about the distribution of data.

The lack of the ability to distinguish between HPLC and LPHC events causes expected values to oversimplify some risk analysis. The difference between U.S. West coast short return interval earthquakes and New Madrid earthquakes can be seen in Figure 3.1, which compares the mean recurrence intervals, for two percent exceedance in fifty years, of the two regions (USGS 20 Mar. 2007. http://earthquakes.usgs.gov). It can be seen that the return period of a spectral acceleration equal to gravity in California is two orders of magnitude larger than that of the Central United States, however, these events have very different loss potential.

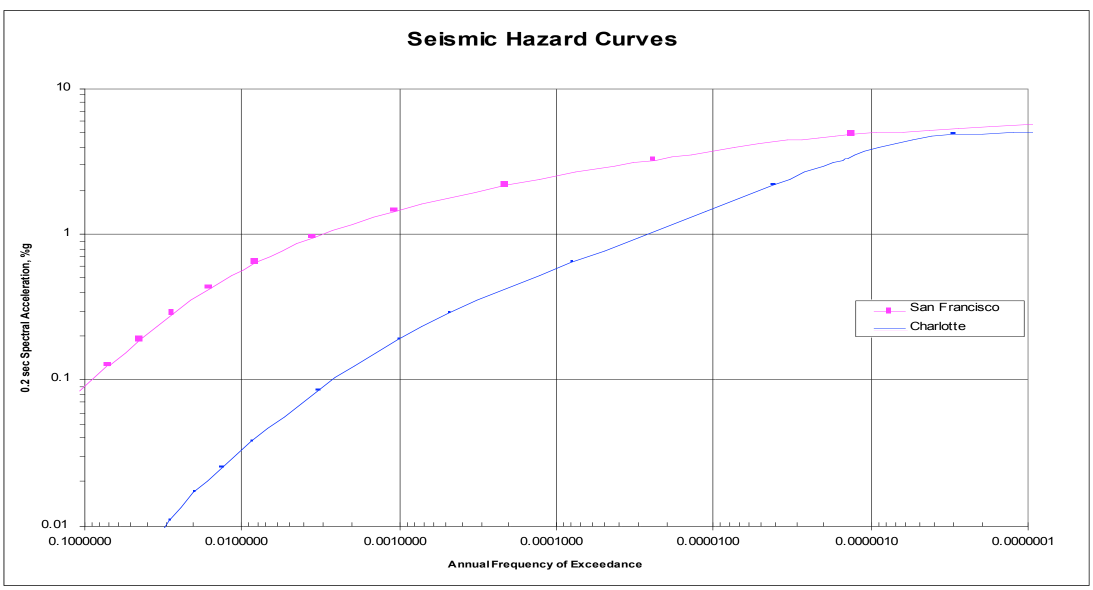

Figure 3.1 Annual frequency of exceedance of 0.2 pseudo acceleration

4. NEW TOOLS FOR RISK-BASED DECISION MAKING

Sociology has the unique perspective to analyze the performance of the built environment from society's point of view. Tierney points out the necessity of the engineering community taking a broader look at the systems they design for the built environment (Tierney 2001). By incorporating the Slovic ideas such as dread and familiarity into a multi-attribute risk comparison model, a better understanding of the societal effects can be obtained.

4.1 The Perception of Risk

Infrastructure is a part of everyone's daily life, making people the major stakeholders in infrastructure. Because of this, one's perception about the way it works and performs is vital to the decision making process. Kahneman and Tversky (2000) first showed that people use more than the expected value to make decisions. Paul Slovic (2000) showed that the most prominent factors lay people use to assess risk are dread, voluntariness, and familiarity. These additional factors are thought to explain the difference between perceived risk and engineering risk.

The events and actions that people perceive as being risky do not always agree with the events and actions that mathematical risk determines as a high risk. A common comparison it that of airline travel with automobile travel. "More than 500 times as many people die on U.S. roads as in airline accidents" (Kluger 2006), yet the same people who fear flying drive their automobile much more frequently and without fear. Slovic formulated a study based on 90 different activities and their perceived risk and perceived benefit, and determined (using factor analysis) that the three primary factors in perceived risk are dread, familiarity and voluntariness.

Dread is described by Slovic as having the characteristics of dreadful, catastrophic, hard to prevent, fatal, inequitable, threatening to future generations, not easily reduced, involuntary and personally threatening (Slovic 2000). Other authors mention dread as a necessity for good risk analysis. Klinke says, "…one should use the results of the existing perception studies as the major heuristic rule for selecting the relevant criteria" (Klinke 2002). Unfortunately, the data from Slovic do not contain information for the built environment. To overcome this lack of data, the idea of dread was studied and a method of representing dread from natural hazards was developed for comparison.

Familiarity is the next most important factor in people's risk perception, according to Slovic. People perceive events in which little is known (by the decision maker) as higher, than when more is known. The third major factor in perceived risk is control or voluntariness. The level to which one chooses, affects the perceived risk. The topic of control and voluntariness will not be included in this study, because the events and action of natural hazards considered for this study involve the same levels of control and voluntariness. Natural hazards occur without our choice, although where we choose to live will always be affected by nature in one way or another.

5. A NEW RISK FRAMEWORK

The development of a new framework for risk analysis must address some of the issues with the current methods of risk analysis. As discussed earlier, good decision making requires valid information and information about values. By incorporating both risk as analysis and risk as feelings, as opposed to choosing one over the other, a more consistent and better model for natural hazard risk can be created. The model should address issues such as LPHC versus HPLC, use of a single metric, concerns of stakeholders, and risk communication. To accomplish this it was decided that a new framework must have more information but in a visual display that can easily be read and understood, so that multiple people gain a more comprehensive understanding from the information. The new risk tool will take the form of a dual-axis graph with rings that represent the three primary risk characteristics: injury, death and dollar losses, centered at the appropriate level of dread and familiarity.

5.1 Familiarity

Slovic included familiarity as one of three primary factors that affect people's risk perception. By considering Slovic's definition of familiarity and considering that "Seismic preparedness was significantly higher among those who had heard, understood, and personalized the risk" (Tierney 2001) a quantity for familiarity can be formed. From statements such as Tierney's just cited it is argued that the more often an event occurs the greater the chance that a person has heard about, understood or personalized the hazard. From this it was decided that familiarity will be relatively higher for events that occur more often and low for those events that do not occur often. To formulate a quantity for familiarity, the expected number of events per year was used as the vertical scale in the new risk framework.

Familiarity might be better represented by linguistic terms, so familiarity was broken into four different ranges. The first range is those that have occurrences of fewer than 10 times per-year in the whole United States; because of the low expected number of events, this group will be considered “Little to No Familiarity.” The next group has an expected number of events per-year greater than a 110, and because of this high return frequency this group will be considered “Very Familiar.” The remaining hazards have an expected number of events per-year in the range of 10 to 110. This range will be split equally into two separate groups of familiarity, with “Not Familiar” describing events that have an expected frequency of 10 times to 60 times per-year, and “Familiar” describing events that are expected more than 60 times per-year but less than 110. The four groups will help to distinguish each hazard’s risk.

5.2 Dread

In a similar manner to familiarity, dread can also be defined quantitatively by considering its definitions. The primary components that will be considered are catastrophic potential and not easily reduced. A quantity called Temporal Response time is introduced. Temporal Response time is the amount of time that is available to take mitigating actions to reduce or eliminate the negative impacts of a hazard. It is a good measure for dread because the ability to reduce a hazard’s affects and the amount time to prepare are directly related. Also, when a hazard occurs suddenly, there is an increase in the catastrophic potential. As an example the Temporal Response time for drought is estimated to be on the order of 40 days. In this time farmers have the ability to replace their crops with ones that require less water, thus reducing catastrophic losses.

By comparing risks based on temporal response, risks can be classified into groups that can be mitigated such as drought, to risks that need more active measures such as earthquakes. By including information about the affects of a risk to the stakeholders a more complete risk representation can be made. The rage of response times is large so a logarithmic scale will be used. The ranges will be divided into groups of weeks, days minutes and seconds. These ranges are associated with very different types of response strategies.

5.3 Additional Data Considerations

When comparing data of natural hazards some simple modification must be made so that information is comparable. First, all dollars must be converted to a single year value using a standard future discount rate formula. Second, the number of people injured and number of deaths will be adjusted in a similar manner using a rate equal to the average population growth over the last 45 years. Adjusting morbidity and mortality for population growth is not a standard practice; however it is believed that this is appropriate. Deaths and injuries will be compared in 2005 adjusted amounts. The adjustment rate used is an average over the time period of 1960-2000. The average was found as 1.07% per year across the United States (CensusScope.com 2007).

5.4 A New Risk Tool

The hazards data collected are from the Spatial Hazard Events and Losses Database for the United States (SHELDUS) as of April 2007. For the event to appear in SHELDUS the losses must have exceeded $50,000 in the year the event occurred. The data collected include 18 natural hazards: Avalanche (A), Coastal storms (C), Drought (D), Earthquake (E), Wildfire (Wf), Flooding (Fl), Fog (Fg), Hail (Hi), Heat (He), Landslides (Ls), Lighting (Lt), inland Storms (S), Tornadoes (Tr), Hurricanes (Hr), Tsunami (Ts), Volcano (V), Wind (Wd), And Winter Weather (Ws). The data for all 18 hazards tallied and are plotted in Figure 5.1.

Figure 5.1 can be used to distinguish and compare risks from natural hazards. For example, three events that seem very comparable according to Figure 5.1 are Hurricanes, Coastal Storms, and Heat events. Additionally, the manner in which one prepares for these events is also similar. In all three events one needs to stock up on supplies, stay in a protective place, and wait out or evacuate.

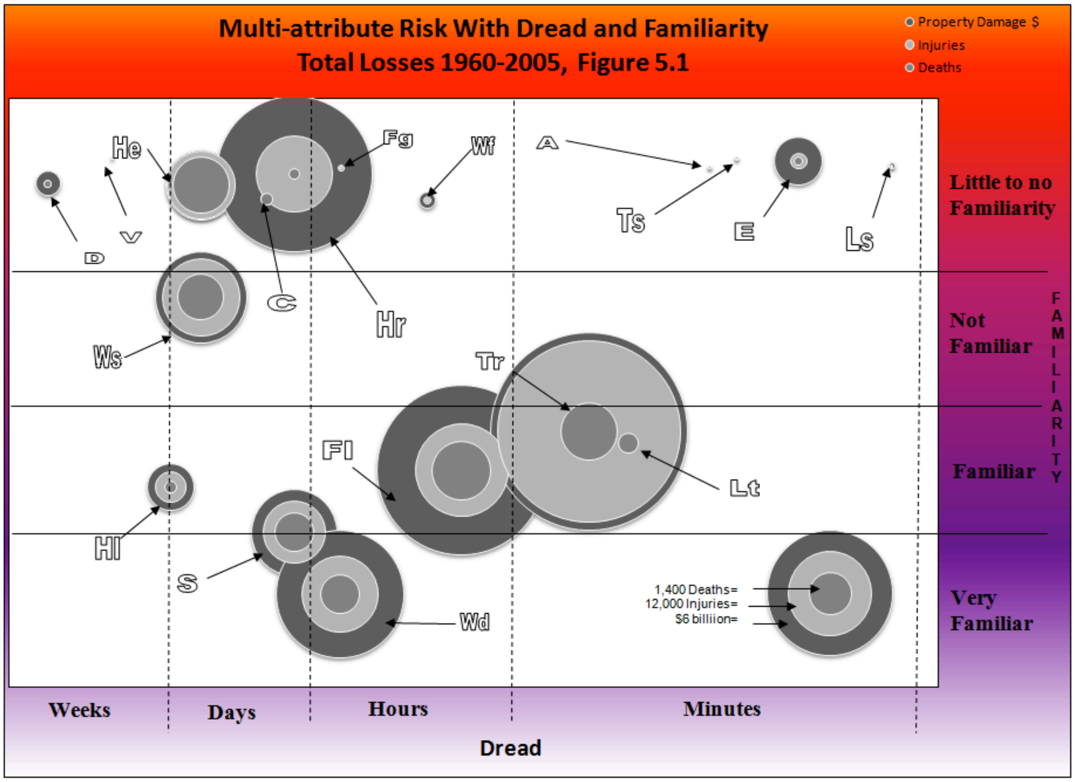

Figure 5.1 Common hazards graphed with expected outcomes on risk perception axes

5.5 Risk Groups

As discussed earlier, it is convenient to divide the dread axis into response time categories of weeks, days, hours and minutes, since each would be associated with different types of response and mitigation strategies. For hazards that have long Temporal Response times, such as drought, actions can be taken to alleviate the loss potential. For short Temporal Response times, pre-event planning and training would be better mitigating measures. In Figure 5.1 the greatest risk based on dread and familiarity are those in the upper right corner. These events have shortest temporal response times (a few minutes or less) and are in the "Little to No Familiarity" group. Thus, earthquakes, avalanches, landslides and tsunamis have the highest potential risk. However when the data considering deaths, injuries and property losses are also considered it appears that earthquakes pose the greatest risk of the four.

The figures presented thus far are based on total losses for each hazard, implicitly incorporating probability by reflecting the number of events and the loss associated with each event. We can also display expected losses given the occurrence of a single event, which is presented in Figure 5.2. The rings can be interpreted as conditional losses given an event, but the ordinate location of each set of rings still reflects the relative frequency of occurrence.

The major difference between Figure 5.1 and 5.2 is in the relative size of the rings in the lower three quarters of familiarity. These events cause few losses per event and thus appear minor compared to those in the upper part. All of the largest morbidities per event appear in the upper quarter of familiarity. By showing a direct correlation between familiarity and traditional risk (the product of probability and consequence), familiarity can seen to have validity as an appropriate risk measure. It can be used effectively with other risk metrics to develop better risk-based decision making. Figure 5.1 and Figure 5.2 both represent losses by hazard across the United States. Not everyone, however, faces equal exposure to various hazards, and graphs can be developed for the local level.

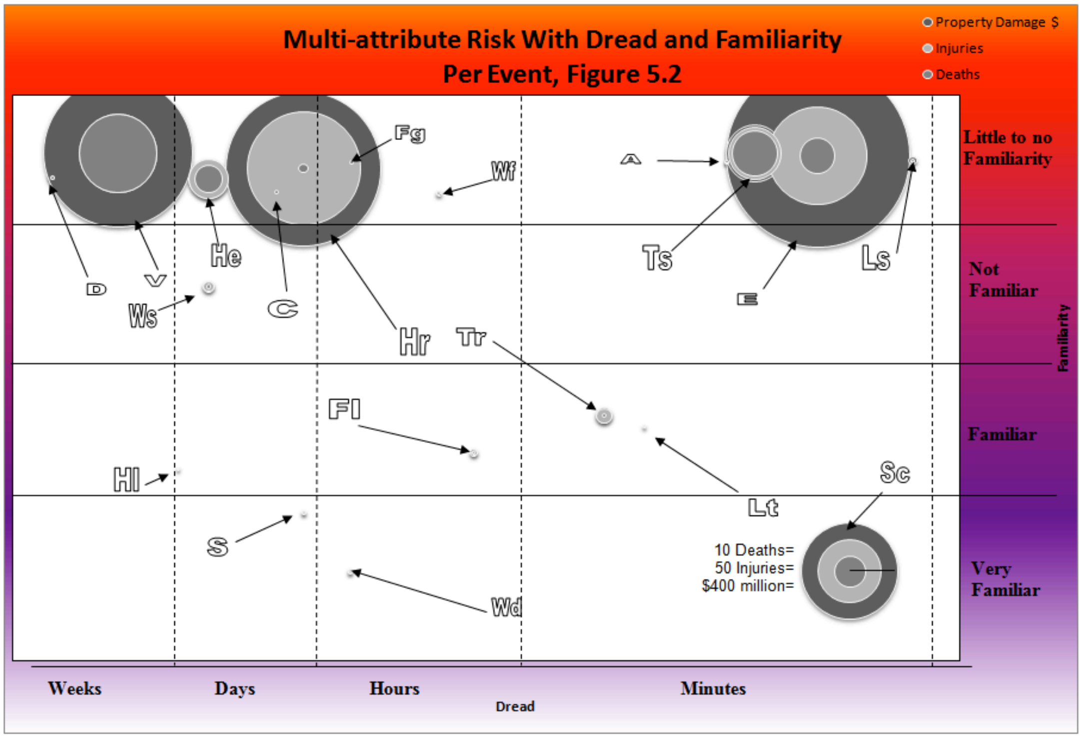

Figure 5.2 Common hazards showing expected outcome per event

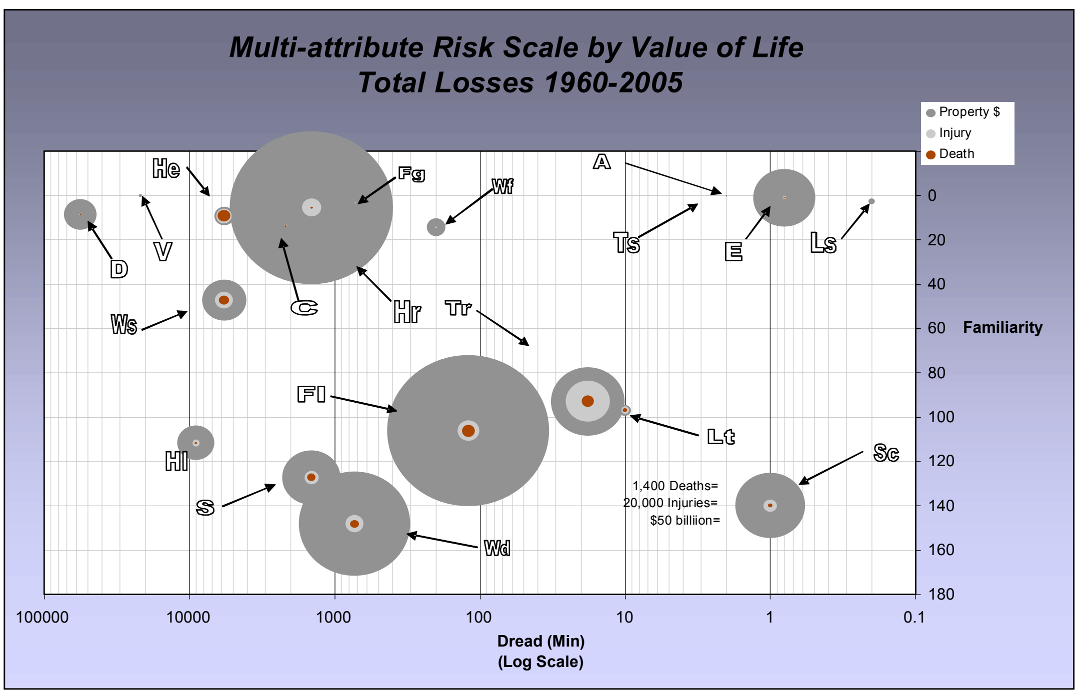

Figure 5.3 Common hazards with consequences scaled

5.6 The Scale

The manner in which the graph is scaled is also very important. Rather than displaying deaths, injuries and dollar losses in an unreduced way, one may use an existing relationship between deaths and dollar losses. Using $3 million as an appropriate value of human life for risk analysis, and 12% of that for injury, one gets Figure 5.3, displays very different information from Figure 5.1. Figure 5.3 shows that natural hazards risk is primarily dominated by economic losses. The models presented have demonstrated that perceived risk is a valid measure of risk, and this can be quantified for analysis and used to create a better representation of risks from natural hazards.

6. CONCLUSION

It has become increasingly evident that risks need to be assessed more than just probability multiplied by consequence, but also include society's reaction to such events. Traditional risk measures lead to questions that are tough to answer. These problems can be lessened by including more information in our risk analysis. Additionally, by creating a risk analysis that is visual and multidisciplinary we can help to create better risk communication between professions and among different sectors of society.

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