Capabilities-Based Approach to Measuring the Societal Impacts of Natural and Man-Made Hazards in Risk Analysis

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Abstract: This paper presents a *capabilities-based* approach to identifying and quantifying the expected overall societal impact of natural hazards in engineering risk analysis. Drawing on the work in development economics and policy by philosopher Martha Nussbaum and Amartya Sen, for which he won the Nobel Prize in Economics in 1998, the societal impact is defined in terms of the impact on selected individual *capabilities*, the *functionings* individuals are able, still able, or unable to achieve in the aftermath of a hazard. Individual capabilities capture the net societal impact of hazards, which includes likely benefits and opportunities in addition to losses. A general methodology is discussed for practically implementing the proposed approach to quantifying the expected societal impact, modeled on the framework currently used by the United Nations to assess the level of development of societies around the world. This proposed *capabilities-based approach* can be used with different methods or techniques for risk and decision analysis and when assessing risk for diverse types of hazards that range from minor to catastrophic.

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Introduction

Risk analysis for natural and man-made hazards (or *risk assessment*) is the process of (1) quantifying the *probabilities* of potential *consequences* in various hazard scenarios, and of (2) evaluating that information to decide whether and how to act, under conditions of uncertainty (Vose 2000; Bedford and Cooke 2001).

In the context of civil engineering, risk analysis is generally motivated by a concern with protecting public safety and consequently is concerned with the *societal* impact of a hazard. According to Lindell and Prater (2003), there are two primary reasons why it is important to assess the impact on society of natural hazards. First, information from risk analysis can be used to design effective hazard mitigation strategies. Second, such information can aid in determining the impact of a hazard on various subpopulations within a community, so that we can determine if any group is likely to be disproportionately affected and act in an appropriate manner.

There are four, increasingly recognized limitations with traditional approaches to predicting the societal impact of natural hazards in engineering risk analysis. First, the focus of the civil engineering community historically has been limited to measuring consequences that are more easily quantifiable (e.g., fatalities and physical damage and, more recently, on some economic impacts). However, the civil engineering community increasingly recognizes the importance of factoring in broader, but less easily quantifiable, impacts. The societal impacts of hazards should broadly include the potential effects of a hazard upon the operation of economic, social, political, and ecological systems within communities, because impacts on those systems directly affect the lives of individuals within affected communities. Furthermore, it is important to consider the potential opportunities created by a natural hazard, in addition to its negative impacts. Current approaches consider only the negative impacts. Second, current approaches lack an accurate, uniform, and consistent metric for quantifying consequences. Third, prevailing approaches to risk analysis are based on implicit value judgments. Fourth, value judgments are often inferred by soliciting individual preferences, which may lead to potentially inaccurate assessments of the societal impacts of hazards.

To overcome these limitations, we propose a *capabilities-based approach* to predicting the societal impact of natural and man-made hazards. A capabilities-based approach was first developed by philosopher Martha Nussbaum and economist Amartya Sen, who won the Nobel Prize in Economics in 1998 for this work and its application to development economics and policy. In this approach, *individual capabilities* refer to the *functionings* individuals are able, still able, or unable to achieve. Functionings are valuable states of doing and being, for example, being adequately nourished (Sen 1993). Throughout this paper, our reference to "capabilities" follows Nussbaum's and Sen's definition. Thus, our use of capabilities is independent of other notions used in disaster studies and, in particular, does not refer to the ability of an individual (or household, community, or system) to recover from a disaster. Rather, more broadly, capabilities refer to dimensions of the well being of individuals.

In their work, Nussbaum and Sen proposed conceptualizing the level of development of a society in terms of the levels of capabilities' attainment of its citizens. Currently, the United Nations (UN) quantitatively measures the degree of development or deprivation in countries around the world on this basis. In the context of development, the capabilities-based approach is used

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also to reveal potential development inequalities among population subgroups (based, for example on geography, ethnicity, gender, or occupation), using a process of disaggregation (Anand and Sen 2000).

In this paper, we show how the capabilities-based approach can be extended and used to assess and quantify the expected societal impacts of natural and man-made hazards. We explain the reasons for conceptualizing the societal impacts of hazards using a capabilities-based approach, where the potential benefits and losses due to a hazard are measured and compared in a uniform way by using individual capabilities as a metric. We also discuss the practical quantification of the societal impact using a method modeled after the one used by the UN to measure development.

There are four sections in this paper. The first summarizes two current approaches to risk analysis in civil engineering, performance-based earthquake engineering (PBEE) and consequence-based engineering (CBE). The second discusses common limitations with their analysis of the societal impact of hazards. The third introduces our proposed capabilities-based approach to societal impacts and shows how the proposed approach avoids these limitations. The fourth and final section discusses the practical implementation of the proposed approach.

Current Prevailing Approaches to Risk Analysis in Civil Engineering

Currently, probabilistic methods of risk analysis are at the foundation of engineering design codes and are used in major structural projects (AASHTO 2008). Probabilistic approaches use advanced techniques such as analytical or numerical integration, simulation, moment-based methods, or first- and second-order methods (FORM/SORM). Furthermore, software that combines engineering models, knowledge, and expertise have been developed to predict potential losses from floods, wind storms, and earthquakes (e.g., HAZUS and MAEviz).

In addition to innovations in engineering computations, modeling, and software, there is increasing recognition of the need to incorporate the findings from social science with technical expertise and knowledge to predict the impact of hazards on society (An et al. 2004). As An et al. (2004) write, "Over the past decade, earthquake engineering and similar natural hazard based research activities have begun to integrate social science questions into technical research agenda." This trend is reflected, they argue, in the creation and work of the three National Science Foundation (NSF) engineering research centers, the Multidisciplinary Center for Earthquake Engineering (MCEER), the Pacific Earthquake Engineering Research Center (PEER), and the Mid-America Earthquake Center (MAE). As a result of some of the research funded by these centers and additional studies, there is an extensive literature in sociology and disaster studies that examines the effects of past disasters on households, vulnerable populations, or the societal impact for a case-specific examination (van Willigen et al. 2005; Kajitani et al. 2005; Dash and Gladwin 2007; Dash et al. 2007). Such research often identifies patterns in the recovery process among families, individuals, communities, or businesses, as well as obstacles to rapid recovery faced by these groups (Mileti 1999; Fothergill et al. 1999; Petterson 1999; Dahlhamer and D'Souza 1997; Peacock and Girard 1997; Nigg 1996; Tierney 1992, 1994; Bates and Peacock 1992; Peacock et al. 1987).

While techniques and software for quantifying the probabilities of potential consequences have significantly improved over the past few years and there has been significant progress in understanding empirical trends in disaster vulnerability and recovery, there remains a need for a satisfactory method to define and predict the societal impact of a hazard. More specifically, there remains a need for a framework for conceptualizing the connections among diverse kinds of losses and distinguishing which losses are relevant and important to consider when determining the societal impact of a hazard. In the next two sections, we examine two representative recent attempts to expand the kinds of societal impacts considered in risk analysis, showing how such attempts remain incomplete. After proposing our capabilities-based approach, we discuss the role of the extensive findings from the social sciences in this approach.

Performance-Based Earthquake Engineering

One recent approach to the societal impacts of hazards in risk analysis has been proposed in the context of PBEE. The PBEE approach is geared towards seismic hazards and their related consequences. In particular, PBEE tries to incorporate additional, societal seismic safety issues, going further than simply accounting for the concerns of those who own, invest in, or reside in particular structures to consider the impact that earthquakes have upon both local and national communities (May 2001b).

In addition, PBEE tries to incorporate the consequences of hazards that go beyond those traditionally considered (e.g., fatalities and direct economic losses). As part of the PBEE approach, May classifies the potential consequences of earthquakes into *externalities* and *interdependencies*. Externalities are the physical consequences on other structures or systems caused by the failure or damage of a particular structure. Examples of externalities are the damage caused by fires induced by an earthquake [e.g., 110 fires ensued after the Northridge earthquake (Stern and Fineberg, 1996)], and the pounding of buildings, where the movement of one building due to an earthquake may affect other, undamaged nearby buildings (e.g., pounding affected numerous high-rise buildings in Mexico City after the 1985 earthquake). Interdependencies focus on the interconnectedness of various systems or parts of a community. Disruption or harm to one segment of a community may have other, direct implications for other sectors. Using May's example, communities rely upon power, water, fuel, and transportation networks to function effectively. Failure of one of these networks disrupts the operation of communities or the services offered by them.

The method for incorporating these broader societal consequences proposed by PBEE is to measure all consequences in terms of economic losses. However, advocates of PBEE grapple with the practical implementation of this method. For example, there remains an unanswered question of what economic value to assign to loss of human lives and/or injuries (May 2001b). In particular, it is unclear whether to assign different dollar values to different lives and, if so, on what basis such distinctions and interpersonal comparisons should be made. Should, for example, differences be based on differential life expectancies or on the degree to which individuals have chosen to expose themselves to certain risks (May 2001b)? There are additional, theoretical limitations with this method explored in the next section.

Consequence-Based Engineering

Another recent attempt to broaden the consequences of natural hazards considered in engineering risk analysis is termed CBE or consequence-based risk management (CRM) and was proposed in its original form by Abrams et al. (2004). CBE makes explicit its emphasis on the societal impacts of hazards for the development of effective decision support systems. "The intent [. . .] is to provide practicing engineers with a new framework for minimizing losses due to property damage, human life and business interruption that implicitly considers system-related losses when prescribing mitigation actions." (Abrams et al. 2004). The CBE methodology attempts to identify the modeling uncertainty and to quantify the risks to societal systems, with the aim of improving policy and decision making by providing a more accurate and comprehensive assessment of the likely societal impact of hazards.

While the CBE has the merit of understanding the need to broaden the consequences of a hazard beyond the ones traditionally considered, some challenges facing CBE, as currently formulated, have been identified by Wen et al. (2003). To become an effective decision tool, CBE must find a way to communicate risk to a variety of audiences and define who the relevant stakeholders are. In addition, it is necessary to find an objective way to determine key threshold notions, such as "acceptable uncertainty" and "fair risk."

The PBEE and CBE are two examples of the current approaches that are attempting to build on the findings of the social sciences and leverage the state-of-the-art engineering knowledge, models, and software to define more broadly and predict the societal impact of hazards. In this paper, we identify additional challenges common to these and other approaches.

Limitations of the Current Approaches to Risk Analysis

In addition to the specific challenges and limitations with PBEE and CBE discussed above, there is one general limitation: current approaches do not focus on the most relevant information for determining the societal impact of hazards. As a result, the consequences currently considered still do not capture the societal impact in a satisfactory manner. In this section we discuss four aspects of this general limitation (Murphy and Gardoni 2006).

1. **Not accounting for broader societal impacts.** Consequences from a hazard are both *focal* and *auxiliary*. Focal consequences are immediately evident. Examples include the number of fatalities, the number of injuries, the number of damaged structures, and direct economic losses. Focal consequences include the externalities and some of the interdependencies discussed by May (2001b). Auxiliary consequences are less evident and generally less immediate. One type is the additional consequences that impact the well being of individuals that are not traditionally considered in practice (e.g., fatalities, injuries, physical damage, and direct economic losses), including, for example, mental trauma (Stallen et al. 1998). A second type is the broader indirect effects of hazards on society, including changes to the economic, cultural, and political circumstances of a society outside of the areas that experienced physical damage (Stallen et al. 1998), which impact the lives of individuals. To illustrate, the 1994 Northridge earthquake caused job losses equal to 69,000 person years of employment and "about half of these were outside the area that experienced structural damage." (Gordon et al. 1996, 2002).

   Typically, only focal consequences are considered in risk analysis. For example, the Federal Emergency Management Agency (FEMA) (FEMA 2001) study examined the consequences of earthquakes for a building inventory. The consequences considered included capital losses (repair and replacement costs for structural and nonstructural components, building content loss, business inventory loss) and income losses (business interruption, wage, and rental income losses). The PBEE and CBE recognize the need to expand these consequences, however, they still fail to incorporate the auxiliary consequences described above because their focus remains on areas in which there is physical damage, and they lack a conceptual framework for relating the consequences to the well being of individuals.

   In addition, natural and man-made hazards might also bring opportunities to the society, which need to be accounted for in the aftermath of a hazard. Consider the Kobe earthquake of 1995. After the earthquake, the damaged Kobe Harbor lost business that shifted to the Yokohama Harbor and other Japanese harbors and did not return to Kobe even after the reconstruction (Chang 2000). Evidence of the increased business and opportunities the Yokohama Harbor enjoyed include the opening of the Yokohama Port Cargo Center in 1996, the first Japanese deepwater, high-standard container terminal in 2001, and the New Yokohama International Passenger Terminal in 2002. More recently, in 2004 the Port of Yokohama was designated as the "Super Hub Port" by the national government. If we only look at the losses experienced by Kobe Harbor we would overestimate the overall impact of the earthquake on Japan. In the risk analysis for an earthquake, it is important to account for all of the potential benefits, like those that the Yokohama Harbor enjoyed.
2. **Lack of an accurate, uniform, and consistent metric for quantifying the societal impact.** There currently is no satisfactory uniform metric to measure or predict the societal impact of a hazard. Having a uniform metric is important so that the diverse consequences can be combined to produce an overall, composite picture of the impact of hazards. Stewart et al. (2006) note the importance and difficulty of having a uniform metric. They write, "The consequences of a failure event are generally measured in terms that directly affect people and their environment, such as loss of life or injury and economic losses [. . .] A major difficulty in estimating these consequences is how to compare direct economic losses (building damage, production losses), indirect losses (user delay or inconvenience, impact on economic growth, unemployment), and nonmonetary losses resulting from loss of life or injury, damage to the environment, social disruption, etc. The problem of establishing a common denominator for those different attributes is far from trivial."

   One attempt to formulate a uniform metric has been to look at the monetary value of losses. This measure is used by FEMA to quantify potential earthquake losses and has been adopted by PBEE (May 2001b). From this perspective, risks are defined in terms of the value (annualized) of losses to general building stock with respect to the share of total value of the building inventory (replacement value) that such losses represent. This approach has two main drawbacks. First, as advocates of PBEE recognize, it might not be immediately apparent which monetary value to assign to, for example, the loss of an individual life. Second, even when possible, the monetary value might not convey the societal impact of what is lost.
3. **Value judgments are not transparent.** Prevailing approaches to risk analysis often are based on implicit value judgments about the goods that society ought to promote or

the harms that should be prevented. There are two problems with keeping the underlying assumptions or value judgments in risk analysis implicit. First, it is difficult to critically assess and potentially improve a risk analysis approach, its outcomes, and decisions when value judgments are implicit. Public scrutiny is an important component for ensuring that there is a fair and equitable distribution of risk. It also helps guarantee that risk policies reflect what actually is best for society as a whole. Second, a methodology that has explicit value judgments ensures that there is public endorsement of the level of risk aversion used (Stallen et al. 1998). Keeping value judgments implicit undermines such public support.

4. **Basing value judgments on preferences may lead to potentially inaccurate assessments of the societal impacts of hazards.** Public and personal preferences are often the basis for the choices that engineers, risk analysts, and decision makers make about what level of risk is acceptable. In the context of earthquake engineering, for example, "The issue of societal risk might be thought of as a matter of asking about the concerns of the public—what citizens value or fear—when considering potential earthquakes." (May 2001a). There are two problems with basing judgments about acceptable risk on preferences. First, preferences might not reflect what is of value and might be based on irrelevant information. Second, preferences are difficult to determine in a noninfluencing way.

   There are three reasons why preferences might not reflect what is of value or provide relevant information to consider in risk analysis,, and engineering design. First, preferences might be formed on the basis of *misperceptions* concerning the actual risks individuals face (Slovic 1987). In fact, individuals are typically more afraid of rare, catastrophic events, such as airplane crashes where a large number of people may die at the same time, than more frequent accidents where fewer people may die at the same time but more people may die overall, such as automobile accidents.

   Second, even when individuals are aware they might face some level of risk, they might be *indifferent* to its actual magnitude (May 2001b). As a consequence, preferences might be different, even when the actual risks are comparable. For example, consider two areas with a similar seismic risk, Japan and California. Cultural, education, and other socioenvironmental conditions affect the awareness of and preparedness for earthquakes. Japan experiences small earthquakes every few months, making Japanese citizens more conscious about the actual risks they face. On the contrary, Californians more rarely experience earthquakes and this might explain why they are more prone to ignore the actual risks they face (Palm 1995).

   Third, individuals might have their preferences satisfied and still be objectively deprived. As Sen and Nussbaum highlight, individuals adjust to their circumstances and formulate their preferences based on what is realistic, given their situation (Sen 1989; Nussbaum 2001). So individuals with limited options formulate *adaptive preferences*, not desiring more than what they can realistically expect. Thus, the number and quality of options that are available to individuals should also be accounted for when considering the preferences individuals express.

   The second general issue is that it is difficult to accurately ascertain such preferences in an unbiased and noninfluencing way. One prevailing method for identifying preferences is through the use of surveys. The method of surveys assumes that individuals can articulate and rank their preferences accurately, which is typically not the case. Individuals are frequently uncertain as to what their preferences are. In addition, the process of questioning may influence the formulation of preferences. As a result, the process of surveys "can induce random error (by confusing the respondent), systematic error (by hinting at what the 'correct' response is), or unduly extreme judgments (by suggesting clarity and coherence of opinion that are not warranted)." (Fischhoff et al. 1980). Thus, formulations based on the outcomes of surveys might not represent and promote the actual preferences of members of society but rather those of the surveying agency (Murphy and Gardoni 2006).

The capabilities-based approach presented in this paper allows risk analysis to expand the consequences considered beyond life losses and direct monetary costs and to quantify the societal impact of a hazard in a consistent way. The quantification reflects what is relevant and important to the well being of people and society.

Definition and Benefits of a Capabilities-Based Approach

A capabilities-based approach was first developed by philosopher Martha Nussbaum and economist Amartya Sen, who won the Nobel Prize in Economics in 1998 for this work and its application to development economics and policy (Sen 1999). This approach is the theoretical framework for the UN's Human Development Index (HDI), which is used to measure the level of development or deprivation of all societies around the world. A central question in development economics is how to define and measure the *standard of living* of individuals within a society, as a way of capturing their well being. From a capabilities-based approach, the standard of living of individuals is determined by examining "the ability of people to lead the kind of life they have reason to value" (Anand and Sen 2000). This ability is measured in terms of the *capabilities* of individuals. To define capabilities, it is first necessary to introduce *functionings*, which are "valuable acts or [. . .] states of being," (Sen 1993) that encompass the various things of value an individual does or becomes in his or her life. Examples of functionings include being alive, being healthy, being sheltered, being mobile, and being educated. *Capabilities* are defined as the ability of individuals to achieve these functionings.

The HDI measures the level of development of a society or a subset of a population using three capabilities (the capability to live a long and healthy life, the opportunity for being knowledgeable, and the capability of having a decent standard of living). Because capabilities are not directly quantifiable, in practice, indicators are used to measure the level of capabilities attainment. Each indicator gauges a specific capability (Raworth and Stewart 2003; United Nations Development Program 2007).

In this paper, we propose to measure the *net (positive and negative) societal impacts* of natural and man-made hazards by looking at the impact of a hazard on the capabilities of individuals, and so, on their standard of living and well being. A few selected capabilities can be used to assess the expected change in the quality of life of individuals in the society in the aftermath of a hazard. The relevant capabilities to consider are problem specific and need to be appropriate. For example, in development economics, the capabilities used include the ability to avoid escapable morbidity, live a long and healthy life, and be educated.

To determine the net societal impact, risk analysts should focus on selected capabilities likely to be impacted in the aftermath of a hazardous scenario. Individual capabilities also include and reflect the potential benefits brought by a hazard because they capture what an individual can realistically do or become, which may be positively or negatively impacted by a hazard. Therefore, both expected benefits and losses due to a hazard are measured and compared in a uniform way by using individual capabilities as a metric.

The proposed approach is different from standard monetary or utilitarian approaches in risk analysis. To illustrate, consider the following scenario. Say there are two houses of exactly the same value, both of which are destroyed by an earthquake. The first house is the primary and only house of an individual. The second house is a secondary summer house for an individual. If they are both destroyed by a hazard, the economic loss is the same. Given that there are no other losses, the monetary loss (or utility in this example) would be the same. However, the impact on the lives of the two individuals, and what they are able to do, is substantively different. A capability-based approach can capture this difference because it focuses on how what individuals can do or achieve is impacted.

The proposed capabilities-based approach overcomes the limitations described in the previous section and captures the societal impacts of natural and man-made hazards. Below we show how the proposed approach helps address these limitations. We also discuss four additional benefits of the proposed approach:

1. **Capabilities define the societal impact of a hazard going beyond the consequences traditionally considered.** Current approaches consider specific consequences of hazards, typically selected based on the ease of quantifiability and only some of which might be indicators of individual well being, while leaving out other important consequences that directly or indirectly affect the well being of individuals. By contrast, the capabilities-based approach considers directly the impact of these disparate, specific consequences on the well being of individuals within a society. In addition, both expected benefits and losses due to a hazard are measured and compared in a uniform way by using individual capabilities as a metric. As we discussed in the previous section, not including these benefits in the account of the societal impacts of hazards and limiting the focus to negative impacts leads to overestimating the consequences of a hazard.

   Thus, the capabilities-based approach has the general benefit of focusing the attention of risk analysts directly on what is most worth protecting and improving, namely, the capabilities, which are the constitutive aspects of individuals' well being. As a result, the impact accounted for by the proposed capabilities-based approach allows for a more complete, better educated, and more accurate decision-making process.
2. **The capabilities-based approach quantifies the net societal impact of a hazard in a uniform and consistent manner.** To accurately assess the societal impact of a hazard using the prevailing methods, several different kinds of consequences must be considered. Such methods must determine which consequences to consider, how to quantify, and how to combine these consequences. By contrast, only a few, carefully selected capabilities need to be used to summarize the overall societal impact of a hazard. The impact of a hazard on selected capabilities can provide a comprehensive picture of the impact on the lives of individuals. The challenge of combining and quantifying multiple, disparate, and often incompatible consequences is not an issue for the capabilities-based approach. As the work on the HDI by the UN illustrates, quantification of the impact of a hazard on capabilities is both possible and practicable. We discuss the process of quantification in detail in the next section. The key aspect of the capabilities-based approach is that both potential benefits and losses can be measured and compared in a uniform way using the capabilities of individuals as a metric.
3. **The value judgments are made explicit.** In the capabilities-based approach, the overarching goal is to protect and promote the well being of individuals, defined in terms of their capabilities, in a society. This can be achieved by minimizing the probability that capabilities will be reduced after a hazard. The minimization of the loss of capabilities leads to a reduction of the net societal impact of a hazard. This approach values promoting and protecting specified individual capabilities. This value judgment is explicit and easily communicable to the public. This explicit value commitment to capabilities makes the tasks of communication, justification, and critique of existing approaches to risk analysis and mitigation easier and more transparent.
4. **The capabilities-based approach is a more accurate and transparent measurement of actual impacts of hazards on individuals' standard of living.** The proposed approach avoids the problems associated with adaptive preferences, misperceptions of risks, and indifference to risks because it does not appeal to personal preferences to identify which values to protect and consider in engineering risk analysis and probabilistic design. In the proposed approach, the capabilities of individuals are the values to protect and promote. Capabilities more accurately and comprehensively capture the actual impact of hazards on individual well being, including potential losses and benefits associated to a hazard. Because capabilities are the constituents of the individual well being, they focus the attention of engineers and policy makers directly upon what matters when evaluating risks or considering alternative designs, namely, how lives will be affected by choices that are made.

In addition to avoiding the limitations of the prevailing approaches, the capabilities-based approach has the following four additional strengths:

5. **The capabilities-based approach is adaptable and scalable.** The capabilities-based approach offers a way of conceptualizing and quantifying the expected societal impact of hazards. It can be used for any type of hazard (natural or man made) of any magnitude (from minor to catastrophic). It can be used to gauge the societal impacts of hazards at different phases (immediately after the occurrence of a disaster, in the short term, and in the long term). It can be used to quantify into a single metric a variety of diverse consequences that might be hazard specific.
6. **Using a capabilities-based approach in risk analysis facilitates communication among, and consistent public policy decision making in, development and hazard mitigation.** By adopting a capabilities-based approach, risk analysis would implement an approach consistent with that already in use in development economics and policy. Capabilities would be used both when predicting the societal impact of a hazard and when measuring the development of a society. This would facilitate the process of bridging analyses from the two areas, leading to a comprehensive assessment of the societal well being both based on the level of development of a country and the risks that societies face. The

need for this kind of assessment is widely recognized in development economics and by the UN (2005). As a step towards bridging these two areas, in previous work we have proposed how to evaluate hazard mitigation policies from a capabilities-based approach (Murphy and Gardoni 2007b)

7. **Using a capabilities-based approach can lead to a more satisfactory understanding of the acceptability and tolerability of risk.** In Murphy and Gardoni (2007a), we argue that the acceptability and/or tolerability of risks posed by natural and man-made hazards should be based on the evaluation of the likely societal impact of potential hazards, defined in terms of the expected changes in the capabilities of individuals. The proposed capabilities-based approach offers a transparent, easily communicable way for determining the acceptability and the tolerability of risks.
8. **As in its original context, a capabilities-based approach can be used to reveal potential inequalities in a society.** It is common for some groups in a society to be subject to higher risks than others. A capabilities-based approach has already been used in its original context (development economics and policy) to assess potential inequalities among population subgroups based on geography, ethnicity, gender, or occupation. The same approach can be used to determine differential risks that such groups face and factor that information into determinations of public policy and resource allocation priorities for mitigating natural and man-made hazards (Murphy and Gardoni 2007b), and into decisions about the acceptability and tolerability of societal risks (Murphy and Gardoni 2007a).

Practical Implementation of a Capabilities-Based Approach

In this section we consider the question of how to practically implement the proposed approach. We propose and discuss a *hazard impact index* (HII), which is constructed based on the UN's HDI for development economics and policy, to gauge the expected societal impact of natural and man-made hazards.

HDI as a Model for Assessing the Societal Impact

The HDI, currently used by the UN to measure the levels of development in a society, offers a more promising method for predicting the societal impact of a hazard. The HDI selects a few, relevant capabilities to consider to assess the standard of living of individuals. Since capabilities are not directly quantifiable, indicators are then used to measure the level of each of the selected capabilities. The information from each indicator is converted into a uniform scale creating a *capability index*. Finally, the capability indices are combined to form a *hazard development index*.

The same method should be used to predict the likely impact of a hazard, resulting in a *hazard impact index* (HII). Using a method like that of the HDI to calculate the HII is promising for two reasons. First, it allows us to get a more accurate and complete picture of the societal impact of a hazard than current alternative methods. Second, as we discuss below, information from engineering models and expertise as well as social science research on disasters can be included in the prediction of the HII. Thus, it can incorporate state-of-the-art information from diverse subject areas.

Selection of Capabilities

In implementing the capabilities-based approach to risk analysis one needs first to identify which capabilities should be taken into consideration. Guiding this decision, there are three general criteria to consider. First, in Sen's words, "The focus has to be on the underlying concerns and values, in terms of which some definable capabilities may be important and others quite trivial and negligible." (Sen 1993). Second, the minimum number of capabilities possible should be chosen (*capabilities parsimony*). Third, each of the capabilities selected should provide information that cannot be ascertained from the other capabilities (*capabilities orthogonality*).

Given the underlying concern of risk analysts, which would guide the choice of capabilities, is to evaluate overall safety, the following two capabilities seem plausible candidates to use to determine the societal impact of a hazard: the capability to escape preventable morbidity and the capability to own property and maintain its integrity. Natural and man-made hazards typically impact individuals' physical safety and the safety and integrity of their property. These two capabilities are orthogonal in the sense that if we use solely one (e.g., escaping morbidity), we would not capture the impact of a hazard on the second one (e.g., property ownership and integrity). For example, an epidemic is likely to lead to a decrease in the capability of individuals to escape morbidity, but is unlikely to significantly affect the capability of individuals to maintain the integrity of their property. On the other hand, tornados are likely to damage the property of individuals, without necessarily leading to a high number of deaths or corresponding decrease in the capabilities of individuals to escape preventable morbidity. Additional capabilities might need to be chosen only if the two mentioned above do not sufficiently describe the underlying safety concern. Otherwise, additional capabilities would not provide more information. In what follows, we use these two capabilities to illustrate the steps in the construction of the HII.

Selection and Calculation of Indicators

Once the desired capabilities are selected, one needs to have a measure for each of them. However, since capabilities are not themselves directly measurable, indicators of the capabilities have to be identified to measure the impact of a hazard on the selected capabilities. The indicators need to be selected so that they track in practice the particular capability in which we are interested and to which they are associated (Raworth and Stewart 2003). Sociological studies can be used to find and demonstrate such associations.

In engineering risk analysis, the value of indicators must be predicted. There are two methods that might be used to predict such values. The first method is more empirical. Looking at the value of the indicators for past disasters can provide a guide for the likely value of future hazards. It is in this context that social scientific studies on past disasters can provide valuable resources in such predictive exercises. One limitation with this method is that this formulation does not incorporate available engineering models and expertise. The second method is to use software, such as HAZUS or MAEviz, to predict the likely value of some indicators. For indicators that are not currently covered by available software, additional work might be required, but they could be predicted in a similar fashion.

Weighing of Capabilities Indices

After the information is collected for each indicator, the information is converted into a uniform scale creating a *capability index*. A capability index is a dimensionless quantity where the recorded value for a particular region is normalized by the reasonable average value across all regions. Examples of normalizations are given in Fukuda-Parr and Shiva Kumar (2003). This normalization process makes it possible to combine the capability indices computed before and after a hazard to form an aggregated HII.

When formulating the HII, it is necessary to consider whether to weigh the various capabilities indices. Following the position adopted in the case of human development (Jahan 2003), in our view, the capability indices should be given equal weight. Each capability has a value that is incommensurable and irreducible. No amount of one capability can be substituted for the absence of another capability. So, for example, no amount of nourishment can be substituted for lack of shelter. Since "there is no assumption of substitution among the dimensions of the variables representing them" (Jahan 2003), it is reasonable to assign each index equal weight.

Time Dependency (Emergency, Short-, and Long-Term Impact)

One final issue to consider is how to predict the different impacts of a hazard during the emergency, short-term, and long-term phases. Focusing solely upon the most basic capabilities or the elementary achievement of capabilities will not provide an accurate picture of the likely societal impact of hazards in the short and long term. A hazard might seem to have no likely lingering impact on society in the short and long term if only the most basic capabilities or the elementary achievement of certain capabilities are used. There are two approaches one might use to account for this time dependency. The first is to change the capabilities considered in the various phases. The second is to change the indicators that are used to gauge the same capabilities over time. Below we describe each approach as well as its strengths and weaknesses.

The first approach is to change the particular capabilities considered over time. For example, during the emergency period immediately following a hazard, the emphasis could be upon predicting certain basic capabilities, which are minimum conditions for survival. The capabilities considered could then be similar to those prioritized in development economics and policy, including being able to survive the hazard, not be injured, be sheltered, and have access to medical care and nutrition. In the short and long term, the relevant capabilities to consider could change. The task would then be to identify which nonsurvival capabilities are relevant. A limitation with this approach is that there would be different hazard impact indices. Each phase would have a different likely HII, based on different underlying capabilities. Since each index is defined differently, it would not be possible to compare the likely impact over time.

An approach proposed by Anand and Sen (2000) in the context of development economics and policy, which addresses this limitation, is to supplement the HII for the likely short-term and long-term impact with additional indicators for each of the capabilities considered in the emergency phase. A base level or threshold of individual capabilities (such as the ability to have shelter) would be predicted during the emergency phase. The same capabilities could be impacted beyond such a minimum threshold in the short and long term. The indicators could then change to reflect the more nuanced impact on the capabilities. So, for example, the ability to be sheltered could first be predicted in terms of the percentage of the population that is homeless as a result of a hazard in the emergency phase. This same capability would later be predicted in terms of a capability to find permanent residence during the short and long term. One advantage of this approach is that one can monitor the impact over time to determine the likely speed of recovery. However, there are two problems with this approach. First, the introduction of more indicators requires the prediction of additional information in the aftermath of a hazard to feed into the model. Second, one could argue that the introduction indicators, even of the same capabilities, generate a different index. As a result, the comparison across time still might need to be considered with some caution. Despite these weaknesses, we believe this second approach is preferable because it provides a more consistent measurement of the impact of the hazard on society over time.

Disaggregation

Finally, the distribution of the societal impact of a hazard is important to consider and an adequate approach should provide this information. Frequently, subgroups within a population face differential consequences of a hazard. Such differential consequences raise questions of justice. Intuitively, it seems unjust for some subgroups within a society, including geographical, ethnic, gender, and age groups, to face significantly more dire consequences from a hazard than other subgroups. To ascertain the likely distribution of consequences, we can use the method of disaggregation. The UN uses a similar method to measure the level of development of subgroups within a society (Jahan 2003). The method of disaggregation consists of computing the HII for each subgroup. Such disaggregation will provide information about likely differences in the consequences associated with a hazard. Ideally, the differential levels of the HII for all subgroups should be equal.

Hazard Impact Index versus Disaster Risk Index

The UN recognizes that successful development and effective natural hazard mitigation are interconnected. This recognition has led to the formulation and implementation of the disaster risk index (DRI). The DRI developed as part of the UN Development Programme (Bureau for Crisis Development and Recovery 2004) to measure the impact of sociopolitical-economic conditions on the potential fatalities associated with hazards. The DRI computes risk in terms of the number of fatalities. Conceptually, this is defined to be equal to the hazard (that captures both the likelihood of occurrence and the likely intensity) times the population living in an exposed area, times a vulnerability factor that depends on the sociopolitical-economic conditions of the considered population. Such a vulnerability factor inflates or deflates the expected number of fatalities, based on the level of development (not the safety of the infrastructures) of the considered society.

While the DRI tries to capture the effects of different social conditions and differences on the actual impact of a hazard, it has the following two limitations. First, it does not give an overall picture of the societal impact of a hazard, but instead limits its focus to the prediction of the number of fatalities. Therefore, it has the same first limitation of the current approaches discussed above. Second, the determination of the expected number of fatalities is only based on empirical correlations and considerations.

An underlying assumption of the DRI is that we can infer the safety of a society's infrastructure based on the knowledge about its resources. While the degree of development of a society might be to some degree correlated with the structural vulnerability of a society's infrastructure, it is a rough approximation to use an inflating/deflating factor based on the sociopolitical-economic considerations.

A more appropriate and accurate way to assess the vulnerability of a society's infrastructure is using engineering considerations, models, and expertise. Software such as HAZUS and MAEvis can be used to assess the vulnerability of a society's infrastructure based on sound engineering considerations. Such models directly explain why there is likely to be an increased number of fatalities because they directly consider the actual performance of a given structure/infrastructure subject to specified hazards. The prediction of the likely societal impact should leverage such engineering knowledge. The HII can draw upon these valuable resources from engineering to predict the expected values of the indicators.

Conclusions

In this paper, we critically discussed limitations with how various approaches to risk analysis in civil engineering treat the societal impacts of natural or man-made hazards. Approaches typically identify the kinds of consequences too narrowly, considering only consequences that are easily quantifiable, such as the numbers of fatalities or damaged structures. They also lack a uniform and consistent metric for quantifying societal consequences and rely upon implicit and potentially inaccurate value judgments when evaluating risks. In response to these limitations, we have developed the theoretical foundation for an alternative, capabilities-based approach to defining and predicting the societal impact in risk analysis. In this approach, the societal impact is defined in terms of the changes in individual capabilities, the functionings individuals are able, still able, or unable to achieve in the aftermath of a hazard. Individual capabilities capture the net societal impact of disasters, including potential benefits and opportunities, in addition to losses. The practical implementation of the proposed approach is discussed and a method for predicting capabilities proposed, which includes the selection of capabilities, the selection and calculation of indicators, the weighing of capability indices, and how the formulation might change during the different phases that follow the occurrence of a hazard.

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