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The Role of Society in Engineering Risk Analysis: A Capabilities-Based Approach

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This article proposes a new conceptual framework in engineering risk analysis to account for the net impact of hazards on individuals in a society. It analyzes four limitations of prevailing approaches to risk analysis and suggests a way to overcome them. These limitations are a result of how societal impacts are characteristically accounted for and valued. Prevailing approaches typically focus too narrowly on the consequences of natural or man-made hazards, not accounting for the broader societal impacts of such hazards. Such approaches lack a uniform and consistent metric for accounting for the impact of the nonquantifiable consequences (like psychological trauma or societal impacts) and rely upon implicit and potentially inaccurate value judgments when evaluating risks. To overcome these limitations, we propose an alternative, *Capabilities-Based Approach* to the treatment of society in risk analysis. A similar approach is currently used by the United Nations to quantitatively measure the degree of development in countries around the world. In a Capabilities-Based Approach, the potential benefits and losses due to a hazard are measured and compared in a uniform way by using *individual capabilities* (functionings individuals are able, still able, or unable to achieve) as a metric. This Capabilities-Based Approach provides a foundation for identifying and quantifying the broader, complex societal consequences of hazards and is based on explicit, value judgments. The Capabilities-Based Approach can accommodate different methods or techniques for risk determination and for risk evaluation and can be used in assessing risk in diverse types of hazards (natural or man-made) and different magnitudes that range from minor to catastrophic. In addition, implementing a Capabilities-Based Approach contributes to the development of a single standard for public policy decision making, since a Capabilities-Based Approach is already in use in development economics and policy.

KEY WORDS: Capabilities; Capabilities-Based Approach; risk; society

1. INTRODUCTION

Risk and uncertainty are key aspects of most engineering problems. The inherent uncertainties of engineering problems have associated risks. Risks vary from the simple malfunctioning or failure of a process or product to catastrophic events due to *natural* or *man-made hazards*. *Risk analysis* (or *risk assessment*) is the process of (1) quantifying the probabilities of potential *consequences* in various hazardous scenarios (*risk determination*) and of (2) evaluating that information to decide whether and how to act, under conditions of uncertainty (*risk evaluation* or *risk management*) (Rowe, 1980; Vose, 2000; Bedford & Cooke, 2001; Haimes, 2004).

In the past, engineering decisions and analyses did not account for uncertainties and were deterministic. Decisions were based on incomplete information

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and potentially resulted in inaccurate designs. In some cases, designs were overengineered, rendering a system or structure unnecessarily protected against unlikely risks. In other cases, designs were underengineered, underestimating the risks associated with a particular design and making a system or structure excessively vulnerable. Currently, risk analysis is used by many engineering sectors, including structures, transportation, construction, energy, chemical processing, and aerospace (Bedford & Cooke, 2001; Corotis, 2003a). An historical overview of the development and implementation of methodologies for risk analysis in engineering can be found in, for example, Haimes (2004) and Bedford and Cooke (2001).

In addition to contributing to the appropriate engineering of a particular design, risk analysis information is valuable for politicians and other decisionmakers. It provides the necessary information on the likelihoods and consequences of hazards, enabling politicians and decisionmakers to make well-informed and responsible policy priorities and decisions (Finkel, 1990; Pate-Cornell, 1996). However, "much research is still needed to improve methods for quantitative risk and uncertainty analysis and to better understand its evolving contribution to individual, organizational, and societal decision making" (Cullen & Small, 2004).

Our article focuses on the *kinds of consequences* considered in the process of risk analysis. We argue that currently consequences are defined too narrowly and do not reflect the real impacts of hazards upon individuals and society. We also show how the *Capabilities-Based Approach* (Sen, 1989, 1999a, 1999b; Anand & Sen, 2000) provides a theoretical foundation for identifying and quantifying potential consequences in a more satisfactory way. A similar conceptual framework is currently used by the United Nations (UN) to quantitatively measure the degree of development in countries around the world. In a Capabilities-Based Approach, the potential benefits and losses due to a hazard are measured and compared in a uniform way by using *individual capabilities* (specified functionings individuals are able, still able, or unable to achieve) as a metric. Engineers and decisionmakers can identify and compare more accurately and comprehensively both the *influence domain* (who is impacted by hazards) and the *net impacts* (how individuals are affected by such scenarios). This increased knowledge can improve the formulation of engineering policy and regulation. In addition, the language of the Capabilities-Based Approach is easily communicable to the public, providing a way for politicians to communicate and justify their decisions regarding safety.

There are four sections in this article. The first describes the key aspects of the Capabilities-Based Approach. The second explains in greater detail the conceptions of and approaches to risk. The third discusses four limitations with current approaches to risk analysis. The fourth section explains the Capabilities-Based Approach to risk analysis, shows how this approach avoids the limitations discussed in Section 3, and discusses two additional benefits.

2. DEFINITIONS AND CURRENT APPLICATIONS OF A CAPABILITIES-BASED APPROACH

In this section, we define the key terms of the *Capabilities-Based Approach* and we show how this theoretical framework has been used in practice in a different field, development economics. This provides the background to our discussion of risk analysis and society.

2.1. Description of a Capabilities-Based Approach

Nobel prize-winning economist Amartya Sen and philosopher Martha Nussbaum are the primary architects of the Capabilities-Based Approach (e.g., Sen, 1989, 1999a; Nussbaum, 2001a,b). Our article draws upon the specific analysis of capabilities provided by Sen. To understand *capabilities*, it is necessary first to discuss the concept of *functionings*. *Functionings*, defined as "valuable acts or . . . states of being" (Sen, 1993), refer to what an individual does or becomes in his or her life that is of value. Examples of functionings include escaping morbidity and mortality, being adequately nourished, being literate, and having mobility. *Capabilities* refer to the specific functionings that are feasible for an individual to choose to achieve. An individual has a certain capability if the individual is able to achieve the corresponding functioning, given his or her available personal, material, social, institutional, and legal resources. An individual's capabilities, then, are a function of the real options he/she has available.

There is an important connection between capabilities and positive freedom. Individuals are free to the extent that various combinations of functionings that are open to him or her can be achieved. Such freedom goes beyond the absence of external interference. An individual can be free from external interference and still have no valuable options in terms of how he or she is going to live his or her life. Positive freedom reflects the real feasibility of individuals being able to choose from among valuable options.

From the perspective of the Capabilities-Based Approach, an individual's *standard of living* should be assessed by considering his or her "ability . . . to lead the kind of life" he or she has "reason to value" (Anand & Sen, 2000). Individuals are free to choose the life they will lead if there are a number of alternative ways of living that are of value that individuals are capable of achieving. If an individual has no ability to choose the course of his or her life, his or her quality of life itself is diminished. Freedom impacts the overall quality of an individual's life or standard of living (Sen, 1993).

Capabilities are distinct from utilities. Whereas capabilities focus on which valuable doings and beings individuals can choose to achieve, utilities "focus on mental satisfaction" or the pleasure or happiness of a particular individual (Sen, 1999a). However, because satisfaction is difficult to measure, utility is determined frequently by looking at people's preferences or choices. Utilities are assigned to represent a preference function. In other words, if an individual chooses A over B, then A has more utility than B.

Using utilities as a metric to capture the standard of living of individuals has one fundamental limitation. Happiness or preference-satisfaction is not a sufficient indicator of an individual's standard of living. The phenomenon of adaptive preferences shows why this is so. Sen (1999a) writes: "People will adjust their expectations based on what they expect to come. So you could have someone who adjusts to a life of poverty and will learn to take pleasure in small things despite being very deprived and living a reduced life." Individuals living in conditions of extreme poverty and abject deprivation can adjust to their circumstances and formulate their expectations and preferences accordingly. All of the minimal expectations and preferences of such individuals can be satisfied. Consequently, they can be said to be happy and so, from the utilitarian perspective, be said to enjoy a high standard of living. Yet, despite their happiness, such individuals are objectively deprived. Utilitarianism does not take into account the number and quality of options that are available to individuals.

Capabilities are also distinct from other metrics of well-being, like John Rawls's primary goods (Rawls, 1971). Primary goods are all-purpose means that enable individuals to pursue their goals, whatever those goals may be. Examples of such goods include rights, liberties, income, opportunities, and the social bases of self-respect. There are two problems with using primary goods to assess the standard of living of individuals (Sen, 1999b). First, this ignores differences in what Sen calls interpersonal conversion rates, or the overall freedom of individuals to pursue their goals with the same amount of goods. Someone with a handicap will require additional resources to have the same freedom to pursue his or her ends as a healthy individual. Second, primary goods focus on the *means* to well-being or freedom, while capabilities are valuable *ends*.

From the Capabilities-Based Approach, public policy should focus on promoting *capabilities* rather than *functionings*. By focusing on capabilities, policy is concerned with the freedom of individuals to achieve a preferred standard of living, rather than the achievement of that standard of living itself. This is because there is a link between justice and capabilities or freedom. To illustrate: "If the social arrangements are such that a responsible adult is given not less freedom (in terms of set comparisons) than others, but he still 'muffs' the opportunities and ends up worse than others, it is possible to argue that no particular injustice is involved" (Sen, 1993).

2.2. Implementation of a Capabilities-Based Approach in Development Economics

In this article, we propose measuring the actual societal impacts of a natural and man-made hazard by examining the effects a hazard might have on the standard of living of individuals. A Capabilities-Based Approach can be used in risk analysis by selecting appropriate capabilities for assessing the impact of a hazard. To see how this would work, we discuss in this section the use of the Capabilities-Based Approach in development economics and policy and demonstrate in Section 5 how the approach can be used in risk analysis.

In development economics and policy, a central issue is the standard of living of individuals. Historically, income was proposed as a measure to gauge individuals' standards of living and assess a country's levels of development; however, as discussed above, this measure does not account for several other factors that affect one's standard of living. From a Capabilities-Based Approach, development is measured in terms of the overall standard of living of individuals, as captured by looking at specified capabilities. The goal of development projects should be to enhance the selected capabilities of individuals. "[T]he purpose of development is to improve human lives by expanding the range of things that a person can be and do, such as to be healthy and well nourished, to be knowledgeable, and to participate in community life" (Fukada-Parr, 2003).

The UN and development agencies now measure the development of societies based on this capabilities framework. Since 1990, the United Nations Development Program has published the Human Development Report (HDR) annually. The HDR provides tools to measure and analyze development issues and guides the formulation of development policy priorities. One of these tools is the Human Development Index (HDI). There are currently five human development indices, the original HDI, the Human Poverty Index for developing countries (HPI-1), the Human Poverty Index for selected countries that are part of the Organization for Economic Cooperation and Development (HPI-2), the Gender-Related Development Index (GDI), and the Gender Empowerment Measure (GEM).

The HDI is a summary measure of human development. The other indices are more specific and they either measure deprivations (HPI-1 and HPI-2) or gender inequalities (GDI and GEM). Each index is constructed starting from a few (three or four) functionings that are considered to be the most relevant. For example, for the HDI, the functionings selected are the ability of living a long and healthy life, the opportunity for being knowledgeable, and the ability of having a decent standard of living (see Fig. 1). Each of these functionings provides information that cannot be ascertained from the other functionings. Then, *indicators* are selected to measure each functioning. So, for example, in the case of the HDI, the life expectancy at birth is selected as the indicator of the first functioning. The data collected for each indicator are then converted into a uniform scale through a *Capability Index*. Finally, all the Capability Indices are combined into the HDI. The HDI is useful to and easily understood by policymakers and the public. It provides "a simple measure [that] is more understandable to the policy maker and the public, sending a clear message about what makes the measure go up or down" (Fukada-Parr, 2003).

A tool like the HDI can be used in the context of risk analysis. In risk analysis, a few relevant functionings or capabilities can be selected to assess the change in the quality of life of individuals after a hazard. The functionings chosen need to be tailored to best capture a specific aspect of the standard of living that might be impacted.

3. CONCEPTIONS OF AND APPROACHES TO RISK

According to a widely accepted definition, risk refers to a set of scenarios s_i, their associated probability of occurrence p_i, and consequences x_i (Kaplan & Gerrick, 1981). A common feature of the various approaches to risk analysis is that they determine consequences by considering the direct harm to human health or the economic impact of hazards. For example, the consequences of an earthquake typically are measured by counting the number of fatalities, injuries, and damaged structures. We propose to employ capabilities as meta-quantities to measure the broader societal impacts of a hazard.

3.1. Risk Determination and Evaluation

Risk assessment can be divided into two main domains: *risk determination* and *risk evaluation* (Rowe, 1980). Below we define each area.

3.1.1. Risk Determination

Risk determination is the process of quantifying the levels of risk associated with particular hazards. Once the kinds of consequences one is interested in have been identified, several methods of risk determination can be used to determine the probabilities of their occurrence. For a summary of available

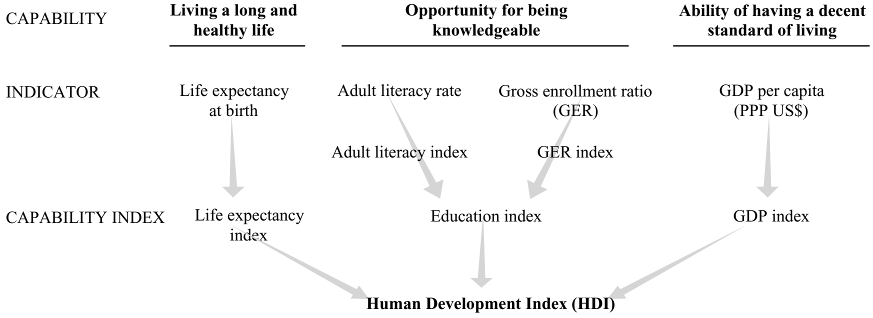

Fig. 1. Derivation of the Development Index (HDI).

approaches, see, for example, Pate-Cornell (1996), Haimes (2004), and Cullen and Small (2004).

Methods of risk determination range from greatly simplified to very refined. Which method is appropriate for a particular situation depends on a number of factors, including the magnitude and likelihood of the potential consequences, the importance of the decisions that will be made on the basis of risk determination information, decision-making constraints, and the availability of data. So, for example, most of our daily problems do not require a sophisticated treatment of uncertainties; sound risk management decisions have been made for many years without considering uncertainties and without resulting in catastrophic outcomes. On the other hand, there are cases and situations whose complexity warrants more refined and accurate determinations of risk.

3.1.2. Risk Evaluation

Risk determination alone does not provide information on the acceptability of the risk associated with a hazardous scenario. *Risk evaluation* (or *risk management*) is the process of formulating a value judgment about the outcome of the risk determination process, deciding whether and how to act upon that information provided (Rowe, 1980). A particular level of risk may be judged acceptable. Alternately, a decision may be made to take measures to reduce the level of risk.

To evaluate the acceptability of risk correctly, the relevant consequences first must be considered in the risk determination process and then assessed in light of additional considerations in the risk evaluation process (Corotis, 2003b). This assessment in turn guides the choice of courses of action to take. Several approaches are available in the literature for risk evaluation and acceptance (Rowe, 1980). For example, in *Risk Comparison* approaches, the risk is compared to selected benchmarks, criteria, or value judgments. In *Cost-Effectiveness of Risk Reduction*, various risk reduction strategies are evaluated against direct economic considerations. In *Cost-Risk-Benefit Balancing*, additional considerations regarding potential economic benefits to society are added into the consideration. Combinations of the above approaches are also possible.

4. LIMITATIONS OF THE TRADITIONAL APPROACHES TO RISK ASSESSMENT

There are four general limitations of traditional approaches to risk determination and evaluation in engineering. This section summarizes each limitation or the corresponding need. In the next section, we show how the use of the Capabilities-Based Approach in risk analysis avoids these limitations.

1. **Narrow identification of consequences and failure to account for potential benefits.** Typically, only the *focal* consequences of a hazard are included. Focal consequences are those that are immediately apparent. Examples of standard focal consequences include the number of fatalities in the case of an earthquake or hurricane, the number of individuals infected after the outbreak of an infectious disease, the number of houses without electricity after a blackout, or the economic loss from the crash of the stock market.

   However, hazards also have numerous *auxiliary* consequences. There are two types of auxiliary consequences: (Type 1) additional immediate impacts on individuals or systems, (Type 2) broader indirect effects of such scenarios on society. Hazards can alter the economic, cultural, and political circumstances of a society (Stallen *et al.*, 1998a). These changes in turn influence the lives of individuals across society. Both types of auxiliary consequences are typically overlooked.

   To illustrate auxiliary consequences, consider Hurricane Katrina, which affected New Orleans and the greater Gulf Coast in August 2005. An example of an auxiliary Type 1 consequence is the negative affect on the mental health of survivors (Stallen *et al.*, 1998a, 1998b). An example of an auxiliary Type 2 consequence is the ramification of the hurricane for farmers in the Midwest. Many farmers in the Midwest use barges to carry their corn, soybeans, and wheat down the Mississippi River to the port of New Orleans for export. Since the hurricane damaged the waterways and grain-handling facilities, barges were no longer an economically viable option, resulting in higher transportation and logistical costs. These additional costs for transportation challenged the planned reductions of farm subsidies designed to comply with international free trade agreements. To get an accurate sense of the consequences to consider when determining and evaluating risk, there is thus a need to consider both focal and auxiliary consequences.

While there are several techniques available to help identify and map out consequences associated with a hazard, like, for example, the Hierarchical Holographic Modeling (Haimes, 1981 and 2004) or the Ishikawa (Cause and Effect) Diagrams, we recognize the general need to broaden the spectrum of consequences considered in practice. It is important to consider this broader set of consequences because "whether a physical infrastructure is disabled owing to a natural cause, a disgruntled employee, or a terrorist act, the [direct] consequences may be similar, although the impacts—especially the psychological and political impacts—are likely to be significantly different" (Haimes, 1999).

In addition, natural and man-made hazards might also bring opportunities to the society. These opportunities should be accounted for in the aftermath of a disaster. For example, the harbor of Yokohama, Japan indirectly benefited from the Kobe Earthquake of 1995. In fact, the damaged Kobe harbor could not serve as the usual port for business and trade. The Yokohama port became the preferred choice for many businesses, many of which continued to use the Yokohama port even after the Kobe harbor was rebuilt. 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.

2. **Need for an accurate, uniform, and consistent metric for quantifying consequences.** Once one takes a broader view of the consequences of hazardous events, the challenge of quantification becomes increasingly difficult and complex. One complexity is that the number of potential consequences to consider increases exponentially. As Abrams *et al*. (2004) write: "Social-economic impact is difficult to quantify because of the large number of consequences possible resulting from disrupted services following [for example] an earthquake, making the total economic loss and overall consequence difficult to estimate." There is no method yet developed for quantifying the nonfatal physical or psychological harms to individuals or the indirect impact on individuals of the broader societal consequences of hazards.
3. **Lack of transparent value judgments in risk determination and evaluation.** Underlying prevailing approaches are implicit *value judgments*. Such value judgments state, for example, the goods that society ought to protect or promote or, alternately, the harms from which society should protect individuals. Implicit judgments are also made about how to rank, weigh, and balance competing values. Safety, efficiency, and fairness are examples of values. These implicit value judgments motivate (or provide the rationale for) each approach to risk determination and risk evaluation. For example, in one approach to risk determination, the *Worst-Case Scenario Approach*, the implicit value judgment is that certain harms must be prevented at all costs, regardless of whether this involves sacrificing the promotion of other values. There are two problems with keeping the underlying assumptions or value judgments implicit.
   (a) It is more difficult to communicate the justification of a particular risk assessment approach, its outcomes, and the decisions made on the basis of these outcomes to the public. This is more likely to make the approach, outcomes, and decisions seem mysterious and questionable. The purpose being promoted by risk policies becomes clearer and more acceptable if the relative weights assigned to particular values are made explicit.
   (b) Keeping value judgments implicit also makes it more difficult to scrutinize and critique a risk assessment approach, its outcomes, and the decisions made on its basis. Public scrutiny is important to help guarantee that the distribution of the benefits and burdens of a particular risk policy are fair and equitable. Such scrutiny can offer greater assurance that the relative weights given to various values are appropriate and based on what is best for the society as a whole. It would also help to ensure that there is public endorsement of the level of risk aversion used (Stallen *et al*., 1998b).
4. **Preference-based and potentially inaccurate value judgments.** This may lead to potentially inaccurate assessment of impacts of hazards.

Choices of risk analysts and decisionmakers about acceptable risk and design performances are often made on the basis of public or personal preferences. May (2001a) articulates a common view when he writes: "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." This is problematic for two reasons. Preferences might not track what is valuable and, in any case, preferences are hard to discern in a noninfluencing way.

(a) There are four reasons why preferences might not track what is valuable. Preferences potentially provide irrelevant information about what is of value. Preferences may be formed on the basis of misinformation or without sufficient appreciation of known information. Finally, respecting preferences potentially contributes to injustice.

Preferences might provide irrelevant information about value. Individuals may have preferences that are inimical to their own well-being or the overall well-being of society. Individuals may also have *adaptive preferences*, a phenomenon that social scientists and philosophers have discussed extensively (Sen, 1989, 1999a; Nussbaum, 2001a, 2001b). In the case of adaptive preferences, individuals often do not develop a desire for what they in fact value, in order to avoid disappointment when the desire goes unfulfilled.

In addition, individuals might have *misperceptions* about the risks they face. For example, they may be more afraid of rare, catastrophic events, like airplane crashes, where a large number of people may die at the same time, than more frequent accidents where few people die at the same time, like automobile accidents.

Even when aware of risks, citizens can be *indifferent* with respect to the actual risks they face (May, 2001b). For example, in Japan, where the seismic risk is comparable to California, there is a significantly higher social awareness and preparation for earthquakes. One of the reasons may be that citizens experience small earthquakes every few months. This works as a reminder of the risk coming from a major potential earthquake. In California, on the contrary, earthquakes are rarely felt. If the same questions are asked in California and in Japan the answers would be significantly different, while the seismic risk is comparable. Cultural, educational, and other socioenvironmental conditions would also influence individuals' answers.

Finally, respecting preferences may also contribute to or entrench injustice. In an unfair society, for example, the equitable distribution of the risks and benefits of the management of hazards may not be a value. In such contexts, fair public policy dealing with hazards could not be developed on the basis of preferences.

(b) A common method in practice for identifying subjective preferences is to ask individuals their preferences using surveys. This method assumes that individuals can accurately articulate their preferences that are normally not communicated in verbal form or ranked numerically. Moreover, when individuals are uncertain about their preferences, then the actual process of questioning may shape and influence the preferences that are expressed. The process "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). If elicited values and preferences can be manipulated in the way suggested, then the resulting survey information may reflect the interests of the questioner rather than the interests and preferences of those surveyed (Fischhoff *et al.*, 1980). Because questionnaires may not yield an accurate representation of preferences, policy formation based on preferences can become unresponsive to, and in the worst case work against the interests of, those impacted by such policy decisions.

The Capabilities-Based Approach presented in this article allows risk analysis to account for the net impact of hazards going beyond the consequences typically considered and to quantify all consequences in a consistent way. The quantification reflects what is relevant and important to the well-being of people and society.

5. BENEFITS AND IMPLEMENTATION OF A CAPABILITIES-BASED APPROACH TO RISK ANALYSIS

In this section, we show how the Capabilities-Based Approach could be implemented in risk analysis and how a Capabilities-Based Approach addresses the four limitations of current approaches reviewed in the previous section. After, we list two additional benefits of the proposed approach.

To determine the net impact of a hazard, risk analysts should focus on selected capabilities likely to be impacted in the aftermath of a hazard, instead of looking at individual consequences. The change in these capabilities can be used to determine both the potential societal benefits and losses of the hazard. Following the choice of capabilities, indicators can be developed to measure the impact of the hazard on the selected capabilities.

1. **Capabilities allow us to measure the impacts of hazards that go beyond the consequences traditionally considered.** The emphasis of the Capabilities-Based Approach is on enabling individuals to achieve valuable functionings. Applied to risk assessment, this suggests that we consider which specified capabilities individuals would or would not still be able to achieve in the aftermath of a hazard. Capabilities work as meta-quantities. The impact on specified capabilities encompasses or captures all the potential consequences.

In a Capabilities-Based Approach, risk refers to the probability that individual capabilities will be reduced due to a hazard. This understanding of risk would add depth to risk determination by considering the broader impact of hazards instead of a few specific consequences. When evaluating risk, all the different impacts on society are considered (see Fig. 2 for an illustration of the concepts). The more comprehensive account offered by the Capabilities-Based Approach allows for a more complete, better educated, and more accurate decision-making process. Because the Capabilities-Based Approach takes into account the broader impacts of hazards, it offers a more relevant and more complete picture

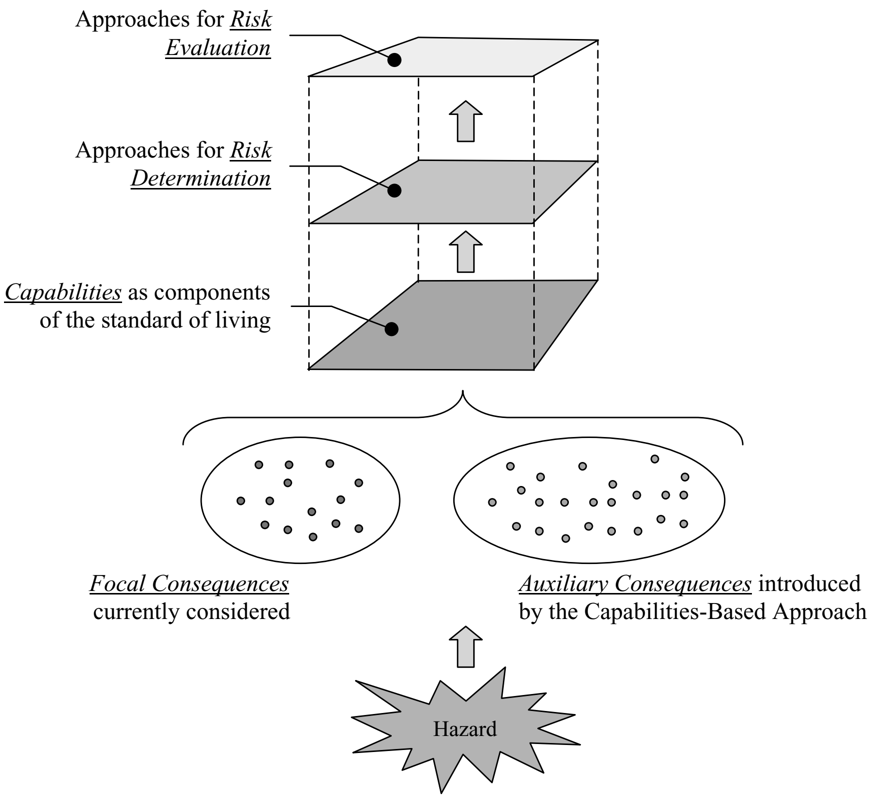

Fig. 2. Illustration of how a Capabilities-Based Approach can be used in risk analysis.

of the consequences of a hazard. The picture is more relevant because capabilities are what ultimately we should be concerned with, given that they are constitutive elements of individual well-being. The picture is also more complete because the functionings act as overarching quantities that encompass the individual consequences. This makes the choice among different strategies well-informed. The Capabilities-Based Approach also provides resources for making principled decisions among different risk reduction strategies. Because the same metric of value is used in each strategy, the choice among strategies also becomes more easily comparable.

Work is being done in the area of development economics to build a *Capabilities-Based Decision-Making Procedure* for choosing among particular development projects. For an example of this procedure, see Clements (1995). Such a procedure could provide a model for decision-making in risk assessment.

There are two fundamental benefits of the Capabilities-Based Approach with respect to the available approaches. First, capabilities are ultimately what risk analysts should be concerned about protecting, since capabilities are the constitutive aspects of individual well-being. Current techniques work at the level of specific consequences, some (but not necessarily all) of which could serve as indicators of individual well-being. However, these approaches lack the conceptual framework for linking particular consequences with individual well-being. Second, because capabilities act as overarching quantities that encompass individual consequence, a few, properly selected capabilities can be used to represent the actual implications of several consequences for individuals' well-being. So, even though one might consider several consequences instead of fewer capabilities, the dimensions of the problem of identification and quantification would grow, ultimately unnecessarily increasing the complexity and the uncertainty in the risk analysis process. The Capabilities-Based Approach would simplify and streamline this process.

2. **The Capabilities-Based Approach allows for quantification of the net effects on the standard of living of individuals in society.** As the work on the Human Development Indices illustrates, quantification of the capabilities of individuals is possible and practicable. The UN HDI provides a model for quantifying capabilities. The considered capabilities are problem specific and might change based on the type of hazard and the time-phase of the hazard (e.g., emergency response, short-term, or long-term recovery). Capabilities enable easier quantification because they are symptomatic and therefore easily measurable and filled with information.

   Gauging the capabilities of individuals is accomplished by asking for specific figures of factors that provide information about particular capabilities. As in the formulation of the Human Development Indices, after identifying the specific capabilities that one wants to gauge, indicators can be selected to measure each capability. The data collected for each indicator are then converted into a Capability Index. Finally, all the Capability Indices are combined into a *Hazard Impact Index* (HII).

   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 Capability Indices of the capabilities of individuals as a metric.
3. **The value judgments in risk determination and risk evaluation are explicit as are the particular capabilities that are the focus.** The goal is to minimize the likelihood that capabilities will be reduced. The capabilities approach makes maximizing capabilities (or minimizing reduction of capabilities) the goal in order to minimize the societal impact of hazards. The value judgment is explicit as is the particular capabilities that are the focus of concern in the risk reduction strategies. The weights assigned to each Capability Index in developing the HII would require some value judgment, which would be made explicit in the construction of the index itself. This explicit value commitment makes the tasks of communication, justification, and critique of existing approaches to risk easier and more transparent.
4. **The Capabilities-Based Approach is a more accurate measurement of actual impacts of hazards on an individual's standard of living.** The perspective does not rely upon individual preferences to identify the values to be protected through risk reduction strategies. Thus,

it avoids the concerns about adaptive preferences and biased preferences that can yield a distorted, often unjust, picture of the values to protect and the weight to accord to those values. The primary value promoted by the Capabilities-Based Approach is the capabilities of individuals. Because the Capabilities-Based Approach measures benefits in terms of real contributions to the standard of living, risk analysis from the capabilities-based perspective offers a more informative indicator of the real net benefits, in terms of contributions to an individual's standard of living, than particular projects would have, and is a more accurate measure of potential losses and damages.

In addition to avoiding the limitations of prevailing approaches, the Capabilities-Based Approach has two additional strengths.

5. **The Capabilities-Based Approach is adaptable and scalable.** Capabilities can be used to quantify any kinds of consequences. The approach can be used in assessing risk in diverse types of hazards; it can be used for hazards of any magnitude (from minor to catastrophic); it can accommodate different value judgments that could be influenced by the nature of the hazard and the magnitude of the risk. This general approach can be used, with the appropriate capabilities, to assess the societal impacts of both natural and man-made hazards, immediately and in the short and long term. The appropriate capabilities are selected consistent with the overall goal of risk analysis and with what we are interested in assessing (in terms of individuals' standard of living).
6. **The use of a Capabilities-Based Approach in risk analysis contributes to the development of a single standard for public policy decision making.** Risk analysis would use a conceptual framework consistent with the one used in development economics and policy. This would facilitate the process of bridging analyses from the two areas, when risk analysis is used as an informational tool to choose among development projects.

5.1. Challenges and Future Work for the Capabilities-Based Approach to Risk Analysis

The purpose of this article is to present a conceptual framework for identifying and measuring the impact of a hazard in terms of the capabilities of individuals. There is a range of capabilities that engineering risk analysis might consider (Sen, 1989; Anand & Sen, 2000). A practical challenge is to identify the relevant capabilities and to identify the relevant indicators for each selected capability.

An example of the process of identifying and ranking capabilities has been done by Sen when discussing development economics and policy (Sen, 1989; Anand & Sen, 2000). According to Sen, the choice of capabilities depends on the underlying social concerns or values one is interested in promoting or protecting. When dealing with extreme poverty, for example, you can achieve a significant amount by focusing on a few vital capabilities, like the ability to be well-nourished and well-sheltered. In the case of risk analysis, the capabilities could be different. The choice of capabilities is made based on the underlying concerns that we want to measure. "The focus has to be on the underlying concerns and values, in terms of which some definable functionings may be important and others quite trivial and negligible" (Sen, 1993). To facilitate the implementation in risk analysis of the proposed approach, the minimum number of capabilities possible should be chosen (*capabilities parsimoniety*). Each of the capabilities selected should provide information that cannot be ascertained from the other capabilities (*capabilities orthogonality*).

6. CONCLUSIONS

In this article, we critically discussed the limitations of how commonly used approaches for risk analysis in engineering treat the societal impacts of hazards. Approaches typically identify the kinds of consequences of natural or man-made hazards too narrowly, considering only a few kinds of consequences that are easily quantifiable, like, for example, in cases of earthquakes the numbers of fatalities, injuries, and damaged structures. The actual societal impacts of such hazards are typically ignored. Common approaches also lack a uniform and consistent metric for quantifying noncountable consequences (like emotional trauma or societal impacts) and rely upon implicit and potentially inaccurate value judgments when evaluating risks. In response to these limitations, we have developed a foundation for an alternative Capabilities-Based Approach to the analysis of societal impacts. This approach allows us to, among other things, account for broader, societal consequences of hazards that indirectly impact individuals. Potential benefits and losses are measured and compared in a uniform way, looking at the impact on the capabilities of individuals. The new dimensions accounted for by the proposed Capabilities-Based Approach allow for a more complete, better educated, and more accurate decision-making process. This article lays out the foundation for a Capabilities-Based Approach to risk analysis. Future work will focus on implementing this framework in practice by applying it to specific cases.

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