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A Deliberative Method for Ranking Risks (I): Overview and Test Bed Development

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Risk ranking offers a potentially powerful means for gathering public input to help set risk-management priorities. In most rankings conducted to date, the categories and attributes used to describe the risks have varied widely, the materials and procedures have not been designed to facilitate comparisons among risks on all important attributes, and the validity and reproducibility of the resulting rankings have not been assessed. To address these needs, a risk-ranking method was developed in which risk experts define and categorize the risks to be ranked, identify the relevant risk attributes, and characterize the risks in a set of standardized risk summary sheets, which are then used by lay or other groups in structured ranking exercises. To evaluate this method, a test bed involving 22 health and safety risks in a fictitious middle school was created. This article provides an overview of the risk-ranking method and describes the challenges faced in designing the middle school test bed. A companion article in this issue reports on the validity of the ranking procedures and the level of agreement among risk managers regarding ranking of risks and attributes.

KEY WORDS: Risk ranking; risk prioritization, comparative risk analysis; citizen participation; risk attributes; school risks

1. INTRODUCTION

Interest in risk ranking has been growing. The U.S. Environmental Protection Agency (USEPA) led the way in 1986 with a staff study titled *Unfinished Business*,(1) and followed with two studies conducted by its Science Advisory Board.(2,3) In addition, the USEPA's Regional and State Planning Bureau has supported approximately 50 local and regional comparative risk projects,(4) in which experts and laypeople have worked together to develop rankings for a wide range of risks.(5–8) Other agencies in the United States(9–11) and elsewhere (e.g., Canada(12) and New Zealand(13)) have also engaged in risk ranking. In 1993, the Carnegie Commission on Science, Technology, and Government called on risk regulatory agencies to make much wider use of such methods.(14)

Although policy makers ultimately need to set priorities for risk-management strategies, risks are more easily ranked than management strategies because the number of possible management options far exceeds the number of risks. Ranked lists of risks may also be more stable over time. A ranking of risks should be seen as one input to decision making, not as a final recommendation for management priorities. Risks with middle and low ranks may still deserve management action if they can be effectively reduced at small cost. Conversely, if little can be done to reduce a highly ranked risk, managers should not

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spend resources on it that could provide much more protection if invested elsewhere. However, a high rank may signal the need for research or analysis that could lead to cost-effective management in the future.

In an analysis of past comparative risk efforts, Andrews[15] concluded that exercises "conducted behind closed doors without a public mandate" (p. 18) have been ignored. Although many risk-ranking efforts have been conducted publicly, often by groups of interested stakeholders or experts, most efforts have devoted little systematic attention to the methods employed in framing and performing the rankings. This is not a serious problem if the primary goal is to promote risk communication or foster dialog among stakeholders. However, if the resulting rankings are to be used by regulatory agencies in risk-management decision making, they must be based on normatively justifiable and empirically validated procedures. If they are not, the rankings will be vulnerable to attack on methodological grounds, limiting their usefulness to policy makers.

In our view, a good ranking method should (a) make use of available theory and empirical knowledge in behavioral social science, decision theory, and risk analysis; (b) encourage those doing the ranking to systematically consider all relevant information; (c) assist individual participants in expressing (or constructing) internally consistent rankings; (d) ensure that participants understand the procedures and feel satisfied with both the processes and products; and (e) describe the level of agreement and the sources of disagreement among participants. Agreement among participants is not, in itself, an objective of risk ranking because participants may have legitimate reasons for disagreeing about the relative riskiness of hazards. A good ranking method, however, should produce a similar degree of agreement when rankings are repeated with similar groups of people, allowing for sample size effects.

2. THE CARNEGIE MELLON RISK-RANKING METHOD

To address the needs outlined above, we developed a five-step risk-ranking method (see Fig. 1) that draws on decision theory, risk analysis, and the psychology of risk communication.[16–18] It begins with an iterative refinement of the set of risks to be ranked (Step A) and the set of attributes used to describe those risks (Step B). Each risk is then characterized in terms of each attribute, and this information is combined with narrative descriptions to create a set of standardized risk summary sheets (Step C) to be used in risk-ranking exercises (Step D). Although the rankings can be performed by any group, we have designed the method to be appropriate for use with jury like groups of laypeople, so that policy makers can employ it to assess public preferences. Finally, a thorough description of the deliberations and the resulting rankings is prepared (Step E) for use in risk-management decision making.

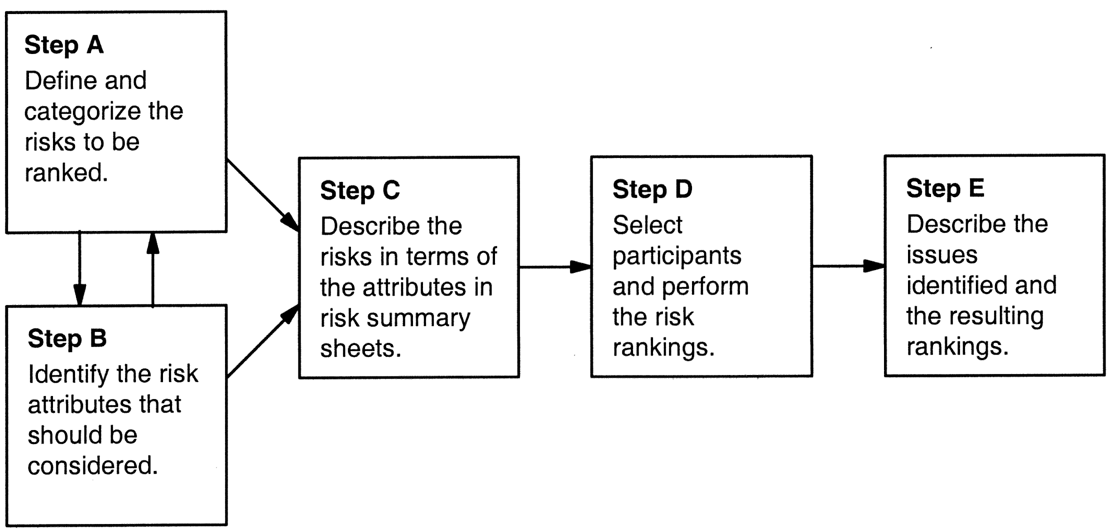

Fig. 1. Steps in the risk-ranking method. Steps A and B overlap in time and require some iteration.

We have reported on the tasks involved in Steps A and B in previous writings.[19,20] In this article, we describe the development of an experimental test bed that helped us to refine our materials (Steps A–C) and ranking procedures (Step D). Analogous issues can be expected to arise in any risk domain. A companion article in this issue[21] provides more detail on the validity of our ranking procedures and the level of agreement among risk managers regarding the rankings of risk and attributes (Step D). Additional work on ranking procedures has been reported elsewhere[22,23]; work on how best to report the processes and results of risk-ranking exercises (Step E) is still in progress.[24]

2.1. The Centerville Middle School Test Bed

Although the research literature provides much useful guidance, the development of materials and procedures has required considerable direct experimentation. To this end, an experimental test bed was developed consisting of a realistic multirisk environment in which the need for risk ranking is compelling.

The test bed is the fictitious Centerville Middle School (CMS). In material provided to participants in the studies, CMS is described approximately as follows:

> CMS is a public school serving 430 seventh-, eighth-, and ninth-graders, located in a suburban residential community in the Midwestern U.S. The school was built in 1971 and is in good repair. The first floor includes administrative offices, 14 classrooms, a cafeteria, an auditorium, a library, and utility space. The second floor includes 22 classrooms, a number of special purpose rooms, a gymnasium, and a swimming pool. Cooking and heating are provided with natural gas. The school grounds are fenced and include a parking lot, athletic fields, a track, basketball courts, and some playground equipment. A two-lane suburban street, a four-lane divided expressway, railroad tracks, and a high voltage power line are located nearby. The neighborhood has little crime and the school grounds are monitored by local police as part of their regular patrol route.

In addition to this description, participants are provided with floor plans, a perspective drawing of the school and its grounds, and a map of the town of Centerville showing the location of the school and other risk-relevant features (e.g., airport and fire department). These figures can be viewed at http://www.epp.cmu.edu/research/EPP_risk.html.

The choice of a school as our risk domain has several advantages. Because most people know and care about risks in schools, little effort is required to brief laypeople before they participate in risk ranking. The school environment involves a wide range of physical, chemical, biological, and social risks, but it does not have an overbearing political component that strongly influences risk perceptions. School risks can be sorted into a manageably small number of categories (e.g., asbestos, infectious diseases, and school bus accidents). Finally, many data on school risks are readily available,[24] which simplifies the task of preparing risk summary sheets.

2.2. Categorizing Risks (Step A)

The results of risk-ranking exercises can be sensitive to the way in which risks are defined and grouped, yet past efforts have devoted little analysis to this step of the process. Morgan, Florig, DeKay, and Fischbeck[19] described many possible bases for categorizing risks. Categories for school risks might be based on the agent responsible for harm (e.g., school bus, infectious disease, radon), the activity that produces the hazard (e.g., transportation, recreation, education), the location (e.g., commuting route, athletic field, classroom), the pathway (e.g., physical trauma, ingestion, inhalation), the end point (e.g., injury, disease, death), the group at risk (e.g., students, teachers, maintenance workers), the entity responsible for creating the risk (e.g., students, parents, teachers, industry, nature), or the entity most responsible for managing the risk (e.g., students, parents, State Department of Education, County Department of Health).

For purposes of risk ranking, Morgan *et al.*[19] argued that categories that can be linked to risk-management interventions are usually the easiest to translate into policy decisions. Thus, "accidents" at CMS were separated into those associated with falls, sports, school buses, and commuting to school, because the interventions for each of these types of accidents would be quite different. Because risk interventions are most often applied at proximal rather than distal points in the causal chain, Morgan *et al.* proposed that risk categorization start with the agent that initiates the processes leading to the undesired consequence. We adopted this strategy for categorizing risks at CMS, while attempting to meet the additional goals that risk categories be logically consistent and easy to comprehend.[16,19]

Most risks have multiple determinants. For example, risks from hazardous materials transported on nearby highways or railroads may be caused by inadequate maintenance of the infrastructure or vehicle (a social or economic agent), drowsy or inattentive operators (a biological or psychological agent), or the specific chemical or biological agent being transported. The most direct causes of in-school accidents are physical, but accidents might also be caused by social or psychological factors (e.g., horseplay, depression). Risks from a collapsing building are caused most directly by falling structural elements, and less directly by excessive snow loads, earthquakes, or tornadoes. For cognitive and administrative simplicity, our categorization efforts focused on the final agents in these causal chains. This emphasis on proximal causes also led us to exclude risks of inaction, such as letting kids drop out of school, not having lifestyle education programs (e.g., on smoking or unprotected sex), or not providing quality counseling services.

After the risks had been sorted by agent, additional distinctions led to finer categorization. For example, common infectious diseases were separated from unusual infectious diseases because their end points differ greatly in severity (e.g., sneezing from a common cold versus death from pneumonia). School bus risks were separated from other commuting risks because the accident rates are quite different and because the former are the school's responsibility, whereas the latter are the students' or parents' responsibility. Finer categorization is not always desirable, however. For example, allergens, food poisoning, and hazardous materials accidents can involve either chemical or biological agents. But because the risk-management strategies used to combat these risks would probably apply to both chemical and biological agents, however, we collapsed across agent in creating the categories for these risks.

Some risks categories are more difficult to delineate than others. Behavioral risks, for instance, are influenced by both school and other environments. Although we were interested only in those behavioral risks attributable to CMS, no one knows how to attribute behavioral risks across multiple environments. Where appropriate, the risk summary sheets describe such ambiguities and report larger uncertainties for quantitative estimates of risk.

Some school risks have significant effects beyond the students that are affected directly. For example, infectious diseases contracted at school can be spread at home and elsewhere. Serious disabilities incurred at school can place significant demands on other family members. Such indirect effects may be important, but they are often difficult to quantify. Where appropriate, the risk summary sheets include qualitative descriptions of such effects.

Finally, interactions among risks may occur both at the level of exposure (e.g., school bus riders may be at greater risk of catching infectious diseases than are students who commute by other means) and at the level of management (e.g., interventions that control unusual diseases also control common diseases). In defining risk categories, exposure interactions were ignored because they seem small for CMS. Management interactions were also ignored because our goal is to rank risks, not interventions.

On the basis of these considerations, the following 22 risk categories were created for CMS: accidental injuries (excluding sports); airplane crashes; allergens in indoor air; asbestos; bites and stings; building collapse; common infectious diseases; commuting to school on foot, by bike, or by car; drowning; electric and magnetic fields from electric power; electric shock; fire and explosion; food poisoning; hazardous materials transport; intentional injury; self-inflicted injury or harm; lead poisoning; less common infectious diseases; lightning; radon gas; school bus accidents; and team sports. For details, see http://www.epp.cmu.edu/research/EPP_risk.html.

2.3. Developing Risk Attributes (Step B)

Although the risk-perception literature clearly indicates that "risk" is a multiattribute concept, it also indicates that the number of attributes people care about is quite large.[20,25] Fortunately, the high correlations among attributes allow one to capture the variation among risks with just three independent factors, which Slovic, Fischhoff, and Lichtenstein[25] labeled *unknown risk, dread risk*, and *societal and personal exposure.* Jenni[20] reanalyzed these factors, reported new data for school risks, and suggested a small number of attributes that may be used to represent the factors. Her recommendations were guided by the strength of the normative argument for relying on the attributes, the comprehensibility of the attributes to participants, and the quality of the data for assessing risks on the attributes. To represent unknown risk, "quality of scientific understanding" and "time between exposure and health effects" are used; to represent dread risk, "greatest number of deaths in a single episode" and "ability of student/parent to control exposure" are used; and to represent societal and personal exposure, mortality and morbidity are used. To minimize framing effects, mortality risk is presented as both the "number of deaths per year" at CMS and the "chance in a million of death per year for the average student" at CMS. Because the risk to the most-exposed student and the average student can be quite different, the "chance in a million of death per year for the student at highest risk" is included as a limited measure of equity. Finally, because it is difficult to assess morbidity accurately with a single metric, morbidity is split into four attributes based on the severity and duration of the illness or injury.

There are substantial uncertainties in estimates of mortality and morbidity for most risks. For each of these attributes, we present best estimates with upper and lower bounds based on 95% confidence intervals. As an additional measure of unknown risk, we constructed a separate attribute labeled "combined uncertainty in death, illness, injury," as described below.

Overall, values for 12 attributes are presented, including the two (formally equivalent) metrics for expected mortality. These attributes are defined below in the context of CMS in order to illustrate the level of detail needed in a specific domain.

1. *Number of deaths per year.* This attribute is the expected number of deaths among the entire CMS student population resulting from one school year of in-school exposure. Deaths are counted no matter how far after the school year they occur. For three risks ("asbestos," "electric and magnetic fields from electric power," and "radon gas"), it is explained that scientists do not yet know whether the low level of exposure encountered at CMS is hazardous, and the probability that the agent poses no risk is specified.

2. *Chance in a million of death per year for the average student.* This attribute is the expected number of deaths per year at CMS ($\times 10^6$) divided by the student population ($n = 430$).

3. *Chance in a million of death per year for the student at highest risk.* This attribute is the expected lifetime mortality risk resulting from one school year of exposure for the CMS student with the greatest exposure. In principle, risk is defined by exposure and susceptibility, but susceptibility information is readily available for only a few school risks. Therefore, we consider the most exposed student rather than the most susceptible student.

4. *Greatest number of deaths in a single episode.* Some hazards kill only one person at a time (e.g., "radon gas"), whereas others can kill many at once (e.g., "airplane crashes"). Because losses in catastrophic events typically increase with their rarity, we define this attribute as the number of student lives lost in a one-in-a-million-year event. Risks that result only in illnesses or injuries (e.g., "lead poisoning") have scores of zero on this attribute.

5–8. *Illness and injury.* The illnesses and injuries resulting from risks at CMS vary in duration from hours to a lifetime and in severity from minor nuisance to profound debilitation. To capture this variation, four nonoverlapping attributes to describe morbidity are used. "More serious long-term cases per year" reflects the incidence of chronic conditions that last for more than 3 months and often involve hospitalization (e.g., a disfiguring burn, loss of vital organ function, any condition requiring long-term institutional care). "Less serious long-term cases" do not involve extended hospitalization (e.g., loss of a finger, mild mental retardation). "More serious short-term cases" are acute conditions requiring hospitalization (e.g., meningitis). Finally, "less serious short-term cases" require only modest medical care and no hospitalization, but involve at least 1 day of missed school or restricted activity (e.g., a bad cold).

9. *Time between exposure and health effects.* For risks at CMS, the time between exposure and health effects ranges from immediate for injuries to 20 to 40 years for cancer from asbestos.

10. *Quality of scientific understanding.* This attribute describes how well scientists know the relation between exposure and health effects for each risk. Understanding is limited for risks such as "electric and magnetic fields from electric power," but fairly complete for risks such as "school bus accidents." Understanding is characterized as low, moderate, or high.

11. *Combined uncertainty in deaths, illness, and injury.* This measure is a weighted average of the uncertainties for the expected-mortality and expected-morbidity attributes. For each of these attributes, uncertainty is represented by the geometric standard deviation, which is taken to be the fourth root of the ratio of the high and low estimates. For risks at CMS, values range from 0.3 to 3.7 and are characterized as low, medium, or high.

12. *Ability of student/parent to control exposure.* Some risks are clearly uncontrollable because there are no reasonable actions that students or parents can take to avoid them. CMS risks that fit this description include "airplane crashes," "electric and magnetic fields from electric power," and "hazardous materials transport." On the other hand, some risks are clearly controllable because they are entirely within the student's volition. "Team sports" is the clearest example of a fully controllable risk. Controllability is characterized as low, moderate, or high.

2.4. Preparing Risk Summary Sheets (Step C)

The risk summary sheets are designed to help participants learn enough about each risk to make informed personal ranking judgments and contribute to group discussions. These sheets, which draw on ideas and strategies from modern risk communication,[18] concisely describe each risk in nontechnical language, with consistent use of attributes and units to facilitate comparisons. The four-page format is small enough (16 cm × 26 cm) to allow the sheets to be spread out and sorted on a table during the ranking exercise. The first page includes a title identifying the risk category, a one-paragraph description of the risk, and a summary table with values and uncertainty ranges for the attributes, as shown in Fig. 2. The interior pages begin with a general discussion of the risk, including what is known and not known about the risk relative to each attribute. This is followed by a discussion of the risk in the specific context of CMS, including relevant comparisons with other schools and with government standards or guidelines (e.g., the USEPA's 4 pCi/L action limit for radon). Finally, there is a description of the actions the school has taken to deal with the risk. This information is intended to (a) provide a realistic context; (b) make it clear that the exercise concerns residual risks; and (c) focus the ranking on how serious the risks are, regardless of the feasibility or cost of additional risk management.

In preparing the 22 risk summary sheets, we drew on available literature,[26] supplemented by interviews of technical and school experts. Estimating mortality and morbidity for each risk often required considerable modeling and judgment. References, assumptions, and calculations have been recorded in separate technical documents, which are normally not used in the ranking process. They can be made available to researchers interested in using the materials. At several stages during the development of the summary sheets, reviews of the risk categories and attributes were obtained from laypeople. In addition, each risk summary sheet was reviewed by two technically trained risk analysts and two laypeople. The lay reviews included tape-recorded read-aloud protocols to allow us to identify miscommunications. Lay reviewers were also asked to offer suggestions for improving the presentations.

To help participants interpret the attribute tables on the first page of the risk summary sheets, a similarly formatted pamphlet, titled "Notes on the Numbers," was prepared which explains the multidimensional nature of risk and provides definitions for each of the risk attributes. To facilitate comparisons of risks on these attributes during risk-ranking exercises, a large chart that ranks all 22 risks according to each attribute was also created. Using this chart, participants can easily determine relative rankings on any attribute. The chart also makes it clear that risks that rank low on one attribute (e.g., the expected mortality from hazardous material spills) can rank very high on another (e.g., the number of deaths from a one-in-a-million-year hazardous material spill). All of these materials can be viewed at http://www.epp.cmu.edu/research/EPP_risk.html.

2.5. Performing the Rankings (Step D)

Throughout the exercise, participants are instructed to rank risks according to their levels of concern about those risks, without regard to the availability or cost of risk-management options.

Our ranking method includes both individual and group rankings. Participants first study the materials on their own and complete initial individual rankings. They then work with others to produce group rankings. These groups provide opportunities for participants to hear and consider alternative opinions and, thus, evaluate and refine their own views. After the group rankings, participants produce final individual rankings, characterize their groups' decision-making processes, and report their satisfaction with these processes and the resulting rankings.

In each of these three stages, risks are ranked in two different ways, so that participants may identify and resolve possible framing effects associated with the procedures. In the holistic ranking procedure, participants consider all of the materials described above and rank the risks by sorting the summary sheets. In the multiattribute ranking procedure, participants make judgments about the relative importance of the various risk attributes using one of several techniques (e.g., swing weights[27,28]). In doing so, participants indicate whether high or low levels of attributes 9 through 12 are associated with greater concern, because these relationships may not be obvious (see the companion article[21] for a discussion of this point). Modest technical support (e.g., a spreadsheet) is required to translate these judgments into multiattribute utility functions and implied rankings of the risks. In the initial individual and group stages, these multiattribute risk rankings are computed immediately and returned to the participants, who are then given the opportunity to

School Bus Accidents

Summary:

Most school bus-related deaths occur among students who are outside the bus either getting on or getting off. Half of school bus injuries occur among students on the bus. At Centerville Middle School half of the 430 students ride the school, almost identical to the national average. Accidents involving more than one death are very rare. Because CMS buses use the Alvarez Expressway and cross the C&LL rail line, the risk of a catastrophic bus accident in Centerville is estimated to be between four and six times higher than the national average.

School bus accident risk for Centerville Middle School*

Student deaths	*Low estim.*	***Best estimate***	*High estim.*
Number of deaths per year	.0001	**.0002**	.0004
Chance in a million of death per year for the average student	.25	**0.5**	1
Chance in a million of death per year for the student at highest risk	0.5	**1**	2
Greatest number of deaths in a single episode		**20 - 50**	
Student illness or injury			
More serious long-term cases per year	.0002	**.0006**	.002
Less serious long-term cases per year	.0004	**.0015**	.004
More serious short-term cases per year	.001	**.002**	.006
Less serious short-term cases per year	.002	**.005**	.015
Other Factors			
Time between exposure and health effects		**immediate**	
Quality of scientific understanding		**high**	
Combined uncertainty in death, illness, injury		**1.6 (low)**	
Ability of student/parent to control exposure		**moderate**	

*See "Notes on the Numbers" for definitions and explanations of assumptions.

Fig. 2. Layout of the front page of a four-page risk summary sheet showing the risk name, a summary paragraph, and a table of key risk attributes. Additional pages include a few-paragraph narrative describing the risk in both national and local contexts, and a description of actions that school officials have taken to address the risk. A risk summary sheet was prepared for each of the 22 risk categories defined for Centerville Middle School (CMS).

reconcile differences between their holistic and multiattribute rankings to create revised rankings.

Thus, in our standard method, there are eight rankings of the risks: holistic, multiattribute, and revised rankings in the initial individual and group stages, and holistic and multiattribute rankings (but no revised rankings) in the final individual stage. Although most of the empirical studies reported in the following section involved pared-down versions designed to test and refine specific materials and procedures, we have used the full method successfully in a number of risk-ranking exercises with lay groups.

3. EMPIRICAL STUDIES USING THE CMS TEST BED

The materials and procedures described above have been used in several studies designed to validate and improve the five-step risk-ranking method depicted in Fig. 1. First, to assess the extent to which participants use the text and table portions of the risk summary sheets, we compared rankings obtained from participants who used either (a) the one-paragraph descriptions of the risks, (b) the attribute tables, (c) both the one-paragraph descriptions and the attribute tables, or (d) the full risk summary sheets.[22] Second, we assessed several different ways to scale and weight risk attributes in order to identify procedures that minimize the elicitation burden on participants and produce the greatest consistency between holistic and multiattribute risk rankings.[22,23] Third, we demonstrated how multiple rankings from individuals and groups can be used to assess the validity of our ranking procedures and level of agreement among participants.[21] Fourth, we conducted six day-long group exercises in which we varied the order of holistic and multiattribute procedures to determine which combinations yield the highest levels of participant satisfaction and intergroup agreement.[24] Content analysis of group discussions was used to determine how the agenda influences the overall level of group discussion and the occurrence of anecdotal comments. Finally, we are currently extending the test bed to include ecological risks and their attributes.[29,30]

4. SUMMARY AND REFLECTIONS

Although the risk-ranking method outlined here can be used with a variety of participant groups, it is specifically designed to be appropriate for use with lay groups. The views of interested stakeholders are important in government decision making, but so too are the views of the general public. There are not enough mechanisms by which members of the general public are given the time and support necessary to develop and express their considered judgments about important matters of public policy. Risk ranking offers a potentially powerful means for gathering public input to help set risk-management priorities.

The CMS test bed has been critical to our ability to develop, evaluate, and refine our risk-ranking method. It has allowed us to conduct numerous controlled experiments with lay and other groups to explore each important aspect of the method. The resulting materials are available to others who wish to use them in teaching or research.

A great deal of effort is required to develop the materials and procedures needed to conduct risk-ranking exercises that yield valid and reproducible results. We suspect that most risk-management organizations would find it quite challenging to produce clear, systematic risk summary sheets that describe the risks they manage to the general public. Nonetheless, we believe that such organizations have a responsibility to produce quality risk-communication materials, even if they never take the next step of conducting risk-ranking exercises. The materials-development process described in this article suggests how they might proceed.

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