Risk and Risk Assessment in Health Emergency Management

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Abbreviations:
ASHE = American Society for Healthcare Engineering
AUDMP = Asian Urban Disaster Mitigation Program
CDC = United States Centers for Disease Control and Prevention
CRED = Centre for Research on the Epidemiology of Disasters (Belgium)
DFID = Department for International Development (UK)
DRM = World Institute for Disaster Risk Management
EMA = Emergency Management Australia
EPA = Environmental Protection Agency (US)
GAO = General Accounting Office (US)
IDNDR = International Decade for Natural Disaster Reduction
NRC = National Research Council
SARS = severe acute respiratory syndrome
SMUG = seriousness, manageability, urgency, growth
SRA = Society for Risk Analysis
STC = Science Technology Center
TFQCDM = Task Force on Quality Control of Disaster Management
UNHDA = United Nations Department of Humanitarian Affairs
UNISDR = United Nations International Strategy for Disaster Reduction
WADEM = World Association for Disaster and Emergency Medicine
WHO = World Health Organization
US = United States

Abstract

This article considers the critical roles of risk and risk assessment in the management of health emergencies and disasters. The Task Force on Quality Control of Disaster Management (TFQCDM) has defined risk as the "objective (mathematical) or subjective (inductive) probability that something negative will occur (happen)". Risks with the greatest relevance to health emergency management include: (1) the probability that a health hazard exists or will occur; (2) the probability that the hazard will become an event; (3) the probability that the event will lead to health damage; and (4) the probability that the health damage will lead to a health disaster. The overall risk of a health disaster is the product of these four probabilities.

Risk assessments are the tools that help systems at risk—healthcare organizations, communities, regions, states, and countries—transform their visceral reactions to threats into rational strategies for risk reduction. Type I errors in risk assessment occur when situations are predicted that do not occur (risk is overestimated). Type II errors in risk assessment occur when situations are not predicted that do occur (risk is underestimated). Both types of error may have serious, even lethal, consequences.

Errors in risk assessment may be reduced through strategies that optimize risk assessment, including the: (1) adoption of the TFQCDM definition of risk and other terms; (2) specification of the system at risk and situations of interest (hazard, event, damage, and health disaster); (3) adoption of a best practice approach to risk assessment methodology; (4) assembly of the requisite range of expert participants and information; (5) adoption of an evidence-based approach to using information; (6) exclusion of biased, irrelevant, and obsolete information; and (7) complete characterizations of any underlying fault and event trees.

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Introduction

The risk for health emergencies and disasters has occupied center stage in public fears in many countries in recent years. Depending on perceived levels of risk, policies are established, actions are prioritized, responses are dimensioned, funding is allocated, and resources are consumed. Risk assessment is the tool that helps systems at risk—healthcare organizations, communities, regions, states, and countries—transform their visceral reactions to threats into rational strategies for risk reduction.

Despite the primacy of risk assessment in health emergency management, little has been published on this topic in the medical literature.[1–8] This article considers the critical roles of risk and risk assessments in health emergency management. Risk and risk assessments are described, errors in risk assessments are identified, barriers to risk assessments are reviewed, and strategies for optimizing the risk-assessment process are suggested, based in large part on definitions put forth by the Task Force on Quality Control of Disaster Management (TFQCDM) of the World Association of Disaster and Emergency Medicine in the recently published *Health Disaster Management; Guidelines for Evaluation and Research in the Utstein Style.*[8] The TFQCDM initiative represents the only attempt to date to define basic terms in health emergency management in the Utstein Style through an international consensus process.

Risk

What is risk?

A staggering number of different definitions of risk—qualitative and quantitative—have been used in health emergency management and related disciplines in recent years (Tables 1 and 2).[1,8,9–22] Compounding the confusion, risk is used as a modifier in numerous other terms, such as risk analysis, risk characterization, risk communication, risk factor, risk management, and risk reduction. As a result, risk may be one of the most elusive concepts in health emergency management. In order to remedy this situation, the TFQCDM recently defined risk in the Utstein Style as "the objective (mathematical) or subjective (inductive) probability that something negative will occur (happen)".[8] This definition of risk has several important implications for health emergency management:

1. Risk is the probability that a situation will occur. For example, the risk of a hazard is the probability that a hazard will occur. The risk of a disaster is the probability that a disaster will manifest as an event. The risk of damage is the probability that damage will occur from the impact of of an event. Accordingly, when thinking about the risk of a given situation, it is helpful to mentally substitute the phrase "probability of occurrence" or "probability that a situation will occur" for the word, "risk".
2. Risk always has a negative connotation. Although risk is the probability that a situation will occur, the situation always is something undesirable or unwelcome. For example, one speaks about the risk of death, not the risk of survival; the risk of damage, not the risk of benefit; and the risk for financial loss, not the risk for profit. From the perspective of health emergency management, risk relates to the probability that a situation will occur with the potential to adversely affect the health of a population, such as a hazard, an event, damage, or a disaster.
3. Risk may be applied to a range of adverse situations. As a result, separate risks exist for: (1) the existence of a hazard; (2) the transformation of a hazard into an event; (3) the transformation of an event into damage; and (4) the transformation of damage into a health disaster. The Utstein Style definitions of these and other key terms in health emergency management are shown in Table 3.[8] Because risk may be used to characterize the probabilities of many different types of situations, it is essential to specify the situation of interest when using the word "risk". The risks with the greatest relevance to health emergency management include: (1) the risk or probability that a hazard will occur or already exists (P_H); (2) the risk or probability that a hazard will become an event (P_{HE}); (3) the risk or probability that an event will lead to health damage (P_{ED}); and (4) the risk or probability that damage will lead to a health disaster (P_{DD}); and (5) the overall risk or probability that a health disaster will occur ($P_{DISASTER}$). This multidimensionality of risk adds another layer of complexity to the use of the word risk in health emergency management.
4. Risk may have an objective or a subjective basis. While the determination of risk aspires to be a scientific process that depends on the systematic identification, collection, measurement, and interpretation of evidence, it necessarily includes (and, at times, may be overshadowed by) a political component that depends on the opinions and values of its participants.

Source	Definition of risk
American Society of Healthcare Engineering (ASHE)[9]	Potential impact that any given hazard may have on the organization
Department for International Development (DFID)[10]	Factor that could adversely affect the outcome of an activity or intervention
Emergency Management Australia (EMA)[11]	A concept used to describe the likelihood of harmful consequences arising from the interaction of hazards, communities, and the environment
Federal Emergency Management Agency (FEMA)[12]	The probability that an event will occur and the consequences of its occurrence
National Research Council (NRC)[13]	Concept used to give meaning to things, forces, or circumstances that pose danger to people or to what they value
Society for Risk Analysis[14]	The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment
United Nations Department of Humanitarian Affairs (UN-DHA)[15]	Expected losses (of lives, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period
United Nations/ International Strategy for Disaster Reduction (UN/ISDR)[16]	Probability of harmful consequences or expected losses resulting from interactions between natural or human induced hazards and vulnerable/ capable populations

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Table 1—Selected qualitative definitions of risk

Source	Definition of risk	Terms
UN-DHA[15] UN/ISDR[16]	$R = (H)(V)$	H = Hazard V = Vulnerability
World Health Organization[17]	$R = (x)(y)$	x = Probability of an event occurring y = Probability of various possible consequences
Zilinskas[18]	$R = (H)(E)$	H = Hazard or harm an agent will cause E = Exposure or what population will be exposed to the agent, at what concentration, and for how long
Misra[19]	$R = (C)(T)(Cm)(S)$	C = Chance T = Toxicity Cm = Concentration S = Time
Shook[20]	$R = (H)(V)/(P)$	H = Threatening event that could cause loss of life or damage to property or the environment V = Susceptibility of vulnerable elements, such as human populations P = Level or degree of planning for and control of hazardous events and vulnerable elements
Arnold[1] Noson[21]	$R = (H)(V)/(M)$	H = Hazard or phenomena that cause harm to human populations V = Vulnerability or susceptibility of human populations to hazards M = Manageability or ability of humans to reduce hazards or vulnerability
TFQCDM[22]	$P_D = f\,(H_N + H_M)(R_H)(V_N + a_1 + a_2 + b_1 + b_2)$	P_D = Probability that event will inflict damage on the society and/or the environment at risk H_N = Hazard dictated by nature H_M = Hazard dictated by man R_H = Probability (risk) that hazard will be converted into an event V_N = Resultant vulnerability as dictated by nature a_1 = Vulnerability augmentation a_2 = Vulnerability mitigation b_1 = Counter-productive disaster response b_2 = Productive disaster response

Table 2—Selected quantitative definitions of risk (R = Risk)

Term	Definition
Hazard	Anything that may pose a danger; a natural or human-made phenomenon or a mixture of both that has the potential to adversely affect human health, property, activity, and/or the environment
Event	An occurrence that has the potential to affect living beings and/or their environment; a realization of a hazard
Damage	The negative result from the impact of an event
Health disaster	A precipitous or gradual decline in the overall health status of a community for which the community is unable to cope without outside assstance
Vulnerability	The susceptibility of the population or the environment to the nature of an event; the susceptibility of an individual or population to injury or contagion
Manage	Organize, regulate, be in charge of; succeed in achieving

Table 3—Other Task Force on Quality Control of Disaster Management (TFQCDM) definitions in health emergency management[8]

Term	Source				
	DFID 10	*EMA* 17,24a	*FEMA* 17,24	*GAO* 28	*Kaiser* 29
Probability of hazard or event occurrence	X		X	X	X
History – previous occurrence of hazard or event			X		
Severity of hazard consequences	X	X		X	
Human impact					X[b]
Extent – maximum area of community affected			X		
Growth – ability of hazard to grow if nothing is done		X			
Vulnerability of people			X		
Vulnerability of property			X		
Manageability		X			
Preparedness					X
Urgency – need to urgently prepare		X			
Response					X[c]

Table 4—Terms in selected risk assessment matrices ([a]Called the Seriousness, Manageability, Urgency, and Growth (SMUG) hazard priority system; [b]Also has terms for property impact and business impact; [c]Includes separate terms for internal and external response)

Barrier	Strategy for optimization*
Definitions of risk, risk assessment, hazard, event, damage, and disaster are unclear	Adopt TFQCDM definitions Substitute “probability of occurrence” for “risk”
System at risk is unclear	Specify and demarcate the system at risk
Time frame of risk assessment is unclear	Specify time frame of risk assessment (e.g., one year)
Hazard is unclear	Identify and characterize hazard of interest
Event is unclear	Identify and characterize event of interest
Damage is irrelevant to health emergency management	Specify health damage as focus of risk assessment (vs. property, financial, environmental, or other type of damage)
Health damage is unclear	Identify, characterize, and quantify the adverse health consequences of event in the population at risk Take into account the vulnerability of the population at risk for the event
Health damage is irrelevant to health emergency management	Characterize health damage in terms of its burden on system at risk (e.g., number and type of injured or ill survivors seeking medical care at a hospital)
Disaster is irrelevant to health emergency management	Specify health disaster as focus of risk assessment (vs. financial, environmental, or other type of disaster)
Threshold for health damage to produce a health disaster is unclear	Identify, characterize, and quantify the capacity required for the system at risk to adequately manage the selected amount of health damage without external assistance Take into account the system at risk’s ability to manage the health damage (manageability)

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Table 5—Conceptual barriers to risk assessment and strategies for optimization (*Before the risk assessment begins)

Type	Barrier	Strategy for optimization
Logistical	Insufficient resources are available to support risk assessment (e.g., funding, material resources, personnel, information, or time)	Identify and assemble of required resources *a priori* Provide adequate time to perform risk assessment
Operational	No gold standard for risk assessment methodology exists	Select risk assessment methodology based on “best practice” considerations (Table 8)
	Participants have a narrow range of expertise	Select participants with requisite range of expertise
	Participants have personal bias	Identify potential bias *a priori* Select participants with range of values, beliefs, and opinions
	Participants with conflicts of interest regarding outcomes of risk assessment	Identify potential conflicts *a priori* Exclude participants with potential conflicts of interest
	Information is of low quality	Identify highest quality information available via an evidence-based approach
	Information is not available	Use best available search methodology Use reasonable default values when information is not available
	Information is biased	Use information from sources with least potential for bias (i.e., peer-reviewed scientific literature)
	Information is irrelevant or outdated	Evaluate information according to relevance and timeliness Use information relevant to system at risk and situation of interest Use up-to-date information
	Fault tree and/or event tree is oversimplified	Completely describe fault tree and event tree Identify and collect all required information
	Participants disagree about results	Report dissenting opinions with results
	Risk characterization is not useable	Produce comprehensible, relevant, and timely risk characterization

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Table 6—Logistical and operational barriers to risk assessment and strategies for optimization

Furthermore, the quantitative definitions of risk shown in Table 2 have additional important implications for health emergency management:

5. Risk is multi-factorial. In particular, the risk or probability that something negative will occur is comprised of various component probabilities. For example, several of the definitions in Table 2 partition the risk into various component probabilities, such as the probability that a hazard will occur, the probability that an event will occur, and the probability that consequences will occur. The TFQCDM definition of "damage probability" comes closest to expressing the full multidimensionality of risk.[22]
6. Although no universally accepted mathematical operation links all of the terms in the risk calculus, multiplication is usually used to relate the various probabilities in the risk calculus (i.e., risk is usually characterized as the product of its component probabilities). In this manner, risk may be conceived to increase in direct proportion to the probabilities of occurrence of factors that increase risk and to decrease in inverse proportion to the probabilities of occurrence of factors that reduce risk.
7. Risk increases with vulnerability (i.e., the risk of a health disaster increases as the probability of the vulnerability of the population at risk (P_{AR}) increases).[8] In particular, the probability that an event will lead to health damage (P_{ED}) depends on the probability that the P_{AR} will be vulnerable to the event.
8. Risk decreases with manageability (i.e., the risk of a health disaster increases as the probability of its manageability decreases).[8] More specifically, the probability that health damage will lead to a health disaster (P_{DD}) depends on the probability that this damage will not be managed adequately by the system at risk without external assistance.

Risk of a health disaster

A key question in health emergency management is: "What is the risk that a given health disaster will occur?" The overall risk or probability that a given health disaster will occur ($P_{\text{HEALTH DISASTER}}$) is the product of these four probabilities:

$$P_{\text{HEALTH DISASTER}} = P_H \text{ x } P_{HE} \text{ x } P_{ED} \text{ x } P_{DD}$$

where: P_H = probability of the existance of a hazard; P_{HE} = probability that a hazard will produce an event; P_{ED} = probability that an event will produce damage; and P_{DD} = probability that the damage that does occur will result in a disaster.

To illustrate how this equation may be applied, first consider the risk of an earthquake-related health disaster in a given community. In this case, the probability that an earthquake-related health disaster will occur depends on: (1) the probability that an earthquake fault exists in or near the community (P_H); (2) the probability that an earthquake will occur within the time frame of the risk assessment (P_{HE}); (3) the probability that the earthquake will cause a threshold amount of injury or illness in the population at risk (P_{ED}); and (4) the probability that the amount of illness or injury in the population at risk (demand for health services) will exceed the ability of the community to provide health services without external assistance (P_{DD}).

As a second example, consider the risk of a pandemic influenza health disaster in the same community. In this case, the probability that a pandemic influenza health disaster will occur depends on: (1) the probability that a strain of influenza virus of sufficient virulence already exists or will occur within the time-frame of the risk assessment (P_H); (2) the probability that this virus will cause infection in the population at risk within the time frame (P_{HE}); (3) the probability that infection will cause a threshold amount of illness in the population at risk (P_{ED}); and (4) the probability that the resulting demand for health services will exceed the community's ability to provide those services without external assistance (P_{DD}).

Risk Assessment

What is risk assessment?

Like the many definitions of risk, a myriad of approaches to risk assessment exist in health emergency management and related disciplines (Table 4 and Appendix A).[10,17,23–29] Adding to the confusion, risk assessment also is known by a variety of names, including risk analysis, hazard analysis, hazard-vulnerability analysis, threat assessment, and vulnerability assessment. To help clarify this situation, the TFQCDM defined risk assessment as the "prediction and estimation of risk".[8] Accordingly, the overall goal of risk assessment is to accurately predict and estimate risk in order to provide risk managers with a rational basis for risk reduction. Although most risk assessment methodologies are based on a logical succession of conceptual, logistical, and operational steps, they vary substantially in terms of which steps they incorporate and how each step is performed (Table 4 and Appendix A).

Risk assessment matrices

The penultimate step in risk assessment is the determination of the total estimated or assessed risk. Risk assessment matrices are a popular technique for estimating risk (Table 4). Two commonly used terms are: (1) the probability of the hazard occurrence; and (2) the severity of the hazard consequences. Individual terms usually are assigned categorical scores (e.g., low, medium, or high) or quantitative scores (e.g., 1–4) and then multiplied to generate a total estimated risk, which usually is expressed qualitatively (e.g., low to extremely high). For example, a hazard with a high probability of occurring or a large consequence is assigned a "high" risk. Risk assessment matrices have a number of limitations, which are described below.

Risk characterization

The last step in risk assessment is risk characterization. Risk characterization is the process of summarizing or translating the technical results of risk assessment into a form that is understandable by risk managers. The goal of risk characterization is to provide descriptions of risk, which are not only accurate, but actually can be used in the risk management process. Risk assessment matrices are popular because they provide results that are easily understood by risk managers with non-technical backgrounds. In addition, risk assessment matrices automatically prioritize results for action according to the practical goals of risk management (i.e., high risk estimates translate into high priority for risk reduction). Disasters also may be prioritized for risk management through a comparison of estimated risk with pre-established risk criteria available in published risk tables.[17] For example, the annual or lifetime odds of death due to specific health disasters may be compared to the odds of death due to a variety of unintentional and intentional, injury-producing events.[30]

Risk Management

The TFQCDM defines risk management as "human actions that are directed towards modification of the probability that a hazard will be converted into an event and eventually into a disaster".[8] While risk assessment leads to an understanding of risk, risk management leads to actions that ultimately result in risk reduction or in some cases, risk augmentation.

Errors in Risk Assessment

A critical step in risk assessment is the prediction that something will occur. In health emergency management, predictions are accurate when they correlate with what actually occurs, including predictions that: (1) a hazard will occur; (2) an event will occur; (3) health damage will occur; and (4) a health disaster will occur. The ultimate goal of prediction in risk assessment is to predict a situation that actually occurs (true positive) and to not predict those that do not (true negative). The prediction of any situation, from a typhoon to an outbreak of the severe acute respiratroy syndrome (SARS), is limited by two types of uncertainty: (1) aleatory uncertainty (based on chance); and (2) epistemic uncertainty (based on an incomplete knowledge of the processes that influence events).[31,32] Because some uncertainty in prediction is unavoidable, predictions are framed as estimates of the probabilities that a situation will occur.

Type I errors of risk assessment

A common error is the prediction of a situation that does not occur (false positive or type I error of prediction). Because risk assessment depends on prediction, type I errors in prediction may lead to an over-estimation of risk (type I error in risk assessment).

Type I errors of risk assessment have a number of serious tangible and intangible consequences. A major tangible consequence is the unintended injury or illness that occurs when prophylactic measures are applied to populations perceived to be at risk. For example, the prediction that Iraq would attack Israel with chemical weapons during the First Gulf War led to the widespread use of gas masks by the Israeli civilian population. The unintended consequence was that eight Israeli civilians were suffocated during the First Gulf War through the improper use of gas masks.[33] In early 2003, United States (US) public health officials launched an aggressive campaign to vaccinate first responders and front-line healthcare workers against smallpox, based on the prediction that an intentional smallpox release was imminent. The unintended consequence was that 21 US civilian smallpox vaccinees developed myocarditis or pericarditis and another developed post-vaccinial encephalitis in early 2003.[34–37] Another serious consequence is the diversion of limited resources away from public health problems, which may be more deserving, such as everyday motor vehicle collisions, gun violence, communicable disease, or environmental degradation.[38–41] In addition, the overestimation of the risk of terrorism-related disasters may have a number of intangible consequences, including loss of various civil liberties, loss of freedom to travel, and a reduction in the quality of life.[42–44]

Type II errors of risk assessment

The opposite type of error in prediction is the failure to predict a situation that does occur (false negative or type II error of prediction). Type II errors in prediction typically lead to an under-estimation of risk (type II error of risk assessment).

Type II errors of risk assessment also have serious tangible and intangible consequences. The most important tangible consequence is the death, injury, and property destruction that ensues when events, damage, or disasters are falsely predicted not to occur. For example, a key factor in the 11 September 2001 terrorist attacks on New York City and Washington, DC was likely to have been the underestimation of the risk of airport security breeches at several critical points (as evidenced by dramatic changes in international airport security after this event).[45] A few weeks later, a chronic under-estimation of the probability that low technology delivery systems would be used by terrorists for the dissemination of biological agents was likely to have been a factor in the deaths and injury resulting from the anthrax letter attacks in the eastern US. More recently, an under-estimation of the probability that a tsunami would occur in the Indian Ocean led to the lack of early warning systems in the affected countries, producing one of the greatest health disasters of the last 50 years.[46] The under-estimation of risk also has many intangible consequences, including economic loss, social disruption, and environmental damage.

Reducing Errors in Risk Assessment

Errors in risk assessment may be reduced in two major ways. The first approach is to change the threshold criteria for prediction (e.g., by increasing or decreasing the requisite information needed to make a prediction).[31] When the threshold criteria are reduced, the number of false positive predictions increases. However, because type I and type II errors in risk assessment inevitably are complementary (e.g., when false positives increase, false negatives decrease, and vice versa), decreasing the threshold criteria simultaneously decreases the number of false negative predictions. In a similar manner, when the threshold criteria are increased,

Level	Evidence Level	Definition
1a	Event case series with homogeneity	Two or more documented examples of events with homogeneous characteristics
1b	Event case series with heterogeneity	Two or more documented examples of events with heterogeneous characteristics
1c	Event case report	One documented example of an event
2a	Extrapolation by consensus group of experts	Reasonable extrapolation from existing data or data gathered for other purposes in support of future occurrence of a disaster by a consensus group of experts
2b	Extrapolation by group of experts	Reasonable extrapolation from existing data or data gathered for other purposes in support of future occurrence of a disaster by a group of experts
2c	Extrapolation by an individual expert	Reasonable extrapolation from existing data or data gathered for other purposes in support of future occurrence of a disaster by an individual expert
3a	Rational conjecture by consensus group of experts	Common sense or logic in support of future occurrence of a disaster by a consensus group of experts
3b	Rational conjecture by group of experts	Common sense or logic in support of future occurrence of a disaster by a group of experts
3c	Rational conjecture by an individual expert	Common sense or logic in support of future occurrence of a disaster by an individual expert
-	Scenario	Imaginary example of a disaster = no evidence

Table 7—Suggested levels of predictive evidence for events

the number of false negative predictions increases, while the number of false positive predictions decreases. This trade-off between false positives and false negatives is an intrinsic feature of risk assessments.

A more satisfactory approach to reducing errors in risk assessment is to increase the epistemic certainty of predictions through strategies that optimize the risk-assessment process. Predictions that more accurately assign all potential situations to true positive and true negative categories will generate lower numbers of false positives and false negatives. Thus, risk assessments that produce a more accurate understanding of the processes affecting the probabilities that situations will occur will reduce both types of errors.

Multiple barriers exist for the accurate estimation of probabilities in risk assessments at the conceptual, logistical, and operational levels (Tables 5–6). Strategies for overcoming these barriers and reducing errors in risk assessments are described.

Conceptual strategies

A key conceptual strategy for increasing epistemic certainty in risk assessment is to use a definition of risk and other terms that the entire risk assessment working group agrees with. Because the TFQCDM developed its Utstein Style definitions through an international consensus process, its definitions currently are the best candidates for universal harmonization in health emergency management.[8]

In addition, the system at risk (e.g., healthcare organization, community, region, state, or country) should be specified before the risk assessment begins. Working groups usually demarcate systems at risk according to their geopolitical boundaries, but may consider other relevant factors, such as demographic, economic, infrastructural, cultural, or environmental characteristics. Clarifying the system at risk is important, because the probability that a situation will occur may vary from location to location. Local risk assessments need not be redundant, since many individual components of the risk calculus are widely shared. The time frame of the risk assessment also should be specified *a priori* (e.g., a one-year time frame is commonly used).

Situations of interest also should be specified before the process begins, because unspecified or vaguely-defined situations may mean different things to different risk assessors. Hazards should be identified and characterized according to their type, magnitude, physical properties, location, extent, onset, and duration (this is important particularly for chemical, biological, radiological, and nuclear hazards). Events of interest should be identified and characterized according to their type, magnitude, location, extent, onset, and duration. The damage of interest should be identified and characterized. Health damage should be clearly distinguished from property, financial, environmental, or other types of damage. The type of health damage with the most relevance to health emergency management should be identified. For example, numbers of injured or ill requiring medical care at hospitals are more relevant to hospital emergency management than are the numbers of dead. At the same time, the P_{AR} should be identified and the probability of its *a priori* vulnerability to this damage should be estimated. The time course of health damage also should be characterized. Similarly, health disasters should be distinguished from financial, environmental, or other types of disasters, and the probability of the manageability of the given health disaster by the system at risk should be estimated. Defining these situations of interest enables the working group to focus its efforts on those probabilities of occurrence that are most relevant to its needs. At the outset of a risk assessment, the working group may decide to restrict its efforts to a limited number of situations of interest, because it would be impractical to address them all. Situations perceived as having extremely low likelihood of occurring or extremely low likelihood of causing some threshold amount of health damage may be reasonably dismissed without performing a full assessment.

Logistical strategies

A key logistical strategy for optimizing risk assessment is to identify, locate, and assemble all of the resources required to conduct a risk assessment before the process begins.[17] Requisite resources include funding, material resources, persons (working group and experts), and time. While the need for facilities, equipment, and supplies may be relatively minor, the need for expert participants and information may be substantial in some risk assessments. The larger the system at risk or the larger (or more complex) the situation of interest, the more resources will be needed. Relevant technical areas of expertise in health disaster risk assessment may include biology, biostatistics, chemistry, criminal science, critical care, disaster medicine, earth sciences, emergency medicine, emergency management, engineering, epidemiology, forensics, infectious disease, law, law enforcement, laboratory medicine, meteorology, microbiology, military science, nuclear science, political science, psychology, public health, public policy, radiation health, radiation physics, sociology, toxicology, and trauma surgery. Communication systems and information technology also may be required to link expert participants and information together. Finally, all of these resources must be managed and coordinated during the risk-assessment process.

Operational strategies

Risk assessment methodology should be selected according to "best practice" considerations. While no gold standard for risk assessment methodology currently exists in health emergency management, the selection of a risk-assessment methodology should be guided by a number of important considerations (Table 8).[4,47] Despite their convenience, risk assessment matrices should be used with caution in risk assessment. Most risk assessment matrices have a number of limitations, including their: (1) dependence on inadequately defined definitions of risk; (2) inconsistent targeting of situations of interest (e.g., the SMUG hazard priority system targets the risk of "hazards", while the FEMA model targets the risk of "events"); (3) dependence on poorly defined terms (e.g., the "seriousness" of a hazard, the maximum "impact" of an event); (4) oversimplification of the number of terms that contribute to risk (e.g., most consider only a limited number of terms in their risk calculus); (5) subjective scoring systems (e.g., "high" or "low" may have different meanings to different risk assessors); and (6) scoring systems that fail to account for exponentially low or high values (e.g., all situations with a high probability of occurrence are lumped together even if they have exponentially different probabilities of occurrence).[17,24]

At the same time, a multidisciplinary coalition of participants should be identified and assembled to perform the risk assessment.[2] Epistemic certainty is enhanced when experts with the requisite spectrum of knowledge and skills find, appraise, and integrate information. Relevant areas of expertise include: (1) knowledge of the system at risk, including its ability to manage a given health disaster; (2) knowledge of the situations of interest, including technical knowledge concerning hazards and associated events, and clinical knowledge of health damage and the underlying vulnerability of the population at risk; and (3) knowledge of the risk-assessment process. Although risk assessment unavoidably includes a subjective component, participants should represent a range of insight, opinion, and values, with an aim to balancing extreme positions and partisanship. A consensus approach is desirable with some mechanism for reporting dissent with the results of risk assessment. Individuals with a potential conflict of interest in the outcome of a risk assessment should be cautiously incorporated into the risk-assessment process (if at all) and only with full disclosure of the conflict of interest. This includes participants with economic or political ties to organizations that stand to benefit when type I errors of risk assessment occur.

Another key operational strategy is the adoption of an evidence-based approach to information use. Borrowing from evidence-based medicine, evidence-based risk assessment involves "the conscientious, explicit and judicious use of current best evidence in making decisions".[48] Evidence-based risk assessment depends on how questions are asked, and how evidence is sought, evaluated, and integrated into the overall analysis. A key step in evidence-based risk assessment is the critical appraisal of the evidence that predicts whether or not a particular event will occur. A suggested hierarchy for the predictive evidence concerning events is in Table 9. At the bottom of this evidence-based hierarchy are scenarios or imaginary examples of events. Scenarios are tantamount to case reports that never have happened. Although scenarios may play a role in modeling theories or dramatizing specific issues, they provide no intrinsic evidence of the probability that an event will occur.

In addition, the evidence used in risk assessment should be acquired preferentially from sources with the least potential for bias, such as scientific peer-reviewed publications. Information from sources with a potential conflict of interest regarding how risk is estimated (e.g., media, government agencies) should be incorporated cautiously into the decision-making process.

The evidence used in risk assessments also should be evaluated according to its geographic, temporal, demographic, social, and cultural relevance. In general, events that took place more recently are more likely to be relevant to contemporary concerns than are events occurring in the remote past, while events that took place in locations that are geographically proximal are more likely to impact local risk than are events occurring in distant locations. For example, before the 2002 US anthrax letter attacks, the treated mortality rate for inhalational anthrax was reported to be 89% based on limited data published prior to 1979.[49] However, during the 2002 attacks, the treated mortality rate for inhalational anthrax was 45%.[50] It also is important to consider the influence of local healthcare environments when extrapolating evidence from one country to another. For example, the mortality rate in the 1995 Tokyo Subway sarin attack may not be transferable directly to North American or European communities, since Japanese paramedics at the time were unable to intubate victims or administer parenteral atropine.[51]

When information is not available to risk assessors, then the reasons for its unavailability should be sought. Information may not exist, information may not be identifiable, or access to information may be restricted due to government or proprietary control. If the underlying causes of information unavailability cannot be remedied, then it may be necessary to use reasonable default values in the risk assessment calculus.

Another key operational strategy for reducing errors in risk assessment is the description of the entire causal chain or fault tree that underlies the probability that a situation will occur.[17] Each micro-event or node in this causal chain not only is necessary for the situation to occur, but also represents a single point of failure, without which the situation will not occur. Once the causal chain is delineated, then all relevant evidence should be sought and integrated into the risk assessment, whether it tends to increase or reduce the probability that the situation will occur. A comprehensive approach increases epistemic certainty by incorporating all evidence relevant to each micro-event.[52] For example, the causal chain for infection of a target population (i.e., an event) following the intentional release of a biological agent by terrorists depends on multiple steps, ranging from the existence of terrorists and the biological agent to numerous technical steps related to the production, storage, and delivery of the agent (Table 9).[53,54] This type of fault tree enables risk assessors to go beyond the simple question of whether a terrorist group is likely to use a particular agent, and consider other variables, including political factors that may affect terrorist ideology, security factors that affect access, or environmental factors that affect exposure. The failure to consider all of the critical steps in the causal chain or include contradictory evidence represents a major source of error in risk assessment.[4] Similar considerations hold for the description of consequent or event trees.

Finally, risk assessment in health emergency management should lead to useable results. Risk characterizations that are incomprehensible, too vague, too detailed, incomplete, irrelevant, untimely, or obsolete have limited applicability to risk reduction. Ultimately, risk should be framed in straightforward practical terms that help risk managers prioritize the efforts of risk management.

Optimizing the Application of Risk Assessment

Accuracy is not the only goal of risk assessment in health emergency management. Ultimately, the products of risk assessment must be transferred to the real world of risk management. Two additional considerations for optimizing the application of risk assessment are described: (1) transparency; and (2) errors may occur.

Risk assessment in health emergency management should be transparent. In a transparent process, the methodology, working group, supporting evidence, and underlying assumptions are clearly identified. Any assumptions based on extrapolations or conjectures should be explicitly stated and any default values used to represent variables when information is unavailable should be revealed. Transparency helps users determine whether the results of risk assessment are accurate, credible, and relevant to their system at risk. Risk assessments from one system at risk that are perceived to be irrelevant by another create a predictable challenge to their application. For example, opaque risk assessments by non-civilian communities (e.g., military or intelligence agencies) are less likely to be accepted by civilian communities and vice versa.[4] Transparency also facilitates the application of components of a risk assessment by one working group to another, thereby helping other groups avoid "reinventing the wheel".

Finally, risk managers should anticipate that errors in risk assessment may occur. Because errors are inevitable, their impact may be reduced by strategies that buffer the consequences of overestimating or underestimating the probability that a hazard, event, damage, or disaster will occur. The principal strategy for buffering errors in risk assessment is the all-hazards approach to health emergency management, in which systems at risk maintain a threshold level of preparedness for all types of situations. In a similar manner, multiple-use strategies also buffer errors in risk assessment. Examples of multiple-use strategies include syndromic surveillance systems, which may be used for any type of infectious disease outbreak and decontamination systems, which may be used for multiple types of contaminants.

Conclusion

Risk assessment is the tool that helps communities and organizations at risk transform their visceral reactions to threats into rational strategies for risk reduction. Errors in risk assessment occur when risk is overestimated or underestimated. Although many challenges exist for risk assessment at the conceptual, logistical, and operational levels, errors in risk assessment are likely to be reduced through a number of strategies that optimize the risk assessment process.

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Component	Description	Source					
		Disaster Risk Management[23]	EMA[24]	FEMA[24]	GAO[25,26]	NRC[27]	WHO[17]
Hazard assessment	Identifies and describes hazards Also called threat assessment	X			X		
Hazard identification	Identifies hazards of interest		X	X		X	X
Hazard description	Describes hazards, including probabilistic estimates of their occurrence, intensity, extent, and duration		X	X			X
Process analysis	Analyzes process leading to an event	X					
Probability analysis	Analyzes underlying causes of an event Includes probabilistic estimates of occurrence of underlying causes of an event May include construction of a fault tree to describe relationship between event and its causes	X					
Hazard mapping	Maps hazards and their characteristics to geographic coordinates	X		X			
Consequence analysis	Analyzes tangible and intangible consequences of an event Includes probabilistic estimates of magnitude of consequences May include construction of an event tree to describe relationship between event and its effects			X			X
Dose-response assessment	Assesses relationship between dose of hazard and its effects					X	
Exposure assessment	Assesses potential exposure*	X				X	
Vulnerability assessment	Assesses vulnerability of system to an event Also identifies and quantifies special populations at risk	X	X	X	X		
Community description	Describes community or system at risk, including its geographic location		X	X			X
Criticality assessment	Assesses criticality of components of system impacted by an event				X		
Risk characterization	Characterizes risk in form relevant to risk management					X	
Risk aversion	Identifies minimum risk the system is willing to accept	X					
Public perception analysis	Analyzes public perception of risk	X					
Hazard prioritization	Prioritizes hazards for emergency management						X

Appendix A—Components of selected risk assessment methodologies (*exposure = (concentration) x (time); EMA = Emergency Management Agency; FEMA = Federal Emergency Management Agency; GAO = General Accounting Office; NRC = Nuclear Regulatory Commission; WHO = World Health Organization)

- Are the terms in the risk assessment methodology adequately defined?
- Is the methodology adequately specified and defined?
- Is the methodology based on objective data whenever possible?
- Does the subjective component of the methodology aim for consensus, with a system for measuring, recording, and incorporating dissent?
- Is the risk assessment calculus or scoring system adequately defined?
- Are the mathematical operations linking the various terms together adequately defined?
- Do the terms in the risk assessment calculus or scoring system include all terms that may influence the result?
- Are the terms in the risk assessment calculus or scoring system adequately defined?
- Are the terms in the risk assessment calculus or scoring system expressed as probabilistic estimates?
- Are default options for any terms in the risk assessment calculus adequately defined?
- Are the terms in the risk assessment calculus or scoring system quantitatively expressed?
- If a scoring system is used, are appropriate weights assigned to the various terms?
- If a scoring system is used, are scores assigned objectively?
- If a scoring system is used, are the scales of sufficient range to express exponentially high or low probabilities?
- If a scoring system is used, are default options for score assignments adequately defined and consistently applied?
- Is the intended result of risk assessment expressed quantitatively?
- Is the intended result of risk assessment expressed as a probabilistic estimate?
- Are the probabilistic estimates in risk assessment accompanied by a measure of uncertainty (e.g., as a range or with 95% confidence intervals)?
- Are the assumptions or default options in the risk assessment calculus transparent?
- Is the methodology validated?

Appendix B—Key considerations for the selection of a risk assessment methodology[4,47]

- Existence of terrorists or group likely to use biological agent
- Selection of raw biological agent by terrorist group
- Avoidance of detection and interdiction by law enforcement authorities at every step prior to release
- Avoidance of illness affecting terrorists which would prevent or mitigate release at every step prior to release
- Assumption of personal risk when no prophylaxis is available
- Possession of requisite financial resources to acquire raw biological agent in sufficient quantity and acquisition of raw biological agent in sufficient quantity OR possession of requisite natural specimen, facilities, technology, technical knowledge and skills, and financial resources to produce raw biological agent in sufficient quantity, and production of raw biological agent in sufficient quantity
- Testing of raw biological agent for viability
- Storage of raw biological agent
- Transport of raw biological agent
- Possession of requisite financial resources to acquire formulated biological agent and acquisition of formulated biological agent in sufficient quantity OR possession of requisite raw biological agent, facilities, technology, technical knowledge and skills, and financial resources to produce formulated biological agent in sufficient quantity, with production of formulated agent in sufficient quantity
- Storage of formulated biological agent
- Transport of formulated biological agent
- Selection of suitable delivery system
- Possession of requisite financial resources to acquire suitable delivery system and acquisition of suitable delivery system OR possession of requisite materials, facilities, technology, technical knowledge and skills, and financial resources to manufacture suitable delivery system, and manufacture of suitable delivery system
- Storage of delivery system
- Transport of delivery system
- Selection of suitable dispersal system[b]
- Possession of requisite financial resources to acquire suitable dispersal system and acquisition of suitable dispersal system OR possession of requisite materials, facilities, technology, technical knowledge and skills, and financial resources to manufacture suitable dispersal system, and manufacture of suitable dispersal system[a]
- Storage of dispersal system[b]
- Transport of dispersal system[b]
- Possession of requisite technical knowledge and skills to use delivery system
- Loading of formulated biological agent into delivery system
- Storage of loaded delivery system
- Transport of loaded delivery system
- Selection of target population
- Recognition of suitable environmental or meteorological conditions
- Deployment of formulated biological agent against target population
- Dispersal of formulated biological agent
- Exposure of target population to biological agent
- Susceptibility of target population to biological agent
- Infection of target population by biological agent

Appendix C—Elements in the fault tree[a] for infection of a target population following the intentional release of a biological agent by terrorists (after Rabkin)[53,54] ([a]Not every element is mandatory; [b]Delivery and dispersal systems may be combined (i.e., 2001 US anthrax letter attacks))