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Chemical, Biological, Radiological/Nuclear and Explosive Risk Assessment

An Analytical Hierarchy Approach

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Abstract

This paper describes the use of the Analytical Hierarchy Process to assess hypothetical risks of representative terrorist-initiated chemical, biological, radiological/nuclear and explosive hazard scenarios. A Multi-Attribute Decision Model was created to evaluate these representative scenarios according to their relative technical feasibility, impact and likelihood of occurrence in order to generate a shortlist of priorities. The model, which was created using the software tool Expert Choice 11, is described in detail. A sensitivity analysis on the data is performed to illustrate how changes in criteria weights can affect the results of the assessment. This paper can be used to assist the public security community in refining the tools, methods and approaches for risk assessment.

Résumé

Le présent article décrit l’utilisation du processus de hiérarchie analytique pour évaluer les risques hypothétiques de scénarios représentatifs de dangers chimiques, biologiques, radiologiques, nucléaires et explosifs exécutés par des terroristes. Un modèle de décision à attributs multiples a été créé pour évaluer ces scénarios représentatifs en fonction de leur faisabilité technique relative, de leur incidence et de la probabilité qu’ils se produisent afin de dresser une courte liste de priorités. Le modèle, qui a été créé à l’aide de l’outil logiciel Expert Choice 11, est décrit en détails. On effectue une analyse de sensibilité sur les données pour illustrer comment des changements dans la pondération des critères peut affecter les résultats de l’évaluation. Le présent article peut être utilisé pour aider la communauté de la sécurité publique à améliorer les outils, les méthodes et les techniques pour l’évaluation des risques.

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Table of contents

List of figures

List of tables

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1 Introduction

The prospect of terrorist-initiated attacks using chemical, biological, radiological/nuclear and explosive (CBRNE) materials is a concern for all levels of decision makers. CBRNE materials are “disruptive technologies” in that they enhance the ability of terrorists to execute high-risk, high payoff attacks. Most Western democracies, as a result of the open government and free market economies, are vulnerable to some form of terrorist attack. The use of CBRNE materials for terrorist purposes could trigger mass panic and have a disproportionate impact on the economy than the immediate effects of an event itself, turning seemingly minor instances into major societal catastrophes.

These concerns over terrorists’ use of CBRNE materials to achieve their aims was heightened by the Japanese cult Aum Shinrikyo’s 1995 use of Sarin gas in the Tokyo subway system. Since the September 11th, 2001 attacks on the World Trade Centre and subsequent anthrax letter attacks in the United States, there has been a growing concern about the continuing risk posed by CBRNE terrorism. However, the nature of the dangers and the risks posed by these letters was not exactly clear.[1] The combination of increasing availability of technology and expertise, as well as a recognized vulnerability to mass-casualty terrorism for certain terrorist organizations is demonstrated by the more recent terrorist attacks – the 1993 World Trade Centre Bombing; the 1995 bombing of the Murrah Building in Oklahoma City; the American embassy attacks in Tanzania and Kenya in 1998; the *U.S.S.* Cole, 2000; and the 2003 Ricin discovery in the United Kingdom.[2] Operations by Coalition Forces in the Middle East have also unearthed small-scale laboratories in Fallujah, Iraq containing chemicals and equipment necessary to produce rudimentary chemical weapons capable of creating poisonous gases and explosives used in improvised explosive devices (IEDs).[3]

Clearly, the recent trends and threats raise several significant issues for decision makers and pose a challenge to the counter terrorism community in evaluating the risks. As one author noted, “a particularly startling feature of the September 11 attacks was the dramatic disruption of the activities of the world’s most powerful nation by a handful of determined individuals.”[4] This suggests that current analytical methods need to be supplemented by vulnerability and risk-based analyses that characterize all forms of physical, information and socio-economic hazards to which individuals are vulnerable. In light of the potential consequences and increasing likelihood of encountering a CBRNE event, there is enormous value in being able to assess the risks posed by the various hazard scenarios in a deliberate, systematic and rigorous manner.

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[1] Bill Kournikakis et. al., Risk Assessment of Anthrax Threat Letters, TR-2001-48 Defence Research Establishment Suffield, 2001.

[2] “Chemical, Biological, Radiological and Nuclear Terrorism: The Threat According to the Current Unclassified Literature,” Center for Counterproliferation Research, National Defence University, May 2001, p. 1.

[3] See “Fallujah Update: Insurgent Chemical/Explosive Weapons Laboratory,” Multinational Force – Iraq, 26 November 2004, Combined Press Information Centre.

[4] Howard Kunreuther, “Risk Analysis and Risk Management in an Uncertain World,” *Risk Analysis* Vol. 22, No. 4., (2002), p. 661.

2 Risk Assessment & The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) can be classified as a Multi-Attribute Decision Model (MADM). According to Yoon and Hhwang, Multi-Attribute Decision Making refers to "making preference decisions (e.g. evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting attributes."[5] A multi-attribute problem exists when one or more of the following characteristics exist: there are a large numbers of attributes or variables, the scoring of the options of these attributes is unclear, multiple stakeholders participate in the estimation process and there is uncertainty about the outcomes. Applications of this analytical method include developing priorities for weapon concepts, prioritizing different weapons mixes in force structure analysis, command decision criteria, procurement bid criteria and evaluation, research and development selection criteria and risk assessment.[6]

The traditional steps of risk assessment are normally described in mathematical terms, with risk (R) being a function of the probability (P) of an event happening and consequences (C) of an event should it happen:

$$R=f_R\,(P, C)$$ [7]

Risk assessment has been described as a process that can be used to "identify ways to reduce risks and liabilities, and determine which risks are acceptable or unacceptable. It looks at assets, threats, vulnerabilities and safeguards, and provides a roadmap of how these items affect each other. The assessment should also provide details about how establishing and improving safeguards will affect the amount of risk for each type of incident."[8] The identification, evaluation and prioritization of risks facilitates the ability of decision makers to differentiate which risks are most important and must be mitigated, which risks are not important and can be treated as discretionary, and which risks fall into the "grey zone" and require some form of consideration for remedial action. The use of a MADM allows decision makers to identify and focus attention on the key issues that matter. This, one group of authors argue, is essential for

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[5] K. Paul Yoon and Ching-Lai Hwang, *Multi-Attribute Decision Making: An* Introduction (SeriesSage University Series on Quantitative Applications in the Social Sciences, 07-104, Thousand Oaks, CA, p. 2.

[6] Mike Bathe, "The Analysis of Subjective Results," Applied Mathematics and Operational Research, powerpoint presentation, Cranfield University, Shrivenham, United Kingdom, 2006.

[7] Robert G. Ross, "Terrorism, Risk and the Public Policy Agenda," Department of Homeland Security, Science and Technology Directorate, draft paper.

[8] Tom O'Brian, "Catastrophe Modeling for Corporate Risk Managers," *Risk Management*; May 2—4; 51, 5., p. 29.

decisions regarding the allocation of resources to deal with or reduce either the impact or probability of occurrence of perceived risks.[9]

The AHP, developed at the Wharton School of Business by Thomas Saaty, allows decision makers to structure a complex problem in a hierarchical model that depicts the relationships of the goal, criteria, sub-criteria and alternatives. The AHP provides decision makers with a structure to organize and evaluate the importance of various objectives and the preferences of alternative solutions to a decision. Typically, this is done through matrices and weighting scales that allow decision makers to rate and compare the various alternatives against competing criteria. Uncertainties and other factors can be included in the decision support models. AHP facilitates the ability of decision makers to apply data, experience, intuition and insight in a logical and structured way.[10]

Expert Choice software is a multi-objective decision support tool based on the AHP technique. Expert Choice provides for the synthesis of expert opinion, and can be useful for forecasting, assessing risk and uncertainty, and deriving probability distributions. It is argued by Expert Choice that "organizations that cannot properly assess risk are unprepared to plan for and react to uncertainty due to the combination of tangible and intangible information involved in risk assessment…[the analytical hierarchy process] overcomes the hurdles of managing risk using a unique process that guides decision makers to incorporate all relevant information to advance the organization towards its goals."[11] Expert Choice helps participants define criteria, sub-criteria and alternatives and organize them into a structured hierarchy. Once participants compare and prioritize the relative importance of the decision objectives, Expert Choice is then used to synthesize the judgements for analysis and recommendations.

The main steps used in AHP and Expert Choice are depicted in Figure 1. They include: (1) defining the risks, (2) establishing criteria and evaluating the risks to determine priorities, (3) synthesize, and (4) sensitivity analysis and validation.

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[9] James S. Finan and W.D. Macnamara, "An Illustrative Canadian Strategic Risk Assessment," *Canadian Military Journal* Autumn 2001, p. 29.

[10] Ernest Forman and Mary Ann Selly, *Decision By Objectives*, p. 43.

[11] www.expertchoice.com/applications/projectriskmanagement.htm

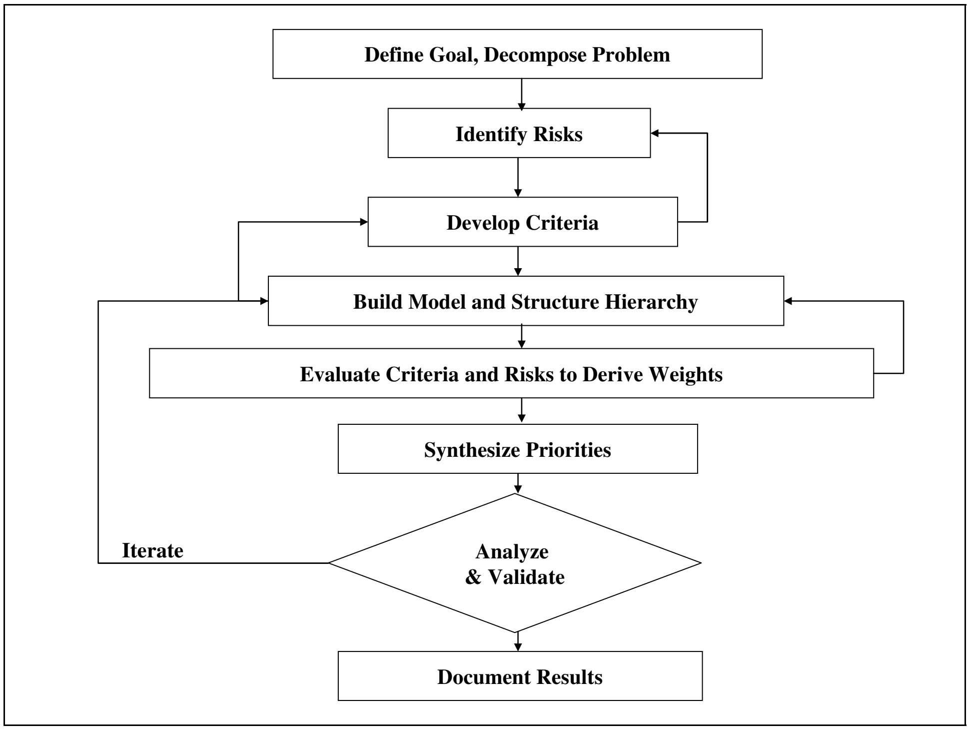

Figure 1: Flow Chart – Decision Process

After the goal is defined, a set of criteria are identified against which the possible choices are evaluated. Information is decomposed into a hierarchy and then synthesized to determine the relative ranking of the alternatives. Both qualitative and quantitative criteria can be compared using judgements to derive weights and priorities. The alternatives are then compared in relation to the criteria using the rating scales that have been developed on the formula grid. Feedback loops are necessary components to refining the results and validating the risk assessment process.

2.1 The Analytical Hierarchy Process Methodology

One of the basic problems in decision modeling is establishing weights or priorities for the alternatives being considered. The AHP is one technique, among other MADM approaches, that may be applied in a risk assessment to establish priorities.[12] AHP enables decision-makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. It does this through deriving "ratio scale weights," to determine the most important risks according to their rank. A mathematical definition of a ratio scale is: admits multiplication by a constant, or is

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[12] For a good discussion of different techniques, see Edward J. Emond, *Developments in the Analysis of Rankings in Operational Research*, DRDC CORA TR 2006-37; DRDC – Centre for Operational Research & Analysis.

invariant under the transformation Y = a X. A ratio scale is said to have a true ‘zero’.[13] The AHP, through the Expert Choice software package, has the added advantage of being able to take expert judgements (subjective judgements by experienced professionals) of the scenarios and convert them into weights through votes. This approach avoids the potential need to engage in lengthy discussions concerning the weights of the criteria, especially if disagreements may be immaterial.

The essence of the AHP is the use of pairwise comparisons as a way of systematically estimating competing priorities. Expert Choice uses a nine point scale (see Table 1) to make the comparisons. The scale consists of subjective judgements that correspond to numerical values (1-9).

Table 1: Expert Choice Pairwise Comparison Scale

Numerical Value	Verbal Scale	Explanation
1.0	Equal importance of both elements	Two elements contribute equally
3.0	Moderate importance of one element over another	Experience and judgement favour one element over another
5.0	Strong importance of one element over another	An element is strongly favoured
7.0	Very strong importance of one element over another	An element is very strongly dominant
9.0	Extreme importance of one element over another	An element is favoured by at least an order of magnitude
2.0, 4.0, 6.0, 8.0	Intermediate values	Used to compromise between two judgements

Each element in the model – objectives, criteria and alternatives – is evaluated on a pairwise basis. This process is repeated for Levels 2 and 3 of the model so that the entire family of criteria is compared against one another and converted into a set of weights (see Figure 2). Each alternative (Level 4) is then compared in a pairwise fashion to each other and in relation to the objective or criterion to produce a set of weights based on an aggregate value function. Comparison modes such as importance, preference or likelihood can be made, depending on the purpose of the model. This results in an overall priority ranking of the alternatives.

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[13] “If we have ratio scale data, then the ratio between two objects with values of 100 and 50 is equivalent to the ratio of two objects with values of 6 and 3. A ratio scale is often defined as one having a true zero point. However, for our purposes, it is easier to think of a ratio scale as one for which equivalent ratios are considered equal.”, Forman, pp. 32, 42-43.

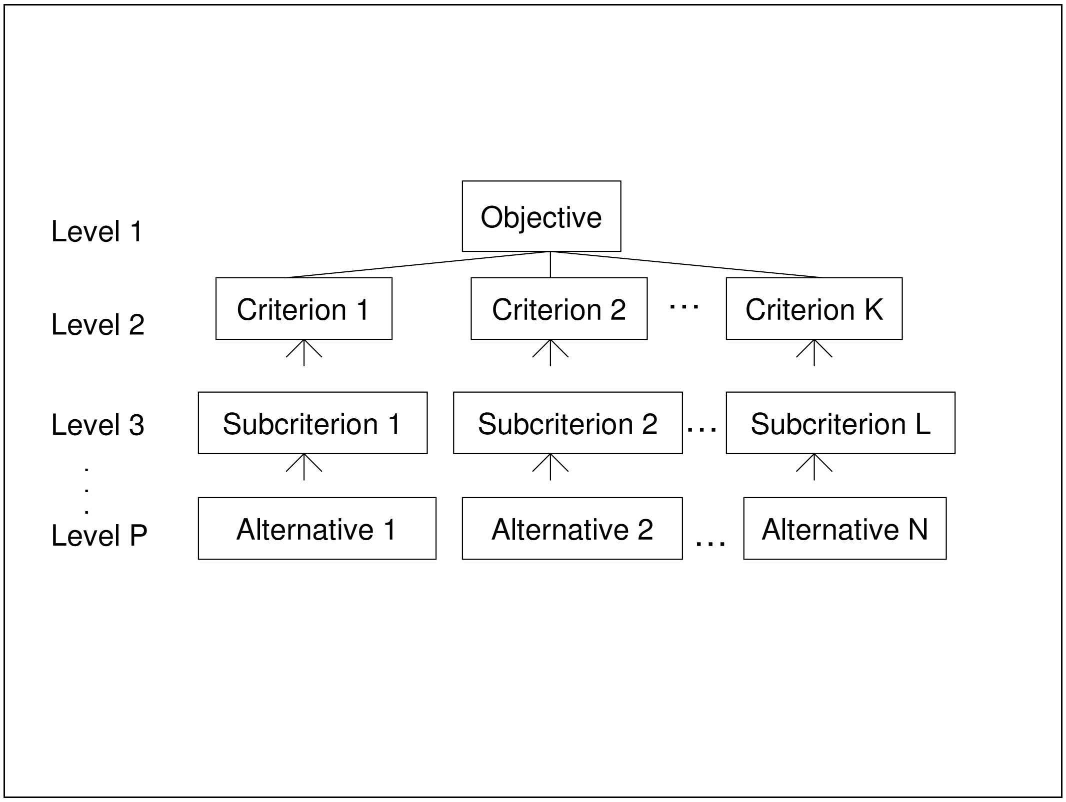

Figure 2: Analytical Hierarchy Process

As mentioned earlier, the process behind the AHP that is used to derive the weights is expressed in terms of a pairwise comparison matrix (PCM). The PCM (see Table 2) is based on obtaining reciprocating values *Wi* (relative values as opposed to weights). Row values above the major diagonal are inverted in their respective columns to complete the AHP matrix. For instance, the values in row A are inverted in column A. The columns are summed to produce values. These values are then normalized by dividing the row values by the total for each column. Weightings for the criteria are derived by averaging the normalized values for each row in the table. This process is carried out to evaluate the alternatives against each criterion. The final rankings are taken by multiplying the weightings for the alternatives against the criteria and then adding the product. Using this technique, rankings are generated for each element in the hierarchy, with the sum of the ranks equal to 1. The final weights for the alternatives are a function of their relative rank against the criteria.

Table 2: Pairwise Comparison Matrix

	A	B	C	D	SUM
A	*Wa/Wa*	*Wa/Wb*	*Wa/Wc*	*Wa/Wd*	*WaS*
B	*Wb/Wa*	*Wb/Wb*	*Wb/Wc*	*Wb/Wd*	*WbS*
C	*Wc/Wa*	*Wc/Wb*	*Wc/Wc*	*Wc/Wd*	*WcS*
D	*Wd/Wa*	*Wd/Wb*	*Wd/Wc*	*Wd/Wd*	*WdS*
				Total	S = 1

One of the advantages of estimating the weights using AHP is that a measure of consistency is used when making paired comparisons. An inconsistency ratio is calculated for each set of judgements. For example, if A > B, and B > C, then if C > A, the result would be inconsistent. For the purposes of this paper, the important point to bear in mind is that the model should be as consistent as possible (between 0.00 and 0.10) so as to avoid any irregular rankings that result from the comparisons.[14]

2.2 Example Hierarchy - Tank Battle Effectiveness

The use of the AHP method is briefly illustrated through an example problem of tank battle effectives. Assume that a military wants to determine the effectiveness of several tanks in battle. Factors such as mobility, firepower and survivability could represent important attributes of tank battle effectiveness. The AHP can easily support more complex hierarchies containing sub-criteria. For example, the criterion mobility can be further broken down into how the tanks negotiate terrain or cross obstacles.[15] The choices of the tanks have been narrowed down to three alternatives: the Leopard 2, the M1 Abrams and the Challenger 2.

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[14] See Expert Choice Version 11, Users Manual, Arlington VA, 2004. The Inconsistency INDEX is calculated for each node (and its cluster of children), and multiplied by the priority of the node, and summed over the entire model. A similar calculation is done for the Inconsistency INDEX for random judgements. The Overall Inconsistency Ratio is the ratio of these two weighted sums.

[15] Example drawn from: Mike Bathe, "The Analysis of Subjective Results,"2006.

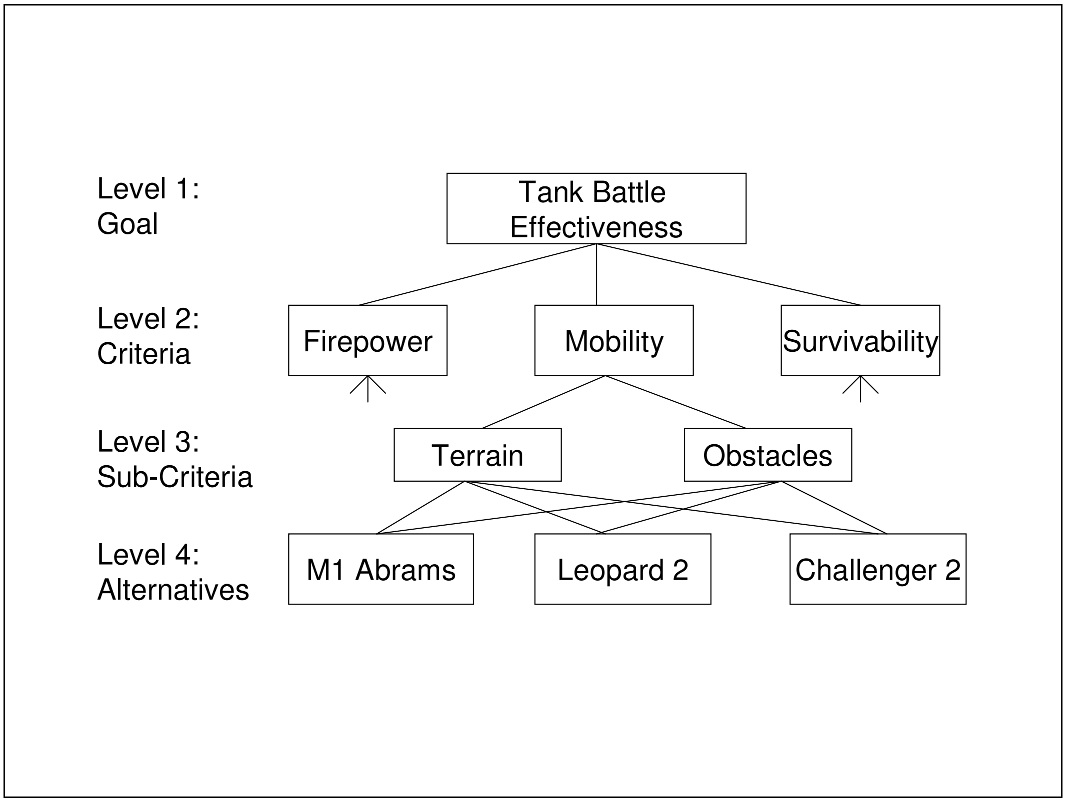

Figure 3: Example Hierarchy

A subject matter expert or group of experts consider firepower strongly preferable to mobility, hence firepower scores 5 against mobility and mobility scores 1/5 against firepower. The scores are represented in the following matrix (Table 3).

Table 3: Pairwise Comparison Table (A)

	Firepower	Mobility	Survivability
Firepower	1	5	
Mobility	1/5	1	
Survivability			1

Firepower is then compared against survivability. Firepower scores 1/3 and survivability scores 3, with survivability being weakly preferable to firepower. The results of these scores are depicted in Table 4.

Table 4: Pairwise Comparison Table (B)

	Firepower	Mobility	Survivability
Firepower	1	5	1/3
Mobility	1/5	1	
Survivability	3		1

The remaining criteria are then compared, resulting in the following table (Table 5).

Table 5: Reciprocal Matrix

	Firepower	Mobility	Survivability
Firepower	1	5	1/3
Mobility	1/5	1	1/7
Survivability	3	7	1

More precise preferences can be obtained by combining the expert judgements of several subject matter experts. The summation process (described in the pairwise comparison matrix found at Table 2) is used to obtain the weights of the criteria summing to one and the measurement of consistency of the expert opinion. In this simple example, the weights for the criteria are as follows:

- Survivability (.28)
- Mobility (.07)
- Survivability (.64)

The weights are calculated using matrix algebra (the principal eigenvector of the comparison matrix) and then normalized to sum to 1. This process is depicted in Table 6.

Table 6: Normalized Matrix

	Firepower	Mobility	Survivability	Sum	Priority
Firepower	.24	.38	.22	.847	.28
Mobility	.05	.08	.10	.220	.07
Survivability	.71	.54	.68	1.93	.64
Sum	1.00	1.00	1.00		1.00

Each alternative is then pairwise compared in the same manner for each criterion. The final results for each alternative are a function of their scores under each criterion coupled with the relative rank of each criterion.

One of the advantages of the AHP is that weights estimated using this process can be measured in terms of their consistency – the extent to which the comparisons are accurate and more or less consistent. Table 7 summarizes the consistency[16] of the representative tank battle effectiveness problem. The important point to make here is that pairwise comparison consistency ratio is below 0.10. If the number was greater than 0.10, the consensus of the expert opinion should be further investigated to determine why individuals or group of individuals hold differing views.

Table 7: Consistency Estimation of Illustrated Example

Lambda max	3.09
Consistency Index (CI)	0.04
Consistency Ratio	0.07

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[16] See Expert Choice Version 11, Users Manual, Arlington VA, 2004. The consistency index (CI) is defined as ($\text{lambda}_{\text{max}}$ – n)/(n-1), where *n* is the size (number of rows) of the comparison matrix and $\text{lambda}_{\text{max}}$ is the overall inconsistency. The consistency ratio is defined as the ratio of the consistency index for a particular set of judgements to the average consistency index for random comparisons for a matrix of the same size.

3 Evaluation Using Multi-Attribute Decision Model

3.1 Consolidated Risk Assessment

Before launching into a discussion of the AHP, it is useful to review the CBRNE Consolidated Risk Assessment (CRA) to help understand how the model works. The CBRNE CRA was initiated in 2002 and is used to inform investment decisions in CBRNE science and technology. The methodology is updated on an annual basis and has been adjusted every year since its inception. Figure 4 displays an illustration of the CRA model.

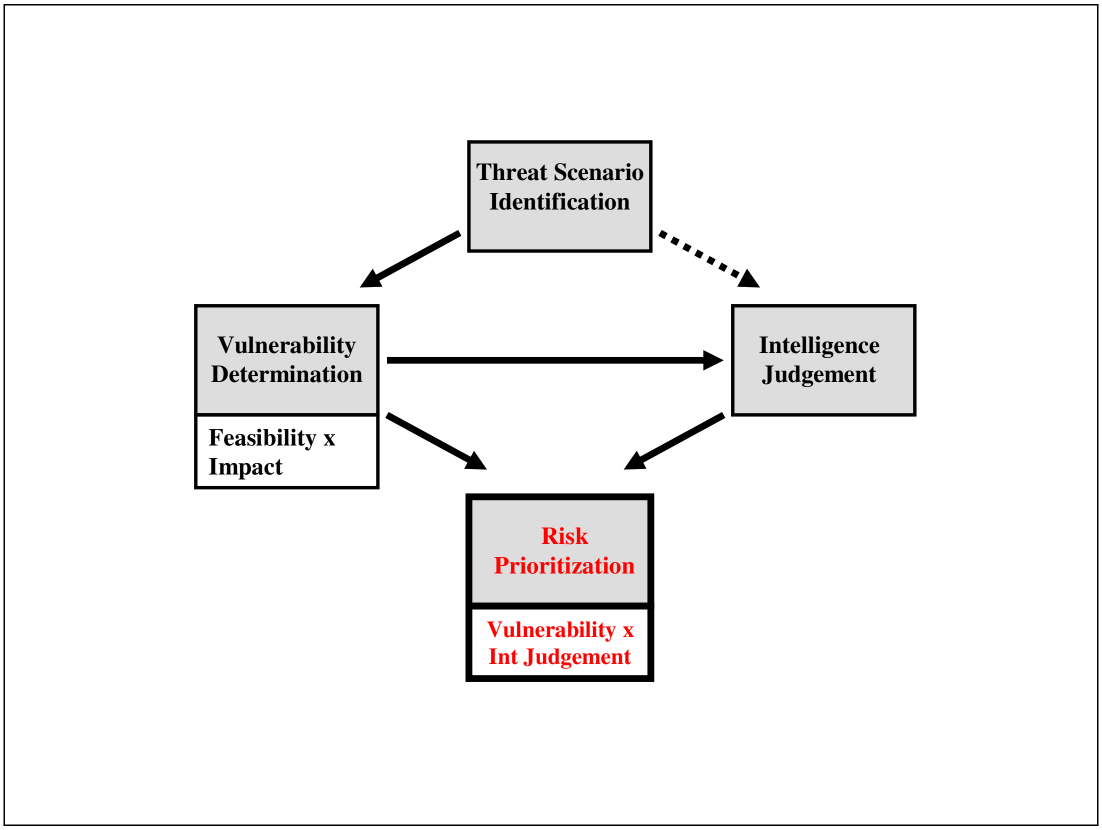


Figure 4: Consolidated Risk Assessment Model

The CRA model follows a structured step-by-step process to examine the risks of CBRNE events. Characteristic scenarios that span the target spectrum (e.g. people, critical infrastructure, agro-systems) are used to briefly describe the nature of individual events. The scenarios are then evaluated for vulnerability by considering relative technical feasibility and impact. Technical feasibility considers aspects such as availability of material, deployment and dissemination, equipment requirements and expertise and knowledge. Impact is evaluated considering human losses, intensity of response, disruption of capability and capacity and economic losses. A vulnerability rating is assigned based on the outcome of the impact and relative technical feasibility scores. The intelligence judgment (or likelihood) of each particular scenario is also provided for each scenario. Intelligence judgment considers parameters such as the amount and reliability of reporting, terrorist intent and capacity to enact the scenario and provides an assessment based on available information. Finally, a risk rating is assigned, taking into account the factors of vulnerability and intelligence judgment.

One of the challenges associated with the CRA model is that it is based on arriving at group consensus with respect to the assessment of particular hazard scenarios. Although differences of expert opinion are considered, its major assumption is that a ‘true’ consensus exists. The CRA process does not provide the opportunity to exploit decision support tools or techniques that automate steps in the risk estimation process. Public security risk management practitioners are looking at the issue, but the CRA is currently focused on an inclusive and consensus based process. Thus, there is a requirement to carry out a risk assessment that exploits and applies decision support systems to be able to incorporate the subjective judgments of all subject matter experts involved and measure the effect of different weightings of the variables on the results that are being sought. This will ensure that the public security community will be in a position to address the highest risks requiring further investment. Such investment could apply to the development of new tools for risk assessment.

3.2 Illustrative Risk Assessment with Expert Choice

Before carrying on with a risk assessment using Expert Choice, it is necessary to qualify this study with a few caveats. The scenarios and data sources used to support this analysis are for illustrative purposes. The intent is to provide a set of scenarios that are generally representative of the types of security hazards that could be encountered. The information in the analysis is not meant to forecast or predict what will happen. In this study, Expert Choice is used as a planning tool that simply illustrates a different way to develop priorities using a rigorous, reproducible and transparent process. Similarly, the data and weightings of the criteria are illustrative of the scores and ratings one might find in a typical AHP model. By employing this approach, it is possible to introduce the AHP and demonstrate the capabilities and functionalities of Expert Choice. In short, this risk assessment is purely hypothetical.

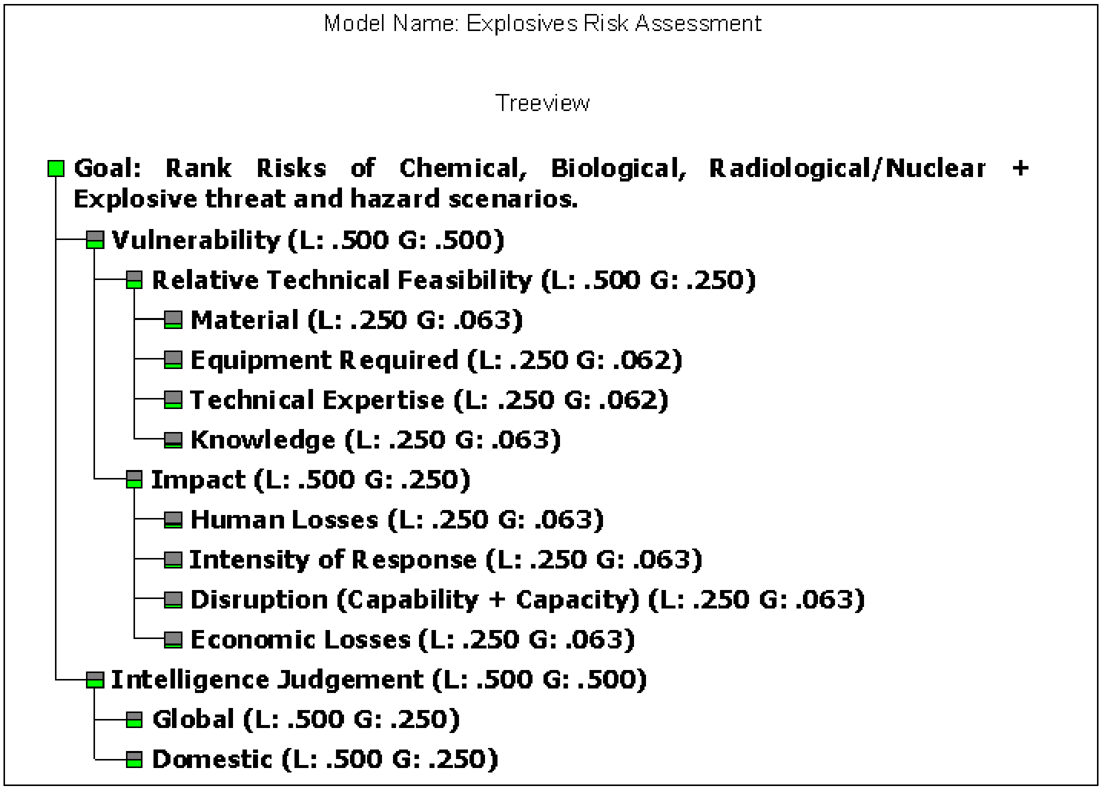
The evaluation process involves an assessment of the hazard scenarios against the criteria followed by a sensitivity analysis. The identification of a notional list of hazard risks scenarios (i.e. alternatives) is the first step. The departure point for the scenarios is to show “how can something go wrong?” Eight hazard scenarios, crossing a wide variety of target domains (e.g., people, food and water supplies, critical infrastructure, the agro-system (plant and animal), consumer products), have been selected for this analysis. The identification process can involve a variety of techniques, such as brainstorming, expert judgement, environmental scanning, Delphi process, surveys etc. To ensure broad coverage, two scenarios for each CBRNE hazard domain have been chosen. The scenarios are listed at Table 8.

Table 8: Representative List of Hazard Scenarios

Chemical	Biological	Rad/Nuclear	Explosive
Aerosol attack with volatile super-agent (e.g. Sarin) in a large enclosed area (e.g. subway)	Aerosol release of a virus (e.g., foot and mouth disease) in open or semi-enclosed space (e.g., feedlot)	Radiological dispersal (outdoors) - e.g. explosion in center of major city	Explosive package on public/mass transit
Introduction of toxic chemical in food industry or system (e.g. distribution plant)	Release of a pathogen or an exotic insect (e.g. Asian Longhorn) into a national forest, park or environment	Aggressively placed source (e.g. in park, under desk, recycle bin)	Attack on Critical Infrastructure; large consequence event, cross border issue

3.3 Criteria for Evaluation

Figure 3 shows the AHP/Expert Choice model used in this analysis. The goal for the particular model under consideration is to rate the CBRNE hazard scenarios in order of importance. Thus, at the first level, the goal is defined as ranking the immediate risk scenarios in order of priority. For level 2, the vulnerability is determined by assessing relative technical feasibility and impact. The relative technical feasibility considers such factors as materials, equipment, expertise, and knowledge. Similarly, impact considers human loss, response intensity, disruption and economic losses. Intelligence judgement (or likelihood) is also assessed under the goal at Level 2 in the model, and includes global and domestic sub-criteria.



Model Name: Explosives Risk Assessment

Treeview

- **Goal: Rank Risks of Chemical, Biological, Radiological/Nuclear + Explosive threat and hazard scenarios.**
  - **Vulnerability (L: .500 G: .500)**
    - **Relative Technical Feasibility (L: .500 G: .250)**
      - **Material (L: .250 G: .063)**
      - **Equipment Required (L: .250 G: .062)**
      - **Technical Expertise (L: .250 G: .062)**
      - **Knowledge (L: .250 G: .063)**
    - **Impact (L: .500 G: .250)**
      - **Human Losses (L: .250 G: .063)**
      - **Intensity of Response (L: .250 G: .063)**
      - **Disruption (Capability + Capacity) (L: .250 G: .063)**
      - **Economic Losses (L: .250 G: .063)**
  - **Intelligence Judgement (L: .500 G: .500)**
    - **Global (L: .500 G: .250)**
    - **Domestic (L: .500 G: .250)**

Figure 5: CBRNE Risk Model

The criteria are then compared on a pairwise basis and values are assigned in terms of their relative importance to the overall goal. Figure 5 also displays the weights for the criteria (where L represents local weightings and G global weightings). The vulnerability assessment (.500) and intelligence judgement (.500) are assessed as having an equal weight. The weights for the next level of analysis (i.e., the sub-criteria) are then developed. In Figure 5, the rating scale for impact (.500) and relative technical feasibility (.500) is displayed. The rankings for the sub-criteria for impact and relative technical feasibility are also displayed. The weights for relative technical feasibility are as follows: Material (.250), Equipment required (.250), Technical Expertise (.250), and Knowledge (.250). The weights for impact are: Human losses (.250), Intensity of Response (.250), Disruption (.250) and Economic Losses (.250).

Intensity ratings for each of the criteria need to be established to evaluate the individual hazard scenarios. The ratings are set out in Table 4. As mentioned earlier, the priorities in the AHP are established through an intensity rating scale, and alternative hazard scenarios are evaluated against this scale to generate a resulting value. A step function, one of five formula types (the five being ratings, step function, increasing and decreasing utility curves, and direct entry of priorities), consists of a scale of prioritized intensities that has been used to automatically calculate the appropriate intensity of each alternative based on data entered in the data grid. Values in the formula grid, which contains user defined formulas to create values for use with the data grid, show that most weight is given to proliferated materials with respect to relative technical feasibility, and to where low levels of technical sophistication are required to execute a CBRNE attack (.900). The subjective judgements for intelligence judgement have been assigned the following intensities: Severe (.900), Substantial (.600), Moderate (.300) and Low (.000). The scenarios are evaluated against the intensity levels under each criterion to further define an overall rating value for each scenario.

Table 9: Formula Grid

Objective/ Formula	Type	.900	.600	.300	.000	WEIGHT (Global)
Material	STEP	Material readily available	Material easily produced	Material technically difficult to produce	Material very technically difficult to produce	.063
Equipment Required	STEP	No specialized equipment off the shelf	Standard lab equipment	Some specialized equipment	Custom designed equipment	.063
Technical Expertise	STEP	Low level (e.g., self-taught)	Bachelor degree or technical training	Advanced technical training	Advanced specialized technical training	.063
Knowledge	STEP	Readily available (e.g., Internet)	Standard open literature	Specialized scientific literature	Closely held military information	.063
Human losses	STEP	>500 deaths; >5,000 injuries	101-500 deaths; 1,001-5,000 injuries	10-100 deaths; 100-1,000 injuries	<10 deaths; <100 injuries	.063
Intensity of Response	STEP	National and international	Provincial scale	Local;, municipal	Restricted	.063
Level of Disruption	STEP	Extensive – recovery and restoration over 1 year	Serious –; recovery and restoration over 1 year <1year to 6months	Moderate – recovery duration <6 to 3 months	Minimal impact on assets	.063
Economic loss	STEP	>1 Billion	500 M to <1 Billion	100 M to <500-	<100 M	.063
Intelligence Judgement (Global)	RATINGS	Severe	Substantial	Moderate	Low	.250
Intelligence Judgement (Domestic)	RATINGS	Severe	Substantial	Moderate	Low	.250

3.4 Results

After establishing the rating scales and deriving weights for the model through the pairwise comparison process, each scenario is rated against each criterion in the data grid and a number is entered as to the expected vulnerability, feasibility or intelligence judgement. Each score provides a ratio scale measurement that contributes to a determination of the overall priority.

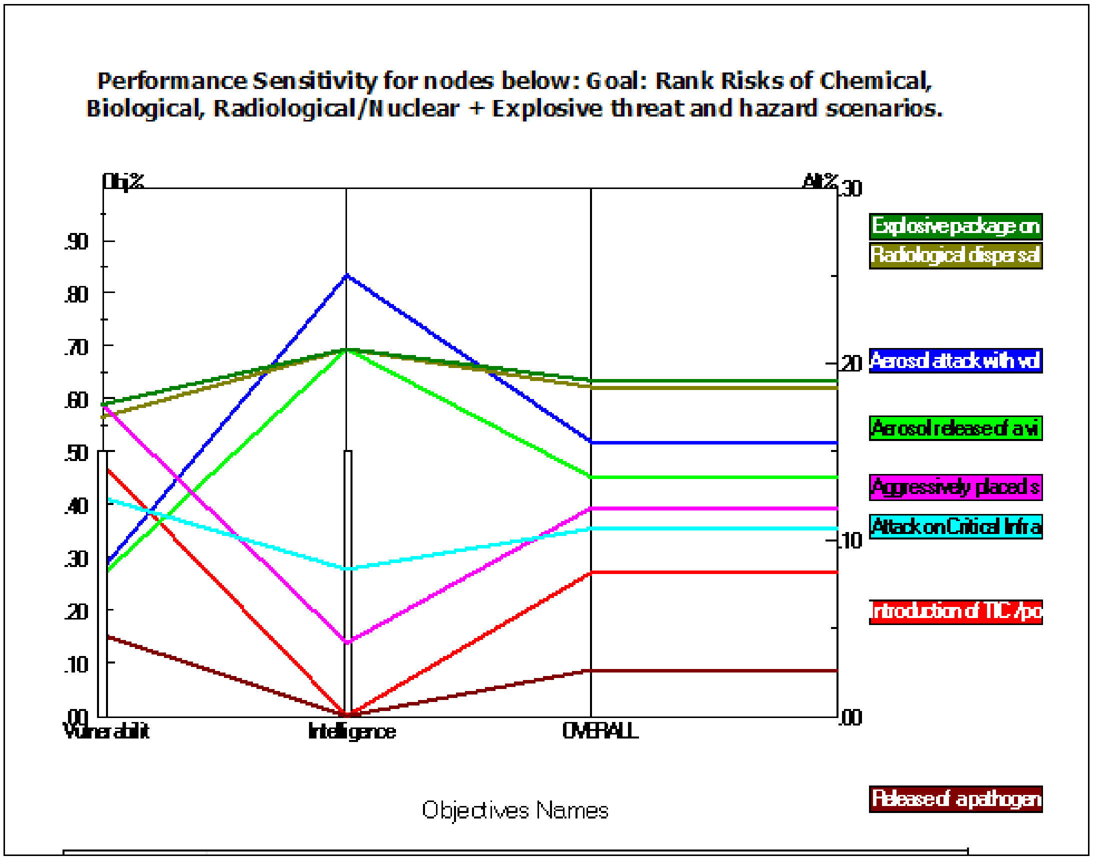


Figure 6: Synthesis of Hazard Scenarios

The results from this illustrative Expert Choice model show that an explosive attack on mass and public transit systems is the highest risk (.190). After this scenario, radiological dispersal device (.186) rates the highest. One of the eight scenarios, the release of a pathogen in a national forest or park (.026), was clearly considered the lowest risk in comparison. Figure 6 presents this information in a performance graph containing the eight scenarios against the two major criteria of concern. Each horizontal line on the graph represents a hazard scenario, and the resulting scores are displayed against the criteria. The bars on the y axis correspond to the weights assigned to the criteria, which in this case have equal weights (.500). It can be seen that a number of scenarios that have relatively high vulnerability ratings are counter-balanced by low weightings for intelligence judgement (likelihood). In contrast, the scenarios that scored high in terms of their scores for intelligence judgement were rated poorly for vulnerability.

3.5 Sensitivity Analysis

Since each sub-criteria has been thus far assigned an equal weight, there is a requirement for a sensitivity analysis to explore potential tradeoffs among the alternatives and examine potential "what-if(s)?"; that is, whether variations among weights of the criteria (i.e., the inputs) significantly affect the overall ratings of the alternatives (i.e., the outcomes). The purpose of a sensitivity analyses is to determine how the alternatives and priorities react to changes in the weightings of the criteria or sub-criteria, which may result in a reordering of the priorities. For instance, changes in intelligence judgement might exert a much larger influence on the results of the risk assessment than previously assessed.

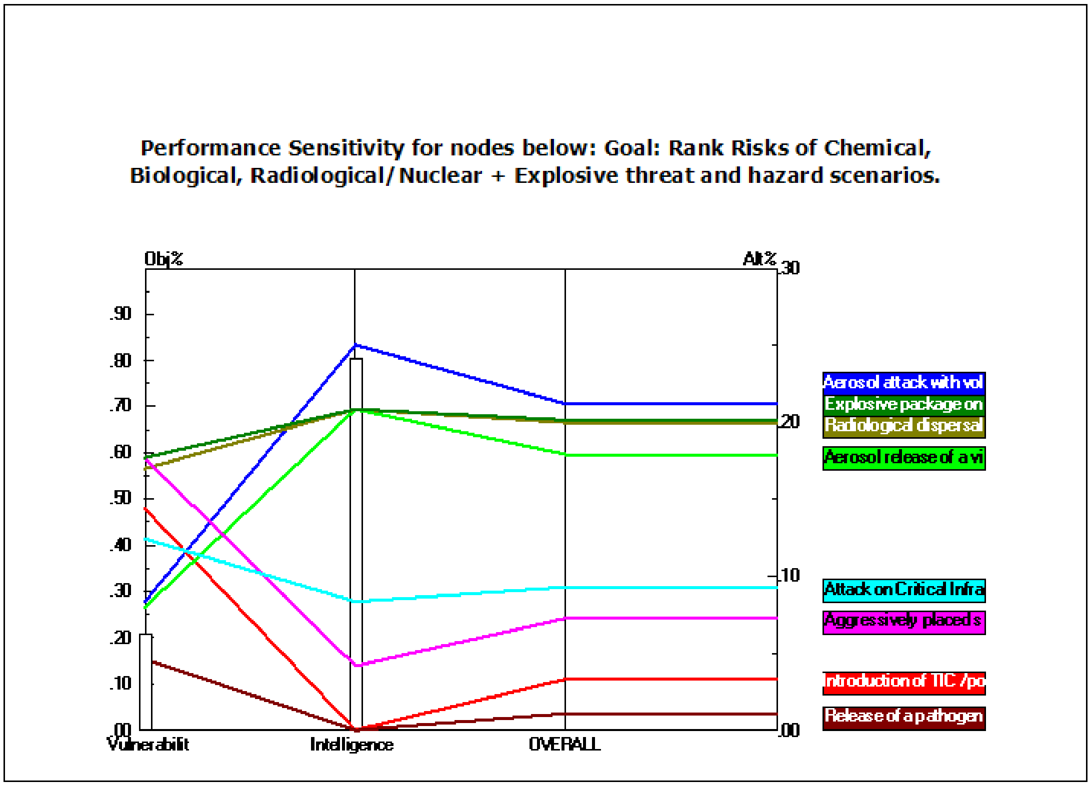


Figure 7: Sensitivity Analysis of Hazard Scenarios

In this example, the sensitivity analysis is performed by raising the importance of the criterion "Intelligence Judgement" to .80, and lowering the Vulnerability (technical feasibility + impact) to .20. The results of this analysis are presented in Figure 7. If the weighting for intelligence judgement were to increase, the ordering of the priorities would be different. The aerosol attack with a non-contagious agent (anthrax) becomes the highest risk overall when Intelligence Judgement is considered the most important factor. Conversely, if vulnerability were to become the most important factor and was elevated to a rating of .80, the explosive attach on public mass transit would be rated as the highest scenario. When a sensitivity analysis on the factors is performed by changing the weighting of Vulnerability (from .500 to .200) and Intelligence Judgement (from .500 to .800), the scenario rankings remain relatively consistent. The sensitivity analysis enables instantaneous discussion of whether or not changes in the weights are required, and can generate discussions among decision makers concerning the reasons as to why one scenario rates more highly than another, or vice versa.

4 Conclusion

This paper has explored the application of a Multi-Attribute Decision Model, the AHP, to aid in a decision analysis problem by rank ordering a list of representative CBRNE hazard scenarios. The concept in this paper is useful from the point of view of demonstrating to the public security community that alternative tools, methods and approaches can be used to assess risk and establish priorities among competing goals, criteria and alternatives using qualitative and quantitative estimates. The use of electronic software packages, such as Expert Choice 11, provide greater insight by automating steps in the assessment process. In particular, the capability to perform a sensitivity analysis can facilitate the analysis of tradeoffs of the different alternatives.

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List of symbols/abbreviations/acronyms/initialisms

AHP	Analytical Hierarchy Process
CBRNE	Chemical, biological, radiological/nuclear and explosive
CRA	Consolidated Risk Assessment
DND	Department of National Defence
IEDs	Improvised explosive devices
MADM	Multi-Attribute Decision Model
OPI	Office of Primary Interest
PCM	Pairwise comparison matrix
R&D	Research & Development

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13. ABSTRACT

This paper describes the use of the Analytical Hierarchy Process to assess hypothetical risks of representative terrorist-initiated chemical, biological, radiological/nuclear and explosive hazard scenarios. A Multi-Attribute Decision Model was created to evaluate these representative scenarios according to their relative technical feasibility, impact and likelihood of occurrence in order to generate a shortlist of priorities. The model, which was created using the software tool Expert Choice 11, is described in detail. A sensitivity analysis on the data is performed to illustrate how changes in criteria weights can affect the results of the assessment. This paper can be used to assist the public security community in refining the tools, methods and approaches for risk assessment.

Le présent article décrit l’utilisation du processus de hiérarchie analytique pour évaluer les risques hypothétiques de scénarios représentatifs de dangers chimiques, biologiques, radiologiques, nucléaires et explosifs exécutés par des terroristes. Un modèle de décision à attributs multiples a été créé pour évaluer ces scénarios représentatifs en fonction de leur faisabilité technique relative, de leur incidence et de la probabilité qu’ils se produisent afin de dresser une courte liste de priorités. Le modèle, qui a été créé à l’aide de l’outil logiciel Expert Choice 11, est décrit en détails. On effectue une analyse de sensibilité sur les données pour illustrer comment des changements dans la pondération des critères peut affecter les résultats de l’évaluation. Le présent article peut être utilisé pour aider la communauté de la sécurité publique à améliorer les outils, les méthodes et les techniques pour l’évaluation des risques.

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CBRNE, Risk Assessment, Decision Analysis, Multiple Attribute Decision Models, Analytical Hierarchy Process