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Linguistic Evaluation of Terrorist Scenarios: Example Application

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Abstract

In 2005, a group of international decision makers developed a manual process for evaluating terrorist scenarios. That process has been implemented in the approximate reasoning Java software tool, LinguisticBelief, released in FY2007. One purpose of this report is to show the flexibility of the LinguisticBelief tool to automate a custom model developed by others. LinguisticBelief evaluates combinations of linguistic variables using an approximate reasoning rule base. Each variable is comprised of fuzzy sets, and a rule base describes the reasoning on combinations of variables' fuzzy sets. Uncertainty is considered and propagated through the rule base using the belief/plausibility measure. This report documents the evaluation and rank-ordering of several example terrorist scenarios for the existing process implemented in our software. LinguisticBelief captures and propagates uncertainty and allows easy development of an expanded, more detailed evaluation, neither of which is feasible using a manual evaluation process. In conclusion, the Linguistic-Belief tool is able to 1) automate an expert-generated reasoning process for the evaluation of the risk of terrorist scenarios, including uncertainty, and 2) quickly evaluate and rank-order scenarios of concern using that process.

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John C. Cummings of the Advanced Concepts Group (ACG) at Sandia National Laboratories was the sponsor of this effort under a Laboratory Directed Research and Development (LDRD) project. John suggested the example application and defined the scenarios to be evaluated. Also, he proposed the graphical technique for interpreting the rank-ordering of the scenarios.

Dennis Mangan, Sandia National Laboratories (consultant) assisted with the example risk assessment process and provided guidance on its use.

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Executive Summary

In 2005, a group of international decision makers developed a manual process for evaluating terrorist scenarios. This report is an example application of the LinguisticBelief tool to that risk assessment process, using five example scenarios. The Laboratory Directed Research and Development (LDRD) program at Sandia National Laboratories (SNL) sponsored this work. The work was performed between October 1, 2006 and February 15, 2007 at SNL in Albuquerque, New Mexico.

The purpose of this report is to demonstrate the application of the tool. To that end, in this unclassified report, the risk assessment process is not identified and the scenarios that were evaluated are not identified.

The original process does not include uncertainty. Example scenarios were evaluated without considering uncertainty to illustrate the automation of the original process.

Since in actual application there is significant uncertainty, much of it epistemic, example scenarios were evaluated considering uncertainty using the built-in capabilities of the LinguisticBelief tool. The scenarios were rank-ordered using the complementary cumulative belief/plausibility function.

With the automation of the original process, using the techniques built into LinguisticBelief improvements to the original process can be made in the following areas:

1. Uncertainty can be captured and propagated.
2. Arbitrary numeric scores can be removed.
3. All variables can be evaluated using fuzzy sets.
4. The process can be expanded easily to reason at a finer level.

In summary, this report documents the application of the LinguisticBelief tool for an evaluation of risk of terrorist scenarios. LinguisticBelief captures and propagates uncertainty and allows easy development of an expanded, more detailed evaluation, neither of which is feasible using a manual evaluation process.

In conclusion, the LinguisticBelief tool is able to automate an expert-generated reasoning process for the evaluation of the risk of terrorist scenarios, including uncertainty, and quickly evaluate and rank-order scenarios of concern using that process.

Acronyms

CBRNE	chemical, biological, radiological, nuclear, and explosive
LDRD	Laboratory Directed Research and Development
SNL	Sandia National Laboratories

1 Introduction

A terrorist act is not a random event; it is an intentional act by a thinking malevolent adversary. Much of the uncertainty in estimating the risk of a terrorist act is epistemic (state of knowledge) instead of aleatory (stochastic); for example, the adversary knows what acts will be attempted, but we as defenders have incomplete knowledge to know those acts with certainty.

Many of the variables involved in evaluating a terrorist scenario are difficult to express numerically; for example, “soft” consequences such as “Damage to National Security” or “Fear in the Populace,” or “soft” measures of “Technical Expertise” such as “Low Level” or “Advanced Technical Training.” A linguistic model allows such non-numeric variables to be considered.

To model how we as a defender evaluate the selection of scenarios by an adversary, we applied approximate reasoning with fuzzy sets; to capture the epistemic uncertainty in the evaluation, we applied the belief/plausibility measure of uncertainty from the Dempster/Shافر Theory of Evidence. [Darby 2006] We developed the LinguisticBelief Java software to automate these techniques. [Darby 2007]

In 2005 a group of international decision makers developed a manual process for evaluating terrorist scenarios. This report applies the LinguisticBelief tool to automate that risk assessment process. We had no interaction with the developers of the risk assessment process, and they had no knowledge of our work. One purpose of this report is to show the flexibility of the LinguisticBelief tool to automate a custom process developed by others.

The purpose of this report is to demonstrate the application of the tool. To that end, in this unclassified report, the risk assessment process is not identified and the scenarios that were evaluated are not identified.

The existing risk assessment process is discussed. The implementation of the process in the LinguisticBelief tool is presented. Five terrorist scenarios are evaluated and rank ordered. Enhancements to the original process are suggested and discussed.

2 Summary of the Risk Evaluation Process

This section summarizes the original, manual risk assessment process.

The process was designed to evaluate a wide range of terrorist scenarios: chemical, biological, radiological dispersal, nuclear, and conventional explosive (CBRNE).

The process models the variables linguistically, and uses a rule base for combining variables. Uncertainty is not considered. The variables and linguistics were defined by the working group according to the way the group decided to model the problem and were based on the definitions created in the original, manual process. This document does not attempt to define all linguistics used, but does define the relevant terms found in the tables of constituents.

2.1 Original Risk Evaluation Process

In the process, the scenarios are evaluated by “Risk Level,” which is defined as a combination of “Intelligence Judgment” and “Vulnerability.” “Intelligence Judgment” is the likelihood of the scenario. “Vulnerability” is a combination of “Relative Technical Feasibility” and “Potential Impact.” “Relative Technical Feasibility” is a combination of “Material,” “Equipment,” “Technical Expertise,” and “Knowledge.” “Potential Impact” is a combination of “Dead/Injured,” “Intensity of Response,” “Disruption of Capability/Capacity,” and “Economic Loss.”

Each of these variables is segregated into bins. For example, “Intelligence Judgment” is segregated into: “Unlikely,” “Possible,” “Emerging,” and “Likely.”

Table 2-1 lists the constituent variables for “Relative Technical Feasibility,” which is segregated into the bins of Table 2-2, using the aggregate score from each constituent.

Table 2-1. Constituents of “Relative Technical Feasibility”

Score	Material	Equipment	Technical Expertise	Knowledge
9	Material readily available (e.g., commercially available product or frequently occurring in nature)	No specialized equipment	Low level	Readily available
6	Material easily produced	Standard laboratory and dissemination process	Bachelors degree or technical school level	Standard open literature
3	Material difficult to produce	Some specialized equipment	Advanced technical training	Specialized scientific literature or declassified military documents
0	Material very difficult to produce or acquire	Custom-designed or manufactured equipment	Advanced specialized technical training	Closely held military information

Linguistic Evaluation of Terrorist Scenarios: Example Application

Table 2-2. Bins for “Relative Technical Feasibility”

Score	Relative Technical Feasibility
25+	High
17-24	Medium
9-16	Low
0-8	Very Low

Table 2-3 lists the constituent variables for “Potential Impact,” which is segregated into the bins of Table 2-4, using the aggregate score from each constituent.

Table 2-3. Constituents of “Potential Impact”

Score	Dead/Injured	Intensity of Response	Disruption of Capability/Capacity	Economic Loss
9	More than 500 dead or 5000 injured	National or international	Extensive (major facility; restoration; recovery greater than one year)	More than \$1 billion
6	From 101 to 500 dead or from 1001 to 5000 injured	State or province	Serious (extensive remediation and decontamination; recovery six months to one year)	From \$500 million to \$1 billion
3	From 10 to 100 dead or from 100 to 1000 injured	Local	Moderate (equipment written off or modest decontamination; recovery three to six months)	From \$100 million to \$499 million
0	Fewer than 10 dead or 100 injured	Restricted	Minimal (little impact on capability or capacity)	Less than \$100 million

Table 2-4. Bins for “Potential Impact”

Score	Relative Technical Feasibility
28+	Catastrophic
19-27	Critical
9-18	Moderate
0-8	Low

Table 2-5 is the rule base for evaluating “Vulnerability,” and Table 2-6 is the rule base for evaluating “Risk Level.”

Linguistic Evaluation of Terrorist Scenarios: Example Application

Table 2-5. Vulnerability

Vulnerability	Relative Technical Feasibility			
Potential Impact	High	Medium	Low	Very Low
Catastrophic	Extreme	Extreme	High	Moderate
Critical	Extreme	High	High	Low
Moderate	High	Moderate	Moderate	Low
Low	Moderate	Low	Low	Low

Table 2-6. Risk Level

Risk Level	Intelligence Judgment			
Vulnerability	Likely	Emerging	Possible	Unlikely
Extreme	Immediate	Immediate	High	Emerging Concern
High	Immediate	High	High	Discretionary
Moderate	High	Emerging Concern	Emerging Concern	Discretionary
Low	Emerging Concern	Discretionary	Discretionary	Discretionary

2.2 Evaluation and Ranking of a Scenario with the Process

Using this process, a scenario is evaluated by assigning it a unique bin for each of the following “basic” variables:

1. “Material”
2. “Equipment”
3. “Technical Expertise”
4. “Knowledge”
5. “Dead/Injured”
6. “Intensity of Response”
7. “Disruption of Capability/Capacity”
8. “Economic Loss”
9. “Intelligence Judgment”

Using the bins for these “basic” variables and the rules in Tables 2-1 through 2-6, the unique “Risk Level” bin for the scenario is calculated.

For example, assume the following for a particular scenario. “Material” is “Material difficult to produce.” “Equipment” is “Some specialized equipment.” “Technical Expertise” is “Advanced specialized technical training.” “Knowledge” is “Standard open literature.” With these assignments, using Tables 2-1 and 2-2, “Relative Technical Feasibility” is “Low” since the sum of the scores is 12.

Linguistic Evaluation of Terrorist Scenarios: Example Application

Assume that “Dead/Injured” is “From 101 to 500 dead or from 1001 to 5000 injured.” “Intensity of Response” is “Local.” “Disruption of Capability/Capacity” is “Serious (extensive remediation and decontamination; recovery six months to one year).” “Economic Loss” is “From \$100 million to \$499 million.” With these assignments, using Table 2-4 “Potential Impact” is “Moderate” since the sum of the scores is 18.

Assume that “Intelligence Judgment” is “Emerging.”

With “Relative Technical Impact” “Low” and “Potential Impact” “Moderate,” Table 2-5 indicates a “Vulnerability” of “Moderate.” With “Vulnerability” “Moderate” and “Intelligence Judgment” “Emerging,” Table 2-6 indicates a “Risk Level” of “Emerging Concern.” Therefore, the “Risk Level” of this scenario is “Emerging Concern.”

A scenario is ranked by “Risk Level” (decreasing) as: “Immediate,” “High,” “Emerging Concern,” and “Discretionary.” The rank of the example scenario is “Risk Level” “Emerging Concern,” therefore, any other scenario with “Risk Level” of “High” or “Immediate” is of more concern.

3 Implementation of the Process in LinguisticBelief

This section summarizes the implementation of the risk assessment process of Section 2 in the LinguisticBelief tool.

3.1 Summary of Techniques Used in LinguisticBelief

The references discuss the techniques of belief/plausibility, fuzzy sets, and approximate reasoning, and their implementation in the LinguisticBelief code. [Darby 2006 and 2007]

For the purposes of this report, the following summary information is provided. When we use linguistics (words) to classify events the words have a type of uncertainty called “vagueness.” For example, yesterday was “sunny,” public confidence in the stock market is “high,” etc. Vagueness is uncertainty as to how to classify a *known* event. For example, assume we know how tall John is, but instead of saying John is 6 feet 2 inches tall we categorize John as “tall” without a precise definition of “tall.” The linguistic (word) “tall” is vague. Vagueness can be addressed using the mathematics of fuzzy sets.

The belief/plausibility measure of uncertainty from the Dempster/Shافر Theory of Evidence is an extension of the probability measure of uncertainty that can better capture epistemic uncertainty. Belief/plausibility is a superset of probability and under certain conditions belief and plausibility both become probability. Under other conditions, belief/plausibility become necessity/possibility, respectively. Belief/plausibility addresses a type of uncertainty called “ambiguity.” The uncertainty associated with predicting an event in the future is ambiguity.

A simple example illustrates the difference between aleatory (stochastic or “random”) uncertainty and epistemic (state-of-knowledge) uncertainty, and the use of a belief/plausibility

Linguistic Evaluation of Terrorist Scenarios: Example Application

measure for an example involving ambiguity. Consider a fair coin, heads on one side, tails on the other, with each side equally likely. The uncertainty as to the outcome of a toss—heads or tails—is aleatory. The probability of heads is $\frac{1}{2}$ and the probability of tails is $\frac{1}{2}$. The uncertainty is due to the randomness of the toss. Suppose, however, that I do not know the coin is fair; the coin could be biased to come up heads, or the coin could even be two-tailed. Now that I have epistemic uncertainty, my state of knowledge is insufficient to assign a probability to heads or tails; all I can say is the likelihood of heads (or tails) is somewhere between 0 and 1. To consider epistemic uncertainty as well as aleatory uncertainty, belief/plausibility can be used as the measure of uncertainty. With total ignorance about the coin, the belief that the toss will be heads is 0 and the plausibility that the toss will be heads is 1; similarly, the belief that the toss will be tails is 0 and the plausibility that the toss will be tails is 1. Belief/plausibility form an interval that can be interpreted as giving the lower and upper bound of probability. If I have enough information, both belief and plausibility reduce to a single value, probability. Figure 3-1 illustrates this concept. Epistemic uncertainty can be reduced with more information. If I toss the coin a few times and a heads and a tails occur, I know the coin is two sided; with more tosses I can evaluate the fairness of the coin. Aleatory uncertainty cannot be reduced with more information.

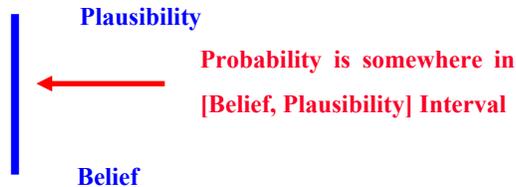


Figure 3-1. Belief/Plausibility as Bounds on Probability

Approximate reasoning is a rule-base for combining fuzzy sets for different linguistic variables. For example, “Bad” “Health” and “Poor” “Wealth” cause “Not so Good” “Quality of Life.”

The LinguisticBelief code uses an approximate reasoning rule base to evaluate combinations of linguistic variables expressed as fuzzy sets, considering uncertainty using the belief/plausibility measure.

3.2 The Risk Assessment Process in LinguisticBelief

A model in LinguisticBelief consists of basic variables and rule variables, with each variable described by fuzzy sets. Rule variables are combinations of basic variables and/or other rule variables as specified by a rule base.

Figure 3-2 shows the variables for the process described in Section 2 as implemented in LinguisticBelief.

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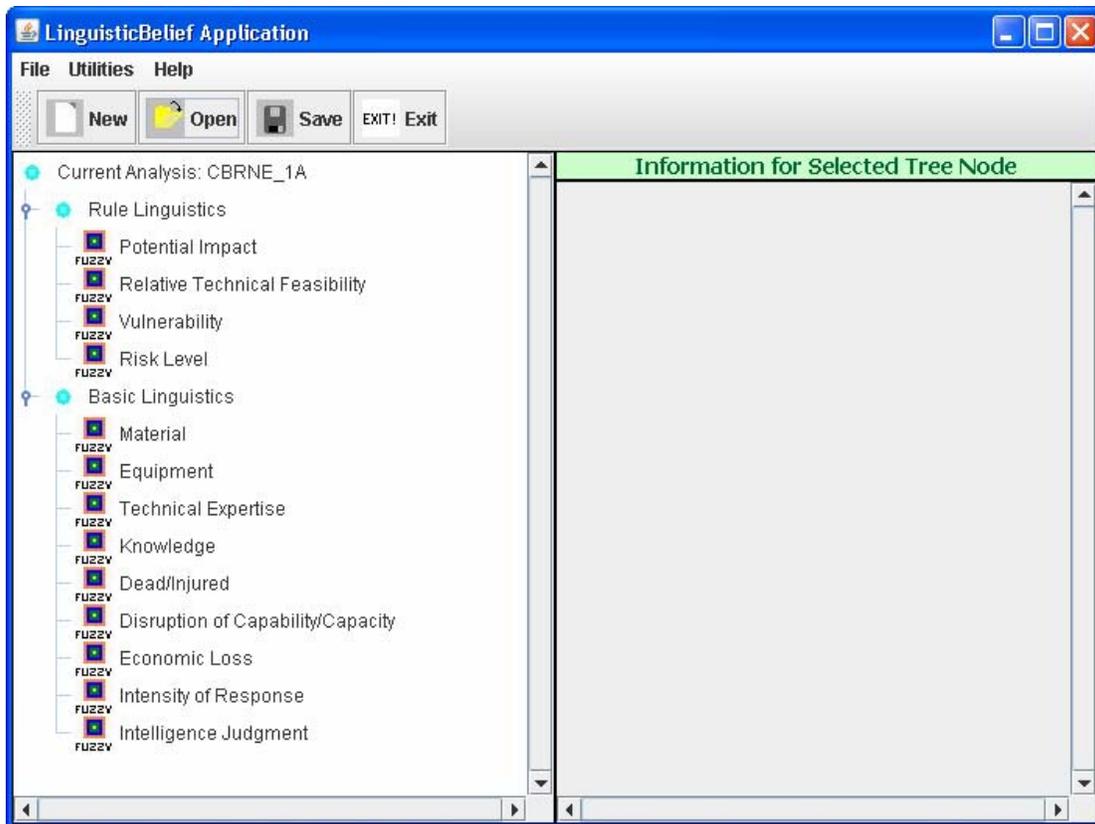


Figure 3-2. Model of Process in LinguisticBelief

The fuzzy sets for each variable are the linguistics (word descriptions) provided in Section 2. For example, Figure 3-3 shows the fuzzy sets for “Intelligence Judgment;” these are the same as the bins used in Table 2-6.

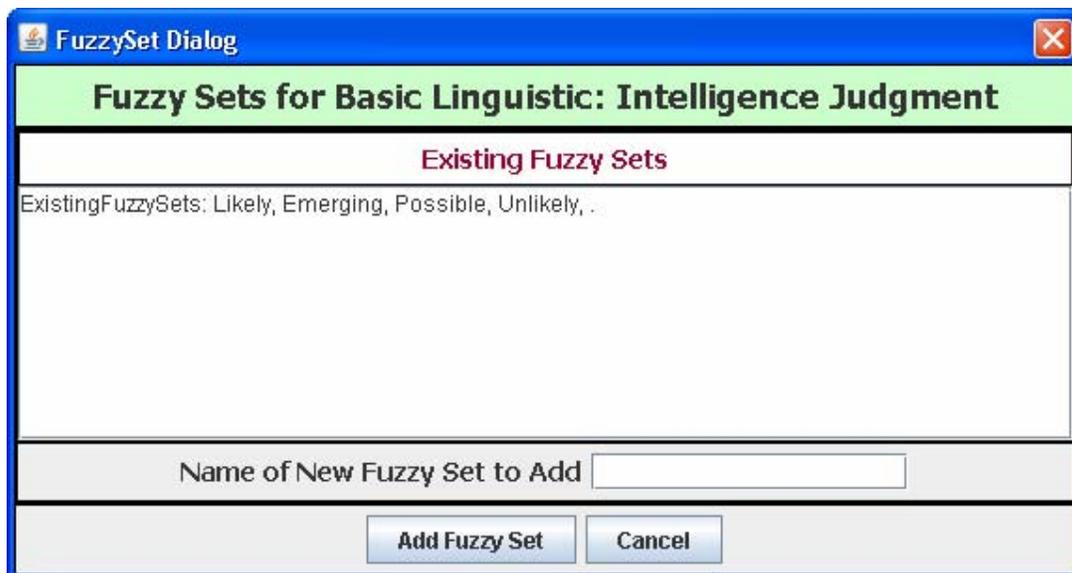


Figure 3-3. Fuzzy Sets for “Intelligence Judgement”

Linguistic Evaluation of Terrorist Scenarios: Example Application

The approximate reasoning rule base implemented in LinguisticBelief for the risk evaluation process is based on the information in Tables 2-1 through 2-6. The rule base in LinguisticBelief is identical to the combinations of variables specified in these tables.

Figure 3-5 shows a portion of the rule base for “Relative Technical Feasibility.” Note that the arbitrary numeric scores used in Tables 2-1 through 2-4 are not required in an automated rule base; these scores are only used in the original manual process as surrogates for a rule base for combining the linguistics for the constituents of “Relative Technical Feasibility” and “Potential Impact.” As discussed in Section 5, it is recommended that arbitrary numeric scores not be used to represent linguistic variables.

Figure 3-4 shows the rule base for “Risk Level.”

Rules for RuleLinguistic: Risk Level		
Fuzzy Set for Input Linguistic: Vulnerability	Fuzzy Set for Input Linguistic: Intelligence Judgment	Output Fuzzy Set for Rule (blank if rule not set)
Extreme	Likely	Immediate
Extreme	Emerging	Immediate
Extreme	Possible	High
Extreme	Unlikely	Emerging Concern
High	Likely	Immediate
High	Emerging	High
High	Possible	High
High	Unlikely	Discretionary
Moderate	Likely	High
Moderate	Emerging	Emerging Concern
Moderate	Possible	Emerging Concern
Moderate	Unlikely	Discretionary
Low	Likely	Emerging Concern
Low	Emerging	Discretionary
Low	Possible	Discretionary
Low	Unlikely	Discretionary

Specify Output Fuzzy Set for Selected Rule: Discretionary

Figure 3-4. Rule Base for “Risk Level”

Rules for RuleLinguistic: Relative Technical Feasibility					
Fuzzy Set for Input Linguistic: Material	Fuzzy Set for Input Linguistic: Equipment	Fuzzy Set for Input Linguistic: Technical Expertise	Fuzzy Set for Input Linguistic: Knowledge	Output Fuzzy Set for Rule (blank if rule not set)	
Readily Available	No Specialized	Low Level	Readily Available	High	
Readily Available	No Specialized	Low Level	Standard Open Literature	High	
Readily Available	No Specialized	Low Level	Specialized Scientific Literature or Declassified Military Docum.	High	
Readily Available	No Specialized	Low Level	Closely Held Military Information	High	
Readily Available	No Specialized	BS or Technical School	Readily Available	High	
Readily Available	No Specialized	BS or Technical School	Standard Open Literature	High	
Readily Available	No Specialized	BS or Technical School	Specialized Scientific Literature or Declassified Military Docum.	High	
Readily Available	No Specialized	BS or Technical School	Closely Held Military Information	Medium	
Readily Available	No Specialized	Advanced Technical Training	Readily Available	High	
Readily Available	No Specialized	Advanced Technical Training	Standard Open Literature	High	
Readily Available	No Specialized	Advanced Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	No Specialized	Advanced Technical Training	Closely Held Military Information	Medium	
Readily Available	No Specialized	Advanced Specialized Technical Training	Readily Available	High	
Readily Available	No Specialized	Advanced Specialized Technical Training	Standard Open Literature	Medium	
Readily Available	No Specialized	Advanced Specialized Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	No Specialized	Advanced Specialized Technical Training	Closely Held Military Information	Medium	
Readily Available	Standard Lab and Dissemination	Low Level	Readily Available	High	
Readily Available	Standard Lab and Dissemination	Low Level	Standard Open Literature	High	
Readily Available	Standard Lab and Dissemination	Low Level	Specialized Scientific Literature or Declassified Military Docum.	High	
Readily Available	Standard Lab and Dissemination	Low Level	Closely Held Military Information	Medium	
Readily Available	Standard Lab and Dissemination	BS or Technical School	Readily Available	High	
Readily Available	Standard Lab and Dissemination	BS or Technical School	Standard Open Literature	High	
Readily Available	Standard Lab and Dissemination	BS or Technical School	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Standard Lab and Dissemination	BS or Technical School	Closely Held Military Information	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Technical Training	Readily Available	High	
Readily Available	Standard Lab and Dissemination	Advanced Technical Training	Standard Open Literature	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Technical Training	Closely Held Military Information	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Specialized Technical Training	Readily Available	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Specialized Technical Training	Standard Open Literature	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Specialized Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Standard Lab and Dissemination	Advanced Specialized Technical Training	Closely Held Military Information	Low	
Readily Available	Some Specialized	Low Level	Readily Available	High	
Readily Available	Some Specialized	Low Level	Standard Open Literature	High	
Readily Available	Some Specialized	Low Level	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Some Specialized	Low Level	Closely Held Military Information	Medium	
Readily Available	Some Specialized	BS or Technical School	Readily Available	High	
Readily Available	Some Specialized	BS or Technical School	Standard Open Literature	Medium	
Readily Available	Some Specialized	BS or Technical School	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Some Specialized	BS or Technical School	Closely Held Military Information	Medium	
Readily Available	Some Specialized	Advanced Technical Training	Readily Available	Medium	
Readily Available	Some Specialized	Advanced Technical Training	Standard Open Literature	Medium	
Readily Available	Some Specialized	Advanced Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Low	
Readily Available	Some Specialized	Advanced Technical Training	Closely Held Military Information	Low	
Readily Available	Some Specialized	Advanced Specialized Technical Training	Readily Available	Medium	
Readily Available	Some Specialized	Advanced Specialized Technical Training	Standard Open Literature	Medium	
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Readily Available	Custom-Designed or Manufactured	Low Level	Readily Available	High	
Readily Available	Custom-Designed or Manufactured	Low Level	Standard Open Literature	Medium	
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Readily Available	Custom-Designed or Manufactured	BS or Technical School	Standard Open Literature	Medium	
Readily Available	Custom-Designed or Manufactured	BS or Technical School	Specialized Scientific Literature or Declassified Military Docum.	Medium	
Readily Available	Custom-Designed or Manufactured	BS or Technical School	Closely Held Military Information	Low	
Readily Available	Custom-Designed or Manufactured	Advanced Technical Training	Readily Available	Medium	
Readily Available	Custom-Designed or Manufactured	Advanced Technical Training	Standard Open Literature	Medium	
Readily Available	Custom-Designed or Manufactured	Advanced Technical Training	Specialized Scientific Literature or Declassified Military Docum.	Low	
Readily Available	Custom-Designed or Manufactured	Advanced Technical Training	Closely Held Military Information	Low	
Readily Available	Custom-Designed or Manufactured	Advanced Specialized Technical Training	Readily Available	Medium	

Specify Output Fuzzy Set for Selected Rule: **High**

Accept Rules as Shown Cancel

Figure 3-5. Portion of Rule Base for "Relative Technical Feasibility"

4 Evaluation and Ranking of Scenarios

This section evaluates and ranks five scenarios using the LinguisticBelief model described in Section 3.2. First, the scenarios are evaluated without considering uncertainty. This evaluation produces the same results as an evaluation using the manual process described in Section 2. Then, the same scenarios are evaluated considering uncertainty, using the belief/plausibility measure of uncertainty built into LinguisticBelief. Once the scenarios are evaluated, they must be ranked in order of concern; for the example process, scenarios are ranked by “Risk Level.” With no consideration of uncertainty, the ranking is simple, based on the unique “Risk Level” for a scenario. With uncertainty, there is no unique “Risk Level” for a scenario and the ranking is performed using the complementary cumulative belief/plausibility function for “Risk Level.”

4.1 Evaluation Without Consideration of Uncertainty

To evaluate a scenario with LinguisticBelief, for each basic variable evidence is assigned to families of fuzzy sets. A family of fuzzy sets is a collection of fuzzy sets. For example, for “Intelligence Judgment” a family is: “Likely” and “Emerging.” A family may have only one element, for example: “Likely.” Each family of fuzzy sets with evidence is called a focal element. For a variable, if all the evidence is assigned to one fuzzy set, there is one focal element with one fuzzy set and there is no uncertainty for that variable. For example, Figure 4-1 shows assignment of all the evidence to the fuzzy set “Possible” for the variable “Intelligence Judgment.”

Figure 4-1. “Intelligence Judgment” as “Possible” with No Uncertainty

The five scenarios evaluated with no consideration of uncertainty are denoted as: CBRNE_1A, CBRNE_2A, CBRNE_3A, CBRNE_4A, and CBRNE_5A. The “A” indicates that uncertainty was not considered.

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Table 4-1 summarizes the focal elements for the basic variables for each scenario chosen by the group for modeling purposes.

Table 4-1. Focal Elements for Scenarios: No Consideration of Uncertainty

Basic Variable	CBRNE_1A	CBRNE_2A	CBRNE_3A	CBRNE_4A	CBRNE_5A
Material	Easily Produced	Readily Available	Readily Available	Readily Available	Very Difficult to Produce/ Acquire
Equipment	Some Specialized	Standard Lab and Dissemination	Standard Lab and Dissemination	No Specialized	Some Specialized
Technical Expertise	BS or Technical School	BS or Technical School	Low Level	Low Level	Advanced Technical Training
Knowledge	Specialized Scientific Literature or Declassified Military Documents	Standard Open Literature	Readily Available	Readily Available	Specialized Scientific Literature or Declassified Military Documents
Dead/ Injured	More than 500 Dead or 5000 Injured	From 101 to 500 Dead or from 1001 to 5000 Injured	From 101 to 500 Dead or from 1001 to 5000 Injured	More than 500 Dead or 5000 Injured	More than 500 Dead or 5000 Injured
Disruption of Capability/ Capacity	Extensive	Extensive	Serious	Serious	Extensive
Economic Loss	More than \$1 Billion	More than \$1 Billion	From \$100 Million to \$499 Million	From \$500 Million to \$1 Billion	More than \$1 Billion
Intensity of Response	State or Province	National or International	Local	Local	National or International
Intelligence Judgment	Possible	Likely	Likely	Likely	Possible

These focal elements were entered into the LinguisticBelief model for each scenario. The result for “Risk Level” for one of the scenarios, CBRNE_5A, as summarized graphically in the code is provided in Figure 4-2.

The top graph in Figure 4-2 is the belief/plausibility function for “Risk Level,” or the “likelihood” for each fuzzy set for “Risk Level.” Since there is no uncertainty, only one fuzzy set has all the likelihood, in this case “High” with likelihood 1.0 for both belief and plausibility. We are certain that the risk for this scenario is “High.” With specific evidence, both belief and plausibility are the same: probability. Certainty is a case where the probability is 1.0 for one fuzzy set. [Darby 2006 and 2007]

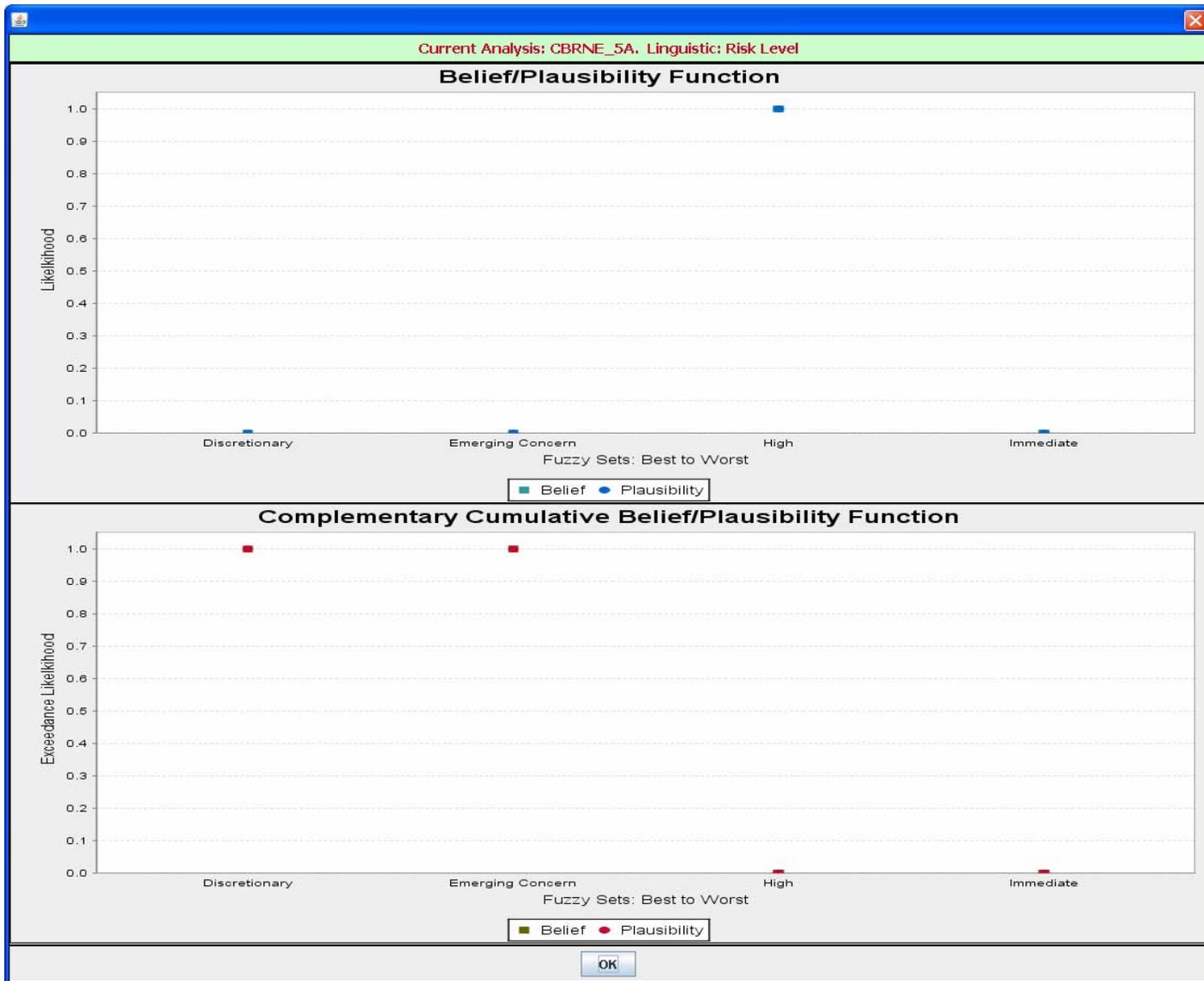


Figure 4-2. Graphical Results for "Risk Level" for Scenario CBRNE_5A

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The bottom graph in Figure 4-2 is the complementary cumulative belief/plausibility function for “Risk Level,” or the “likelihood” of *exceedance* of a fuzzy set for “Risk Level.” The likelihood that “Risk Level” is *greater* than “Discretionary” is 1.0, the likelihood that “Risk Level” is *greater* than “Emerging Concern” is 1.0, and the likelihood that “Risk Level” is *greater* than “High” is 0.0 since we are certain that the risk for this scenario is “High.” The complementary cumulative belief/plausibility function is not needed to rank-order scenarios with no uncertainty. The complementary cumulative belief/plausibility function is used to rank scenarios with uncertainty as discussed in Section 4.4.

The “Risk Level” for the five scenarios with no consideration of uncertainty is provided in Table 4-2. These results were calculated using LinguisticBelief. The same results are achieved using the information in Table 4-1 in a manual evaluation using the process of Section 2.

Table 4-2. Risk Level for Scenarios with No Consideration of Uncertainty

Scenario	Risk Level
CBRNE_1A	High
CBRNE_2A	Immediate
CBRNE_3A	Immediate
CBRNE_4A	Immediate
CBRNE_5A	High

4.2 Ranking Without Consideration of Uncertainty

With no consideration of uncertainty, each scenario has a unique “Risk Level” and the scenarios are ranked by that “Risk Level.” The scenario ranking by decreasing “Risk Level” is given in Table 4-3.

Table 4-3. Ranking of Scenarios by “Risk Level” with No Consideration of Uncertainty

Scenarios Ranked (Decreasing)	Risk Level
CBRNE_2A, CBRNE_3A, CBRNE_4A	Immediate
CBRNE_1A, CBRNE_5A	High
<i>None</i>	Emerging Concern
<i>None</i>	Discretionary

Note that some scenarios have equal ranking; for example, CBRNE_2A, CBRNE_3A, and CBRNE_4A are all ranked “Immediate.” CBRNE_1A and CBRNE_5A are both ranked “High.”

4.3 Evaluation With Consideration of Uncertainty

LinguisticBelief uses the belief/plausibility measure of uncertainty, thereby allowing evidence to be assigned to families of fuzzy sets for each basic variable. For example, Figure 4-3 shows such an assignment for “Intelligence Judgment.”

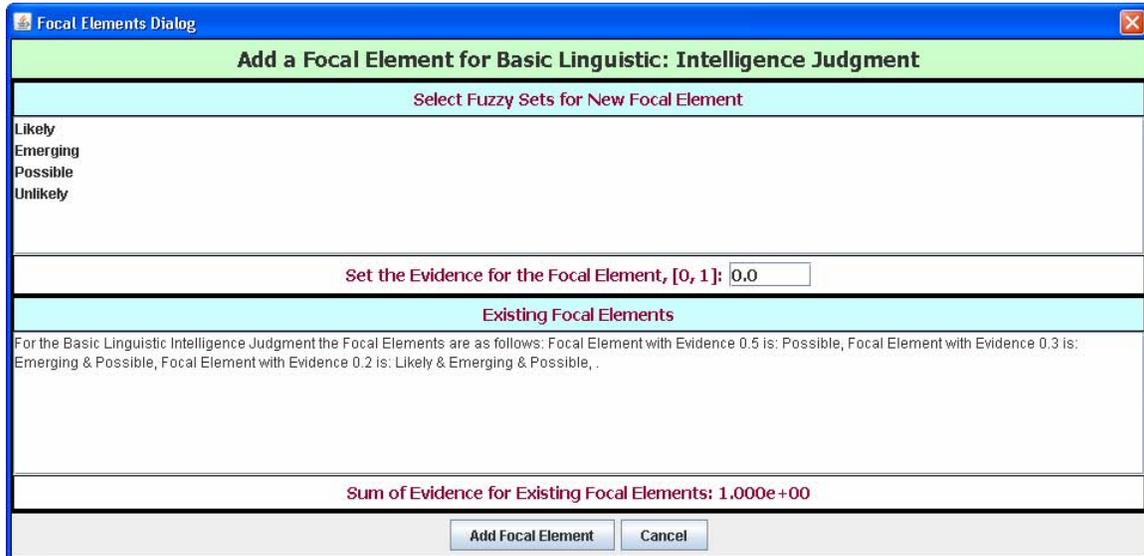


Figure 4-3. “Intelligence Judgment” with Uncertainty

In this discussion, the “&” symbol denotes combinations of fuzzy sets in the family of fuzzy sets for the focal element. If every focal element has only one fuzzy set, belief and plausibility both become probability. If there is only one focal element with only one fuzzy set, that fuzzy set has a probability of 1.0 and there is no uncertainty. Refer to Section 4.1 for a discussion of this situation.

Based on the information available for the scenario of concern, evidence of 0.5 is assigned to “Possible,” evidence of 0.3 is assigned to “Emerging”& “Possible,” and evidence of 0.2 is assigned to “Likely”& “Emerging”& “Possible.” Using these focal elements, the likelihood distribution for “Intelligence Judgment” calculated by LinguisticBelief is given in Figure 4-4.

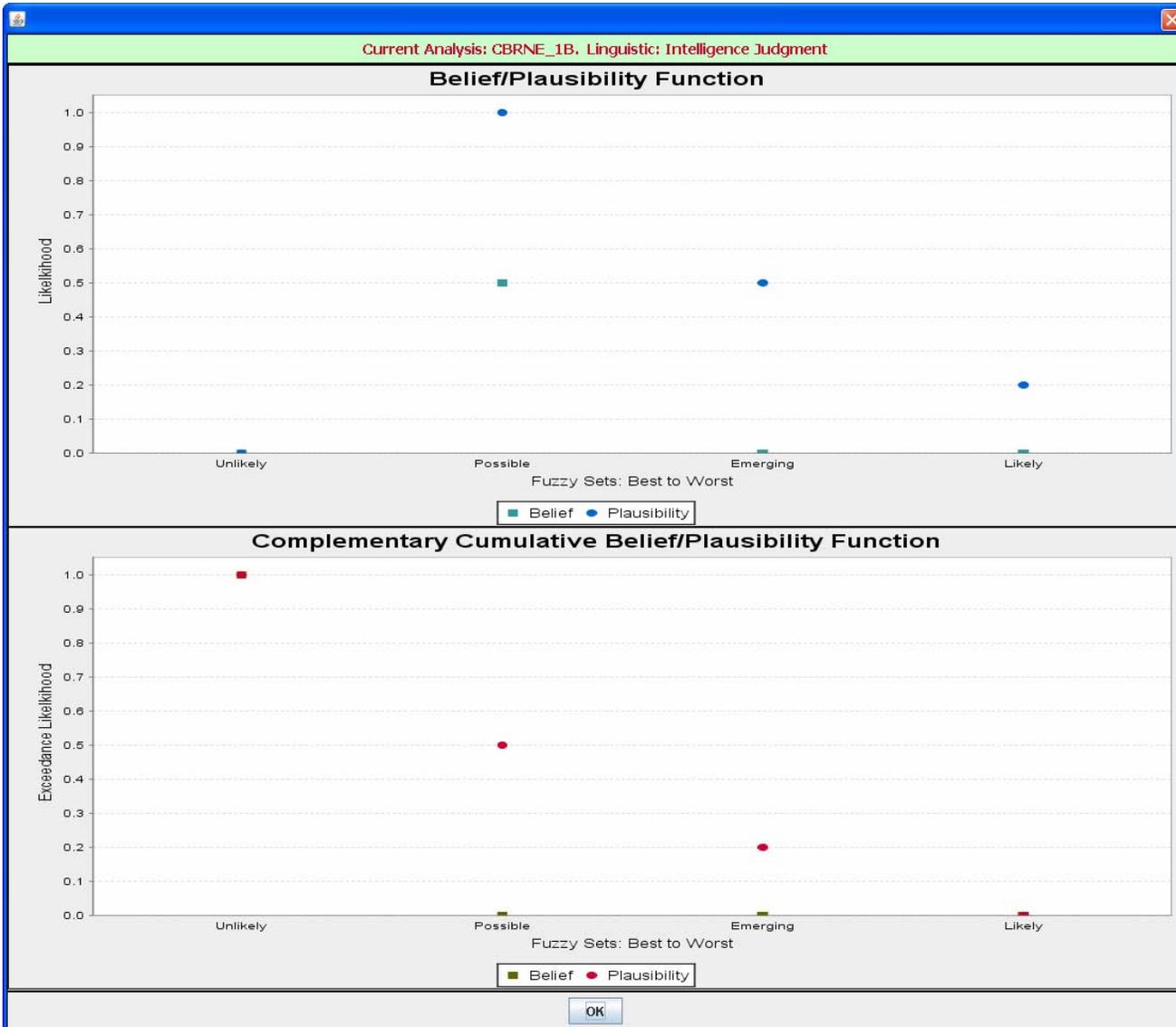


Figure 4-4. Likelihood for "Intelligence Judgment"

Linguistic Evaluation of Terrorist Scenarios: Example Application

Likelihood is given as a belief/plausibility interval. Belief and plausibility can be interpreted as lower and upper bounds on probability, respectively, as discussed in Section 3.1. The top graph in Figure 4-4 shows the belief/plausibility function, or the “likelihood” for each fuzzy set for “Intelligence Judgment.” For example, the likelihood of “Possible” “Intelligence Judgment” is an interval with a lower limit (belief) of 0.5 and an upper limit (plausibility) of 1.0. The bottom graph shows the complementary cumulative belief/plausibility function, or the “likelihood” of *exceedance* for each fuzzy set. For example, the likelihood that “Intelligence Judgment” is *greater* than “Possible” is an interval with lower limit (belief) of 0 and upper limit (plausibility) of 0.5. Note that both the belief and plausibility for *exceeding* “Likely” will always be zero, since “Likely” is the worst of the fuzzy sets (ordered from best to worst).

The five scenarios of Section 4.1 were evaluated considering uncertainty. The five scenarios evaluated with uncertainty are denoted as: CBRNE_1B, CBRNE_2B, CBRNE_3B, CBRNE_4B, and CBRNE_5B. The “B” indicates that uncertainty was considered. Table 4-4 summarizes the focal elements for these scenarios.

Figure 4-5 shows the result from LinguisticBelief for “Risk Level” for one of the scenarios, CBRNE_5B.

4.4 Ranking With Consideration of Uncertainty

Using the complementary cumulative belief/plausibility function, scenarios can be ranked by non-zero plausibility of exceeding the “worst” fuzzy set (decreasing). For scenarios with equal ranking by plausibility, these scenarios are subranked by belief of exceeding the fuzzy set (decreasing). Figures 4-6 through 4-10 graphically illustrate this ranking criteria applied to the five scenarios.

Table 4-4. Focal Elements for Scenarios: With Uncertainty

Basic Variable	CBRNE_1B Focal Element – Evidence	CBRNE_2B Focal Element – Evidence	CBRNE_3B Focal Element – Evidence	CBRNE_4B Focal Element – Evidence	CBRNE_5B Focal Element – Evidence
Material	Easily Produced – 0.6 Easily Produced & Difficult to Produce- 0.3 Readily Available & Easily Produced & Difficult to Produce – 0.1	Readily Available – 0.8 Readily Available & Easily Produced – 0.2	Readily Available – 0.9 Readily Available & Easily Produced – 0.1	Readily Available & Easily Produced – 1.0	Very Difficult to Produce/ Acquire – 1.0
Equipment	Some Specialized – 0.9 Specialized & Custom-Designed or Manufactured – 0.1	Standard Lab and Dissemination – 0.5 No Specialized & Standard Lab and Dissemination – 0.5	No Specialized – 0.5 No Specialized & Standard Lab and Dissemination – 0.5	No Specialized & Standard Lab and Dissemination – 1.0	Some Specialized – 0.5 Standard Lab and Dissemination & Some Specialized – 0.5
Technical Expertise	BS or Technical School – 0.8 BS or Technical School & Advanced Technical Training – 0.2	BS or Technical School – 0.8 Low Level & BS or Technical School – 0.2	Low Level & BS or Technical School – 1.0	Low Level & BS or Technical School – 1.0	Advanced Technical Training – 0.4 BS or Technical School & Advanced Technical Training & Advanced Specialized Technical Training – 0.6
Knowledge	Specialized Scientific Literature or Declassified Military Documents – 0.4 Standard Open Literature & Specialized Scientific Literature or Declassified Military Documents – 0.6	Standard Open Literature – 0.3 Readily Available & Standard Open Literature – 0.7	Readily Available & Standard Open Literature – 1.0	Readily Available -0.3 Readily Available & Standard Open Literature – 0.7	Specialized Scientific Literature or Declassified Military Documents – 0.5 Standard Open Literature & Specialized Scientific Literature or Declassified Military Documents – 0.5

Basic Variable	CBRNE_1B Focal Element – Evidence	CBRNE_2B Focal Element – Evidence	CBRNE_3B Focal Element – Evidence	CBRNE_4B Focal Element – Evidence	CBRNE_5B Focal Element – Evidence
Dead/ Injured	More than 500 Dead or 5000 Injured – 0.5	From 101 to 500 Dead or from 1001 to 5000 Injured – 0.7	From 101 to 500 Dead or from 1001 to 5000 Injured – 0.6	More than 500 Dead or 5000 Injured – 0.4	More than 500 Dead or 5000 Injured – 0.9
	More than 500 Dead or 5000 Injured & From 101 to 500 Dead or from 1001 to 5000 Injured – 0.5	From 101 to 500 Dead or from 1001 to 5000 Injured & From 101 to 100 Dead or from 100 to 1000 Injured – 0.3	From 101 to 500 Dead or from 1001 to 5000 Injured & From 10 to 100 Dead or from 100 to 1000 Injured – 0.4	More than 500 Dead or 5000 Injured & From 101 to 500 Dead or from 1001 to 5000 Injured – 0.6	More than 500 Dead or 5000 Injured & From 101 to 500 Dead or from 1001 to 5000 Injured – 0.1
Disruption of Capability/ Capacity	Extensive – 0.9	Extensive – 0.8	Serious – 0.6	Serious – 0.8	Extensive – 1.0
	Extensive & Serious – 0.1	Extensive & Serious – 0.2	Serious & Moderate – 0.3 Extensive & Serious & Moderate – 0.1	Serious & Moderate – 0.2	
Economic Loss	More than \$1 Billion – 1.0	More than \$1 Billion & From \$500 Million to \$1 Billion – 1.0	From \$100 Million to \$499 Million – 0.6	From \$500 Million to \$1 Billion – 0.7	More than \$1 Billion – 0.8
			From \$500 Million to \$1 Billion & From \$100 Million to \$499 Million – 0.4	More than \$1 Billion & From \$500 Million to \$1 Billion – 0.3	More than \$1 Billion & From \$500 Million to \$1 Billion – 0.2
Intensity of Response	State or Province – 0.6	National or International – 1.0	Local – 0.8	Local – 0.6	National or International – 1.0
	National or International & State or Province – 0.4		State or Province & Local – 0.2	Provincial & Local -0.4	
Intelligence Judgment	Possible – 0.5	Likely – 0.3	Likely – 0.2	Likely – 0.5	Possible & Unlikely – 1.0
	Emerging & Possible – 0.3 Likely & Emerging & Possible – 0.2	Likely & Emerging – 0.7	Likely & Emerging – 0.8	Likely & Emerging – 0.5	

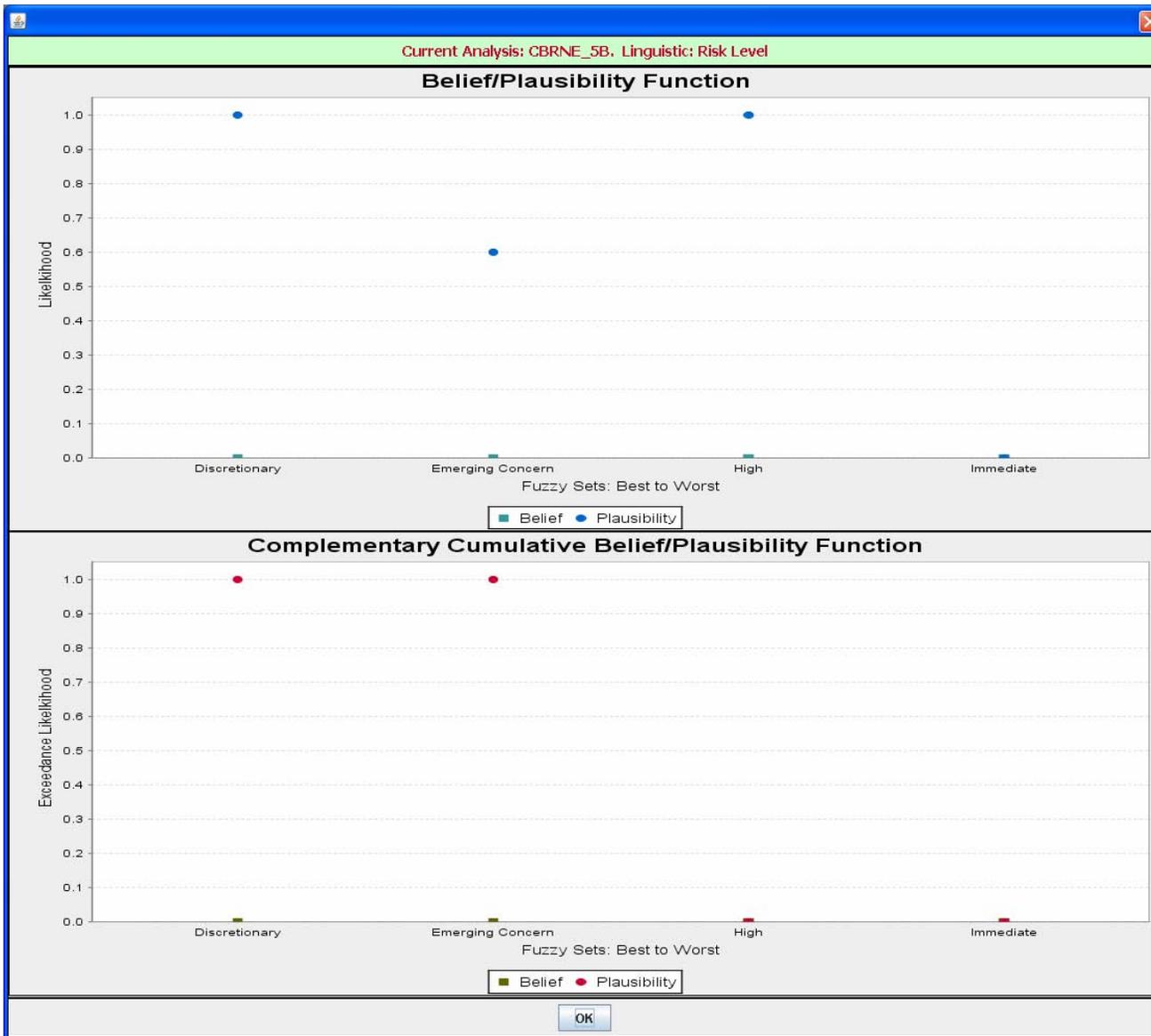


Figure 4-5. "Risk Level" for Scenario CBRNE_5B With Uncertainty

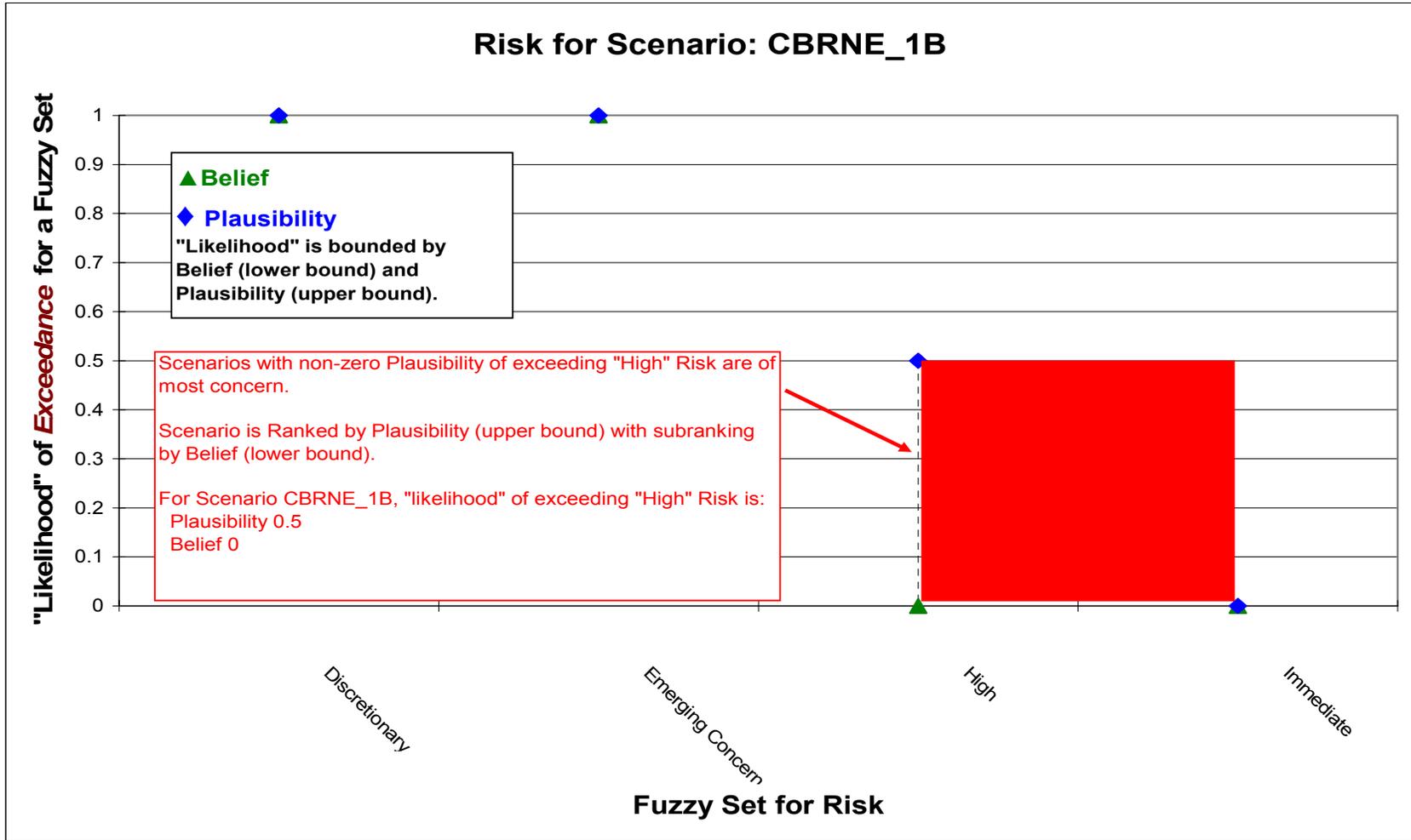


Figure 4-6. Graphical Representation for Ranking of Scenario CBRNE_1B

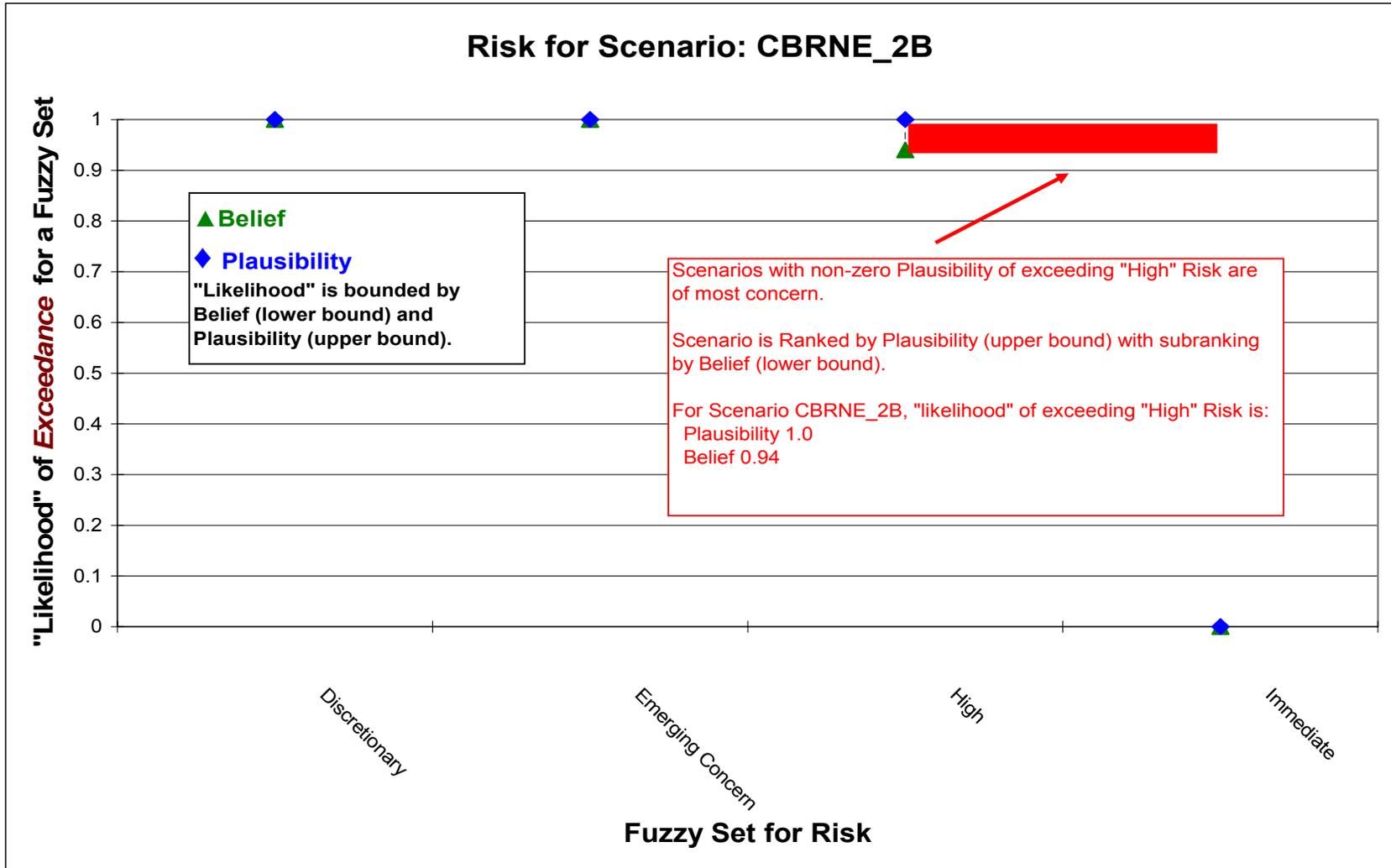


Figure 4-7. Graphical Representation for Ranking of Scenario CBRNE_2B

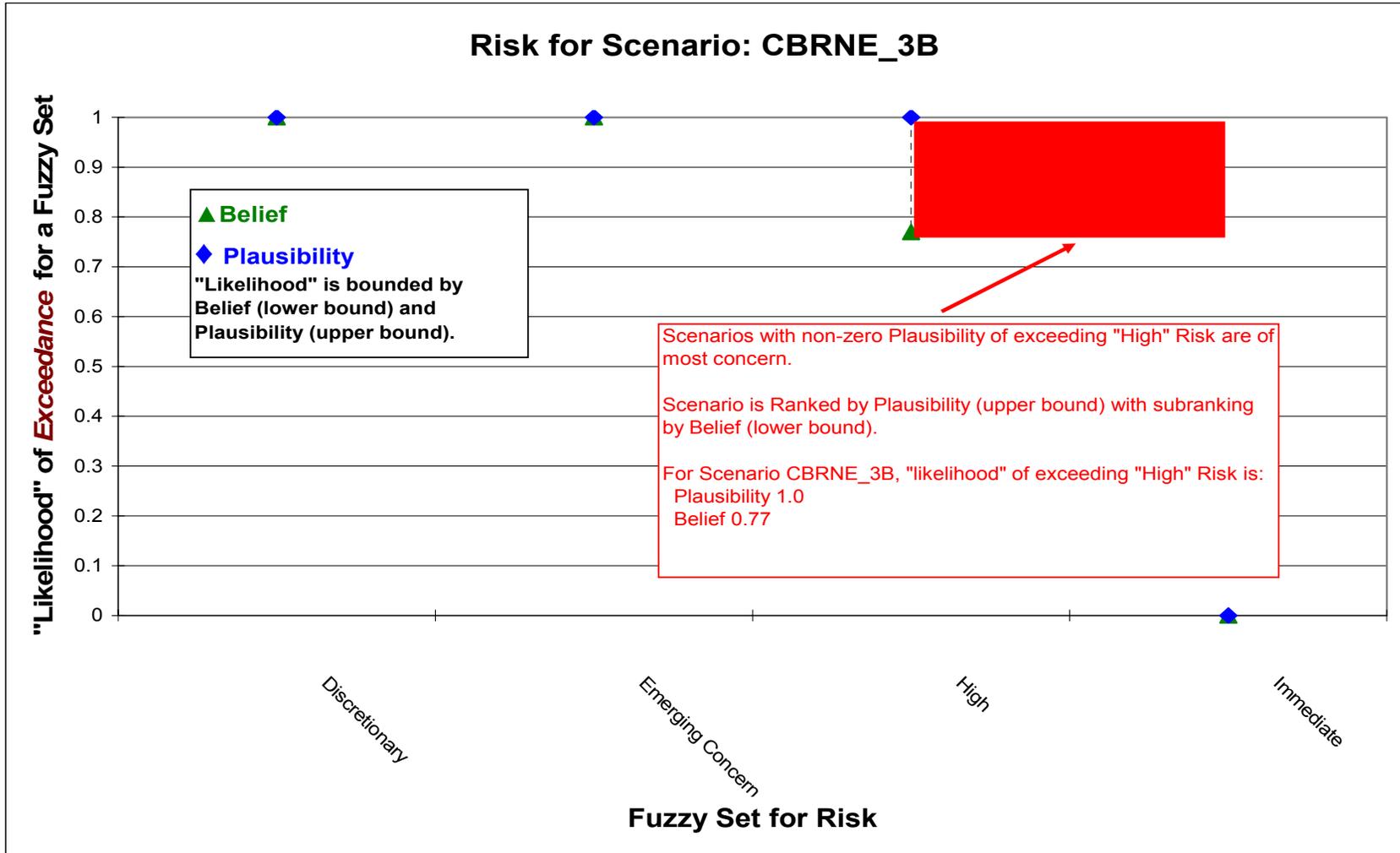


Figure 4-8. Graphical Representation for Ranking of Scenario CBRNE_3B

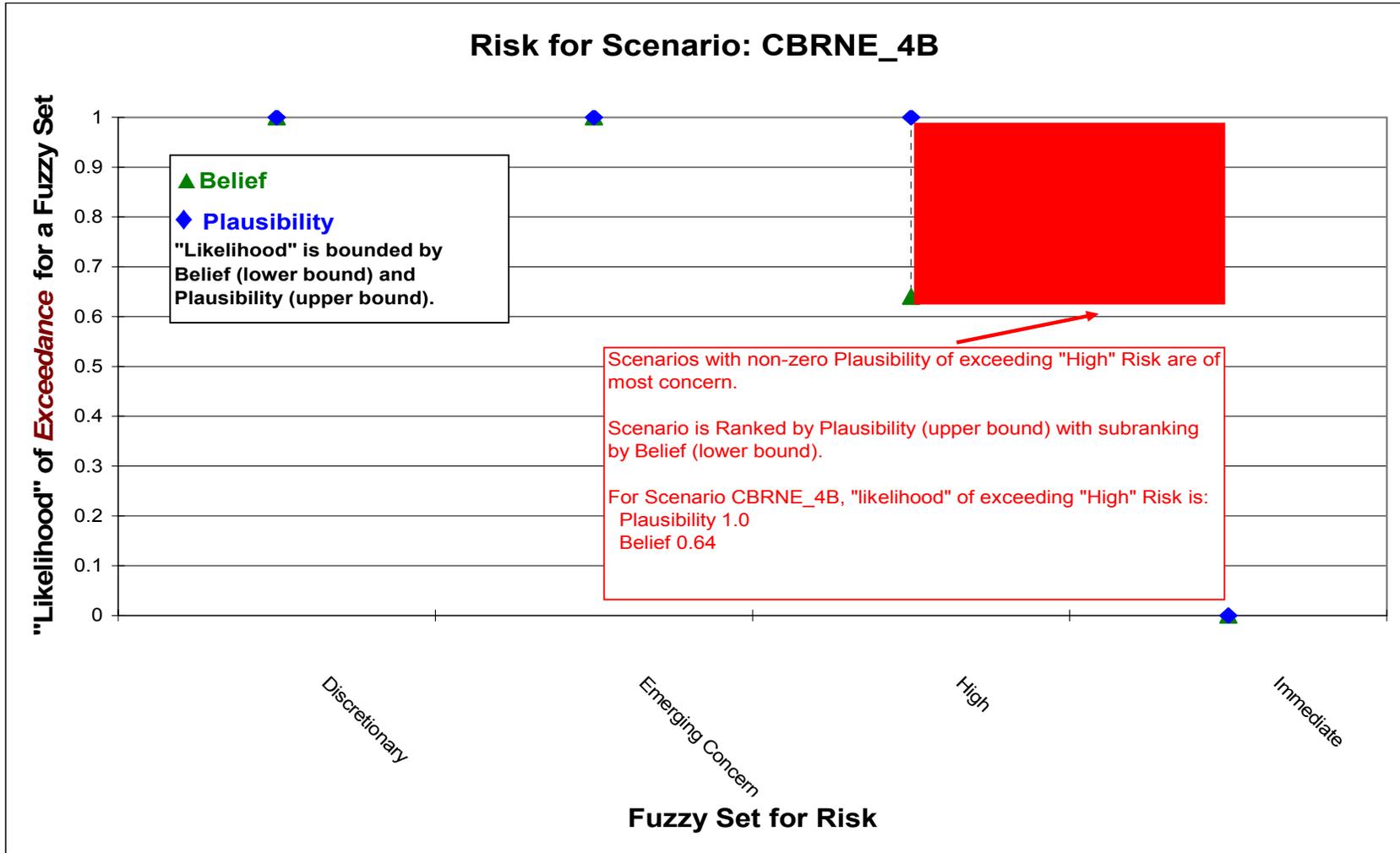


Figure 4-9. Graphical Representation for Ranking of Scenario CBRNE_4B

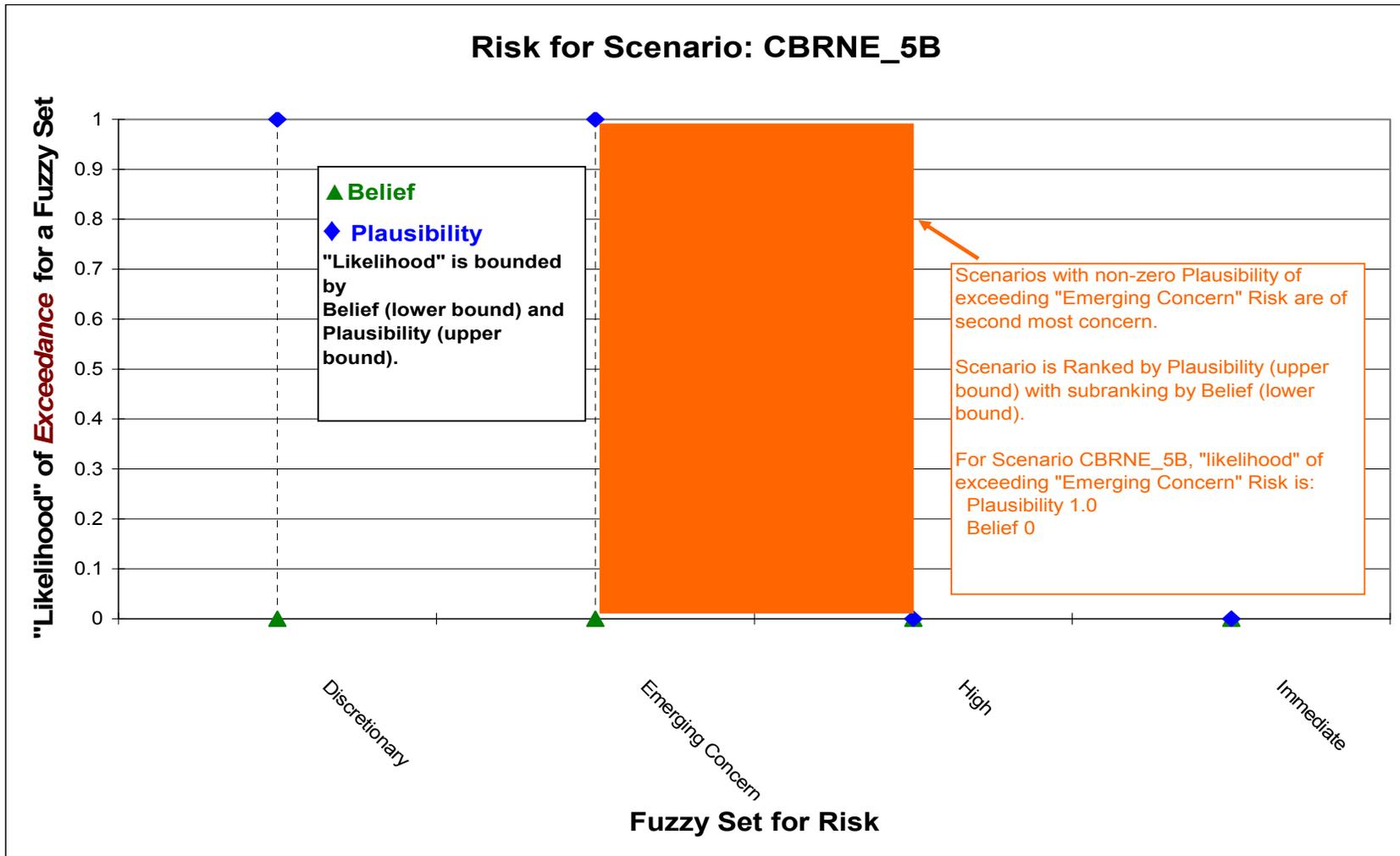


Figure 4-10. Graphical Representation for Ranking of Scenario CBRNE_5B

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The graphs indicate that three scenarios have a plausibility of 1.0 of *exceeding* “Risk Level” “High”: CBRNE_2B, CBRNE_3B, and CBRNE_4B. Of these three, CBRNE_2B has the highest belief, 0.94, of *exceeding* “Risk Level” “High.” Therefore, Scenario CBRNE_2B is of most concern, followed by scenario CBRNE_3B and scenario CBRNE_4B. Of the two remaining scenarios, CBRNE_1B and CBRNE_5B, CBRNE_1B is of more concern since it has a plausibility of 0.5 of *exceeding* “Risk Level” “High,” while scenario CBRNE_5B has zero plausibility of *exceeding* “Risk Level” “High.”

The ranking process has been automated in a Java utility program, RankScenarios. Using this program, the ranking of the scenarios is given in Listing 4-1.

Listing 4-1. Ranking of Scenarios by “Risk Level” Considering Uncertainty

RANKING FOR SCENARIOS CBRNE_1B through CBRNE_5B

For Exceeding Fuzzy Set “High” the Scenarios rank ordered (decreasing) are:

- CBRNE_2B has plausibility of exceedance of 1.0 and belief of exceedance of 0.94
- CBRNE_3B has plausibility of exceedance of 1.0 and belief of exceedance of 0.77
- CBRNE_4B has plausibility of exceedance of 1.0 and belief of exceedance of 0.64
- CBRNE_1B has plausibility of exceedance of 0.5 and belief of exceedance of 0.0

For Exceeding Fuzzy Set “Emerging Concern” the Scenarios rank ordered (decreasing) (not already ranked for a worse fuzzy set) are:

- CBRNE_5B has plausibility of exceedance of 1.0 and belief of exceedance of 0.0

Table 4-5 compares the ranking of scenarios considering uncertainty to the ranking without considering uncertainty from Section 4.1.

Table 4-5. Ranking of Scenarios With and Without Consideration of Uncertainty

Scenarios Ranked (Decreasing) Considering Uncertainty	Scenarios Ranked (Decreasing) Without Considering Uncertainty
CBRNE_2B	CBRNE_2A, CBRNE_3A, CBRNE_4A
CBRNE_3B	CBRNE_1A, CBRNE_5A
CBRNE_4B	
CBRNE_1B	
CBRNE_5B	

Note that the consideration of uncertainty results in a finer ranking of scenarios than the earlier evaluation without consideration of uncertainty in Section 4.1. That is, considering uncertainty none of the scenarios have equal rank, but without considering uncertainty some do. This is because without allowing for uncertainty, the evaluation forces selection of only one bin (fuzzy

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set) for each variable; therefore, similar scenarios that may have slightly different evidence over the bins for a variable are forced to be assigned the same bin with no uncertainty.

It is interesting to note that with consideration of uncertainty scenario CBRNE_1B has a significant likelihood (plausibility of 0.5) of exceeding “High” “Risk Level” (Listing 4-1), whereas without considering uncertainty, scenario CBRNE_1A has no likelihood of exceeding “High” “Risk Level” (Table 4-3).

5 Enhancements to the Process

Section 4 summarized an evaluation of five scenarios using the risk process of Section 2 implemented in the LinguisticBelief tool. As previously discussed, the original risk assessment process was a manual process. With automation in LinguisticBelief, the process can be enhanced.

5.1 Treatment of Uncertainty

The original, manual risk assessment process does not address uncertainty; consideration of uncertainty is not feasible in a manual process. However, there is significant uncertainty, much of it epistemic, in evaluating an intentional terrorist act, and that uncertainty should be included in the evaluation for the results to be more useful.

LinguisticBelief automates the use of fuzzy sets, approximate reasoning, and belief/plausibility for a linguistic evaluation process thereby allowing uncertainty to be captured and propagated.

5.2 Consistent Use of Fuzzy Sets

The bins used for the non-numeric variables are fuzzy sets (words); for example “Intelligence Judgment” is segregated into “Unlikely,” “Possible,” “Emerging,” and “Likely.” Some of the numeric variables- such as “Dead/Injured”- use bins that are not fuzzy as subsequently discussed. One enhancement is to use fuzzy sets for all the variables.

As indicated in Table 2-3, the bins for “Dead/Injured” are: “More than 500 dead or 5000 injured,” “From 101 to 500 dead or from 1001 to 5000 injured,” “From 10 to 100 dead or from 100 to 1000 injured,” and “Fewer than 10 dead or 100 injured.” The purpose of the bins is to reason at a level where differences matter in the context of all the possible scenarios of concern. For example, whether the actual number of deaths is 200 or 300 is not a major factor in ranking a scenario, so both are considered in the bin “From 101 to 500 dead or from 1001 to 5000 injured.” Therefore, the bins *do* solve the problem of reasoning at too fine a level of detail.

However, there is a problem with these bins; they are *too sharp*. The bins are crisp sets, since each specific value of the variable is either totally in or totally out of each of the bins. For example, “501 dead” is completely in the bin “More than 500 dead or 5000 injured” and is not considered in any of the other bins. “500 dead” is completely in the bin “From 101 to 500 dead or from 1001 to 5000 injured.” The sharpness of the bins forces a major distinction between

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“501 dead” and “500 dead” in that these two values are placed in different bins, although the difference in the actual value is minute—one death.

A better approach is to consider “500 dead” as partially in each of two bins, and that can be achieved by re-defining the bins as fuzzy sets, specifically: “More than *about* 500 dead or *about* 5000 injured,” “From *about* 100 to *about* 500 dead or from *about* 1000 to *about* 5000 injured,” “From *about* 10 to *about* 100 dead or from *about* 100 to *about* 1000 injured,” and “Fewer than *about* 10 dead or *about* 100 injured.”

Now, “500 dead” is partially in the two fuzzy sets: “More than *about* 500 dead or *about* 5000 injured” and “From *about* 100 to *about* 500 dead or from *about* 1000 to *about* 5000 injured.” For a specific scenario, if the consequence is known with certainty to be “500 dead,” evidence of 0.5 should be assigned to the each of two focal elements, each focal element containing one of these fuzzy sets.

5.3 Consistent Reasoning with Linguistics

As discussed in Section 1, the original manual process uses numeric scores to assist with part of the evaluation. Specifically, the evaluations of “Relative Technical Feasibility” and “Potential Impact” use the scores in Tables 2-1 and 2-3. However, part of the evaluation does not use numeric scores; for example, the evaluations of “Vulnerability” and “Risk Level” in Tables 2-5 and 2-6 do not use numeric scores.

It is recommended that numeric scores not be used at all, since they have no absolute meaning and are merely used to facilitate the combination of fuzzy sets from different variables. This can be better done by reasoning on the fuzzy sets themselves instead of using arbitrary relative numbers for the fuzzy sets. Figure 3-5 illustrates the rule base for “Relative Technical Feasibility” which is equivalent to the evaluation process using Tables 2-1 and 2-2, but this rule base does not require the use of arbitrary numeric scores.

Also, the use of surrogate numbers to represent linguistic concepts is too restrictive. For example, a linguistic rule base can easily reason on selected outputs as the minimum (or maximum) of selected inputs, or an output can be specified to be greater than the “sum” of its inputs due to synergistic effects. Such rules are difficult to generate using numbers.

5.4 Expansion of the Process

A manual evaluation process is difficult to extend and apply to a large number of scenarios. In LinguisticBelief the automated process can be extended easily and applied to a large number of scenarios.

For example, the original process considers “Intelligence Judgment” as a basic variable in the evaluation of “Risk Level” in Table 2-6. With the LinguisticBelief tool, “Intelligence Judgment” can be expressed easily as consisting of other variables such as “Adversary Estimate of Consequence Achievable” and “Adversary Estimate of Resources Required,” to reflect the adversary consideration of the consequence and resources required in selecting a scenario.

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Furthermore, “Adversary Estimate of Resources Required” can be modeled as consisting of “Adversary Estimate of Information Required” and “Adversary Estimate of Attributes Required” to address both the information-gathering and attribute-gathering aspects of the scenario. Here, adversary Resources include Attributes (equipment, weapons, number of attackers) and Information (perhaps from insiders).

Figure 5-1 shows the LinguisticBelief model with “Intelligence Judgment” expanded in this manner.

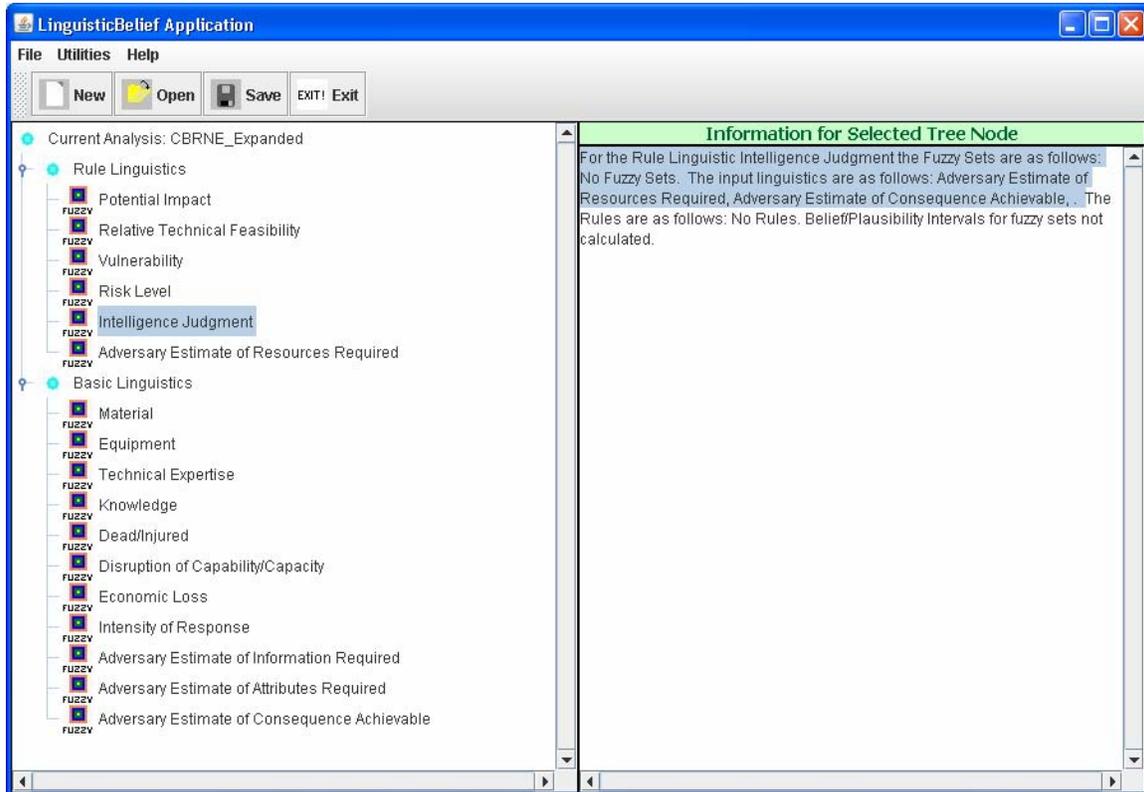


Figure 5-1. Expansion of “Intelligence Judgment” in the Model

6 Summary

The LinguisticBelief tool was applied to automate an existing, manual process for evaluating the potential risk from terrorist scenarios. The original process does not include uncertainty. Example scenarios were evaluated without considering uncertainty to illustrate the automation of the original process.

Since in actual application there is significant uncertainty, much of it epistemic, example scenarios were evaluated considering uncertainty using the built-in capabilities of the LinguisticBelief tool. A technique for ranking scenarios with uncertainty was presented.

With the automation of the original process using the techniques built into LinguisticBelief, improvements to the process can be made in the following areas:

1. Uncertainty can be captured and propagated.
2. Arbitrary numeric scores can be removed.
3. All variables can be evaluated using fuzzy sets.
4. The process can be expanded easily to reason at a finer level.

It is concluded that the LinguisticBelief tool is able to automate an expert-generated reasoning process for the evaluation of the risk of terrorist scenarios, including uncertainty, and quickly evaluate and rank order scenarios of concern using that process.

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