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Evaluating Risk from Acts of Terrorism with Belief and Fuzzy Sets

SAND XXXX

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Presentation Topics

- Risk
  - Intentional acts are different from Random acts
- Uncertainty
  - Epistemic uncertainty
  - Ambiguity and Vagueness
- Adversary/Defender Model for Evaluation of Risk from Intentional Acts of Terrorism

Risk of Terrorist Attack

- Risk = f x P x C
  - Risk of a successful terrorist attack
  - f is frequency of attack
  - P is probability adversaries succeed given attack
  - C is consequence given adversaries succeed
- Risk depends on the Adversary Scenario
  - Scenario: Adversary Resources, Target, Attack Plan
- Why Evaluate Risk?
  - Allocation of Resources for Protection

Risk of Terrorist Attack

- What is frequency f_i for a Scenario "i"?
- Which "i" scenarios?

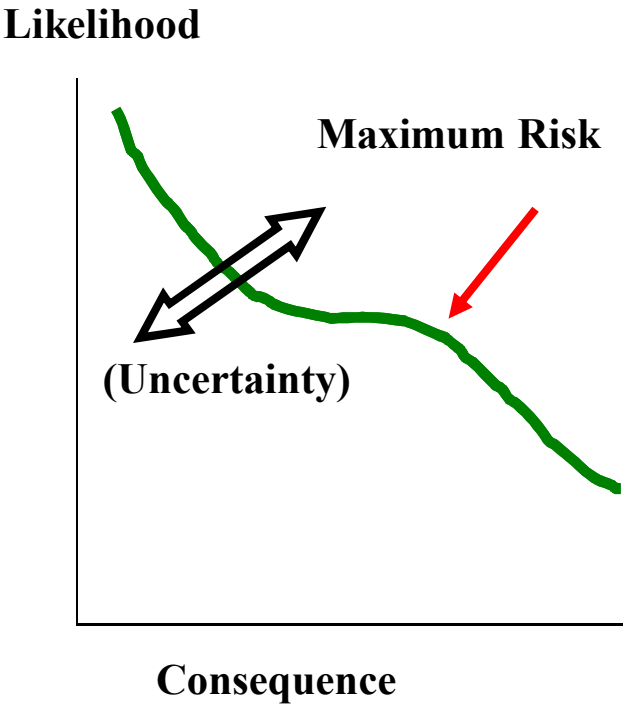
$$Risk_i = f_i \times P_i \times C_i$$

Adversary: Select scenario "i" from choice of *all* scenarios

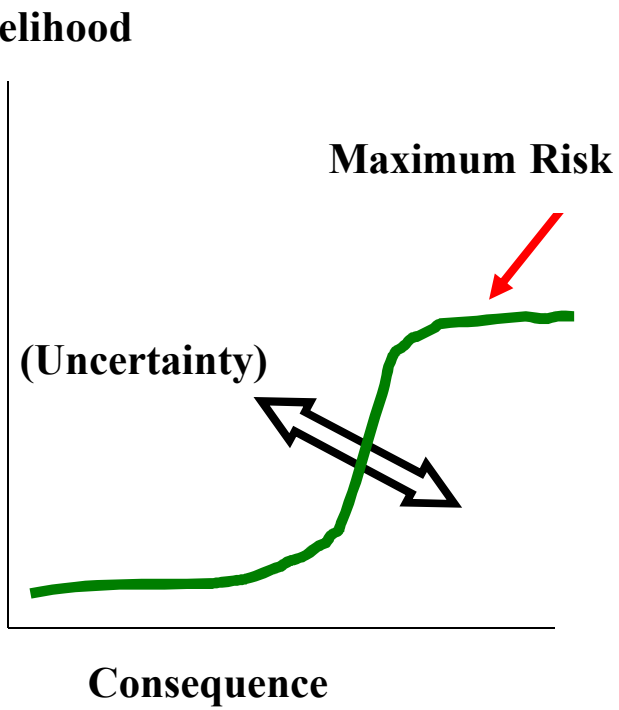
Defender: Evaluate the *single* scenario "i"

Safety Risk vs. Terrorist Risk

Safety Risk (Random)



Terrorist Risk (Intentional)



Uncertainty

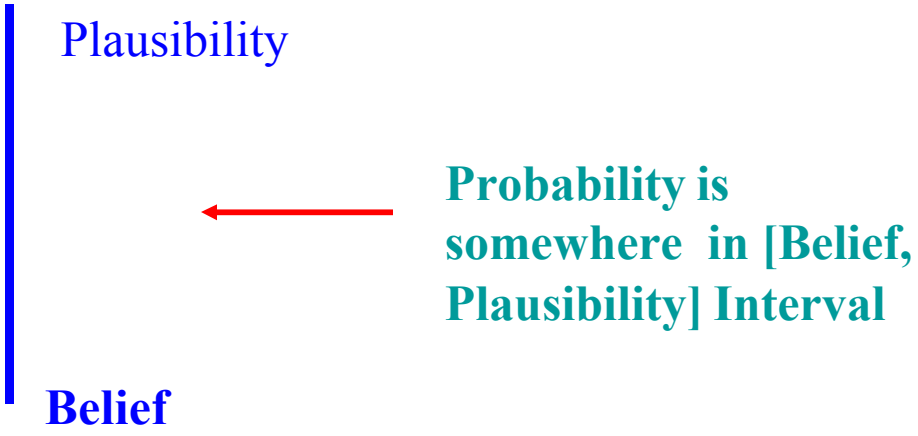
- Ambiguity
  - Uncertainty as to what will occur in the future
    - Dow Jones Industrial Average Close on Dec. 31, 2006
      - Will be one value
      - Ambiguity as to what that value will be
- Vagueness
  - Uncertainty as how to categorize a known outcome
    - Dow Jones close is 11,300 on Dec. 31, 2006
      - Is this “High” ?
      - What do you mean by “High”?
  - Vagueness can be expressed Linguistically (Words)

Belief/Plausibility for Epistemic Uncertainty

- For a Fair Coin
  - Uncertainty is Aleatory (random)
  - Probability Heads is ½
  - Probability Tails is ½
- But if we cannot toss coin, we do not know coin is fair, we do not even knows if coin has Heads and Tails
  - May not be Fair Coin (may be Weighted for Tails)
  - May be Two-Headed or Two-Tailed Coin
  - Epistemic (state of knowledge) uncertainty
  - Insufficient information to assign Probability to Heads and Tails
  - For Total Ignorance
    - Belief/Plausibility for Heads is 0/1
    - Belief/Plausibility for Tails is 0/1
- With more information (actually tossing the coin) we can reduce Epistemic Uncertainty
  - If at least one Heads and one Tails occur in a series of tosses, we know coin has Heads and Tails
  - Many tosses needed to assess if coin is fair
- For Fair Coin we cannot reduce aleatory uncertainty

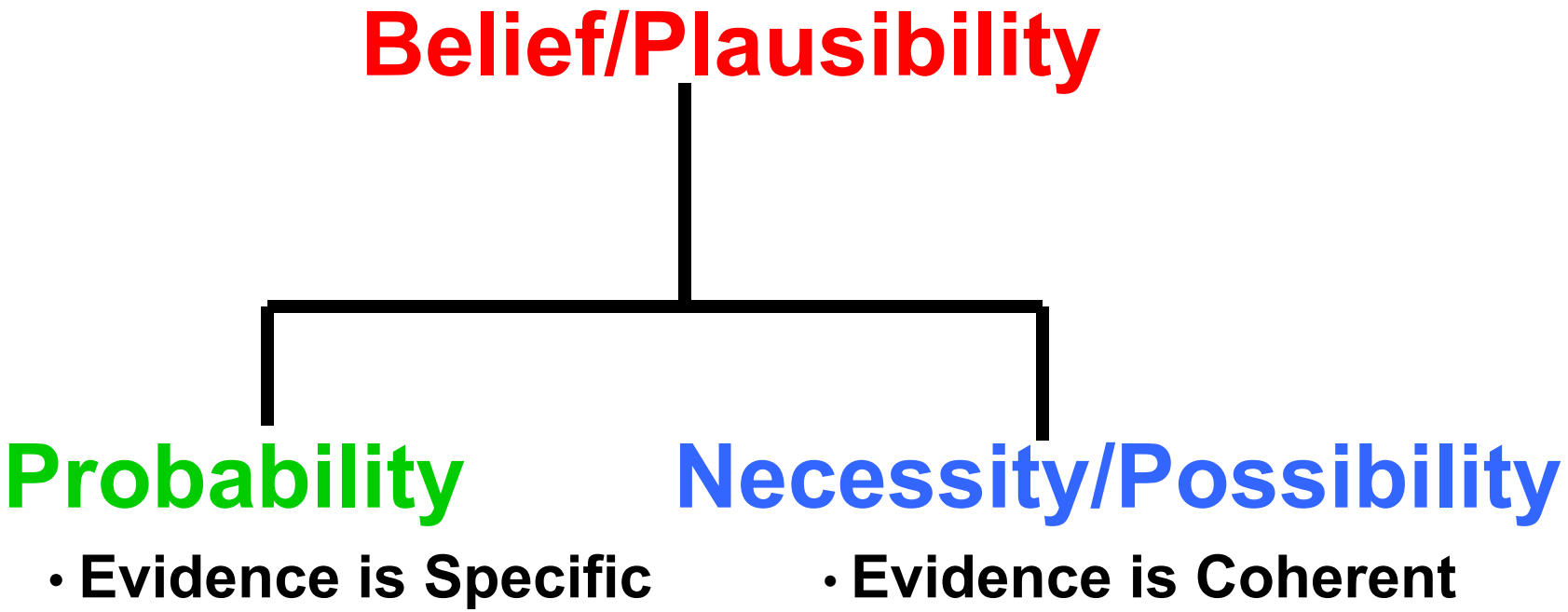
Belief and Plausibility

- Belief / Plausibility form a Lower / Upper Bound for Probability
- Belief is what probability will be
- Plausibility is what probability could be



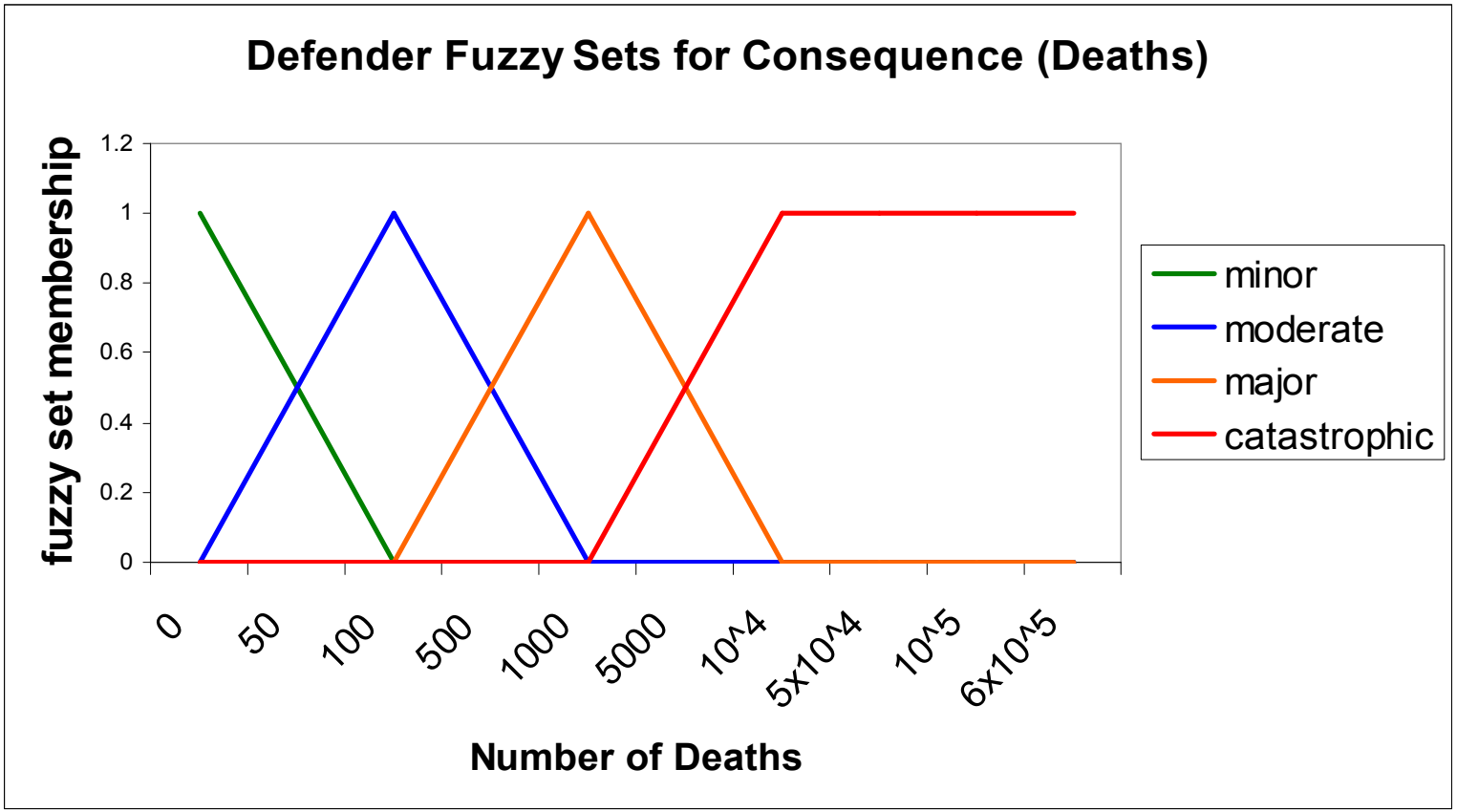
- Similar to a Confidence Interval for a Parameter of a probability distribution; a confidence measure that parameter is in interval, but exactly where in interval is not known
- Belief/Plausibility both reduce to Probability if Evidence is Specific

Measures of Ambiguity



Fuzzy Sets represent Vagueness

- Consequence (Deaths) are “Major”
  - “Major” is fuzzy: between *about* 500 and *about* 5000 deaths



Adversary/Defender Model

- Adversary (them)
- Defender (us)
- Adversary and Defender each have different goals and different states of knowledge
- Risk = Threat x Vulnerability x Consequence
  - Defender goal: Minimize Risk with available resources
  - Adversary goal: Maximize Consequence with available resources (working assumption)
- Adversary is the Threat
  - Epistemic Uncertainty for Vulnerability and Consequence
- Defender knows Vulnerability and Consequence
  - Epistemic Uncertainty for Threat

Defender Model for a Scenario

- Risk = f x P x C = f x (1 – P_E) x C
  - f is frequency of attack
  - P is probability of success given attack
    - P_E is effectiveness of security system in defeating attack
  - C is consequence given success of attack
- f, P, and C are random variables with uncertainty
- Degrees of Evidence to f, P, C based on state of knowledge
- Numerical Convolution using Belief/Plausibility Measure of Uncertainty

Example of Defender Model

- f and P have considerable epistemic uncertainty
- C has only aleatory uncertainty (for this example)
- C is Deaths

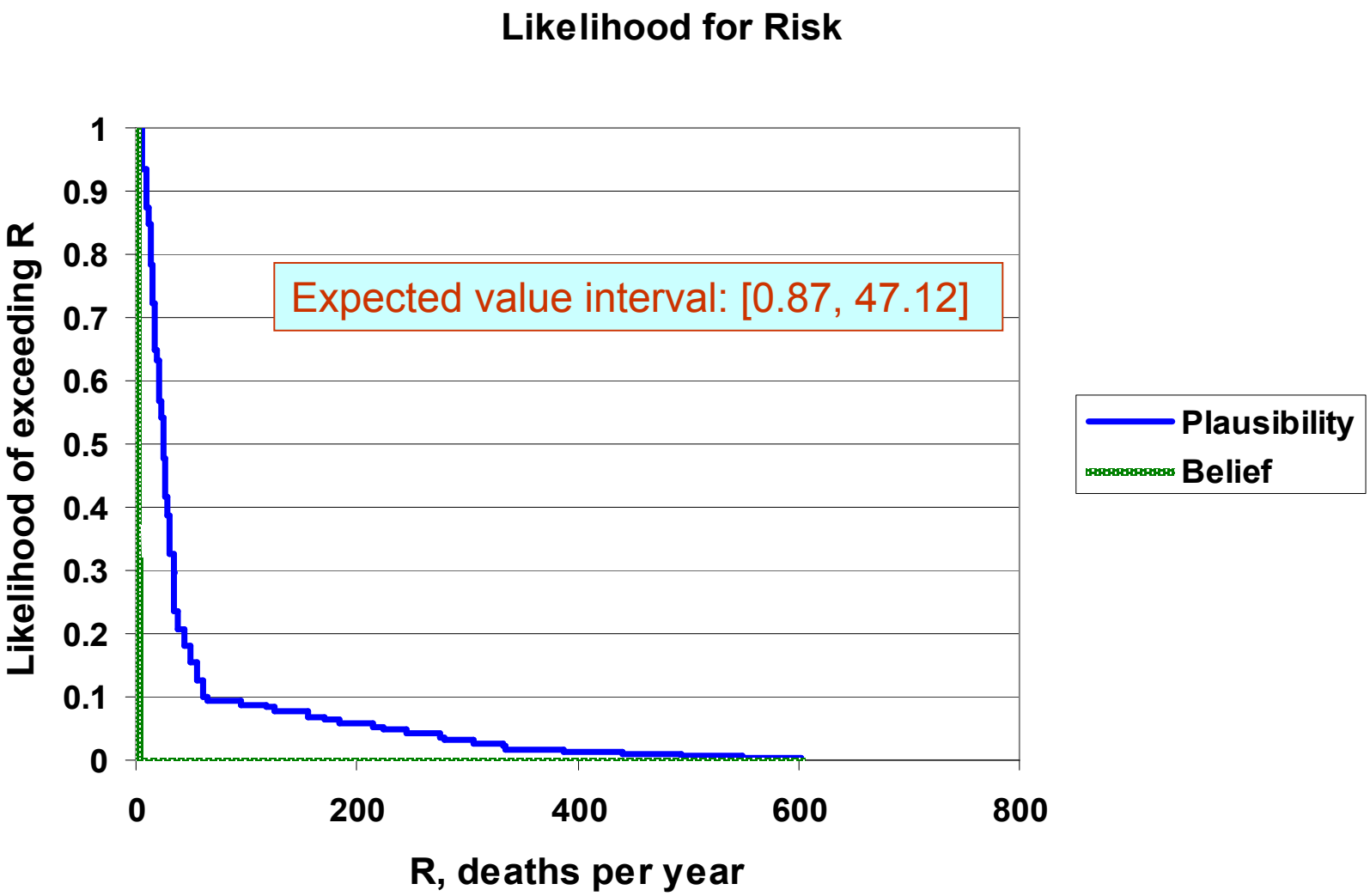
Example of Defender Model

- Evidence for frequency of attack, f, per year
  - 0.1 to interval [1 x 10^{-4}, 0.1]
  - 0.9 to the interval [1 x 10^{-3}, 0.01]
- Evidence for probability of adversary success, P
  - 0.3 to interval [0.1, 0.9]
  - 0.7 to interval [0.3, 0.5]

Example of Defender Model

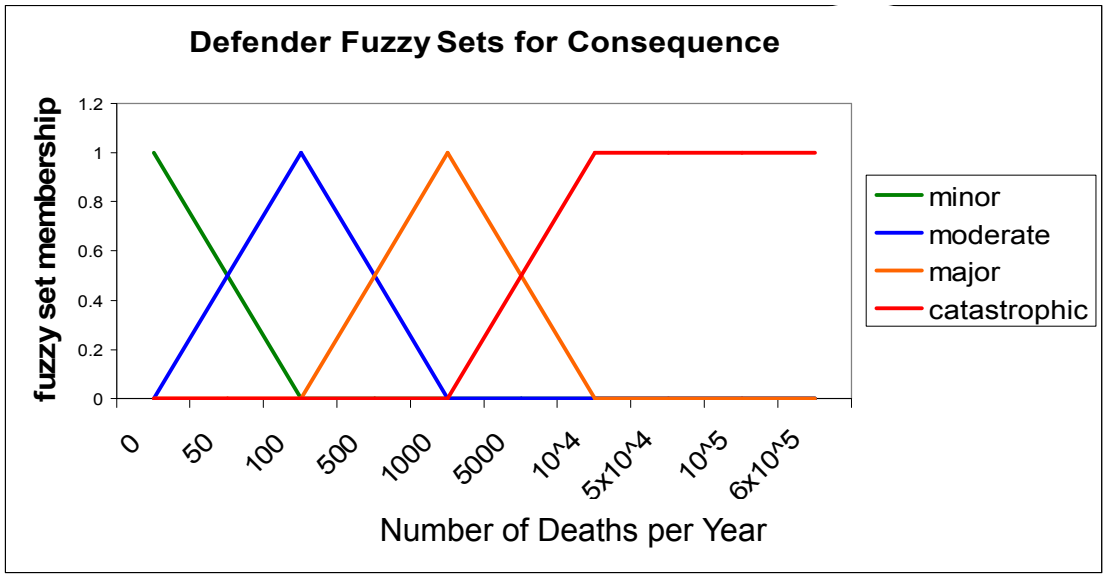
- Evidence for consequence, C, deaths
  - Uniform probability distribution
    - Minimum 1000
    - Maximum 7000
    - Mean 4000

Example of Defender Model

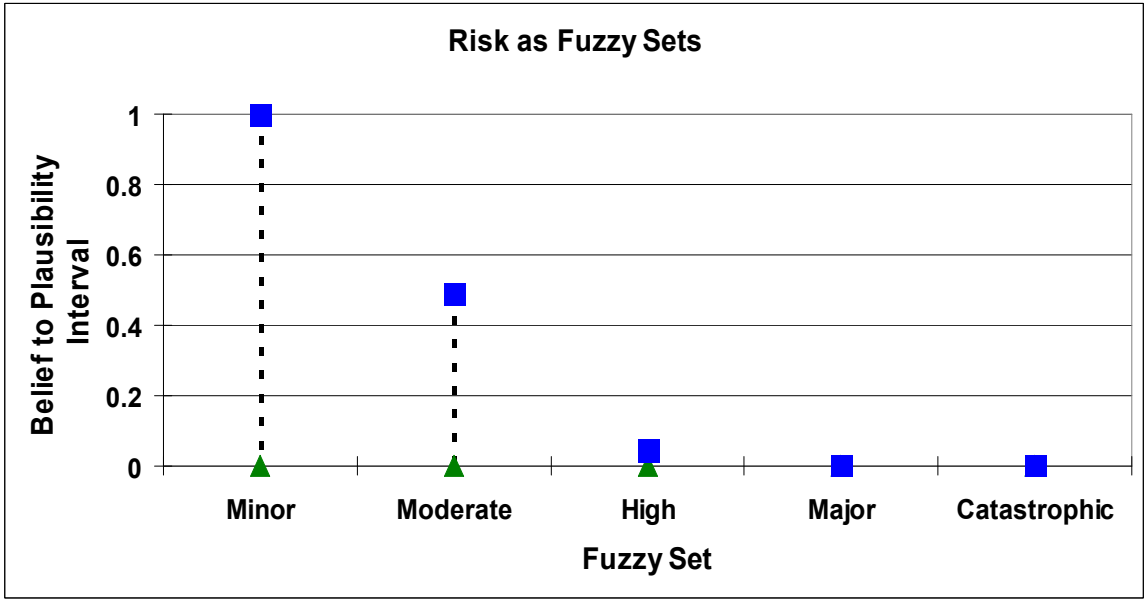


Likelihood for Risk using Fuzzy Sets

Define Fuzzy Sets For Risk:

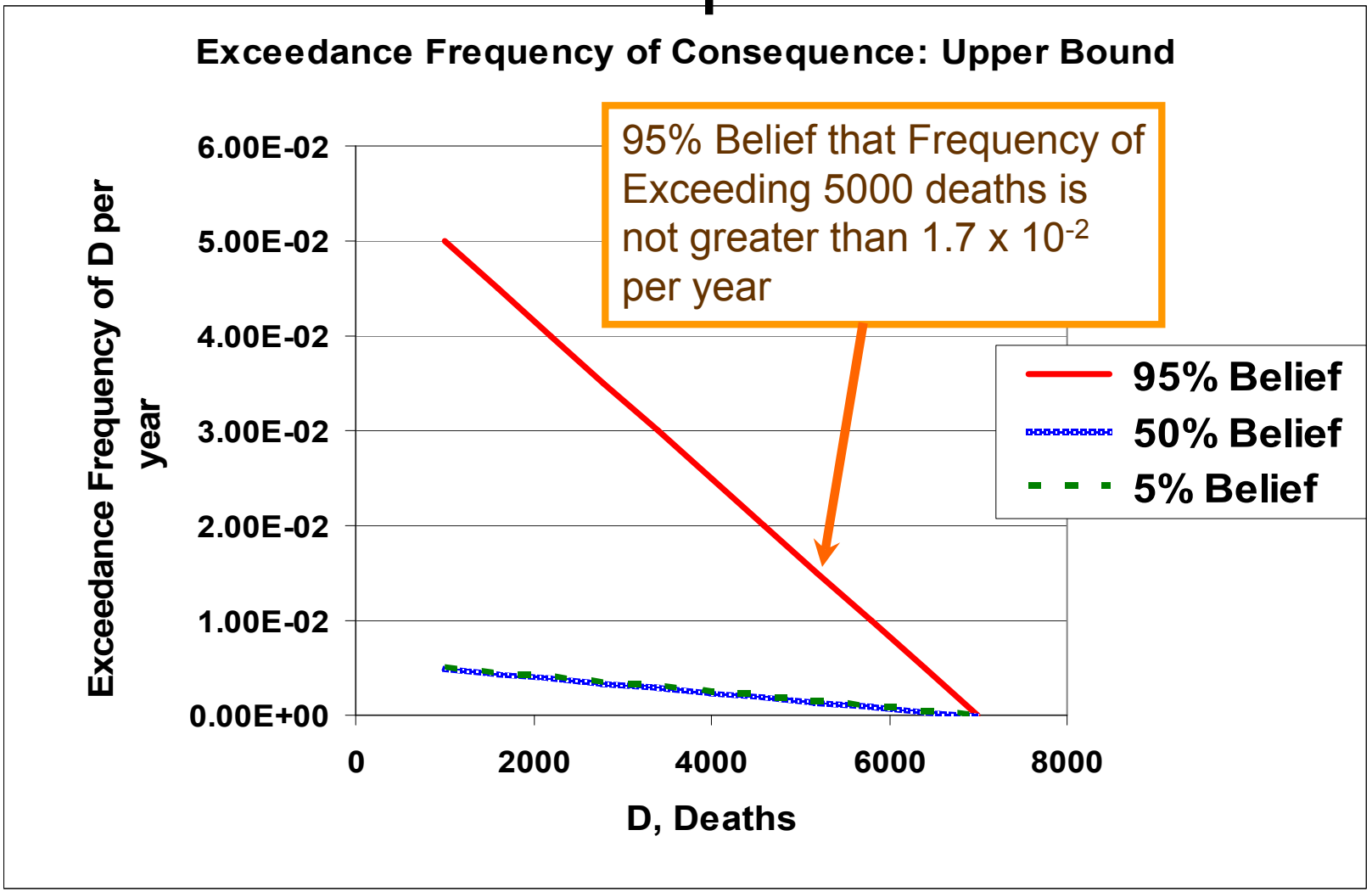


Likelihood of Fuzzy Sets, [Belief, Plausibility]:



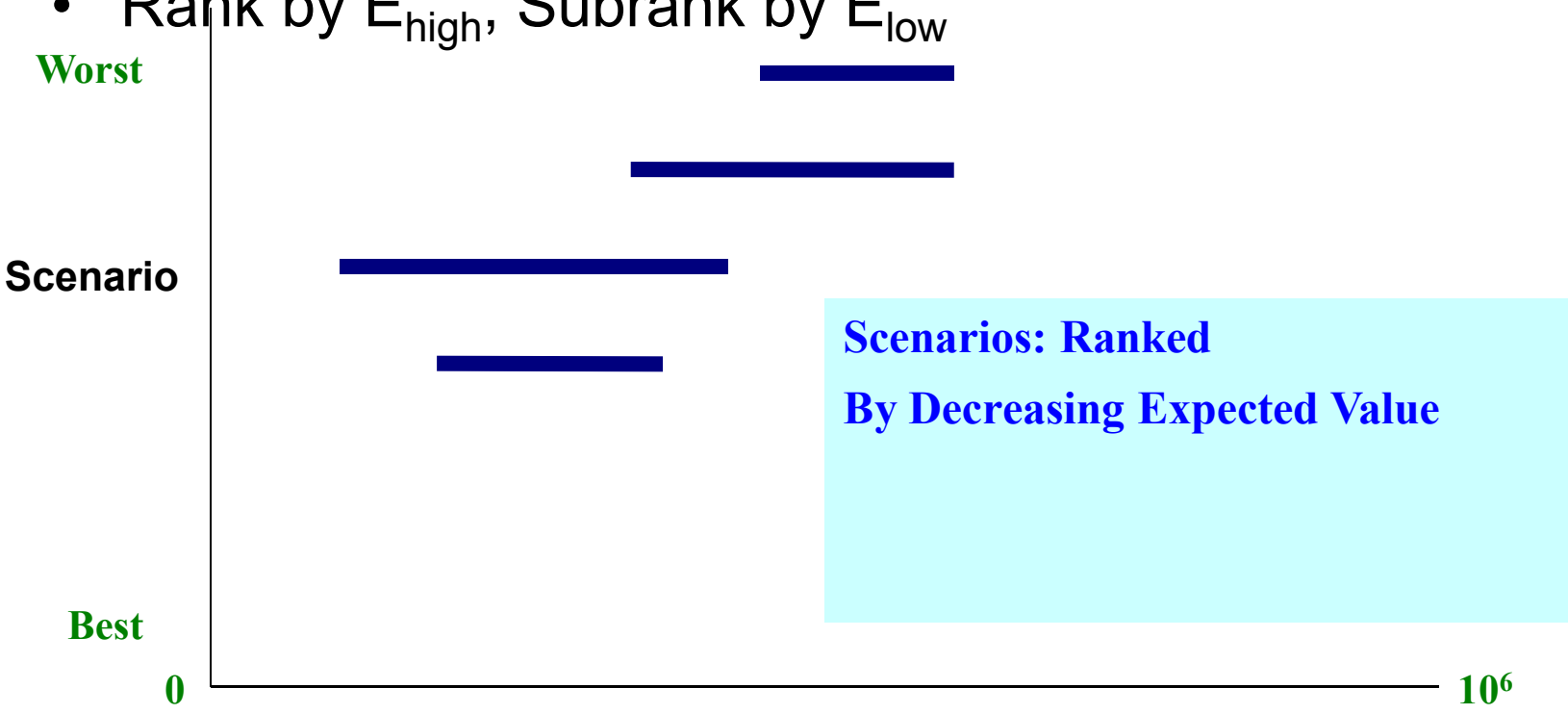
NNSA
National Nuclear Security Administration

Exceedance Frequency of Consequence



Defender Ranking of Scenarios

- For Belief/Plausibility Expected Value is an Interval $[E_{low}, E_{high}]$. Reduces to point (Mean) for Probability
- Rank by E_{high}, Subrank by E_{low}



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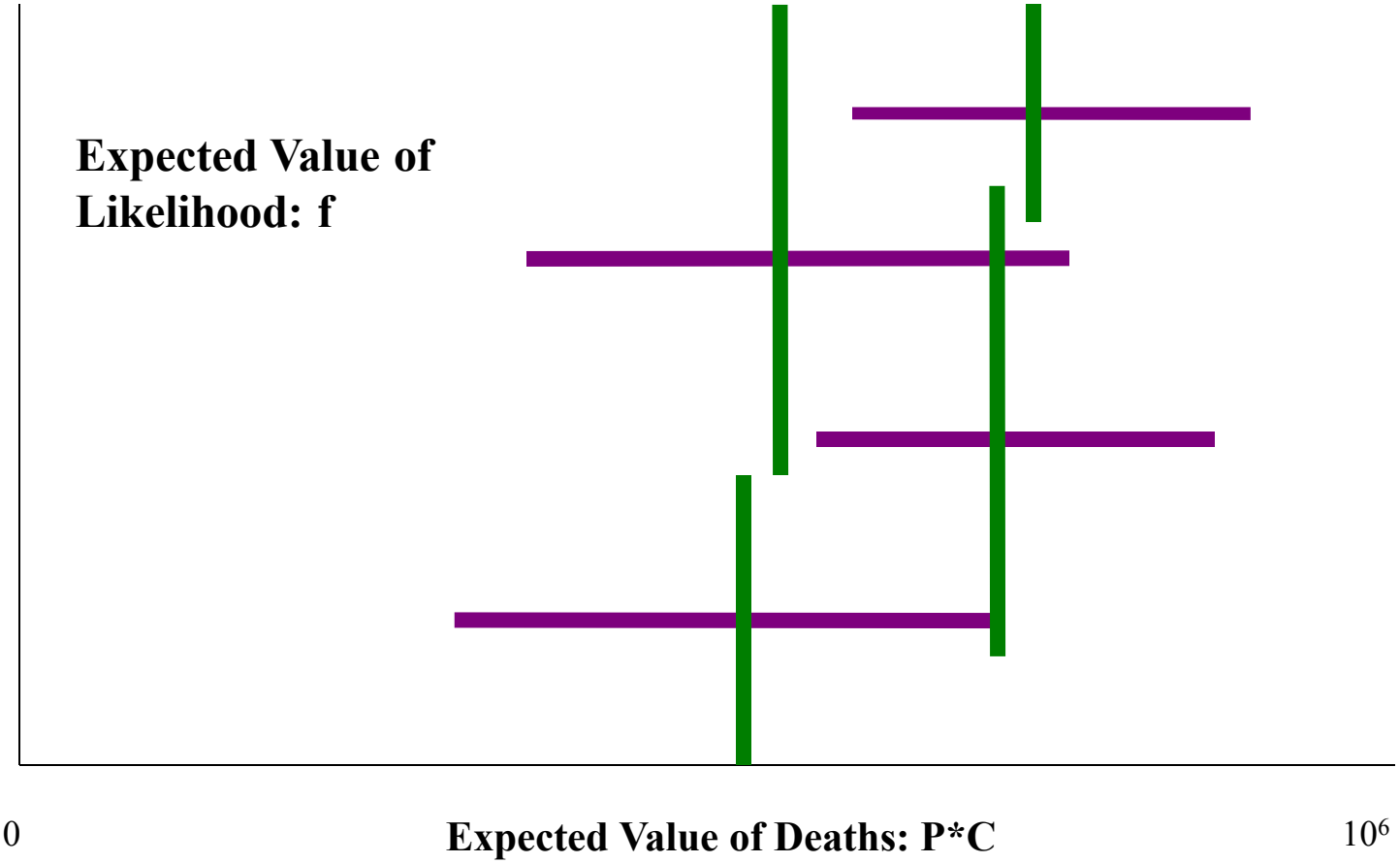
Next Level Of Detail for Defender Ranking



Adversary Model

- Use Surrogate Adversary (Special Forces)
- Adversary has Choice
  - All Variables of concern must be "OK" or

    Adversary will pick another scenario
    - Recruit Insider? Not unless already placed
    - Large Team? Concern about being detected by Intelligence
    - Uncertainty?
      - Door was green yesterday, is red today…What else changed?
- Variables for Adversary Decision are Not all Numeric
  - Consequence = Deaths x Economic Damage x Fear in Populace x Damage to National Security x Religious Significance x …..
  - Deaths and Economic Damage are numeric
  - Fear in Populace, Damage to National Security, and Religious Significance are not numeric

Adversary Model

- Purely Linguistic Model
- Develop Fuzzy Sets for Each Variable
- Develop Approximate Reasoning Rule Base for Linguistic Convolution of Variables to Reflect Scenario Selection Decision Process
- We are not the Adversary, we try to think like the Adversary
  - Considerable Epistemic Uncertainty
  - Use Belief/Plausibility Measure of Uncertainty Propagated up the Rule Base

Adversary Model

- Assume Adversary Goal is Maximize Expected Consequence
  - Expected Consequence ≡ P x C
  - Expected Consequence is Adversary estimate of Consequence, C, weighted by Adversary estimate of Probability of Success, P

Example of Adversary Model

- Rule Base and Variables

Expected Consequence

- Probability Of (Adversary) Success
  - Probability Resources Required Gathered Without Detection
  - Probability Information Required Can Be Obtained
  - Probability Physical Security System can be Defeated
- Consequence
  - Deaths
  - Damage To National Security

Example of Adversary Model

- Linguistics: Fuzzy Sets
  - Expected Consequence = {No, Maybe, Yes}
  - Probability Of Success = {Low, Medium, High}
  - Consequence = {Small, Medium, Large}
  - Probability Resources Required Gathered Without Detection = {Low, Medium, High}
  - Probability Information Required Can Be Obtained = {Low, Medium, High}
  - Probability Physical Security System can be Defeated = {Low, Medium, High}
  - Deaths = {Minor, Moderate, Major, Catastrophic}
  - Damage To National Security = {Insignificant, Significant, Very Significant}

Example of Adversary Model

Rule Base for Expected Consequence

Probability Of Success *Expected Consequence* Consequence	Low	Medium	High
Small	*No*	*No*	*No*
Medium	*No*	*No*	*Maybe*
Large	*No*	*Maybe*	*Yes*

Example of Adversary Model

Portion of Rule Base for Probability Of Success

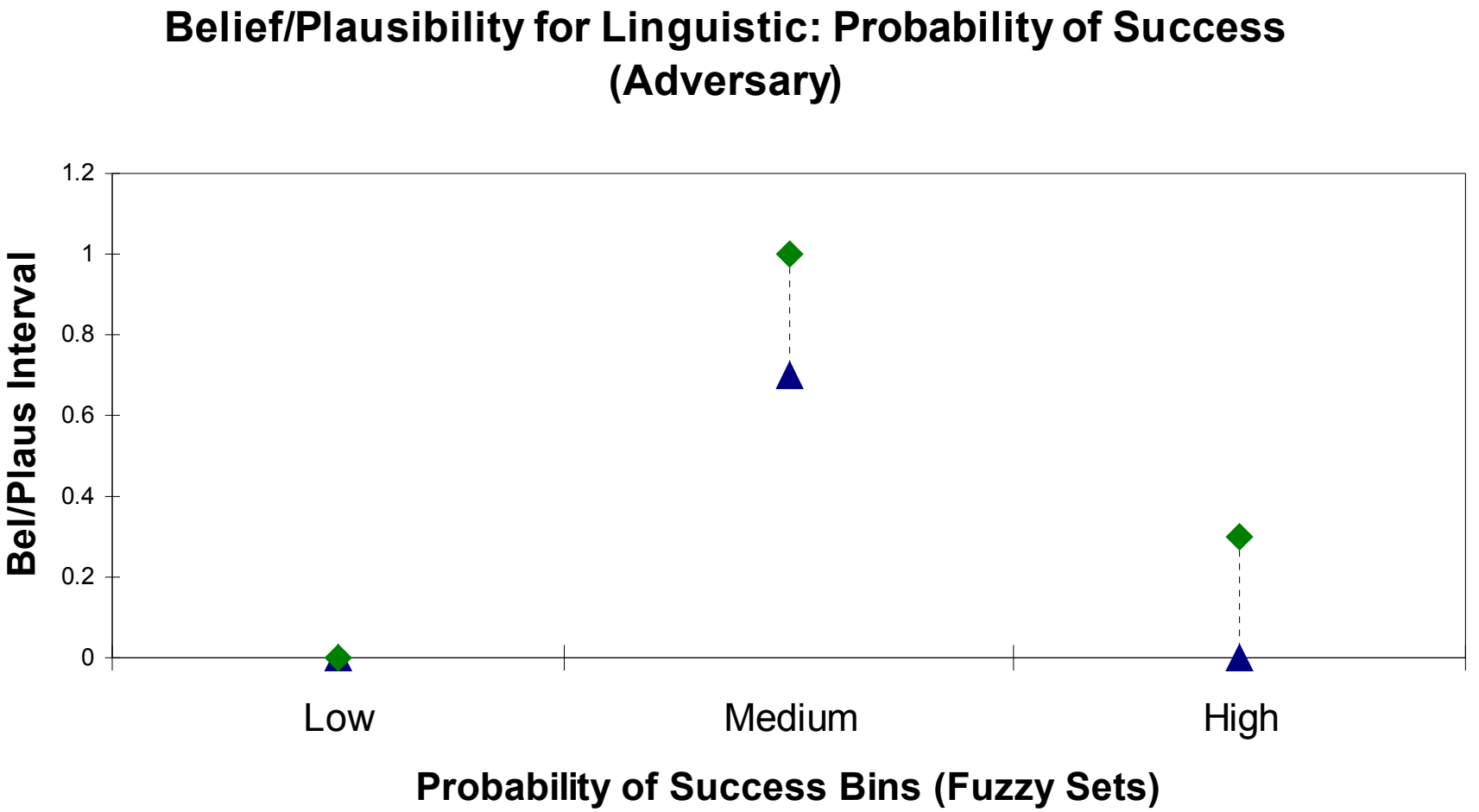
Probability Physical Security System can be Defeated = High

Probability Resources Required Gathered Without Detection ***Probability Of Success*** **Probability Information Required can Be Obtained**	**Low**	**Medium**	**High**
Low	***Low***	***Low***	***Low***
Medium	***Low***	***Medium***	***Medium***
High	***Low***	***Medium***	***High***

Example of Adversary Model

- Focal Elements (Evidence) for A Particular Scenario
  - Deaths
    - 0.8 for {Major, Catastrophic}
    - 0.2 for {Moderate, Major}
  - Damage To National Security
    - 0.1 to {Insignificant, Significant}
    - 0.9 to {Significant, Very Significant}
  - Probability Resources Required Obtained Without Detection
    - 0.7 to {Medium}
    - 0.3 to {Medium, High}
  - Probability Information Required can Be Obtained
    - 0.15 to {Medium}
    - 0.85 to {Medium, High}
  - Probability Physical Security System can be Defeated
    - 1.0 to {Medium, High}

Example of Adversary Model



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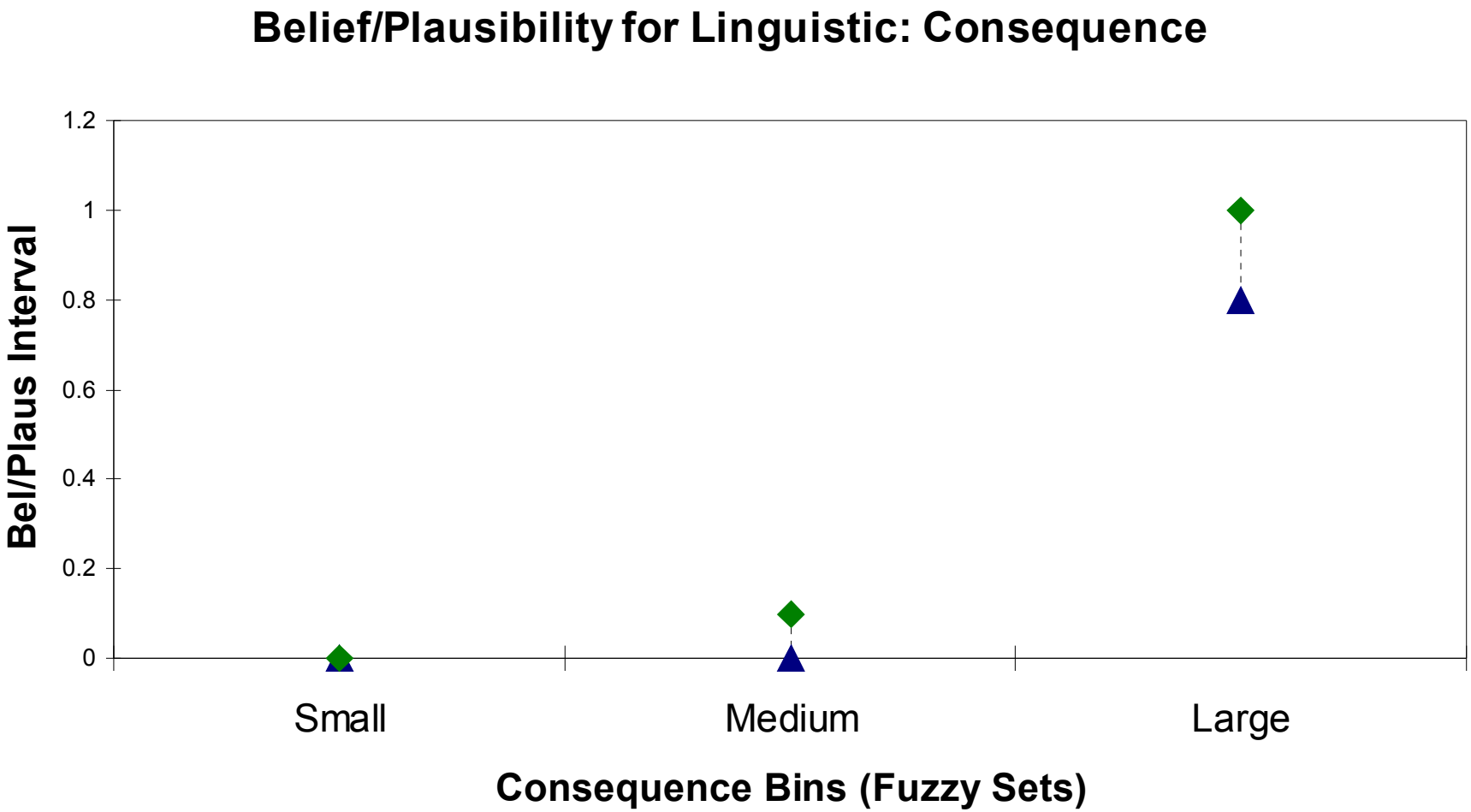
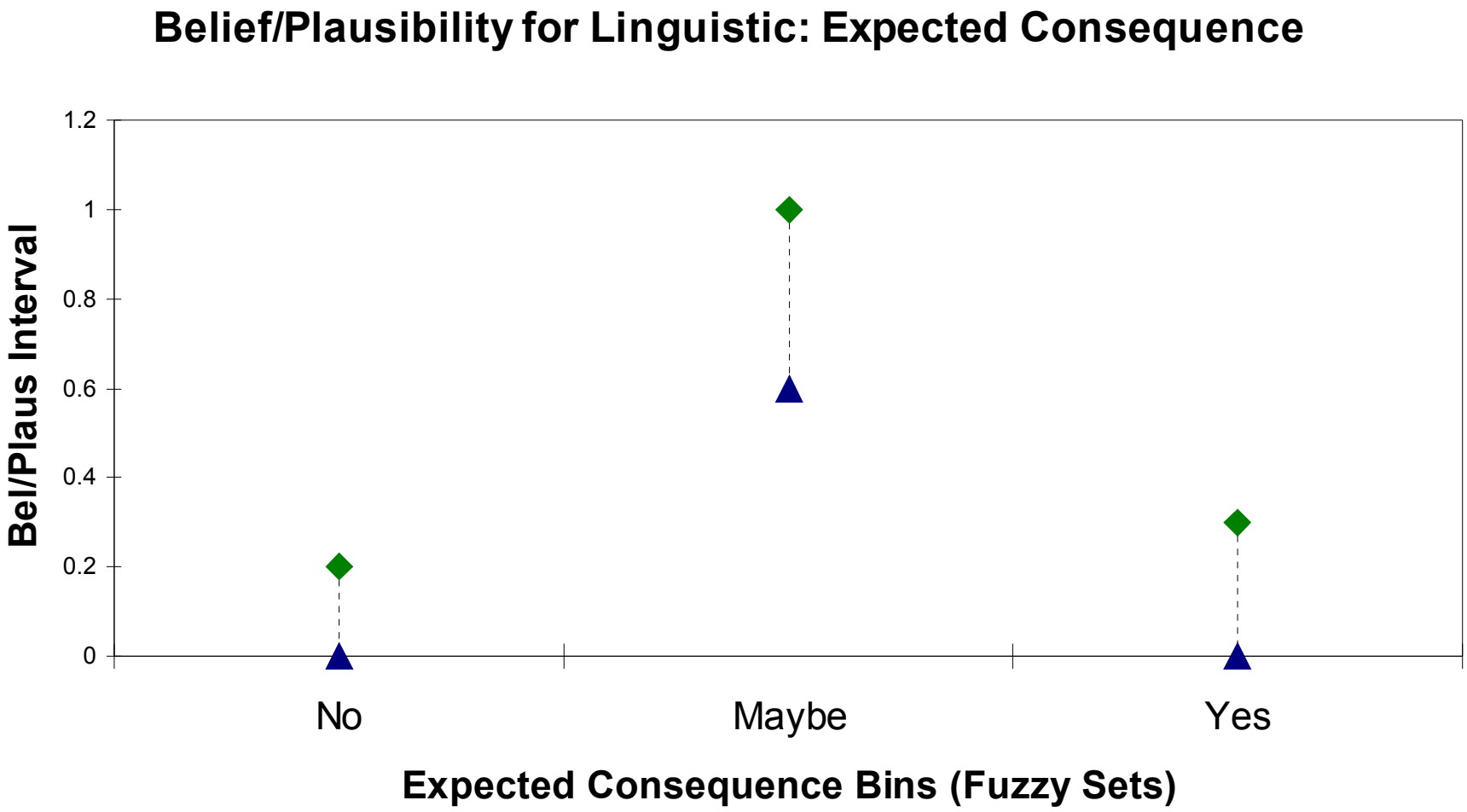


Example of Adversary Model



Ranking of Scenarios from Adversary Model

- Defender (thinking like Adversary) Ranks by Plausibility
  - Rank scenarios based on the plausibility for the worst fuzzy set for expected consequence, “Yes” in the prior example, sub-ranked by plausibility of the next-worst fuzzy sets, “Maybe” and “No” in the prior example
- Note: Actual Adversary using the Model would Rank by Belief
  - “We will not attempt a scenario unless we *believe* it will succeed”… Osama

Software Tools

- Numerical Evaluation of Risk for Defender
  - BeliefConvolution Java code (written by author)
  - RAMAS RiskCalc
- Linguistic Evaluation for Adversary
  - LinguisticBelief Java code (written by author)
  - LANL LEDTools

LinguisticBelief Code