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Risk Informed Investment Decisions for Bioterrorist Threats

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Introduction

In 2004, President George W. Bush signed HSPD-10, "Biodefense for the 21st Century"[1], acknowledging bioterrorism as a threat to our nation and a national biodefense program. As part of our biodefense efforts, our nation makes decisions on investments to prevent, protect from, detect, respond to, and recover from bioterrorist attacks. To guide these decisions, the Department of Homeland Security conducts risk assessments, such as the Bioterrorism Risk Assessment[2]. This paper explores how risk-informed decision analysis can address three hypothetical investment decisions related to preparedness for a bioterrorist attack.

Decisions

This paper addresses three policy decisions related to our national preparedness for a bioterrorist event:

1. For which biological agent should we purchase prophylaxis and how much?
2. How many people should we be able to treat?
3. For which biological agent should we develop new technologies?

These three decisions span a decision timeline, as shown in Figure 1, where the first decision is a tactical, short-term decision. One could expect that this decision may be revisited annually, to update supplies for the coming year. The second decision is a mid-term decision—while a healthcare system typically cannot drastically change overnight the number of patients it could treat, discussions could be initiated immediately to determine how to shift the capacity over time to the desired goal. While some incremental changes in capacity may be achievable immediately, larger changes may require several years to implement. The third question is a strategic, long-term decision, since new technologies often start in the research and development phase before they can be transitioned to a marketable technology. This process may take tens of years, depending on the technology, and research on one biological agent may not necessarily apply toward other biological agents.

[1] The White House (2004), Homeland Security Presidential Directive 10: *Bioterrorism for the 21st Century*.
[2] National Research Council, Committee on Methodological Improvements to the Department of Homeland Security's Biological Agent Risk Analysis (2008), Department of Homeland Security Bioterrorism Risk Assessment: A Call for Change, National Academies Press.

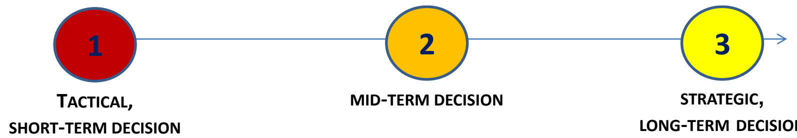

Figure 1. Decision types defined by timeframe in which the solution can be implemented.

The decision types, as well as the beliefs of the decision-maker influence the analysis inputs and guide the presentation of analysis results. This paper explores how these decision types would influence the analysis and presentation of results for a single risk methodology.

Model

The three decisions posed above can all be addressed by analyzing risk of a set of biological agents. The highest risk biological agents would be then preferentially chosen as those for which our nation should be most prepared. For bioterrorist risk analyses, the Department of Homeland Security (DHS) uses a quantitative definition of risk[2] derived from the definition proposed by Kaplan and Garrick[3], where risk can be expressed as a set of triplets of scenario, probability, and consequence. Following the DHS approach, for this analysis, a probability tree with a set of scenarios is defined, with risk of a scenario defined as

$Risk_{scenario} = Probability_{scenario} * Consequence_{scenario}$, where
each path through the probability tree is a scenario,
the probability of a scenario is determined by a probability tree, where each branch has a probability, and
consequence is the number of people infected for a scenario.

Note that for this analysis, the probability tree is simple relative to that which is used by DHS, for computational ease. The probability tree used here is defined by the branches shown in Figure 2, with a total of 180 scenarios. All branches are notional, including the consequence values in the consequence branches. Additionally, notional probabilities were assigned to each branch. For this analysis, the assigned probability of a given consequence was a function of the target and agent of the scenario but independent of the adversary group. The overall probability of a scenario, p_S, was defined as

$$p_S = p(Adversary_S) * p(Agent_S) * p(Target_S) * p(Consequence_S).$$

The probability tree was visually created in Excel using Risk Solver, resulting in the probability tree shown in Appendix 1. For computational ease, the probability tree was also created mathematically in MatLab, allowing for facile manipulation of the probability and results matrices. The risk of each scenario was calculated in MatLab using a series of scripts. This resulted in 180 scenarios, each with its own probability, consequence (infections), and risk value.

[3] Kaplan, S. and Garrick, B.J. (1981), On The Quantitative Definition of Risk. Risk Analysis, 1: 11-27.

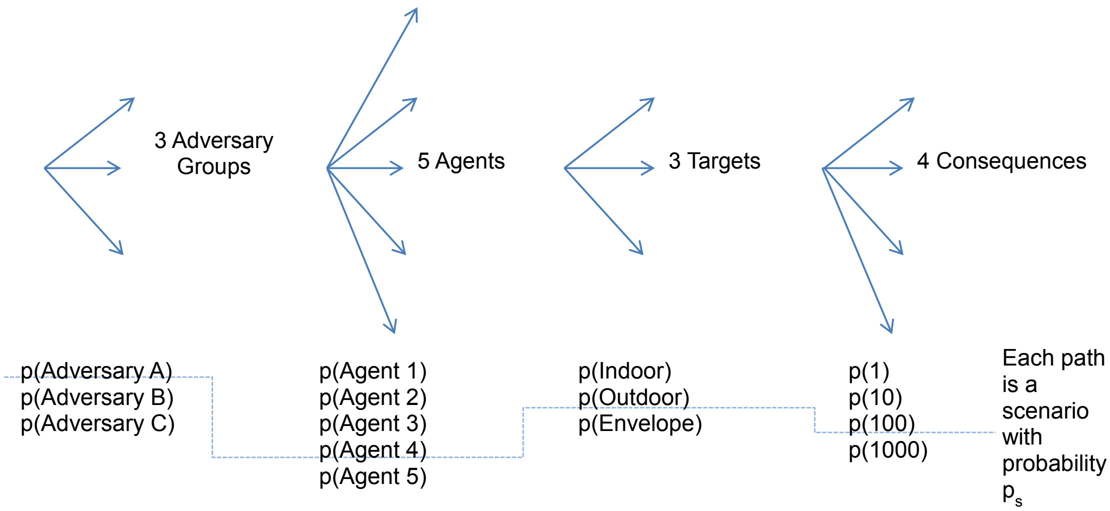

Figure 2. Probability tree branches.

Analysis

Decision 1: For which biological agent(s) should we purchase prophylaxis?

The Center for Disease Control's Strategic National Stockpile[4] is our nation's repository of medicine and medical supplies for a national public health emergency. The SNS is designed to protect the American public in the event of emergencies such as a terrorist attack, pandemic flu, or an earthquake. One could imagine that the Center for Disease Control would periodically assess for which biological agents they would purchase prophylaxis for storage in the Strategic National Stockpile. The hypothetical question posed as Decision 1 may be asked as they decide how to invest in prophylaxis for a bioterrorist event. Risk-based decision analysis could be used to guide this decision, where prophylaxis would be purchased and stockpiled for the highest risk biological agent(s). Since this is a short-term decision, the decision-makers may be comfortable using current knowledge of probabilities of adversaries, biological agents, and targets, so the risk calculation is relevant as defined above.

The calculated risk values for each scenario are plotted in Figure 3 as a function of biological agent. If the CDC decided to purchase prophylaxis for only one biological agent, a decision-maker using this data would purchase prophylaxis for Agent 1, since the highest risk scenario involves Agent 1. If the CDC decided to purchase prophylaxis for two biological agents, a decision-maker using this data would purchase prophylaxis for Agent 1 and Agent 4, since these are the two biological agents used in the highest risk scenarios.

[4] www.cdc.gov/phpr/stockpile/stockpile.htm, accessed December 9, 2012.

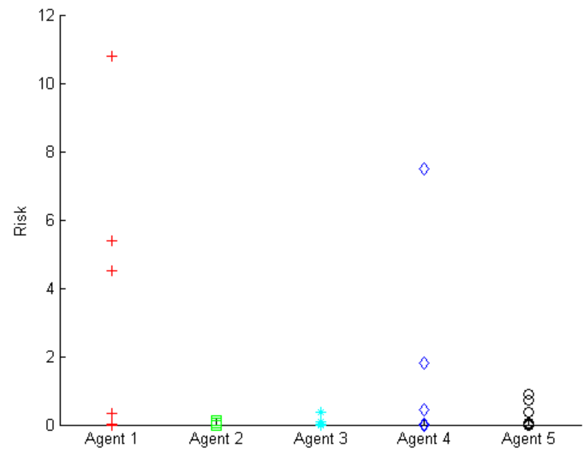

Figure 3. Bioterrism risk of various biological agents.

How much?

To determine how much prophylaxis should be purchased for each agent, the probability of a scenario was plotted, as a function of number of infections of the scenario and biological agent, as shown in Figure 4. A risk-averse decision-maker may want to stockpile for the worst case scenario, and using the data in Figure 4 would decide to purchase 1000 doses for Agent 1 and Agent 4. Another decision-maker may decide to purchase only enough for the most likely scenarios, which ,according to these data, involve only 100 infections for Agent 1 but 1000 infections for Agent 4, so the second decision-maker would decide to purchase 100 doses of Agent 1 and 1000 doses of Agent 4.

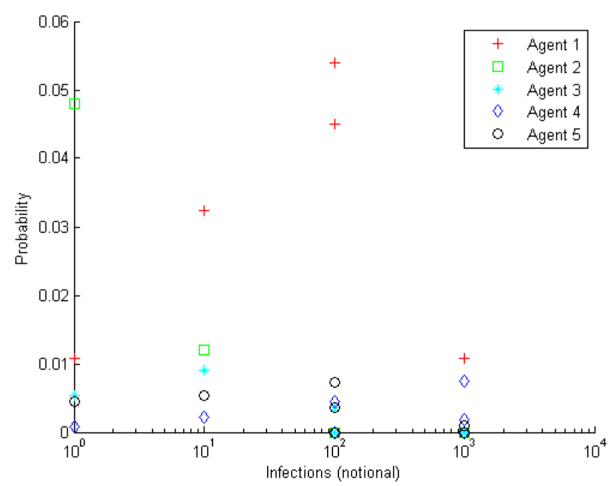

Figure 4. Probabilities of infections, by biological agent.

In real-life, however, a bioterrorist event will likely involve some uncertainty about who exactly was exposed to a biological agent and therefore infected. For an indoor venue, if the adversary correctly informed authorities of when and where a biological agent was released, authorities may have reasonable knowledge of how many people were infected. In addition to those infected, there will be a “worried well” population that would ask for prophylaxis even though they are not infected. Even in this event, the number of doses of prophylaxis needed would be higher than that calculated using this analysis methodology. For a bioterrorist event where there is no intelligence on when and where a biological agent is released, then authorities only know that a bioterrorism attack occurred when symptomatic individuals enter into the medical system and would not know how many individuals are infected. In such an event, public health officials may recommend mass prophylaxis of an entire city, which would make the number of doses needed significantly higher.

Decision 2: How many people should we be able to treat?

A public health official in a large city will also prepare for a bioterrorist event. The hypothetical question posed as Decision 2 may guide investments in state and local public health infrastructure and supplies. This is not necessarily a short-term decision—changes in health care capacity can require layers of policy, investment, and infrastructure changes. As a mid-term decision, a decision-maker, such as local public health official, may not believe that current intelligence on probabilities of biological agent selection and adversaries are valid for his or her mid-term decisions. For this case, the probabilities were modified so that all agents and all adversaries have equal probability:

$$p(Agent1) = p(Agent2) = p(Agent3) = p(Agent4) = p(Agent5) = 0.2$$

$$p(AdversaryA) = p(AdversaryB) = p(AdversaryC) = 1/3.$$

The resultant probabilities for each scenario were plotted by number of infections, for each biological agent, as shown in Figure 5. Using these data, the public health official would want to be able to treat 1000 infections, since this is not only the worst-case scenario but also the most probable using the assumptions discussed above.

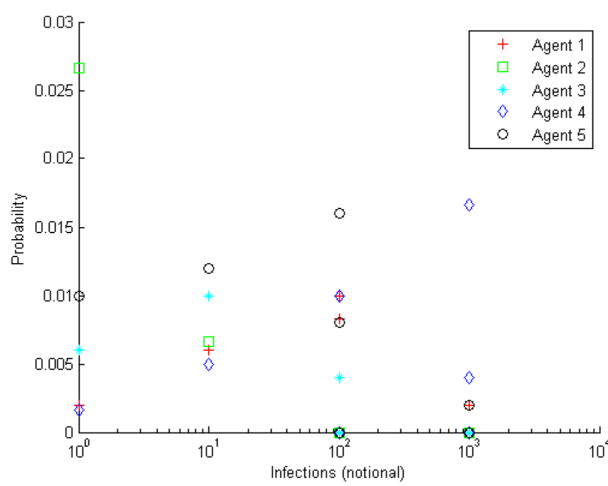

Figure 5. Probabilities of infections, by biological agent, assuming all agents and adversaries have equal probabilities.

Decision 3: For which agent should we develop new technologies?

A research and development organization may want to invest in new technologies that will help our nation’s preparedness for a biological attack. Examples of new technologies that may be agent-specific may include better detection methods or more effective prophylaxis. Since research and development may take many years, and commercialization of the product may take many more years, the research and development decision-maker may believe that long-term, strategic decisions should not be based on current knowledge of probability of threat, but rather on potential of an agent to cause consequences. For this case, as in the previous analysis, all agents and all adversaries are assumed to have equal probability:

$$p(Agent1) = p(Agent2) = p(Agent3) = p(Agent4) = p(Agent5) = 0.2$$

$$p(AdversaryA) = p(AdversaryB) = p(AdversaryC) = 1/3.$$

The calculated risk of the scenarios are plotted by biological agent, as shown in Figure 6. Based on this data, the highest risk scenario involves Agent 4, so the decision-maker decides to invest in new technologies for Agent 4.

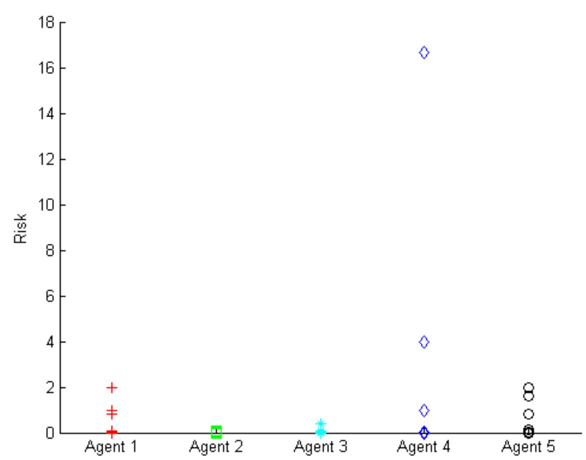

Figure 6. Bioterrorism risk of biological agents, assuming all agents and adversaries have equal probability.

A dissenting decision-maker believes that we have reasonable probabilities for agent selection and is somewhat skeptical about the probabilities for adversary threats, but he doesn't have better adversary data. For this case, the probabilities were modified to reflect the original probabilities given, but the data is displayed as a function of adversary, as shown in Figure 7. This allows the decision-maker to isolate the influence of each adversary and to include (or not) a specific adversary in his or her decision when additional intelligence is available on specific adversaries. This decision-maker decides to invest in a new technology for Agent 1, as the highest risk agent, but also invests some money in new technologies for Agent 4, since it is shown as high risk for multiple adversary types.

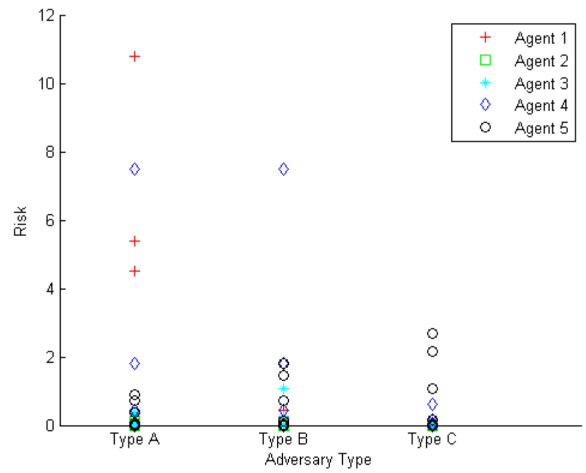

Figure 7. Bioterrorism risk from adversary types, by biological agent.

Conclusions

This paper shows not only how a probability tree can be used for risk-informed decision analysis but also provides examples of how such analysis can be tailored not only to the decision at hand but also to the decision-maker's beliefs. Using the same data set, data was shown in various formats, to emphasize the variables that were of most interest to the decision.

Appendix: Event Tree from Risk Solver