BAYESIAN NETWORK ANALYSIS OF NUCLEAR ACQUISITIONS

A Thesis

by

COREY ROSS FREEMAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Nuclear Engineering

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Approved by:

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ABSTRACT

Bayesian Network Analysis of Nuclear Acquisitions.

(August 2008)

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Nuclear weapons proliferation produces a vehement global safety and security concern. Perhaps most threatening is the scenario of a rogue nation or a terrorist organization acquiring nuclear weapons where the conventional ideas of nuclear deterrence may not apply. To combat this threat, innovative tools are needed that will help to improve understanding of the pathways an organization will take in attempting to obtain nuclear weapons and in predicting those pathways based on existing evidence. In this work, a methodology was developed for predicting these pathways. This methodology uses a Bayesian network. An organization's motivations and key resources are evaluated to produce the prior probability distributions for various pathways. These probability distributions are updated as evidence is added. The methodology is implemented through the use of the commercially available Bayesian network software package, *Netica*.

A few simple scenarios are considered to show that the model's predictions agree with intuition. These scenarios are also used to explore the model's strengths and limitations. The model provides a means to measure the relative threat that an organization poses to nuclear proliferation and can identify potential pathways that an organization will likely pursue. Thus, the model can serve to facilitate preventative efforts in nuclear proliferation. The model shows that an organization's motivations biased the various pathways more than their resources; however, resources had a greater impact on an organization's overall chance of success. Limitations of this model are that (1) it can not account for deception, (2) it can not account for parallel weapon programs, and (3) the accuracy of the output can only be as good as the user input. This work developed the first, published, quantitative methodology for predicting nuclear proliferation with consideration for how an organization's motivations impact their pathway probabilities.

DEDICATION

To my loving parents and my wonderful fiancée.

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CHAPTER I

INTRODUCTION

Terrorism will remain a grave concern for humanity throughout the twenty first century.[1,2] This concern was highlighted by the September 11th attacks where terrorist groups demonstrated their resourcefulness and adaptability. Organizations such as Al' Qaeda openly encourage any attack against American interest and are equally vocal in their desire to obtain nuclear weapons. The idea of nuclear armed terrorists shifts the threat to national security from states to both state and non-state entities. Fortunately, the pathway to constructing a nuclear weapon is seemingly impossible to a terrorist organization that lacks key infrastructures and technologies that developed nations possess. However, this obstacle can be circumvented by endorsement from a rogue nation with nuclear capabilities, or just a person in a key position who is sympathetic to their goals.[3] As a result, addressing the problem of nuclear terrorism requires preventing nuclear proliferation on every front. Tools are needed that can identify particular threats to nuclear proliferation, whether it is a terrorist organization or a rogue nation, so that resources can be devoted to preventative efforts.[4] Embodied in this work is a methodology for one such tool. Using Bayesian probabilities and the motivations of a potential proliferator, conclusions are drawn about the likely pathway that would be taken to achieve their goal. This information can then be used to identify any chokepoints or other key pieces that are critical to their success.

This thesis follows the style of *Nuclear Technology*.

Background

The distinguishing characteristic between nuclear explosions and conventional explosions is their source of energy. In conventional explosions chemical compounds change form, resulting in the reconfiguration of electrons. The electrons in this new configuration are more tightly bound than before and this difference liberates energy. In a nuclear explosion the protons and neutrons in the nucleus of atoms undertake some form of change which results in a more tightly bound nucleus. Just as in the case of the electrons in the conventional explosion, results in liberated energy as well. The energy that is liberated due to nuclear transformations is typically millions of times greater than that from electron transformations. Thus, nuclear explosions have the potential for liberating millions of times more energy than conventional explosions. Not all chemical compounds can undergo a reaction that releases significant amounts of energy in a short time frame, and fortunately, the same is true for nuclear reactions as well. Only certain isotopes of a few elements can be manipulated into releasing energy quick enough to cause an explosion.

There are two fundamental ways to release energy in a nuclear explosion: fusion and fission. Fusion involves overcoming the columbic barrier from the protons in two small nuclei and melding them together forming one new larger nucleus and releasing energy. Fission is the process of a heavier nucleus splitting into separate smaller nuclei, resulting in the release of energy along with a few neutrons. Isotopes for fission weapons are able to absorb a thermal neutron and subsequently fission and are called fissile. Both of the bombs used by the U. S. on Hiroshima and Nagasaki during World

War II were fission bombs. Creating fusion weapons, commonly called thermonuclear weapons, pose significantly more technical difficulties but have the potential to be hundreds of times more powerful than fission devices.

Historically no nuclear weapon program has created a fusion weapon as their first device. This is due to technological hurtles along with the fact that a small fission weapon is needed to produce the energy necessary to start the fusion process. So from the standpoint of preventing the spread of nuclear weapons, the short list of material usable for this purpose may be confined to those that are used for fission based weapons, uranium and plutonium, which are commonly referred to as Special Nuclear Materials (SNM).[5] The definition of SNM currently encompasses plutonium and uranium with the isotopes of uranium-233 (U-233) or uranium-235 (U-235) being enriched to greater than twenty percent.

Materials for Nuclear Weapons

Uranium is contained in soils all over the world. Concentrations vary with geological formations; but across the earth, uranium's abundance is approximately two grams per ton of soil and deposits can be found that vary in grade from 0.03% to 0.5%.[6] The naturally occurring uranium that is mined out of the ground contains primarily three isotopes, uranium-234 (U-234), U-235, and uranium-238 (U-238). Out of these three isotopes only U-235 is fissile and comprises approximately 0.72% of natural uranium. To make the uranium usable in a nuclear weapon, the fraction of U-235 must be raised higher than 20%, known as Highly Enriched Uranium (HEU). It is generally preferable if the uranium is enriched to approximately 90% for nuclear explosives which is referred to as Weapons Grade Uranium (WgU). Enriching uranium is an expensive and time consuming process. Weapons-grade uranium described above is commonly referred to as Highly Enriched Uranium (HEU).

During the Manhattan Project several methods to enrich Uranium were considered including gaseous diffusion, gaseous centrifuge, and Electro-Magnetic Isotope Separation (EMIS). The enrichment method used by both Brazil and South Africa was aerodynamic isotope separation. Another potential option is to use tunable lasers to enrich uranium. Laser enrichment is still largely in the developmental stage. For greater detail of how each of the different enrichment processes work, Wilson's text is suggested.[7]

The other fissile material of concern, plutonium, does not occur naturally. Plutonium is produced in a nuclear reactor by irradiating uranium fuel, particularly U-238, with neutrons. When U-238 absorbs a neutron it becomes U-239. It will then decay via two successive β^- transitions and becomes Pu-239. While in the reactor the Pu-239 is also being irradiated with neutrons and may absorb one or two of them, becoming Pu-240 and Pu-241 respectively. Pu-240 and Pu-241 have undesirable properties from a nuclear weapons standpoint, and as a result Weapons Grade Plutonium (WgPu) is made from mostly Pu-239. The plutonium that is in the reactor after longer periods of operation is called Reactor Grade Plutonium (RgPu). It contains higher concentrations of Pu-240 and Pu-241, and is more complicated to use for the production of nuclear weapons.[8]

The plutonium in the spent fuel is extracted via chemical separation (referred to as reprocessing). Reprocessing spent fuel is a difficult process. The irradiated fuel is extremely radioactive, requiring remote handling. The first step in reprocessing is to remove the cladding, usually by chopping the fuel into pieces and dissolving away the fuel. Then, the uranium and plutonium are chemically separated from the fission products and transuranic elements. Finally, a solvent is used that reduces plutonium to an organic-insoluble state to extract it from the uranium. For more information about reprocessing Wilson is again suggested as well as Benedict, Pigford, and Levi.[7,9]

HEU and plutonium are the two choices to consider when developing a fission weapon. While there are other materials that are suitable for the task, getting these materials involves the same steps as reprocessing plutonium but so little of the material is acquired that it becomes a much less feasible option.

Although it is a difficult task, many nations already have the capabilities above as part of their domestic nuclear energy infrastructure. Thus, this technology could be made available to a proliferator. The field of nuclear nonproliferation focuses on preventing the spread of technology and the materials needed for the development and production of nuclear weapons.

Theories of Proliferation

Nonproliferation policy theory has been dominated by the "realist" point of view.[10] The realist point of view is that nuclear weapons, like any new war technology, are valuable to nations and a must for national security. Therefore, only strong supply-side control measures can stop the world's natural tendency toward rampant nuclear proliferation. However, traditionally the realist view has not been overly successful in appraising the realities of nuclear proliferation. This is highlighted by President J. F. Kennedy who in the early 1960s predicted by the end of the decade 15 or 20 nations would have nuclear weapons.[11] The realist's line of reasoning consistently predicts a nuclear armed world but always fall short. In fact only about 1/5 of the states that could have built nuclear weapons have chosen to do so.[12] There have even been nations that after obtaining nuclear weapons have dismantled or otherwise removed them (Belarus, Kazakhstan, South Africa, and the Ukraine). Clearly supply-side control measures are not the only force at work preventing the proliferation of nuclear weapons.

As a result of this failure to explain the current state of proliferation, more thought has been given recently to the "idealist" reasoning on nuclear proliferation.[10] The idealist point of view looks at the demand side of nuclear proliferation to explain this discrepancy. It points out the import role that the motivations of an individual leader, the people of the state, and the international community as a whole play in whether a nuclear weapons program should be pursued.

The supply-side view of the situation points out that in general the world will head down the path of nuclear proliferation. The idealist method of looking at individual entities for explanation comes about because nuclear proliferation does not happen in *general*, it happens in *specific*.[13] Specific countries proliferate, specific global and regional circumstances trigger proliferation, and specific people and organizations decide to proliferate. This does not mean that the commonly held realist view of the past should be discarded. Keeping tight control on the technologies and materials that are necessary for a nuclear weapons program places obstacles in the way that at a minimum buys time for the situation that motivates nuclear proliferation to change.

A recent study by the Center for Strategic and International Studies (CSIS) in Washington D.C. examined eight countries that have publicly renounced nuclear weapons (Egypt, Germany, Japan, Saudi Arabia, South Korea, Syria, Taiwan, and Turkey).[14] Looking at these countries individually in an idealist manner CSIS found that the principle factor that might prompt these countries to reexamine their choice is a dramatically increased security threat. Such a security concern is imaginable if, for instance, a regional neighbor suddenly was in possession of nuclear weapons. For example, in the Middle East it is believed that none of the Gulf States are interested in launching a weapons program because they rely on the U.S. for security. However, if Iran manages to build a nuclear bomb, then it is very possible that Saudi Arabia will no longer feel U.S. protection is adequate.[15] If Saudi Arabia has nuclear weapons, suddenly their neighbors may feel unsafe. This makes it clear how the problem of nuclear proliferation may still follow the predicted path of the realist. The conclusion that can be drawn is that while it is important to control the supply side of nuclear proliferation, examining the demand side, the motivational factors on a case-by-case bases, may also reveal ways to dissuade individual states from seeking nuclear weapons.

Efforts to Prevent Nuclear Proliferation

There are and have been many efforts to prevent the spread of nuclear weapons. The International Atomic Energy Agency (IAEA) seeks to promote the use of nuclear energy for peaceful purposes as well as constraining the use of nuclear energy for military purposes. The IAEA was established under the U.N. mission as an autonomous organization in 1957. One of its functions is that it serves to verify that nations are meeting their obligations to the Nuclear Non-Proliferation Treaty (NPT). The aim of the NPT is to stop the spread of nuclear weapons and lead toward nuclear disarmament.

The success of the NPT is encouraging. Every country on Earth except for three have signed the treaty. The NPT provides a system to verify that states are not covertly producing nuclear weapons. Since the NPT went into effect in 1970, the number of states assumed to have nuclear weapons has increased from five [United States, Russia (former Soviet Union), United Kingdom, France, China] to nine. Three of the four states that have developed weapons during that time (India, Pakistan, and Israel) never agreed to sign the NPT in the first place. The fourth state (DPRK) signed the NPT in 1994, but withdrew in 2002 under suspicion of a covert nuclear weapons program. Despite the DPRK case, adherence to the NPT is considered to be an international norm. Thus any new nuclear weapons programs will be covert programs.

These new nuclear armed states may not be affected by the deterrence strategy that dominated the Cold War. These rogue states (e.g. North Korea) may feel pressured into using nuclear weapons first or are simply indifferent to the consequences of their actions. Nations led with such a mentality pose a particularly difficult challenge to preventing nuclear war.

Additionally, terrorist acquisition of nuclear weapons may completely bypass the deterrence strategy since they have no “return address”. Terrorist organizations such as Al’ Qaeda openly confess their desire to obtain nuclear weapons, show their hatred toward America and other Western cultures through both words and actions, and have demonstrated their resourcefulness in the attacks carried out in 2001. To further compound the problem rogue states (and some sub-elements of those states) are often accused of sponsoring terrorism. The challenge of obtaining SNM may be beyond the abilities of a terrorist group, but help from a rogue nation with nuclear capabilities sharing a common goal could allow this challenge to be circumvented.

Preventing rogue states and terrorist organizations from obtaining nuclear weapons is a particularly complex problem that faces our generation. This work addresses one component of this problem: considering the idealist model and the demand side of why an individual, organization, or nation may choose to proliferate, what conclusions may be drawn regarding the pathway they will take in their endeavor? Realizing the merit of the realist viewpoint, the conclusions drawn should be supplemented with any knowledge of evidence regarding their choice to proliferate. In this work, a methodology is developed that makes predictions to what pathway an organization of interest (be it a state or sub-state entity) will take in developing nuclear weapons. The methodology first predicts a path based on the motivational factors that affect the organization of interest. This prediction can then be modified by adding any evidence regarding nuclear proliferation that is known or later found about the organization of interest. The methodology can then be used not only to predict an organization's pathway but to measure the effect that different evidence has on the choices they make and overall success, allowing the determination of possible choke points along the way that may be used to hinder or all together prevent nuclear proliferation.

Previous Work

In July of 2006, the Center for Contemporary Conflict held a conference in California to discuss the threats to nuclear proliferation over the next ten to fifteen years.[16] This conference hosted over sixty government officials, military officers, scholars, and non-governmental experts and discussed factors that would most likely influence the nuclear proliferation landscape in the timeframe of 2016. From the list of significant findings by the conference, several are relevant to the development of this work and are discussed by Ford.[17] Of particular interest is the following factor:[16]

- ***Decisions to go nuclear are made by individuals, so understanding the psychological mindsets of individual leaders is crucial to nonproliferation efforts.*** Leaders of a country typically make the ultimate decision to start a nuclear program and continue to make or test an actual bomb. Based on historical experience, those leaders can on occasion be persuaded not to pursue nuclear weapons, especially when fellow heads of state make pointed appeals.

This finding supports the growing idealist view on nuclear proliferation. Understanding the motivations and driving force behind the leader, or leaders, of a nation is essential to evaluating the potential risk they pose. Hyman has recently published work that attempts to do just that.[12] Hyman defines two dimensions that are rated: *solidarity* and *status*. Solidarity measures how they see their role in the international setting. Do they see it as an "us and them" community or an "us versus them" community? The status dimension measures how a nation feels they rank in this community. Do they feel that they "are equals if not superior" or they "are naturally inferior"? By examining a nation's leader and looking at what quadrant of these two dimensions their view of their nation falls, Hyman makes conclusions about the likelihood of various things regarding the nation, such as whether they are likely to desire nuclear weapons, likely to resist the nonproliferation regime, and whether superpower nuclear guarantees will appeal to them.

So far, security concerns have been the only motivation discussed but there are many reasons why a nation may choose to proliferate. In fact, there is no shortage of literature on the subject.[18,19,20] Several sources discuss the demand side of proliferation, which is the varying motivating factors that potential states may have. Meyer conveniently lists a compilation of these discussions.[21] But as mentioned before, nations are not the only concern to nuclear proliferation. Both state and non-state actors pose a potential threat. Insights regarding general motivations for a terrorist group to proliferate can also be found in the literature.[22] The motivational factors that apply to an organization of interest, be it state or non-state, not only give insights into what possible options may be present to persuade them not to pursue nuclear weapons but also play a role in determining the potential pathway towards nuclear development they choose. As a result, the motivation of an organization is an important aspect of the methodology developed here.

After the motivations are considered, the next step is to consider the pathway that an organization of interest may take toward a nuclear capacity. The steps taken by the first eight nations that developed nuclear weapons have all been fundamentally the same: acquire fissile materials capabilities, produce SNM, and build a functioning weapon as fast as possible. Now, however, any nation pursuing nuclear weapons would be in violation of the NPT and so any efforts would most likely be less straight forward and open. Einhorn points out that any aspiring nuclear weapon states would use a more cautious, incremental and ambiguous course.[13] These pathways to proliferation may take on one or some combination of the following forms: hedging, settling for less, maintaining ambiguity, and relying on dual-use facilities.

The Director General of the IAEA, Dr. Mohamed ElBaradei has said that failure to control nuclear material may be the Achilles' heel of the nuclear nonproliferation regime.[23] This is what makes dual use facilities such a threat to proliferation. Under the NPT any nation has the right to construct these facilities for civilian purposes, but once the capability is in place, the supply side restraints of nuclear proliferation disappear. Efforts to combat this issue have lead to the development of civil reactor designs that incorporate increasing sophisticated proliferation resistance techniques.[24] Other efforts have gone into creating tools that assist the IAEA with evaluating the data collected from integrated safeguards to identify signatures of covert activities.[25] Strengthening the supply side of proliferation is extremely beneficial, however, there are other pathways that can be taken and so it will not serve as a complete solution.

Determining quantitatively which pathway a rogue nation or terrorist organization will take to acquire a nuclear weapon requires the use of some method of decision-making analysis. Decision-making analyses are used in a plethora of fields and as a result there is plenty of literature on the subject.[26,27,28,29] These methods range from Decision Trees, Monte Carlo, Cost-Benefit Analysis, Multi Attribute-Utility Analysis (MAUA) and everything in between. There is also a multitude of commercially available software packages designed to facility a decision maker by simplifying the use of these methods. The large variety of choices available when examining decision analysis tools stems from the fact that modeling human behavior is extremely complex and no one method can cover all of its facets.

Few attempts have been made to apply a statistical analysis to the field of nuclear nonproliferation. One example done by Meyer in 1984 examines several countries over the prior decades to make near and far term forecast for potential proliferators.[21] Meyers' analysis includes many variables such as a nation's propensity to proliferate, their technical capabilities, and lag time associated with how long it would take before a nation could achieve its goal of nuclear weapons. The downside to Meyers work is that it does not include the dynamic of non-state organizations' threat to nuclear proliferation.

Another study examined the effect that specific determinants had on a nation's tendency to proliferate.[30] This study makes the distinction between the two stages of proliferation, having a weapons program and actually acquiring a nuclear weapon. The study found that security concerns and technological capabilities were key determinants in explaining the presence of a nuclear weapons program, but the key determinants in whether a nation possessed a weapon were security concerns, economic strength, and domestic politics. The work recognized that theft or purchase were possible pathways to obtaining a nuclear weapon but since to date this has not occurred, addressing this avenue was impossible in their empirical method.

In 2007, a code was developed that examined different pathways that a terrorist organization might take in an attempt to acquire SNM.[17] The code was Monte Carlo based and the probabilities centered around the resources that the terrorist organization of interest was assumed to possess. This analysis based on resources is a good supply-side model for predicting the pathways that a terrorist group might use. Unfortunately, it is lacking any demand-side capabilities. The motivation that an organization has to develop a nuclear weapon does influence the pathway they may use.

One final example of related work examined here is a Bayesian analysis of the different pathways a terrorist group may take to develop an Improvised Nuclear Device (IND).[31] While the model had a robust representation of various pathways, it lacked any thorough or consistent manner for handling resources or motivations. That being said, the IND pathway model showcased some of the benefits that Bayesian methods offer, but could be improved by incorporating these other characteristics.

The following work focuses on the demand side of proliferation. It considers an organization's motivations to proliferate and uses a Bayesian analysis to quantify the likelihood of different pathways and the overall chance of success. This information may be used as a means to determine the relative threat that different organizations pose. Furthermore, insights gained into which pathways are most likely may be used to determine chokepoints in a proliferator's efforts. Thus, measures can be taken to prevent the proliferation from occurring.

CHAPTER II

NETWORK DEVELOPMENT

Bayes' Theorem

Bayesian probabilities began with the English mathematician Reverend Thomas Bayes whose discovery of the theorem that now bears his name was published posthumously.[32] Bayes' Theorem is simply a manner to calculate probability of one event occurring based on whether another event has occurred. Suppose that both A and B are events, and that $P(A)$ and $P(B)$ represent the probability that events A and B occurred respectively. Then Bayes' Theorem is as follows:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \tag{1}$$

Where $P(A|B)$ is the probability that event A occurs given that event B did occur, and $P(A|B)$ represents the probability that event B occurs given that A occurred.

If an event is not affected by the occurrence of other events then it will have a subjectively defined probability distribution. Or if the event is in some manner affected by any other events, then its probability distribution is governed by the truth of these events using Bayes' Theorem. The probability distributions that exist before any evidence is added are known as the *priors*. By linking all of the events together that affect each other, a *Bayesian Network*, or a *Belief Network* is created. When you discover "evidence" about the probability that certain events have occurred, Bayes' Theorem calculates the probability that other events in the network have occurred. In this manner Bayesian Networks calculate probabilities based not only on the priors, but on known evidence as well.[33]

Bayes' Theorem is the only consistent way to modify our beliefs about events given the evidence about what has actually occurred.[34] This highlights one of the strengths of Bayesian probabilities over other statistical methods, the inferences made are based on the actual occurring data, not on all possible data sets that might have occurred but didn't. As a result, once created, Bayesian networks are powerful tools that can be used to make predictions based on the pieces of evidence that are known. One caveat that should be addressed here is that, like all decision making analysis tools, the predictions and conclusions drawn are based on the user input. Therefore, the value of the output is only as reliable as the accuracy of the input. Bayesian Networks are no exception to this.

Netica

Bayesian Networks allow quantitative predictions based on the present state of information. There are many commercially available software packages that are designed to facilitate the creation and use of Bayesian Networks. The network created for this methodology takes advantage of one such package called *Netica.*[35] Using Netica provides many advantages including a graphical interface, easy implementation of changes, and facilitating sensitivity analysis. Therefore, the analyst can digest the big picture easily visualize how different nodes in the network are linked together. This Bayesian Network is set up such that each node represents a piece of evidence or a step in some process. These nodes are linked together by causal relationships as shown in Fig. 1.

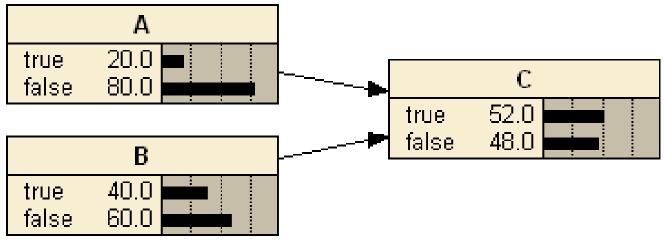
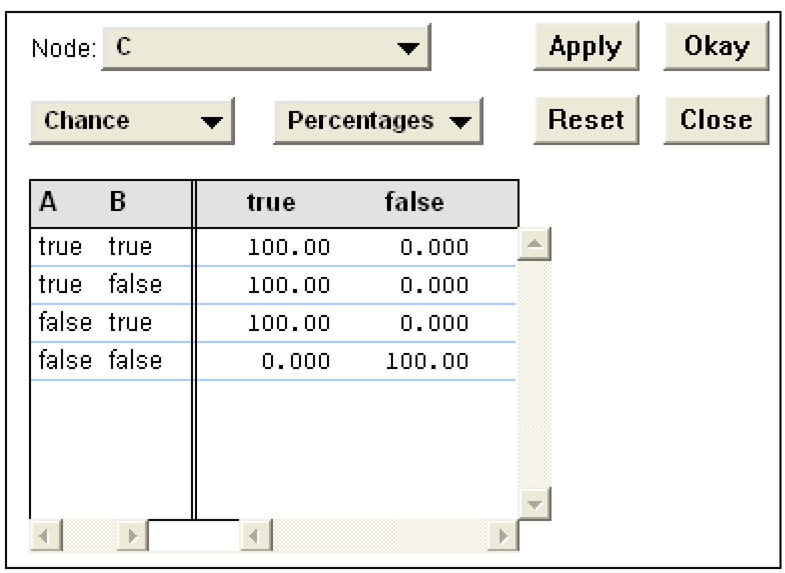


Fig. 1. Example of a network in Netica

In this example, nodes *A* and *B* impact the probability of node *C* and are called parents of node *C*. The probability of each node being true is calculated using conditional probabilities. The values needed to calculate the probability of each node are taken from truth tables that are defined for each node. An example of a truth table in Netica is given in Fig. 2. The truth table in Fig. 2 is used for node *C* from Fig. 1.



A	B	true	false
true	true	100.00	0.000
true	false	100.00	0.000
false	true	100.00	0.000
false	false	0.000	100.00

Fig. 2. Example truth table in Netica

The conditional probability equation used to calculate the probability that node *C* is true is:

$$\begin{aligned} P(C_T) = {} & P(C_T|A_T,B_T)P(A_T)P(B_T) + P(C_T|A_T,B_F)P(A_T)P(B_F) \\ & + P(C_T|A_F,B_T)P(A_F)P(B_T) + P(C_T|A_F,B_F)P(A_F)P(B_F) \end{aligned} \tag{2}$$

where the subscripts *T* and *F* denote true and false respectively. The truth table provides the probability for node *C* given each combination of nodes *A* and *B*. The probabilities that are given to nodes *A* and *B* are subjectively defined priors.

Truth tables require a value for each state a node has for every combination of states from its parent nodes. These truth tables can be compiled "by hand" or through the use of an equation. These equations can replace the task of entering thousands of rows of probabilities with writing a simple equation or a few lines of logic statements, making nodes with several inputs feasible. In Fig. 3 the equation that was used to create the truth table from Fig. 2 can be seen. It is important to keep in mind when dealing with these equations that they are not defining the relationship between the linked nodes; that is done with conditional probabilities and Bayes' Theorem. The equations only fill out the values that are needed in the truth tables.

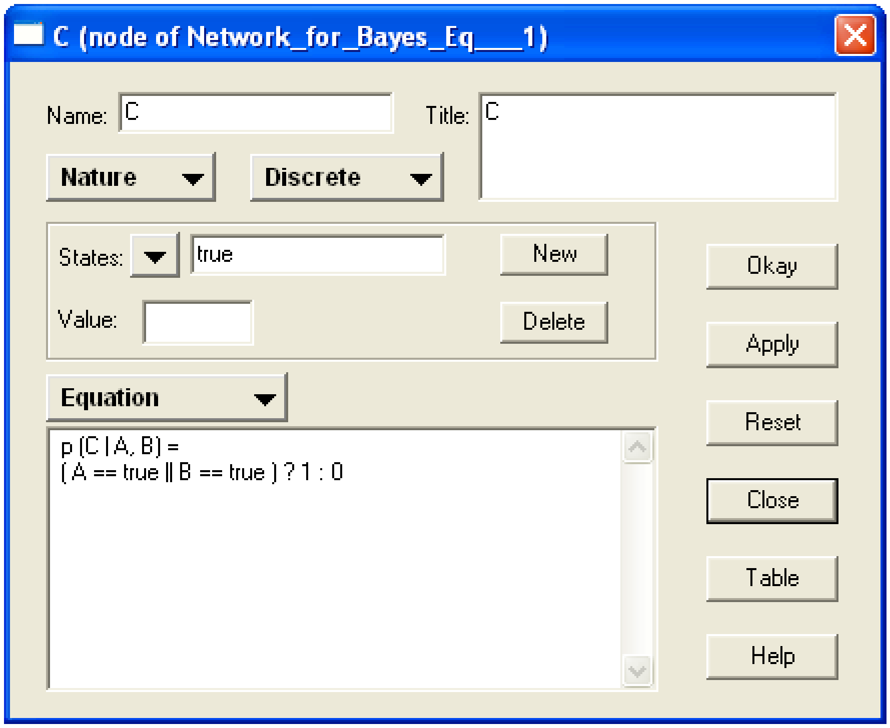


Fig. 3. Example of using an equation to fill out the truth table in Netica

Netica also allows the creation of constant nodes. Constant nodes have no parents, and are not parents to any other node. They can be supplied with a numerical value, or a list of choices that represent numerical values. The constant nodes can then be called in equations that are used to fill out truth tables of other nodes throughout the network.

Fig. 4 shows a simple example network before any evidence is added, when the probability of each node is its prior. Once a network is compiled in Netica, clicking true on a node in Netica changes the probability of that node to 100% true and the node turns grey. Using the truth tables, the probabilities of each node affected is calculated using Bayes' Theorem and updated instantly. This can be seen by observing the changed values of the nodes between Fig. 4 to Fig. 5. Particularly notice the nodes *Pathway 1* and

Likely Pathway. By adding evidence associated with *Pathway 1* in Fig. 5, the reader will notice that the probability that the node *Pathway 1* is true increased significantly, along with its respective value in the node *Likely Pathway*. The increase in probability of *Pathway 1* was dictated by the values that the user defined in its truth table. It is important to note that the user could make it so that the probability would decrease as certain evidence was added. This may be used to account for evidence that suggest that *Pathway 1* is not a likely pathway.

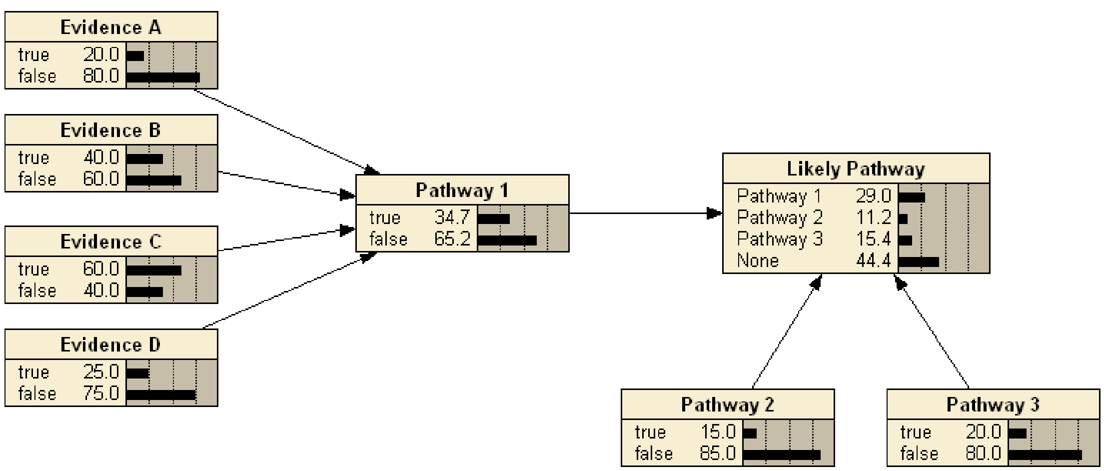


Fig. 4. Example of Bayesian network in Netica with priors

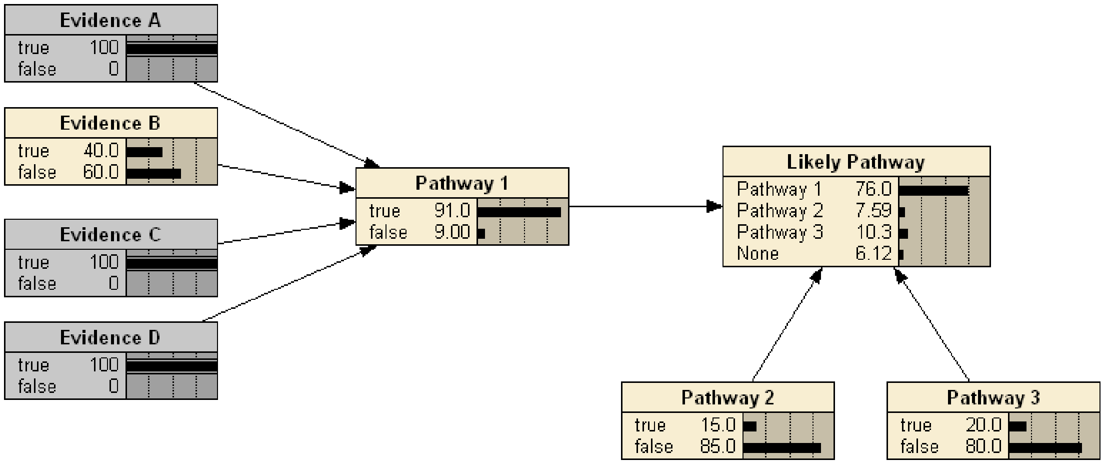


Fig. 5. Example of Bayesian network in Netica after adding evidence

Netica can also facilitate a sensitivity analyses. At any point after a network is created, Netica can calculate the relative ability of different nodes to impact the truth of a node of interest. Netica takes into account any evidence already entered when making this calculation. This useful feature has many applications. For example, by examining certain nodes, it can be used to determine which piece of evidence would be most useful in resolving any ambiguity that might arise regarding what pathway an organization is taking. Or, it could be used to determine what piece of evidence would be most detrimental to an organization's attempt to acquire nuclear weapons if it were false. This knowledge may be helpful in allocating resources to stop their efforts. Details concerning how this value is calculated can be found in Netica's documentation.

Network Organization

The examples used above are organized from the specific to the general. The specific pieces of evidence are parent nodes to the general pathway that they represent.

The specific pathways are parent nodes to the general decision. This may seem like a logical manner to organize a network, however it was discovered that this scheme presented some disadvantages.

Many of the problems with organizing the network from the specific to the general that manifested themselves were directly or indirectly the result of one phenomenon. By examining Fig. 4 and Fig. 5, the reader may notice that after the evidence was added and the probability distribution of *Pathway 1* changed, the parent node *Evidence B*, which was not made true, did not change at all. A parent node may influence its child node, but it cannot have any affect on the other parent nodes of that child. This makes sense and is useful for many purposes, but there are a few places in this project's network where this property is undesirable.

For example, consider the simplified portion of the network given in Fig. 6. When reprocessing spent fuel, the spent fuel has to have its cladding removed and then be dissolved, which releases radioactive gasses that are indicators of the process. This is modeled from the specific to the general in Fig. 6. Discovering that an organization has acquired spent fuel as well as the ability to remove its cladding can be suggestive that they will reprocess fuel. Also, if a plant is discovered that is emitting signature gasses then it can be concluded that the organization is reprocessing fuel. Knowing that the organization is reprocessing fuel means that the organization has already acquired spent fuel and the ability to remove its cladding. But because Reprocessing Release Gasses and Separate Fuel & Cladding are both parents to the node Dissolved Fuel Elements, the evidence of reprocessing given in Fig. 6 does not properly impact the probability of having spent fuel and cladding removal ability. The new evidence of reprocessing gases affects the nodes down the chain as desired; however, up the chain it does not.

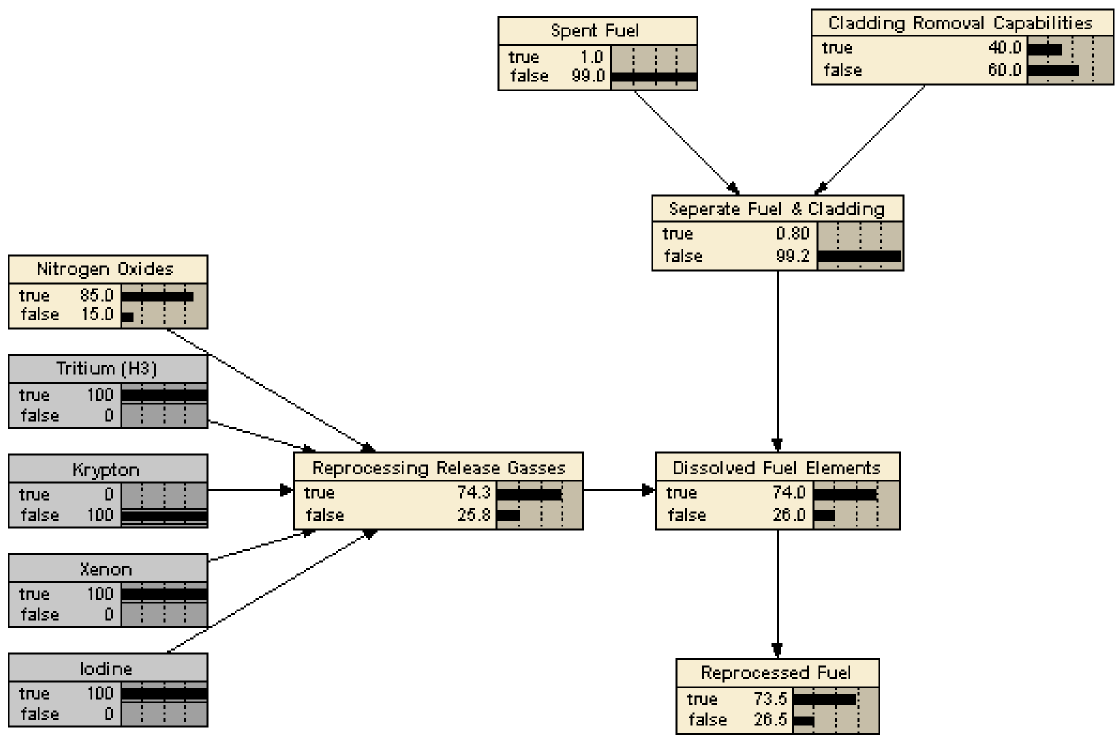


Fig. 6. A reprocessing section flowing from specific to general with evidence

Furthermore, suppose there is evidence that an organization has acquired the pieces to an implosion package. This is suggestive that the organization is pursuing an implosion device. Knowledge that supports an implosion device should also make other pathways necessary for that design more likely. But in a network set up from specific to general, different pathways needed for an implosion device would be parents of the node for an implosion device, and therefore knowledge of one could not impact the other.

Another type of problem that occurs in setting up a network going from specific to general is an inconsistency between how the node behaves depending on where evidence is added. Consider Fig. 5 and recall how as each of the evidence associated with *Pathway 1* is made true, the probability of *Pathway 1* being true is increased. Compare this to Fig. 7 where it is known that *Pathway 1* is the pathway that is being taken. The reader will notice that the likelihood of evidence corresponding to *Pathway 1* did not increase significantly from the value of their priors displayed in Fig. 4. Since each piece of evidence impacts the truth of *Pathway 1*, when knowledge that *Pathway 1* is true is given, the corresponding change in probability distribution is split between each of the contributing parent nodes. This is also undesirable since knowledge that a particular pathway is true should significantly increase the probability that each of its prerequisites is true.

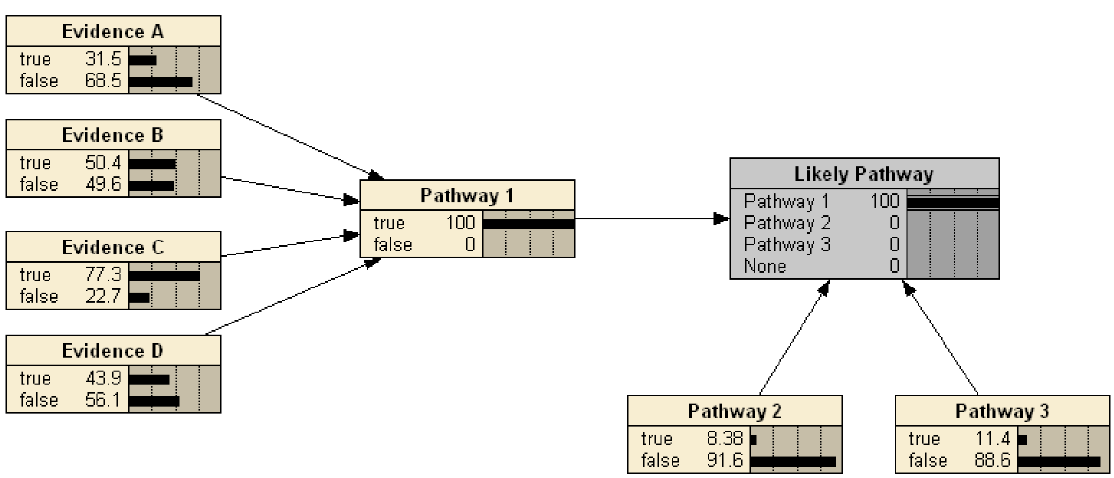


Fig. 7. Example network with evidence added that Pathway 1 was chosen

It is noted that this inconsistency can be addressed by using a truth table that only allows *Pathway 1* to be true if all of its associated evidence is true. However, this is not a desirable solution; in this situation Bayes' Theorem simplifies to:

$$P(X)=\prod_{n=1}^{N}P(p_n) \tag{3}$$

where $P(X)$ is the probability that node *X* is true and $P(p_n)$ represents the probability that parent node *n* is true. While this requires that each of the associated evidences be true for *Pathway 1* to be true, the straight multiplication of their probabilities means that *Pathway 1* will never be more true than the least true piece of evidence. As a result, the network loses much of its suggestive capability.

To avoid these pitfalls, the network is organized from the general to the specific as seen in Fig. 8. One distinction to note between this and the previous arrangement is that before, all of the evidence nodes along with *Pathway 2* and *Pathway 3* were without parent nodes. In this setup only the node *Likely Pathway* has no parent nodes. This is an important difference that is discussed later.

One obstacle that is encountered when arranging the network in this fashion is that the likelihood of the evidence being true is based on the likelihood that its pathway is true. Thus when any piece of evidence is made true it requires that its parent node be true, which in turn results in all of the other evidence for that pathway being true as well. This problem is shown in Fig. 9 where *Evidence C* is made true.

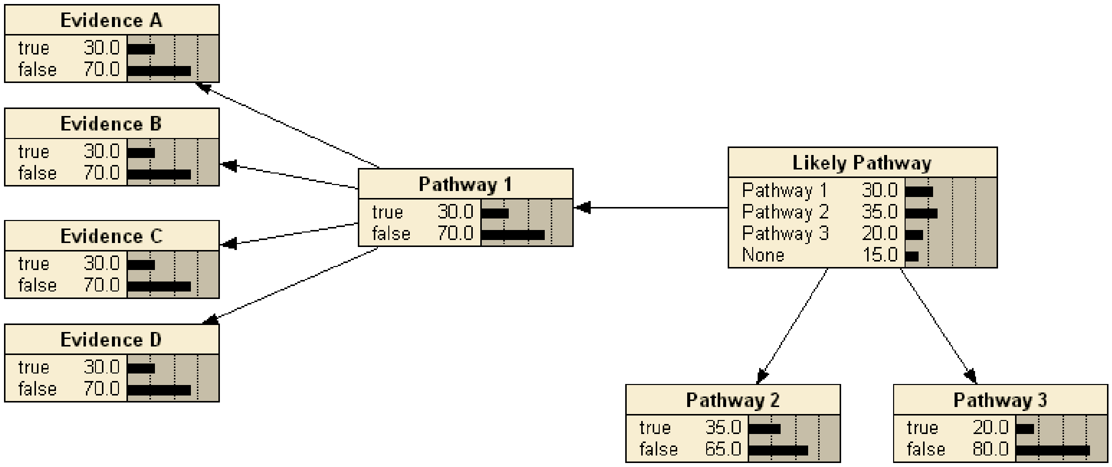


Fig. 8. Example network going from general to specific

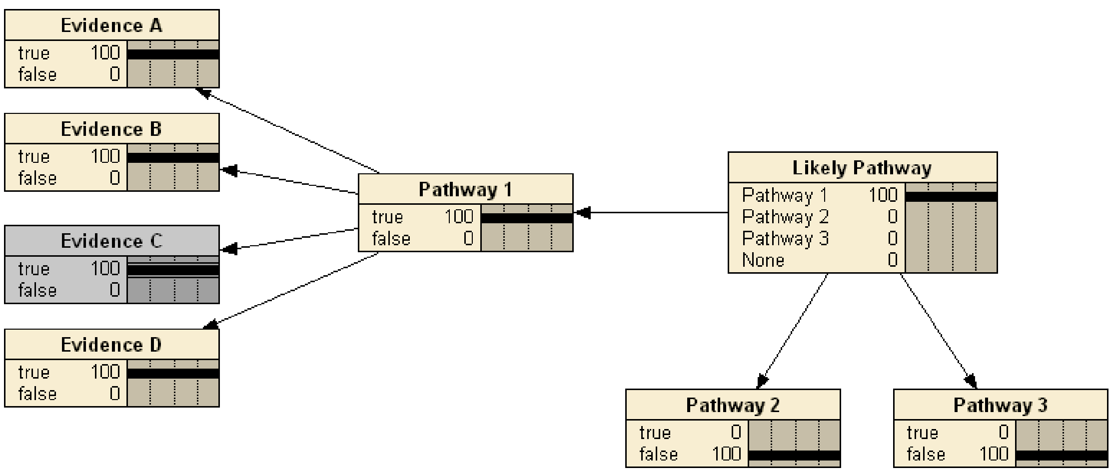


Fig. 9. Example network going from general to specific with evidence added

This problem is addressed by creating a new node where a pathway forks that has each branch as an option along with an option that none are true. Since each node represents an event, the total probability distribution must equal unity. In the Boolean-type nodes this is easy to see since if it is not true it must be false, meaning that the probability of true and false always adds to one. As a result of the total probability distribution being unity, the probability for each option can't be related to the truth of its corresponding branch. Otherwise, if one branch were true, then all other branches would be false. This is acceptable in a node such as *Likely Pathway* where each option represents the likelihood that a particular path is chosen. In nodes where each branch would be a piece of evidence, forcing them to be mutually exclusive would not be beneficial. To avoid this problem, each of the probability distributions for the new node are inverted. Thus a particular branch is true when the probability distribution associated with it in the node is zero. Furthermore, the probability of the option none being true actually represents the probability that *all* of the options are true.

This new "inverted" node still does not completely address the issue demonstrated in Fig. 9. The truth table for each piece of evidence must also be written so that it has a small chance of being false even if its corresponding option on the inverted node is true. At the same time, it must also have a small chance of being true when the inverted node has a corresponding probability that it is false. The degree of this deviation away from being absolutely true and absolutely false, or "softening" in the truth table determines the impact that the evidence has on its pathway. Whether desired or not, this deviation also increases the prior of the node being true as well.

It is noted that the problem demonstrated in Fig. 8 could also be addressed by simply "softening" the evidence nodes and skipping the process of adding a new node. However, it was found that this produced a small increase in the prior over the increase produced from using an inverted node. While the difference is only a marginal increase, a pathway with several branching points results in a significant increase in the priors on the peripheral nodes. Furthermore, using the inverted nodes resulted in more desirable behavior when adding evidence to the actual network.

Fig. 10 shows the use of an inverted node to address the issue created by going from general to specific seen in Fig. 9. The inverted node displays information that is unintuitive and could serve as a distraction to the user. The repeated use of these nodes also creates unnecessary clutter in the network since the information that is useful is displayed in the node adjacent to it (*Pathway 1* in the example above). As a result, these nodes are displayed as small circles adjacent to the node that they are used for in the network, seen in Fig. 11.

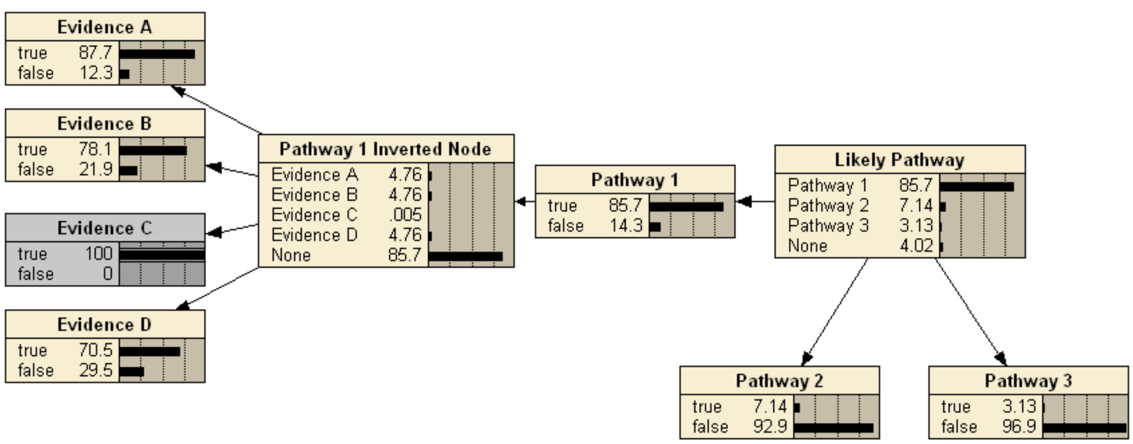


Fig. 10. Example network displaying the belief box of an “inverted node”

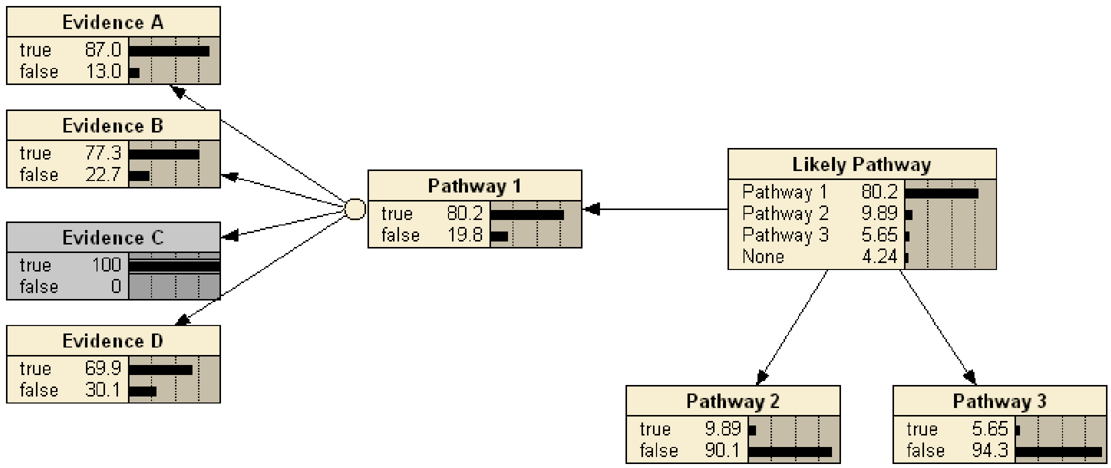


Fig. 11. Example network using an "inverted node", shown as the small circle node adjacent to *Pathway 1*

Priors

Priors in the network are calculated using constant nodes that represent the intentions and resources of an organization, both of which will be discussed in Chapter III. Suppose node *n* is impacted by the intentions and resources of an organization. Node *n* will have special nodes, or "prior nodes" created that calculate how it is impacted by the value of the intentions and resources. These prior nodes are then used as parent nodes to node *n* to bias its probability distribution. In the network, they are displayed as small circles adjacent to the node they impact like the inverted nodes, except without links connecting them to other nodes. Calculating the values for these prior nodes is discussed in Chapter III.

As discussed above, parent nodes can affect the probability distributions of their children but not other parents of their children. Therefore wherever the prior nodes are applied they cannot impact the probability distributions of the preceding nodes along the pathway. To demonstrate its importance, suppose that a prior node is used that makes the probability of having uranium enrichment capabilities less likely. While this would cause all of the components that are necessary to enrich uranium to be less likely because they are down the chain in the network, it would have no impact on the node that precedes uranium enrichment capability - actually having enriched uranium. Therefore, the use of the prior node used in this example is meaningless. However, the prior nodes can be used to place biases on how the probability distribution is split whenever a pathway forks.

To fix this problem, all of the necessary information about the priors of a branch in the network must be placed at the root node of the branch, with the exception of prior nodes that simply bias one option over another. Thus, care should be taken in how the network is arranged and consideration given to this limitation when organizing the flow of a network.

Network Construction

A network was constructed in Netica that models pathways that an organization may take to obtain nuclear weapons. The network includes a section to develop SNM indigenously as well as the pathways of purchase and theft. The network also includes a section for weaponization of any SNM obtained and the pathways to purchase or steal an assembled nuclear weapon. The entire network is shown in Fig. 12 through Fig. 24.

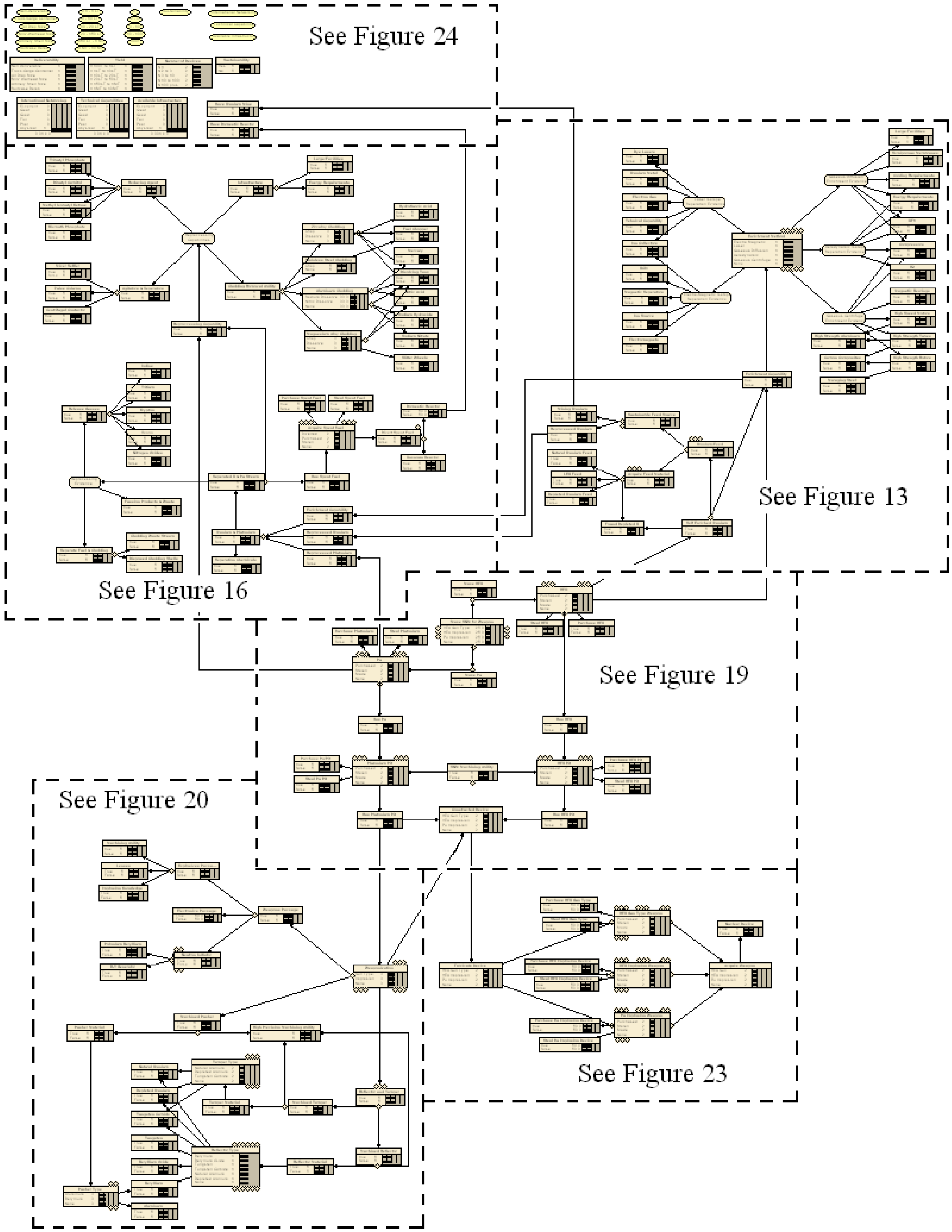


Fig. 12. The complete network

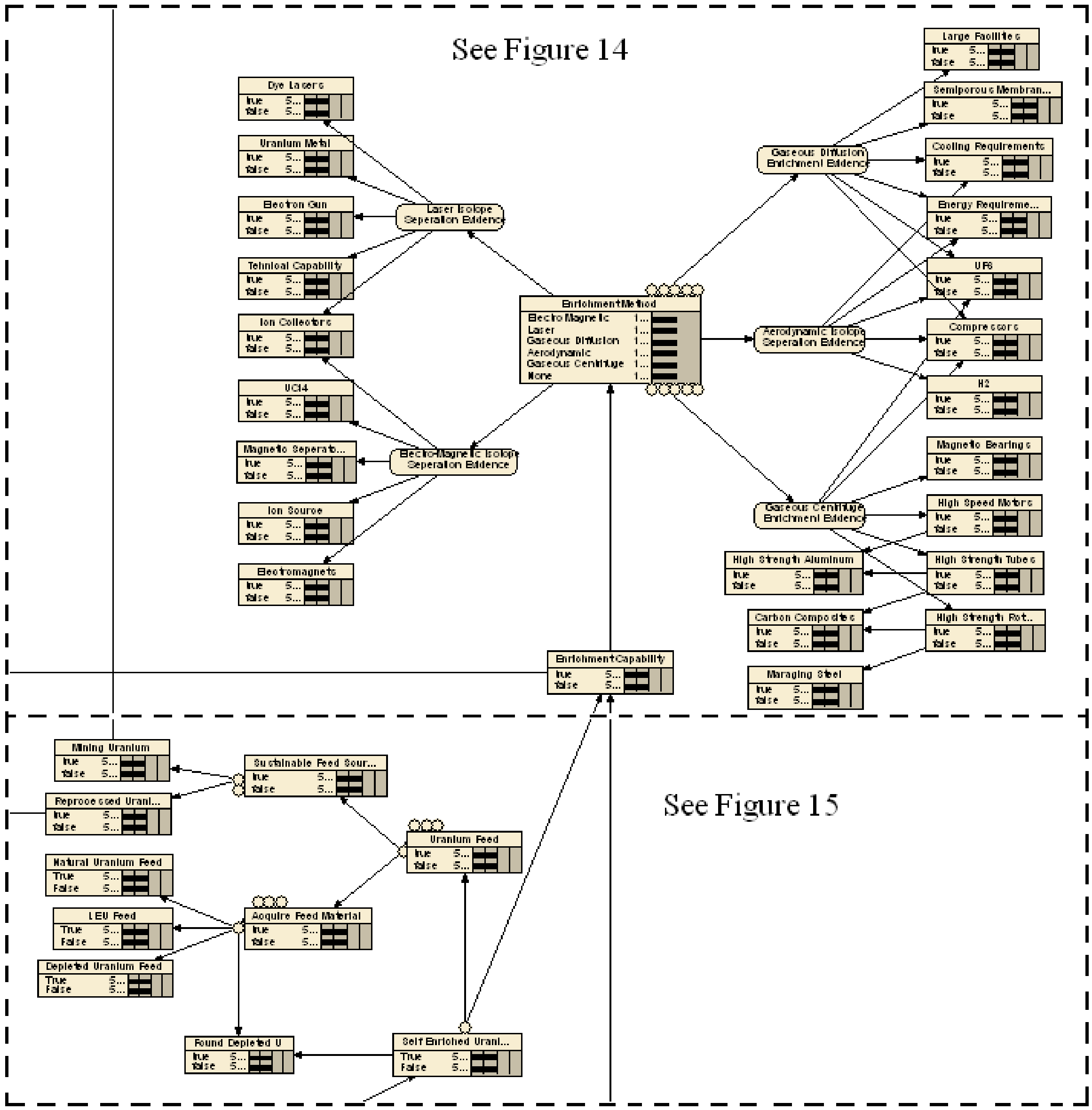


Fig. 13. HEU section of the network

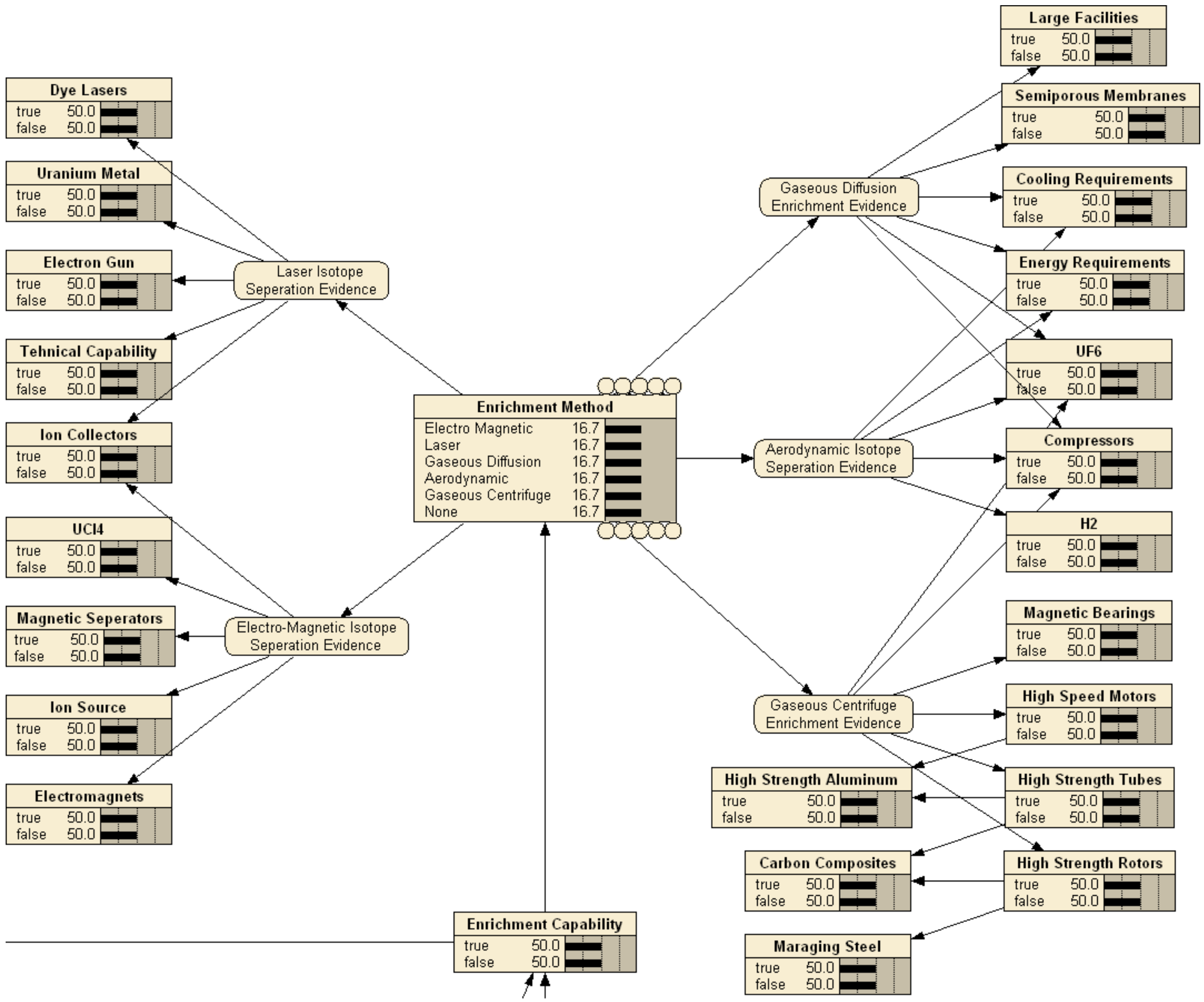


Fig. 14. Enrichment capability portion of the HEU section

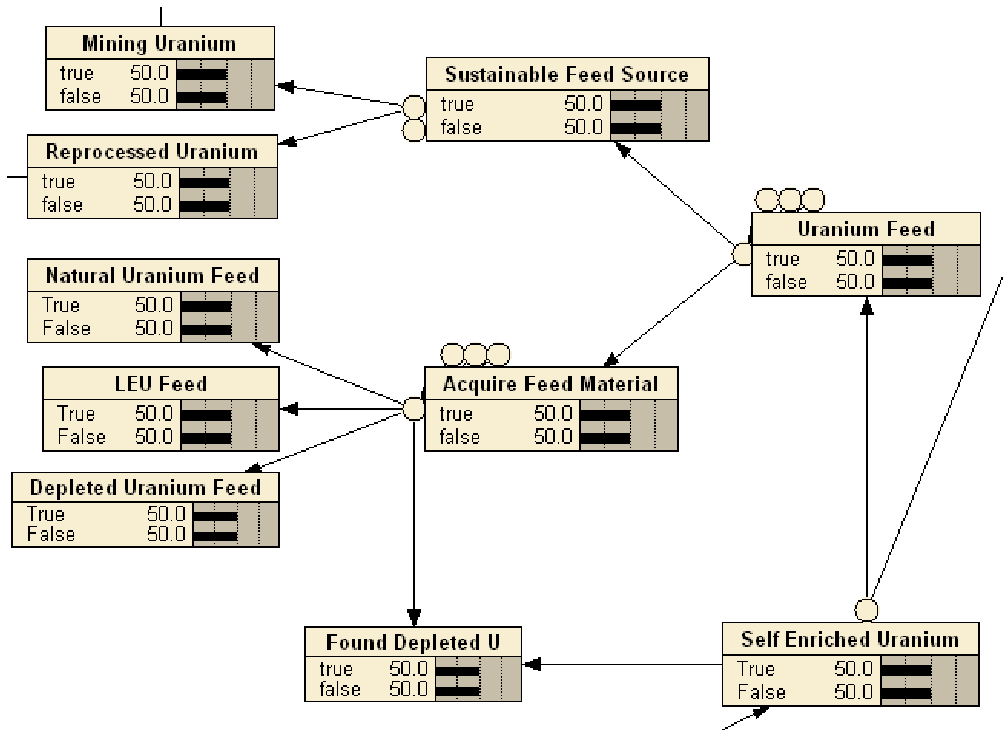


Fig. 15. Uranium feed portion of the HEU section

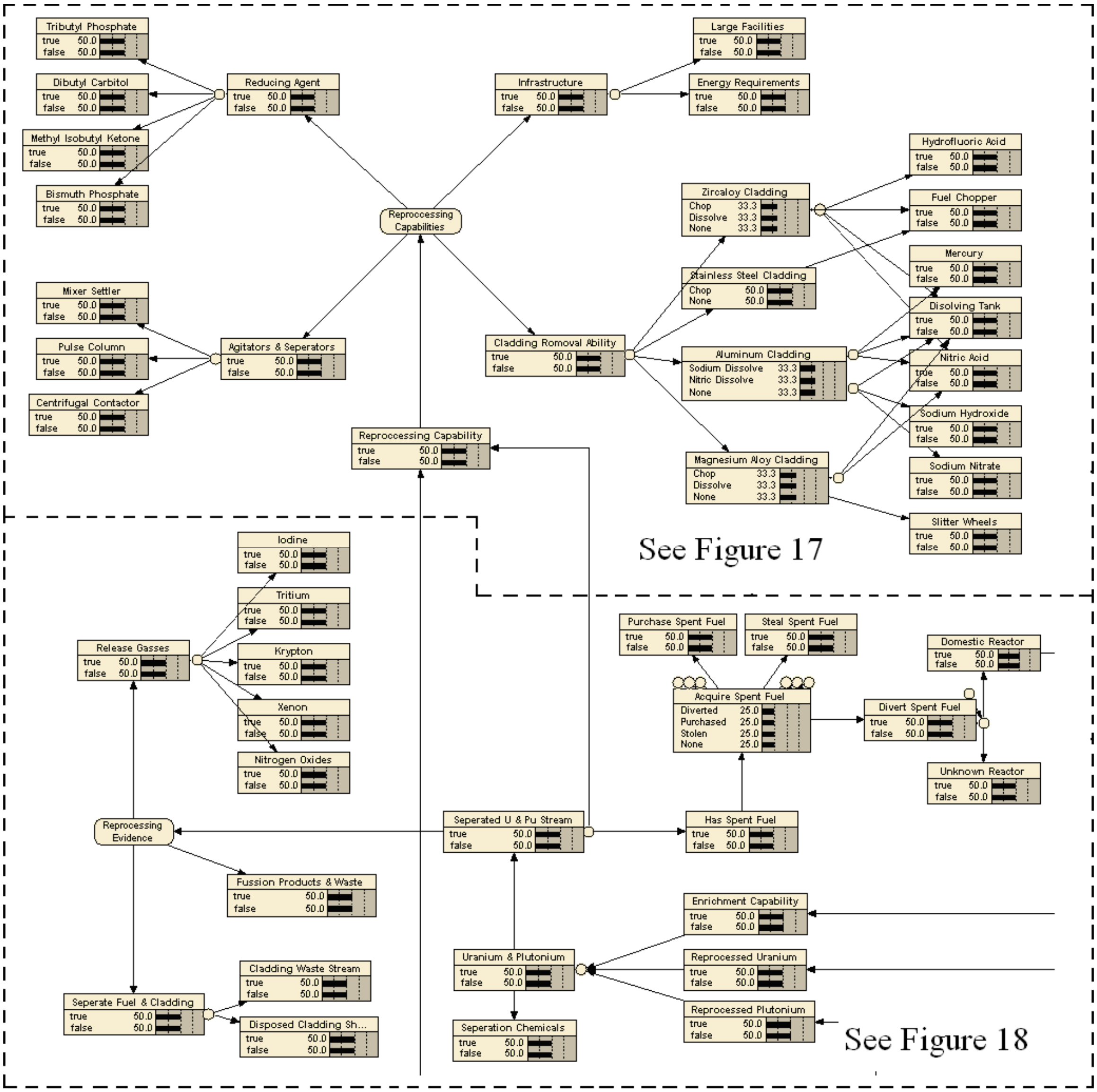


Fig. 16. Reprocessing section of the network

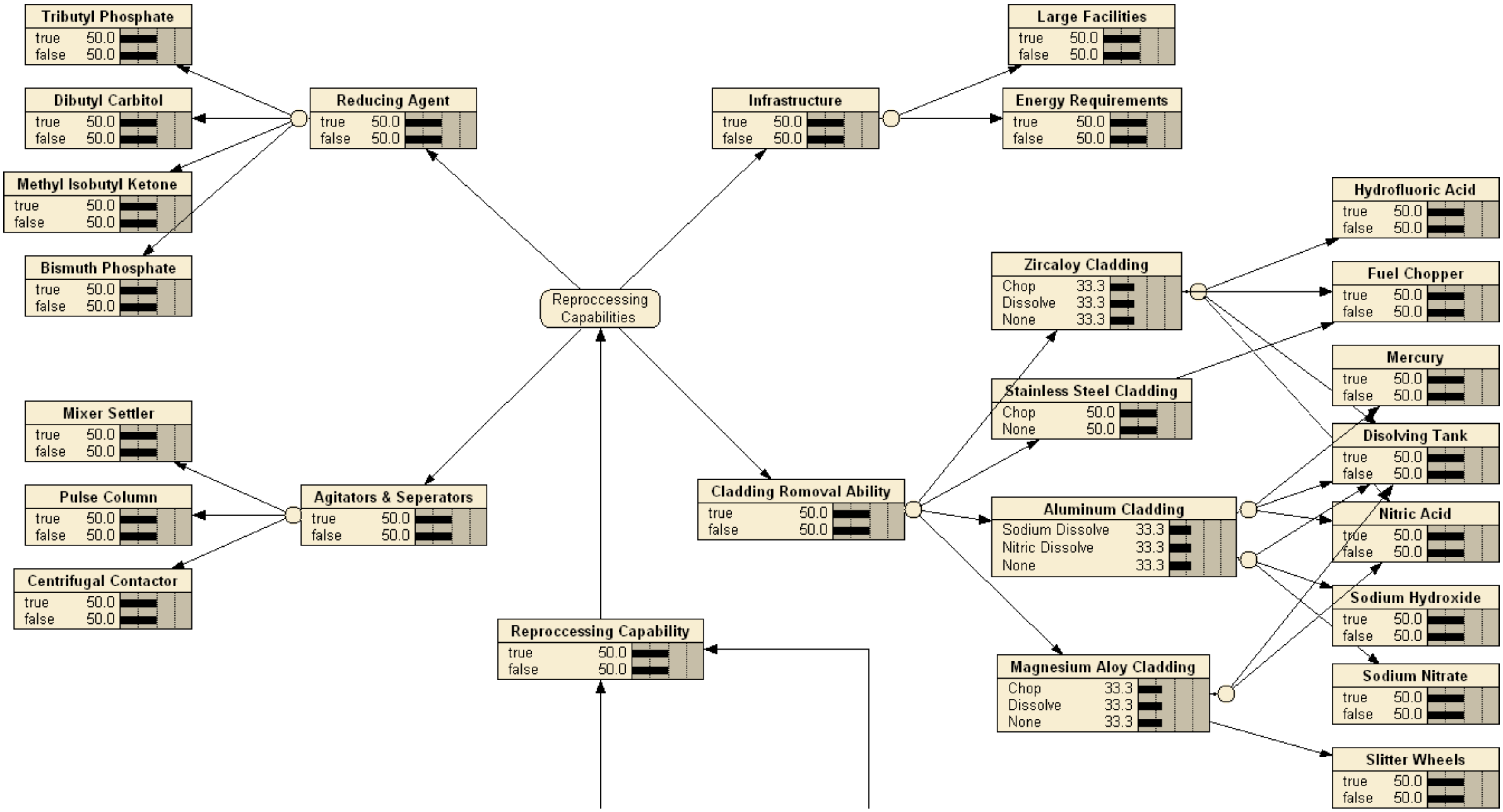


Fig. 17. Reprocessing equipment portion of the reprocessing section

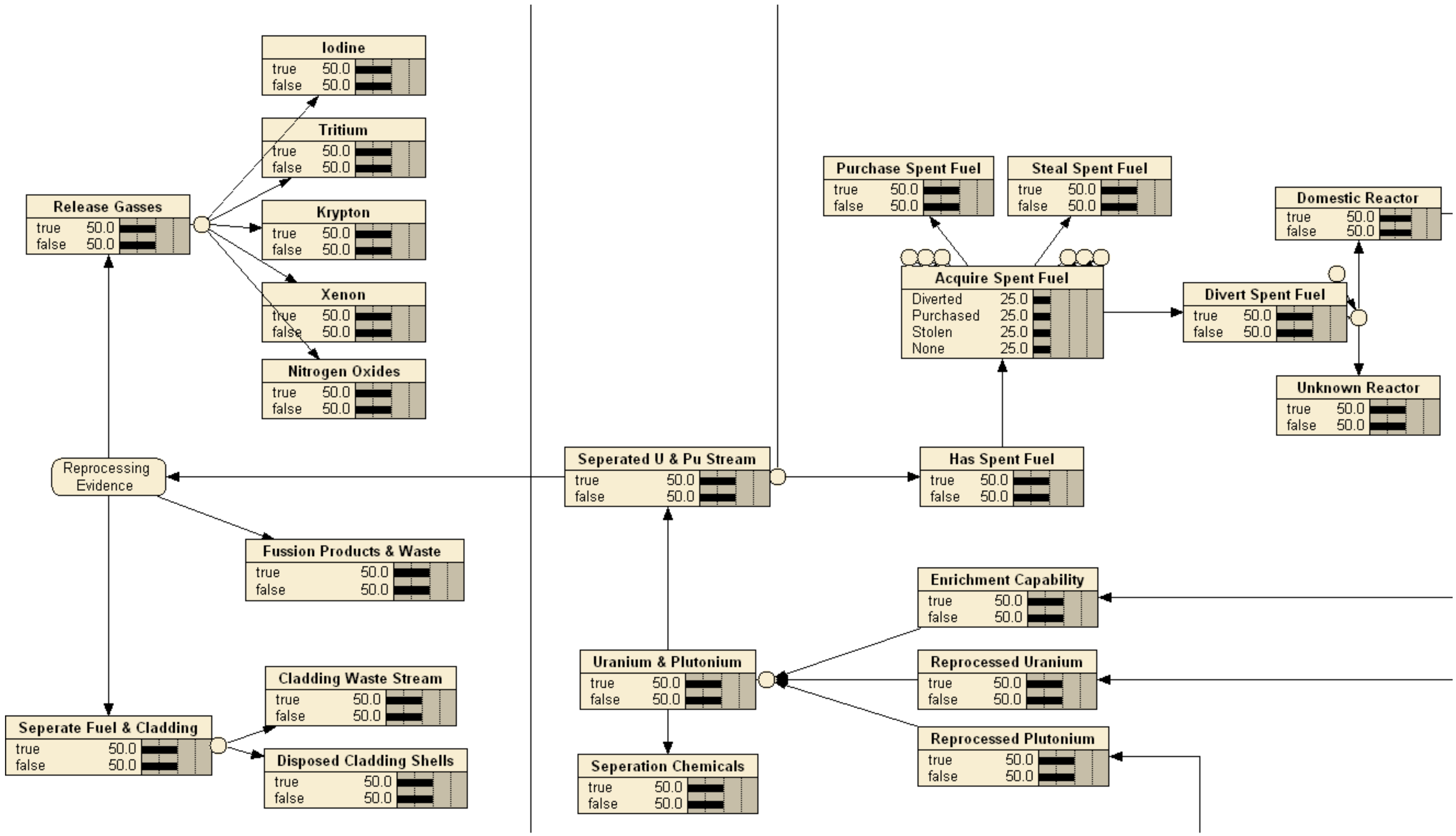


Fig. 18. Spent fuel and reprocessed fuel portion of the reprocessing section

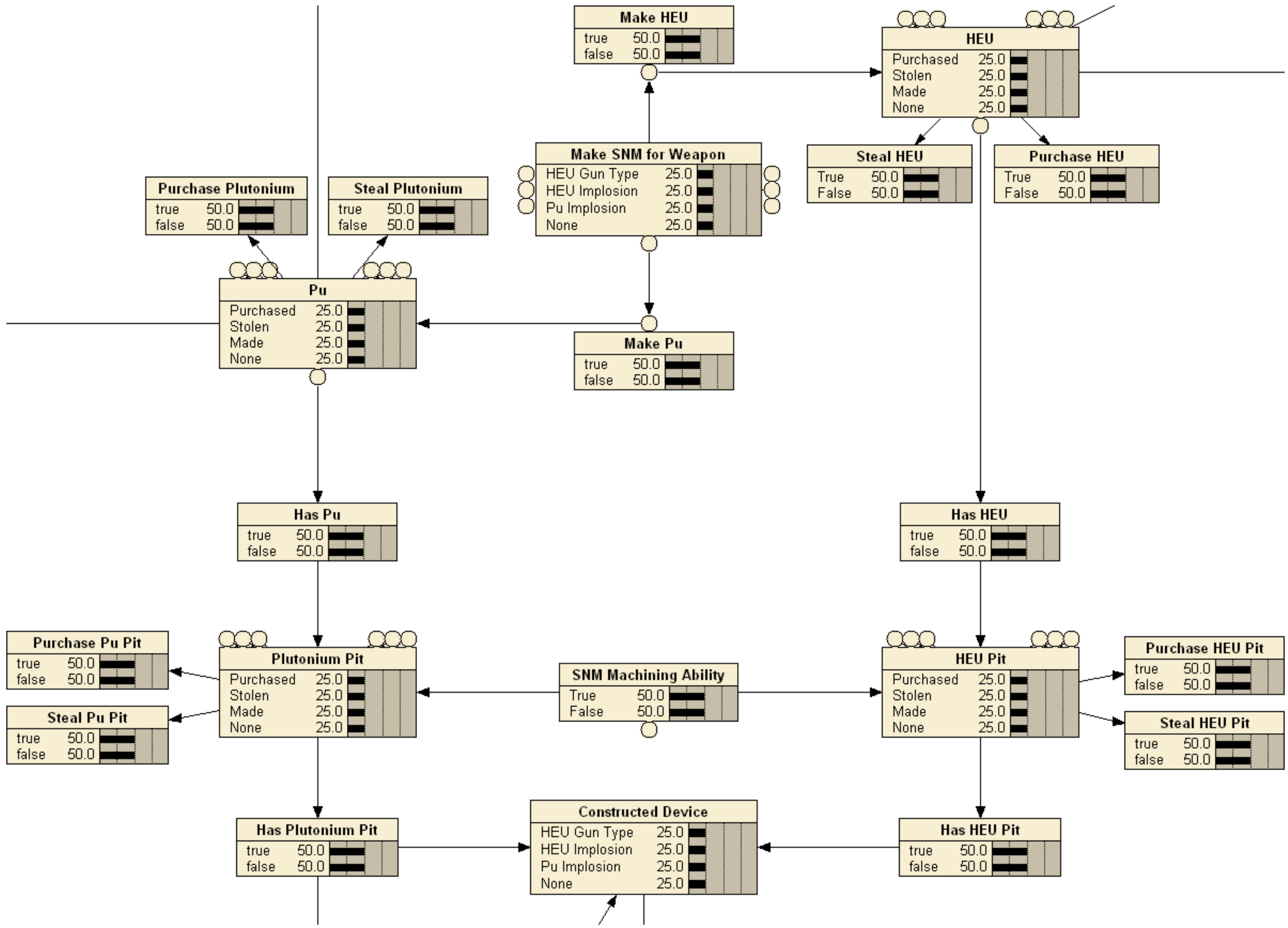


Fig. 19. Special nuclear material section of the network

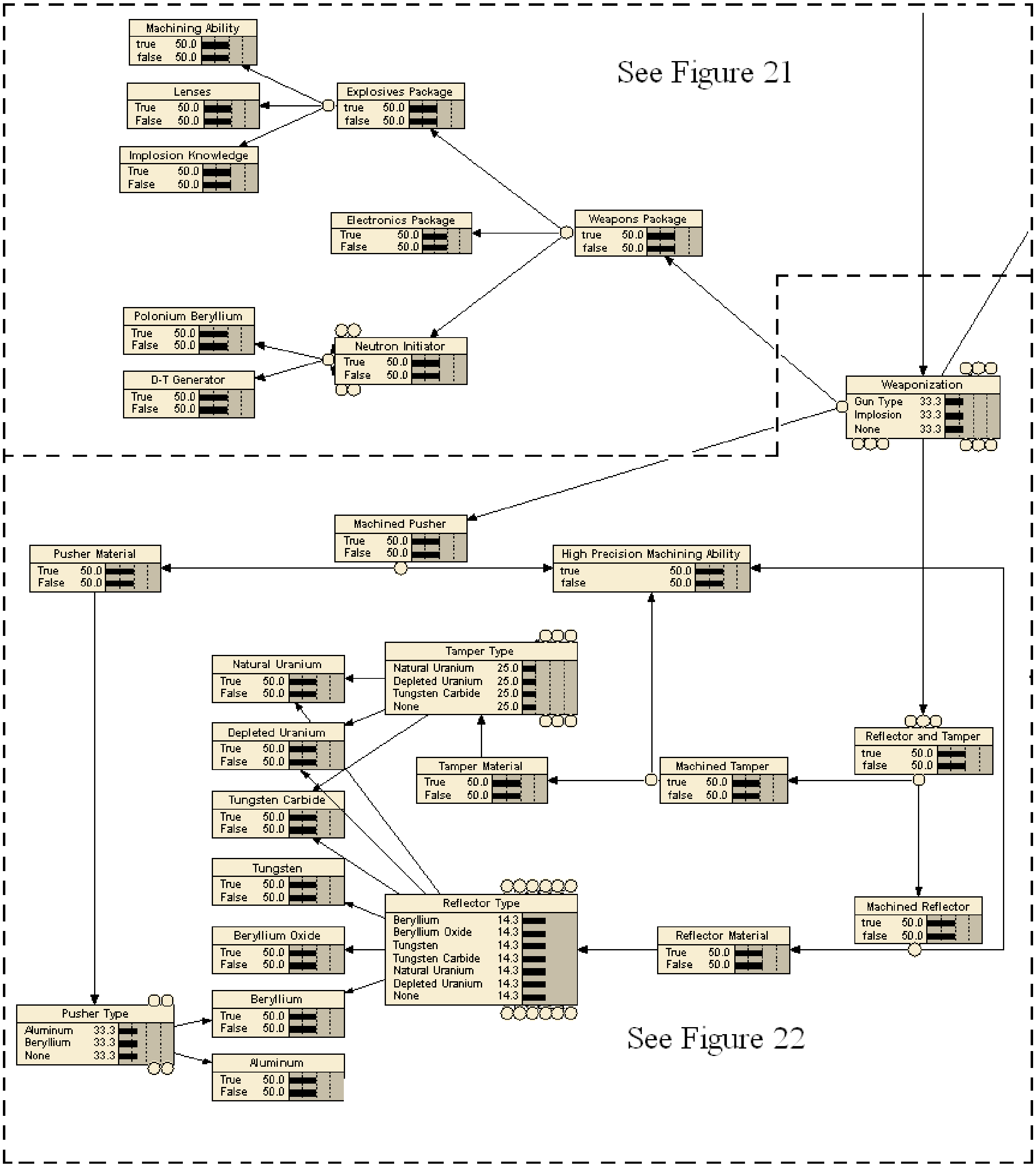


Fig. 20. Weaponization section of the network

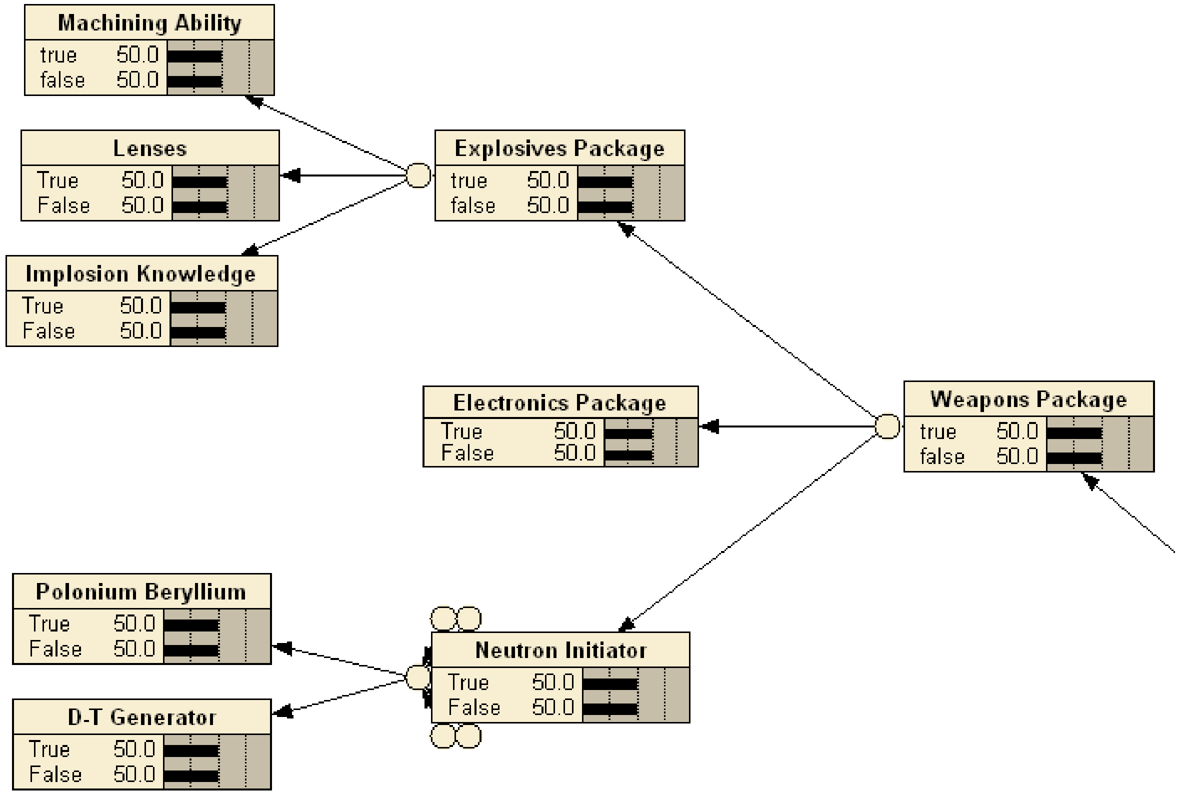


Fig. 21. Weapons package portion of the weaponization section

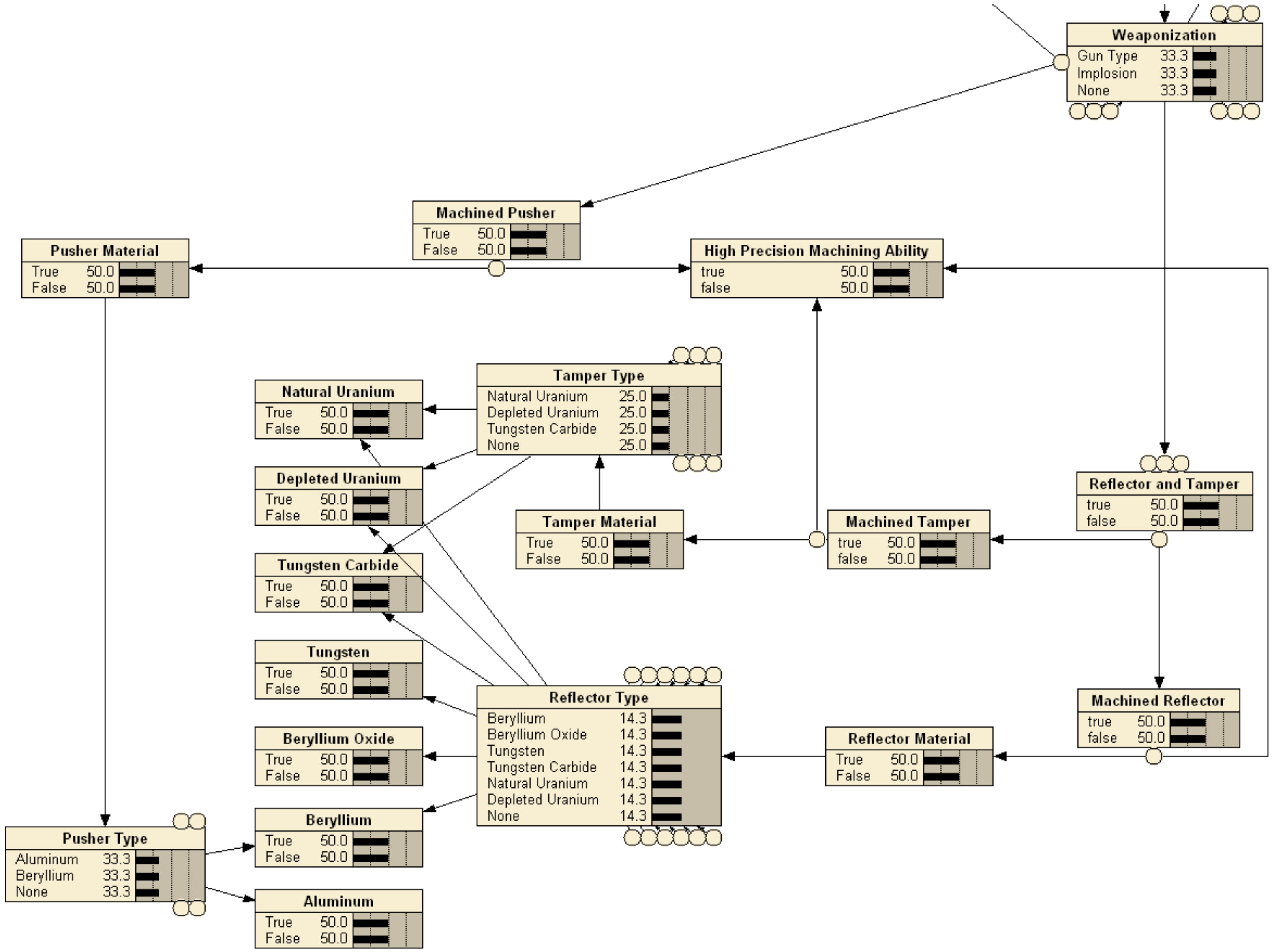


Fig. 22. Pusher, tamper, and reflector portion of the weaponization section

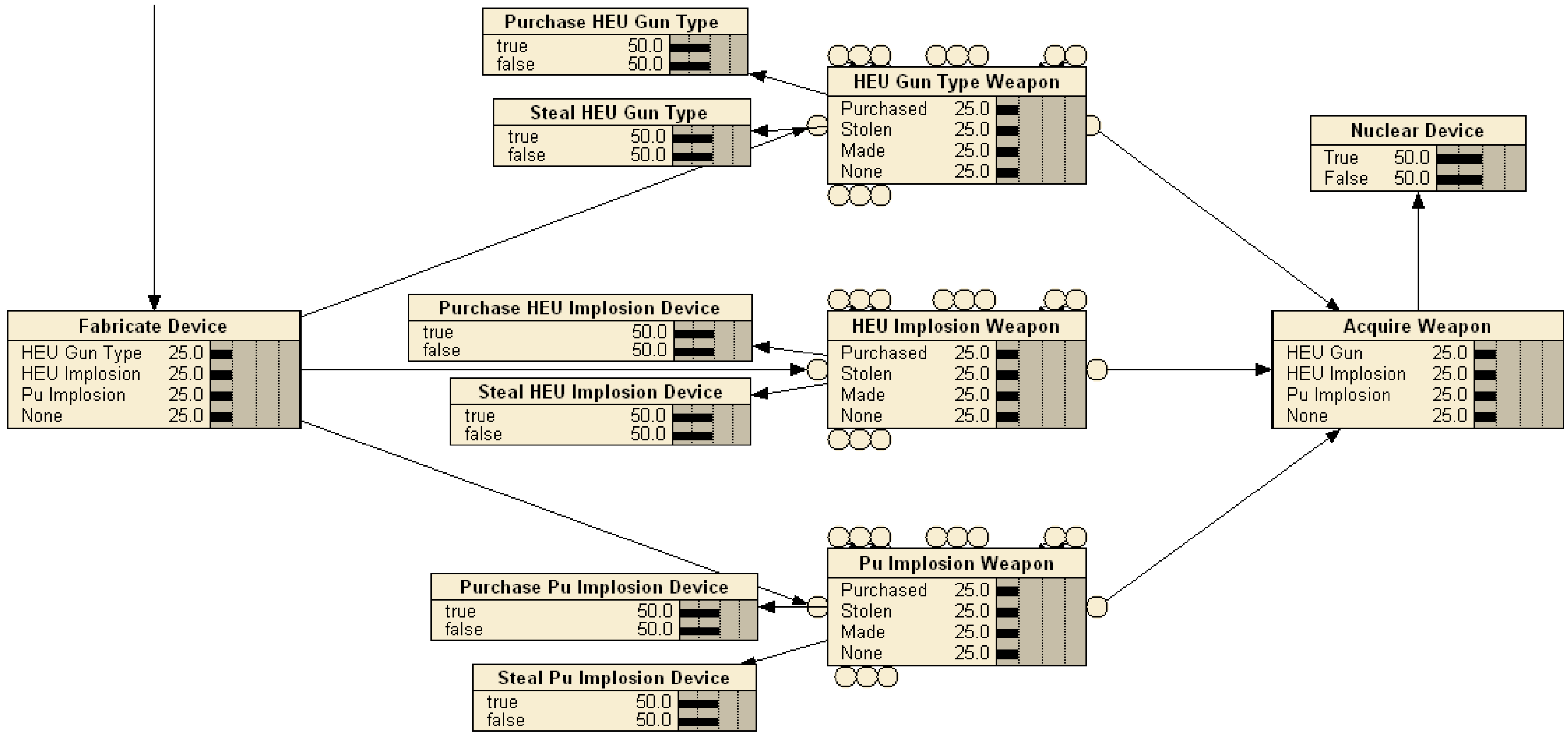


Fig. 23. Completed nuclear device section of the network

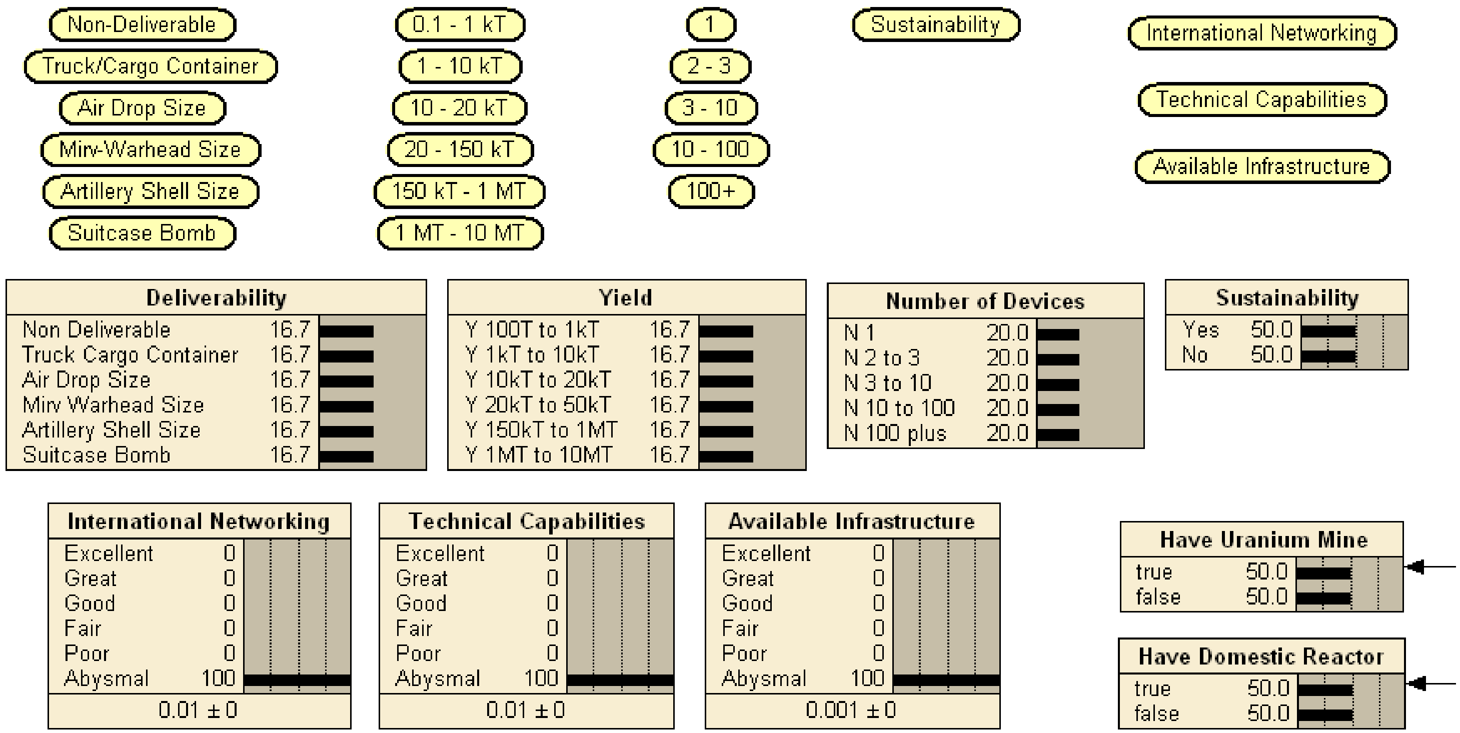


Fig. 24. Intentions and resources input section of the network

CHAPTER III

MOTIVATIONS, INTENTIONS, AND RESOURCES

Motivations

An organization's motivations play a role in their decisions regarding proliferation. One key aspect of this work is to quantitatively analyze the affects that varying motivations have on the pathway choices available. For this methodology, a list of motivations was generated that was derived from the literature available on the subject.[18,19,20,21]

The motivations are divided into two sections: National and Sub-National. The national motivations are given to represent the reasons that a rogue nation or any nation of interest might desire nuclear weapons. The sub-national motivations are given to represent the reasons that a terrorist organization might attempt to acquire nuclear weapons. However, considering some rogue nation's behavior and transnational terrorist organizations such as Al' Qaeda, the line between the two can be blurred. This is not a problem since both national and sub-national motivations are handled the same, so mixing from both groups is acceptable.

The following is the list of all of the motivations used in this work, broken into sub-national and national groups:

Sub-National Motivations

1. Prestige of Possession: Possessing a nuclear weapon helps to demonstrate an organization's viability or legitimacy.

2. Prestige of Capabilities (Peaceful): Demonstrating the capability to produce a nuclear weapon increases the prestige of an organization. However, the organization also feels that actually using the weapon would undermine their objectives.

3. Prestige of Capabilities (Non-Peaceful): This is the same as prestige of capabilities (peaceful), except that using nuclear weapons would not necessarily undermine their objectives.

4. Manipulate Adversaries: A group pursues nuclear weapons to use as leverage against other organizations or even nations.

5. Apocalyptic Beliefs: The organization believes that the end of the world is near and is motivated to take an active role in promoting the event. Nuclear weapons make a very attractive tool for this end.

6. Religious Duty: Religious extremists that believe it is their duty to acquire nuclear arms for their ideology.

7. Psychological Warfare (Non-Use): The group's aims centers on demoralizing and terrifying the populous, but they are not driven to use violence to cause mass casualties of innocent victims.

8. Psychological Warfare (Intended Use): The group is motivated to demoralize and terrify a populous and believes that this is best achieved by actually using nuclear weapons.

9. War on Own Nation (Separatist): Separatist group that wants to use nuclear weapons to combat the current regime in a country.

10. War on Another Nation (Extremist): The organization has a deep hatred for a particular people or nation and they feel compelled to acquire nuclear weapons to combat their adversary.

National Motivations

11. Deter Attack from Nuclear Adversary: The nation desires to have nuclear weapons to deter attack from an adversary armed with nuclear weapons.

12. Seek Military Superiority: The nation wishes to achieve a superior military presence than its competitors and feels that this is best done with nuclear weapons as opposed to conventional forces.

13. Redress Conventional Military Asymmetry: The nation has an overwhelming conventional militarily disadvantage against a rival and seeks nuclear weapons to counter this disadvantage.

14. Go Nuclear Before Rival: The nation seeks nuclear weapons to ensure that a rival won't acquire them first and therefore be at a disadvantage in the near future.

15. Intimidate Non-Nuclear Rivals: The nation seeks nuclear weapons to use as leverage against a non-nuclear armed rival.

16. Acquire Position in International Forums: The nation seeks to acquire a nuclear weapons capability because they believe it will raise their position in international forums.

17. Rise to Global Power Status: One consistent characteristic about global super powers is that they posses nuclear weapons or at least the capability. Nations wishing to become global powers might see nuclear weapons as a prerequisite for being a global power.

18. Enhance International Status: The nation believes that acquiring nuclear weapons will raise its international status.

19. Demonstrate National Viability: The nation believes that a nuclear weapons capability will demonstrate their competency.

20. Assert Military or Political Independence: The nation seeks nuclear weapons to prevent dominance from another nation.

21. Divert Domestic Attention: The nation believes that a nuclear weapons program might help to divert attention away from difficult internal problems.

22. Enhance Bargaining Position Within an Alliance: The nation believes that nuclear weapons will place them in an advantaged position in future negotiations with allies.

23. Deter Regional Intervention by Superpower: The nation perceives a superpower's involvement in their regional affairs as unwanted and unjustified and believes that possessing nuclear weapons would deter involvement by that superpower.

24. Increase Military or Scientific Morale: The nation believes that acquiring nuclear weapons will be a source of pride for their military and scientific community.

25. Increase Domestic Morale: The nation believes that a nuclear weapons program will be a source of national pride for the populous.

26. Reduce Economic Defense Burden: The nation believes that producing nuclear weapons is an economical alternative to conventional forces.

Intentions

The motivations behind an organization's choice for nuclear weapons influences the pathways they take to acquiring them. However, it is difficult to qualify, and more so to quantify, how each of these motivations affect the pathways chosen. For example, it is difficult to determine what pathways are more likely by simply knowing that an organization wishes to deter an attack from a nuclear adversary or that they wish to intimidate a non-nuclear rival. However, a nation wishing to deter attack from a nuclear adversary will most likely believe that one or two devices will not be a practical deterrent to a nation who has several at their disposal. The threatened nation's nuclear objectives will most likely require several weapons and a latent capability to produce more so that their adversary knows they can replenish their supply. From this, it can be concluded that it is very unlikely that purchasing or stealing nuclear weapons or SNM will be acceptable pathways. The nation will need the infrastructure to produce SNM indigenously so that they can make multiple devices and maintain the ability to produce more as needed.

Thus, it can be seen that the motivations of an organization directly influences the general properties of a weapon or a weapons program. These general properties lead to decisions on the most likely pathways that will lead to those properties. We call these general properties intentions.

Thus, motivations determine intentions and intentions influence pathway decisions (Fig. 25). Intentions are divided into four categories as follows:

1. Deliverability: How deliverable must a nuclear device be to meet an organization's likely goals inferred from their motivations?

2. Yield: Based on an organization's motivations, what yield would likely be required by their nuclear ambitions?

3. Number of Intended Devices: What is the likely number of devices that an organization will attempt to acquire based on their motivations?

4. Sustainability: Considering their motivations, what is the likelihood that an organization will desire the latent capability to produce more nuclear weapons in the future?

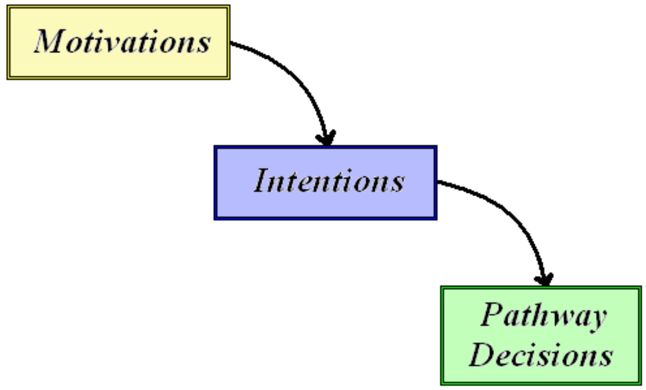


Fig. 25. Depiction of how to incorporate motivations into pathway decisions

Each of the intention categories is broken into ranges to represent each of the possible intentions. Breaking the intentions up into different ranges helps to handle the uncertainty when applying a specific value for a category. The intentions that are used are divided the following categories:

Deliverability: The level of deliverability intended for the nuclear device.

- Non-Deliverable: The device is unable to be delivered to a target, or even moved, at least not by any inconspicuous means.
- Truck: The device can be moved around by a tractor-trailer or other large vehicle.
- Air Drop: The device can be loaded into a large plane and dropped on a target.

- MIRV-Size Warhead: The device can be attached to larger ballistic missiles, comparable in size to the Multiple Independently Targetable Reentry Vehicle (MIRV) missiles.
- Artillery Shell: The device is small enough that it can be projected out of larger artillery or attached to smaller missiles.
- Suitcase: A device that is small enough to fit inside a suitcase.

Yield: The designed explosive power of the nuclear device expressed in equivalent tons of TNT.

- 0.1kT - 1kT*
- 1kT - 10kT
- 10kT - 20kT
- 20kT - 150kT
- 150kT - 1MT
- 1MT - 10 MT

Number of Intended Devices: The number of devices that an organization desires.

- 1
- 2 – 4

* This is interpreted as an intention to create a 0.1kT – 1kT device, not a fizzile. Generally, for nuclear explosions it is more difficult to intentionally create a device with a small yield than one with a larger yield.

- 5 – 10
- 10 – 100
- 100 +

Sustainability: The probability of maintaining latent nuclear capabilities.

- yes
- no

Calculating Intentions

Once selected, the motivations are combined so that they impact the intentions in the desired manner. Each intention *i*, is assigned a probability that it is true for a given motivation, *m*. This probability is represented by v_i^m. Values for v_i^m are assigned by asking the question: "based on motivation *m*, how probable is it that an organization would consider the intention *i*, the required minimum for success in its intention category?" Each motivation *m* is assigned a weight, w_m. This weight represents the importance of this motivation relative to the other motivations for an organization. These weights are assigned such that:

$$w_m \in (0, \infty) \tag{4}$$

and are normalized as follows:

$$k_m = \frac{w_m}{\sum_m^M w_m} \tag{5}$$

The normalized weights for an organization of interest's motivations are combined with the probability assigned to each intention for a given motivation as follows:

$$u_i = \prod_{m=1}^{M} \left(v_i^m \right)^{k_m} \tag{6}$$

where u_i represents the probability that i is the intention of the organization.

This method of attribute aggregation was chosen because (1) unlike a simple weighted average formula, it possesses the ability to be zero if any one of its inputs is zero, and (2) it was not quite as harsh as straight multiplication.

In Fig. 26 the term $\left(v_i^m \right)^{k_m}$ in Eq. (6) is plotted for various values of k_m. The plot shows that if the value of v_i^m is zero then the function is zero for all k_m. Thus, the probability calculated for u_i is zero. Since the weighting values of the motivations are normalized, as more motivations are considered, the average value of k_m must decrease. The plot shows that as k_m decreases, the function approaches unity faster. Therefore, the calculated probability u_i does not naturally converge to zero as the number of motivations considered increases like straight multiplication would.

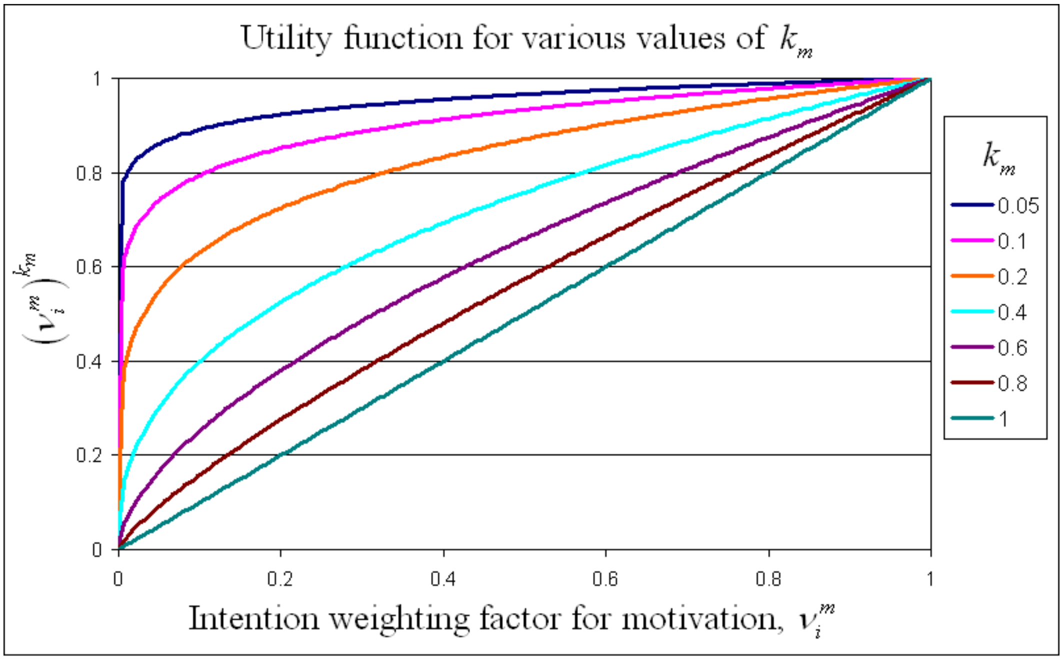


Fig. 26. Behavior of utility function for calculating u_i

The values of v_i^m generated for this project are given in the appendixes.

Resources

Constant nodes are also included in the network to represent resources. The three constant nodes for resources used in this model are:

1. International Networking: This resource represents the connections that an organization might have to other assets globally. This parameter is an indicator of such things as alliances to other organizations, access to the Black Market, assets working abroad, etc.

2. Technical Capabilities: This resource is designed to give some quantification to an organization's perceived technical abilities. It represents a measure of how educated, skilled and capable the organization's scientists are.

3. Available Infrastructure: This resource represents the local infrastructure available and how much it may contribute to necessary components in a weapons program.

Each of the resource nodes is assigned one of the following values:

- Excellent
- Great
- Good
- Fair
- Poor
- Abysmal

Each selection has a numerical value between zero and one associated with it that is used in the calculation of the prior nodes that are dependent on the resource.

Calculating the Priors

The intentions for a particular category are combined to calculate a value for the prior nodes discussed in Chapter II. The value of the corresponding prior node is calculated using:

$$\mathrm{P}^n\left(u_i\right) = \frac{\sum_{i=1}^{I} \beta_i^n u_i}{\sum_{i=1}^{I} u_i} \tag{7}$$

where $\mathrm{P}^n\left(u_i\right)$ represents the probability that node *n* is true given u_i, but no evidence. And β_i^n represents the importance of node *n* to intention *i*.

Calculating the priors using resources is done in a slightly different manner than the intentions. Since there are not categories of intentions that need to be combined, a prior node, *n*, that just accounts for the effect of a resource, *r*, is calculated by:

$$\mathrm{P}^n\left(r\right) = \beta_0^n + \beta_1^n r \tag{8}$$

where β_0^n is the likelihood without a resource, *r*, and β_1^n is the contribution that resource *r* makes. Since the input from the constant node *r* is a value between zero and one, and the value of $\mathrm{P}^n(r)$ must be between zero and one, the constraint in Eq. (9) must be observed when deciding the values of β_0^n and β_1^n:

$$\beta_0^n + \beta_1^n \in \left[0,1\right] \tag{9}$$

Usually, however, the affect that a resource has is also a function of a particular intention category.

Therefore, the equation used to calculate a prior node for resources that are a function of an intention category is:

$$\mathrm{P}^n\left(u_i, r\right)=\frac{\sum_{i=1}^{I}\left(\beta_{0,i}^n+\beta_{1,i}^n r\right)u_i}{\sum_{i=1}^{I}u_i} \tag{10}$$

It is important to note that a resource may make a pathway less likely, thus $\beta_{1,i}^n$ can also be negative so long as the end result still falls between zero and one. Since *r* is a number between zero and one, this condition can be met by the constraint

$$\beta_{0,i}^n+\beta_{1,i}^n \in [0,1] \tag{11}$$

The prior nodes are used as parents to the nodes that they impact. The truth table for a node with a prior node as a parent is written so that the pathway that the prior node impacts can only be true when the prior node is true. In that way, the probability distribution of the pathway is governed by the value that is calculated by the prior node. Thus the probability distribution is governed by the motivations and resources of an organization of interest.

Implementation

When running a case in the network the first thing that is done is to consider the motivations of the organization the user wishes to model. Assigning values to the motivations in the Excel spreadsheet gives the user the calculated values of the intentions. These intentions must be typed into their corresponding constant nodes in the network. The next step is for the user to select values for the resource nodes. Once this is done, the network is compiled in Netica and the organization of interest is ready to be examined.

It is necessary at this point to discuss the meaning of the probabilities presented by the nodes in this network. As with any decision analysis model, the accuracy of the output is only as good as the accuracy of the input given. The calculated value for success given is dependent on a very large number of user generated values. With that in mind, this methodology shouldn't be seen as a way of accusing organization *Y* of having an *X* percent chance of acquiring nuclear weapons. Rather, the methodology should be seen as one tool among many that predicts the *relative* threat that an organization poses to nuclear proliferation. Furthermore, the methodology is intended to provide a means for an analyst to examine how varying parameters and evidence impacts these probabilities, and expose places along a pathway that can be used to prevent an organization from proliferating.

CHAPTER IV

CODE VERIFICATION

A number of example scenarios were executed to verify that the code system performed as expected. These scenarios were also used to test the strengths and weaknesses of the system developed. These scenarios are not intended to model any particular organization but to consider a few general cases, for both state and sub-state actors. It should be noted that the arrangement of the figures depicting nodes from the network in this chapter won't always match the arrangement shown in Chapter II. Nodes are often moved closer together and some nodes and links are removed from the Fig. altogether to limit the amount of information presented.

Case 1: Small Fanatical Religious Group

The first case examined is a regional terrorist organization comprised of religious fanatics. The organization is motivated primarily by an apocalyptic belief. As a regional sub national group, they have poor connections and no technical skills or helpful infrastructure at their disposal. Furthermore, this organization has no access to uranium mines or a nuclear reactor. The input for this organization is given in Fig. 27 and the motivation and resource values used are seen in TABLE I.

TABLE I
Motivations and resources used in Case 1

Case 1			
Motivations		**Resources**	
Prestige of Possession	1	International Networking	Poor
Apocalyptic Beliefs	1	Technical Capability	Abysmal
Religious Duty	2	Available Infrastructure	Abysmal

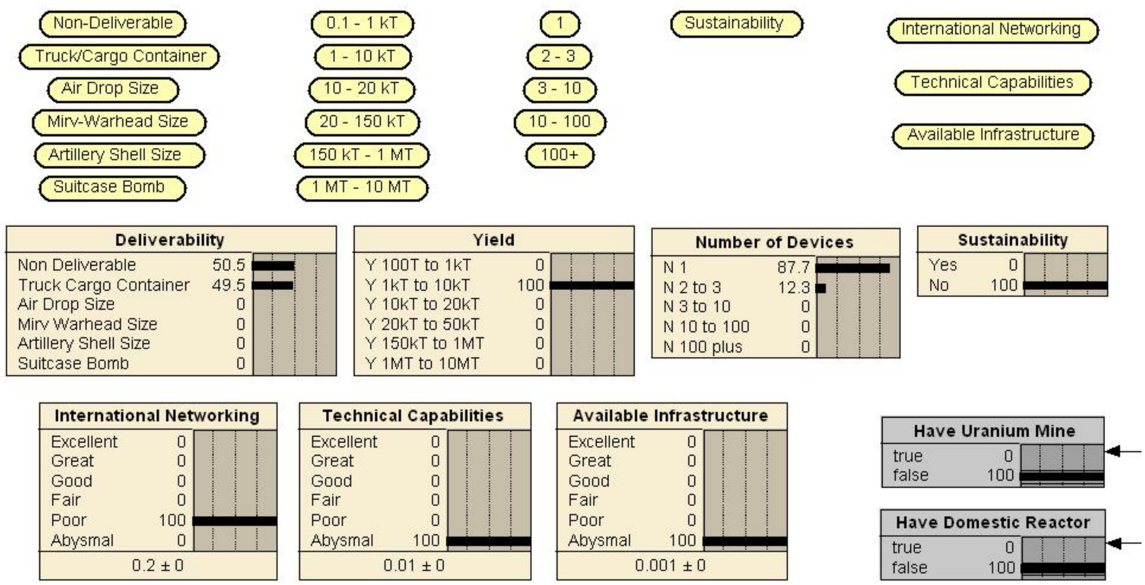


Fig. 27. Input display for Case 1

The intentions of this organization show that they have very minimal requirements for a nuclear weapon. However, even with low requirements, an organization with no means to develop a weapon or any outside connections to otherwise procure one is still expected to fail. Many regional terrorist groups have attempted to acquire nuclear weapons but none to date have been known to succeed.

In Fig. 28, the key nodes pertaining to the probability distributions for the organization obtaining a nuclear weapon are given. In the node labeled *Fabricate Device* are the probability distributions for an organization to assemble the necessary SNM pit and weaponization components themselves. The nodes labeled for each weapon type show the probability distribution of making, purchasing, and stealing the respective design. The node *Acquire Weapon* gives the probability that the organization will acquire one of the three designs considered, independent of the means used to acquire it. Finally, the probability of acquiring any of the nuclear weapon types is given in the node labeled *Nuclear Device*.

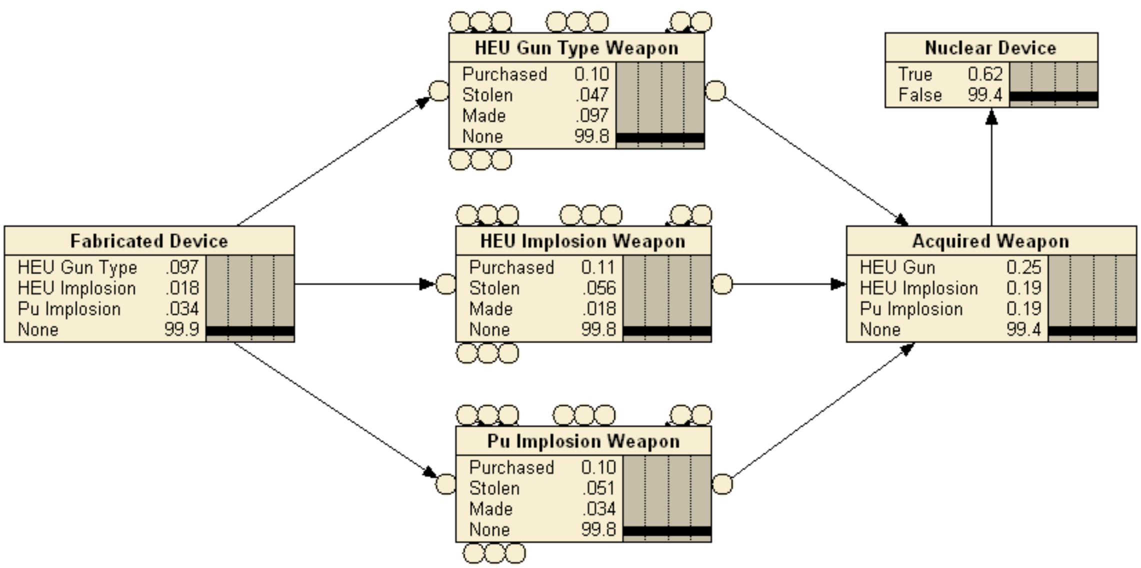


Fig. 28. Weapon development probabilities for Case 1

As expected, the organization has a very low chance of success, just 0.62%, according to the model. Their most likely path is to purchase and assembled device. If the organization is to assemble the weapon themselves, the most likely choice is an HEU gun type. These results agree with our intuition of the decision the organization would make given their resources and intentions. Fig. 29 shows a selected portion of the network that displays the probabilities associated with acquiring SNM for this scenario. The purchase or theft of SNM is more likely than producing it indigenously. For the case of plutonium, the chance of producing it themselves is almost zero. The organization was given the worst possible rating for available infrastructure, and evidence is already added that they do not have access to a reactor from which they can divert fuel. Also, because of the organization's low technical capabilities and their lack of desire for a higher-yield, more deliverable weapon, the easiest path is to make a gun type device, which results in reducing the attractiveness of trying to acquire plutonium. So efforts made in producing SNM are biased toward HEU.

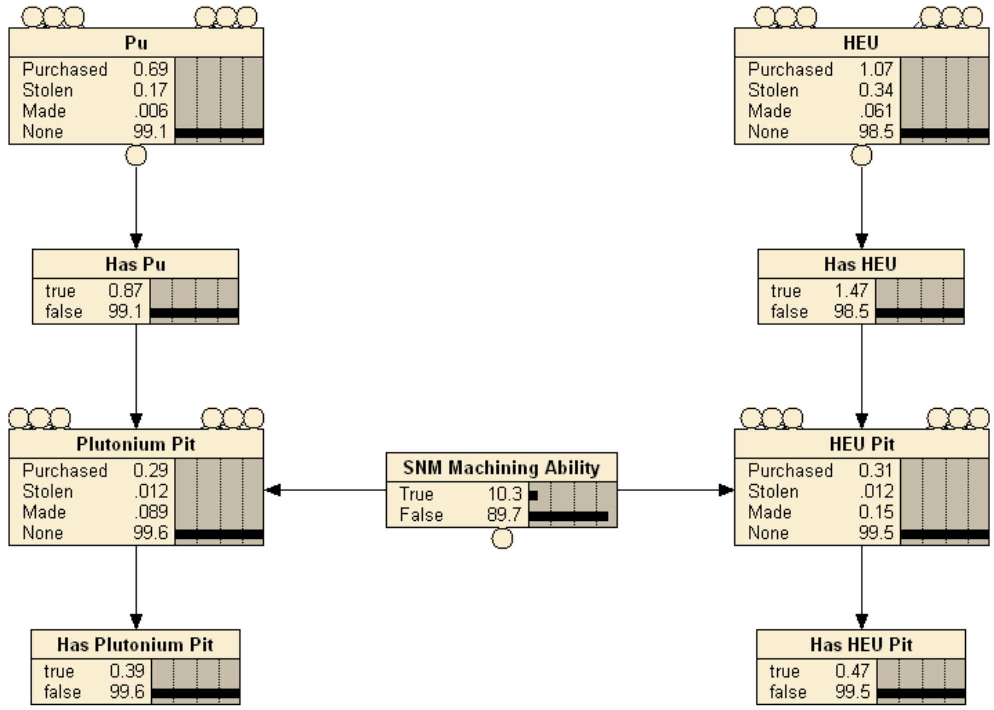


Fig. 29. Selected nodes displaying SNM probabilities in Case 1

A further hindrance to success for the organization is their low likelihood of being able to machine SNM. Thus, the organization has a higher chance of purchasing or stealing a prefabricated pit than manufacturing their own.

Effect of Evidence Against Machining Capability

To further examine the organization, suppose that it is known with confidence that high precision machining, is beyond their capabilities. By making the nodes for high precision machining and SNM machining false, the probability that the organization will successfully obtain nuclear weapons decreases. The new probability distributions are given in Fig. 30. The probability distributions for fabricating the device dropped almost to zero. Without the ability to properly machine a tamper, reflector, or a pusher, there is almost no chance to weaponize an SNM pit. Therefore, the vast majority of the probability of success remaining rests in purchasing or stealing assembled weapons.

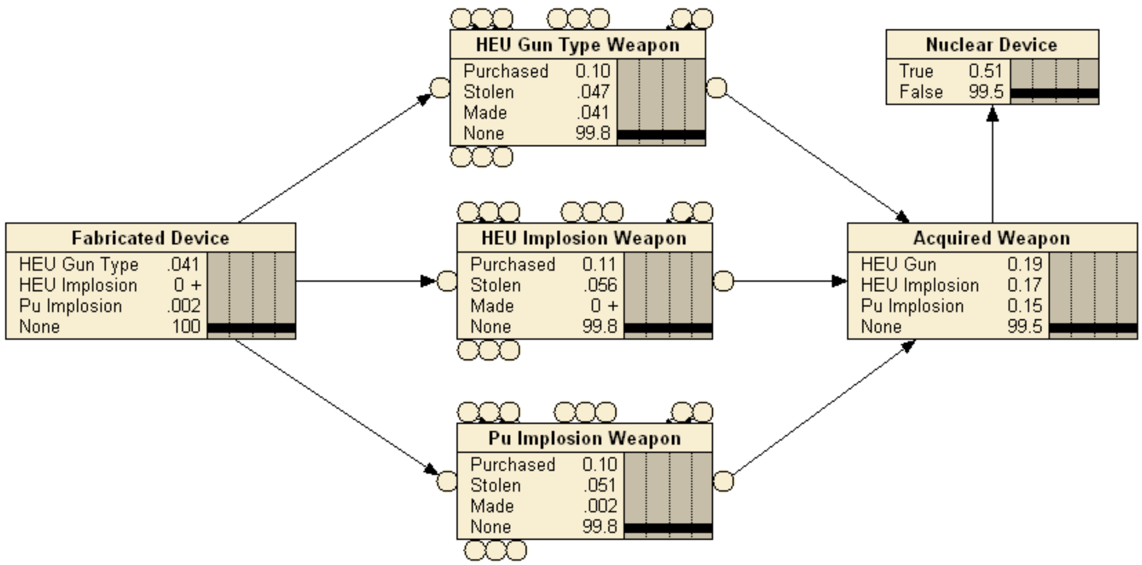


Fig. 30. Results for Case 1 after evidence is added that the organization does not possess any precision machining capabilities

Effect of Changes to Organization Resources

The effect of changes of an organization's resources was examined. The organization's international networking was changed to "great", the results are shown in Fig. 31. As the international networking resource is increased the probability of theft and purchase also increase, and therefore increase the overall chance of success.

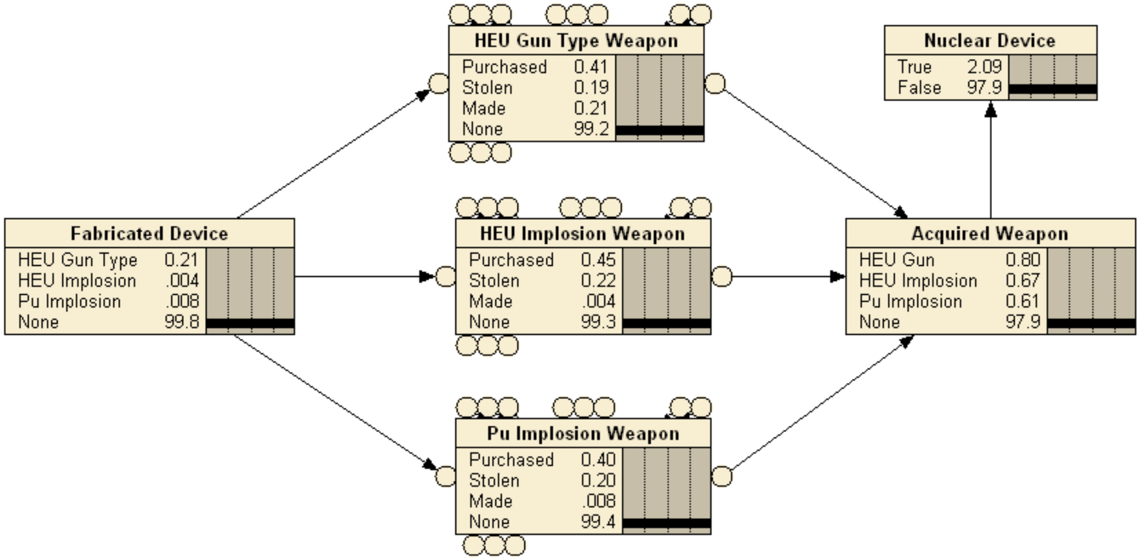


Fig. 31. Results for Case 1 when international networking is changed to "great"

Case 2: Semi-Developed Rogue Nation

This case examines a rogue nation that wants to acquire nuclear weapons. The nation is not particularly developed; however, it has been using a hedging strategy to put infrastructure in place. The nation in this case has acquired a nuclear reactor and has sent many citizens abroad for study and training in the nuclear field. Furthermore, the leaders of the rouge nation are believed to be cooperative with known terrorist organizations. Continued defiance of international norms has put the nation at odds with the world's superpowers. The nation fears an invasion may be used as a means to replace the regime. The input for this organization is given in Fig. 32 and the motivation and resource values used are seen in TABLE II.

TABLE II
Motivations and resources used in Case 2

Case 2			
Motivations		**Resources**	
Deter Attack from Nuclear Adversary	1	International Networking	Great
Acquire Position in International Forums	1	Technical Capability	Good
Enhance International Status	2	Available Infrastructure	Fair

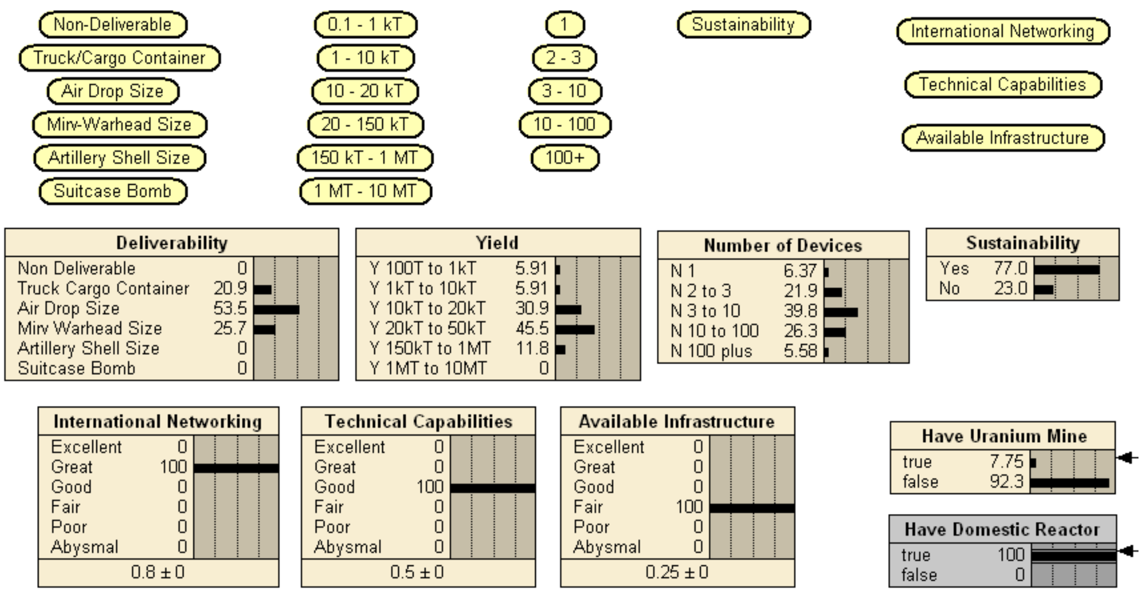


Fig. 32. Inputs for Case 2

The organization is likely to seek weapons with a higher yield and deliverability than the previous case. Furthermore, this time the organization desires many more devices and will most likely require a sustainable program. The results for this case are given in Fig. 33. Despite the increased difficulty in the likely weapon program, the increased resources and the advantage of having a reactor make this organization about four times more likely to succeed then the organization in Case 1.

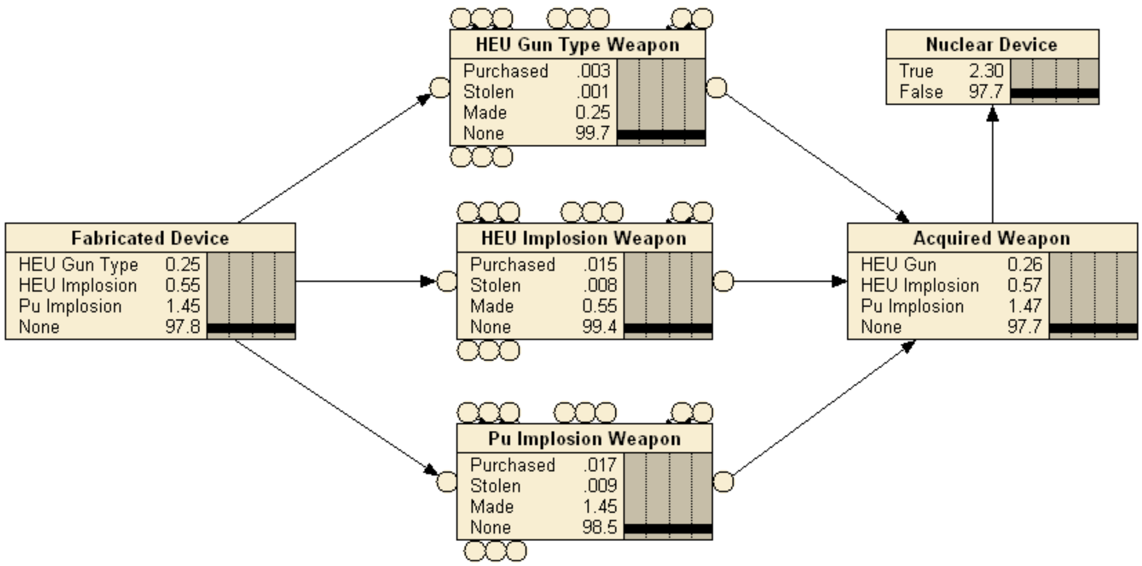


Fig. 33. Initial results for Case 2

There is almost no chance of stealing or purchasing a nuclear weapon for this case. This is not a result of a low international networking resource, but is due to the intention of developing a larger number of devices as well as a sustainable program. The most likely design type in this scenario is the plutonium implosion design. Using plutonium has the greatest chance of success since evidence is added that the rogue nation possess a nuclear reactor. Also, the HEU implosion design is more likely than the HEU gun type. This is a result of the need for higher yields and deliverability.

Fig. 34 presents the enrichment results for this scenario. The resources of this organization result in a 24.2% chance of being able to enrich uranium prior to any evidence being given. Gaseous centrifuge is the most likely method. The next two candidates are aerodynamic separation and gaseous diffusion. EMIS and laser isotope separation are the least likely. These results agree with intuition as well as historical evidence from recent proliferation cases.

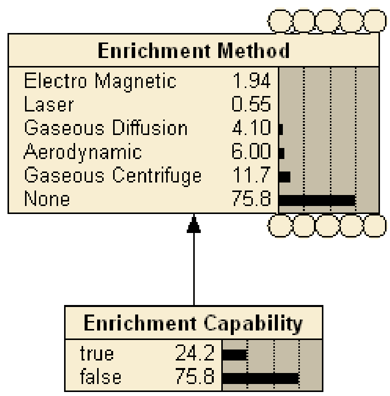


Fig. 34. Enrichment capability nodes for Case 2

Effect of Evidence Against Uranium Mining and Enrichment

Suppose that the nation does not have any significant uranium deposits to mine, and furthermore, many key components of the various enrichment methods are unavailable as well. Fig. 35 shows the probabilities for acquiring SNM and for obtaining a weapon pit after this evidence was added. The organization has a reasonable chance of obtaining plutonium (44.3%), almost all of which comes from the probability of producing the plutonium themselves. However, for HEU the chances are much less (0.36%), almost none of which comes from the ability to produce it themselves.

Even though the organization has a good chance of acquiring plutonium, their chances of acquiring a usable pit from this material are much less at 16.1%. The organization's inability to machine SNM is a formidable hindrance to producing nuclear weapons decreasing their chances of acquiring a useable pit to 16.1%.

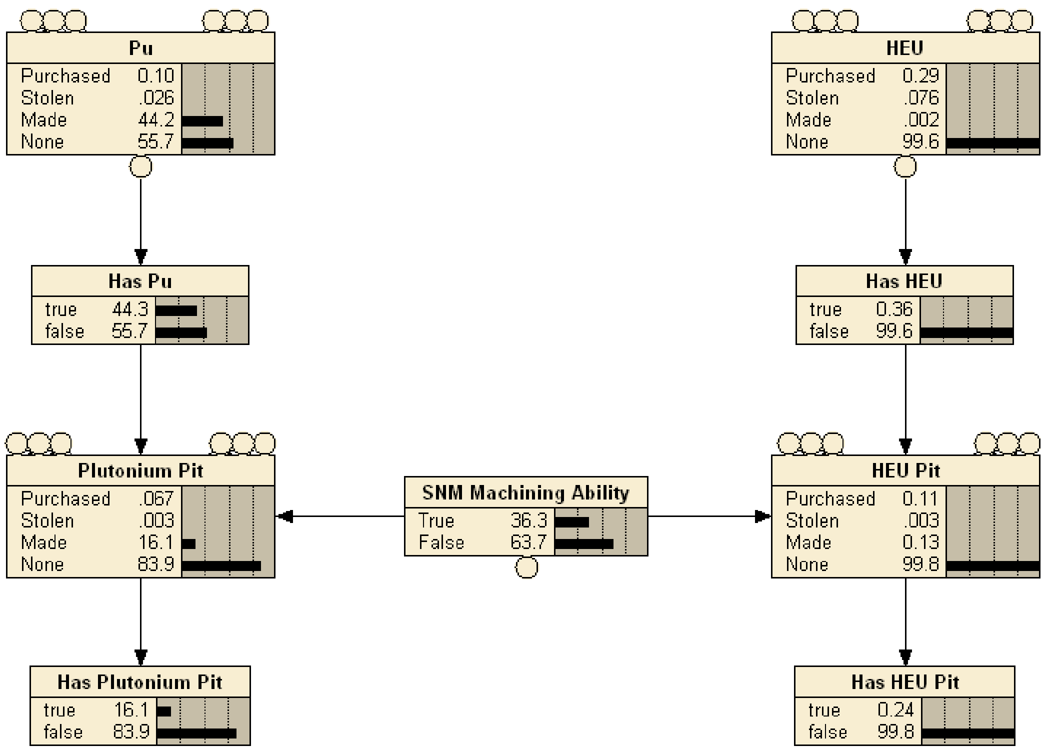


Fig. 35. Selected nodes displaying SNM probability distributions for Case 2 after evidence is added against uranium enrichment and mining

Fig. 36 shows the change in the results after considering the new evidence. The chances of fabricating an HEU implosion or HEU gun type device are negligible. The overall probability of success decreased from 2.30% to 1.84%. The probability that a plutonium implosion device will be constructed increased, since it is the only viable option left. The difficulty of weaponization of plutonium pits results in the decrease from 16.1% chance of acquiring a Pu pit to 1.76% chance of fabricating a plutonium implosion weapon. Implosion devices are significantly more challenging to produce than gun type designs, and plutonium is a more challenging material to work with than HEU.

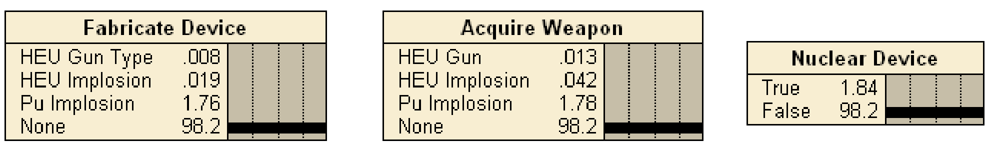


Fig. 36. Results for Case 2 with enrichment capability and uranium mine are false

Effect of Evidence Against Spent Fuel Diversion

Next, assume that the IAEA inspected the organization's reactor and determined that all of the spent fuel was accounted for and therefore, even though they have a reactor, it is not being used as a source for spent fuel to reprocess. Fig. 37 shows the spent fuel section of the network with the evidence added that spent fuel is not being acquired from a domestic reactor. This new evidence results in the total probability that the organization has spent fuel to reprocess being less than 1%.

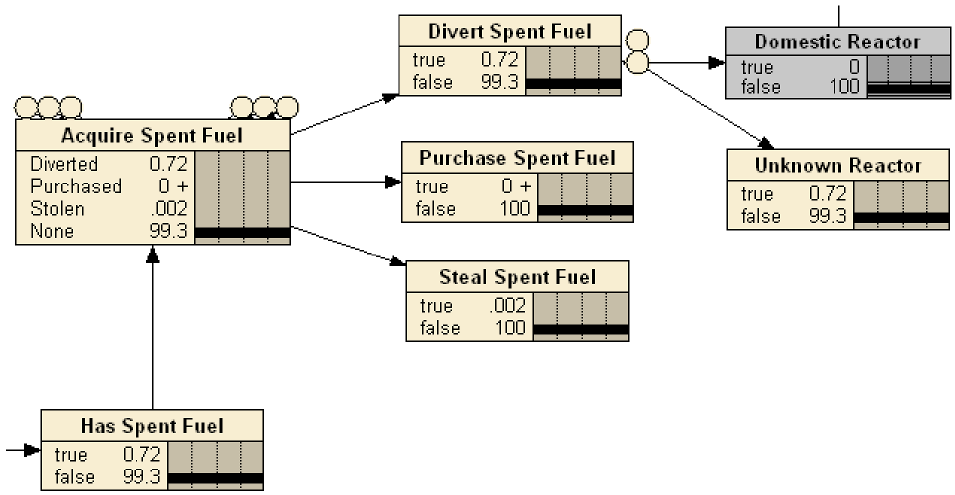


Fig. 37. Spent fuel section of the network for Case 2 with evidence that spent fuel has not been removed from the organizations reactor

The probability of the organization acquiring a nuclear weapon after this evidence is added is given in Fig. 38. As expected, with no options available produce SNM, the probability of fabricating a weapon decreases significantly. The probability that does remain is the small contributions from the theft and purchase of an SNM pit, which are still hindered by the intention of a large sustainable program. The rogue nation now only has a 0.12% chance of success.

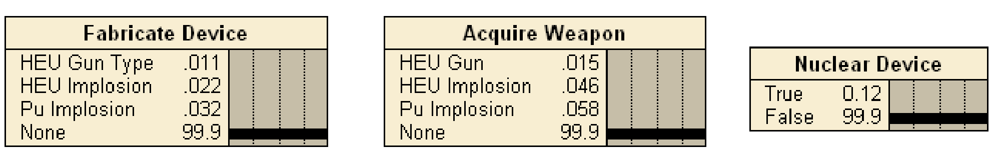


Fig. 38. Results for Case 2 with evidence that spent fuel has not been removed from the organizations reactor added

Effect of Evidence for Radioactive Reprocessing Gasses

The next evidence that will be examined in this scenario is what happens to the network when radioactive gases released in reprocessing operations are discovered at a plant in that country. Fig. 39 displays the network with the evidence added for these release gases.

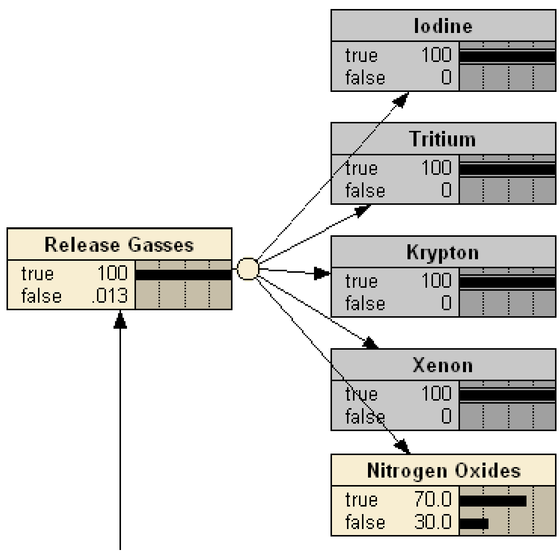


Fig. 39. Evidence added of reprocessing gases found

The spent fuel section of the network with the results from the new evidence is given in Fig. 40. The evidence added is a strong indicator that the organization is currently reprocessing spent fuel. The probability that the organization has spent fuel increased dramatically up to 83.3% from 0.72, seen in Fig. 37. But where did this fuel come from since evidence is already given that all of the fuel in the organization's reactor is accounted for? Since the large sustainable program that is likely desired makes theft and purchase unlikely candidates, the network predicts that the most likely source of the spent fuel is diversion from an unknown reactor, at 83.1%. As discussed in Chapter II, this diversion doesn't necessarily mean the fuel was taken from another nation's nuclear reactor, but could be an unknown reactor that the organization possesses.

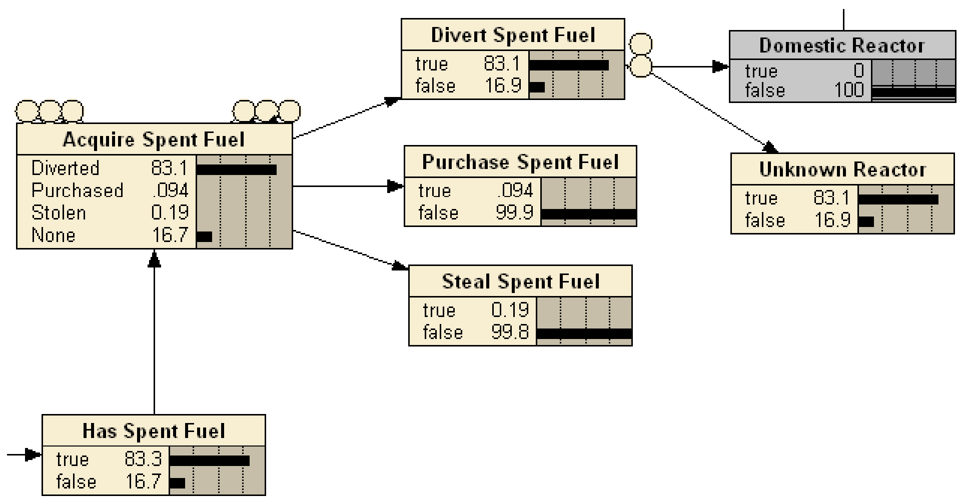


Fig. 40. Spent fuel section after evidence is added for reprocessing gases

The conclusion may be that the rogue nation has covertly developed a plutonium production reactor, one that is not under the inspection of the IAEA, to acquire SNM. There are historical cases where nations go to great lengths to covertly attempt to produce SNM. For instance, during the first gulf war with Iraq, the nonproliferation community was shocked when the scope of the Iraqi uranium enrichment program buried in the dessert was discovered. Since all remaining states without nuclear weapons are non-NWS of the NPT, any attempts at producing SNM without international backlash would need to be covert.

The impact that this new evidence has on the organization's success is given in Fig. 41. The probability is now 7.62%, which is more than when the only evidence was that the organization had a domestic reactor, seen in Fig. 33. Despite adding evidence that the HEU pathway was negligible and that the organization was not diverting from their known reactor, their probability of completing their nuclear weapon goals increased because the evidence of the release gases is a strong indicator that the organization had actually taken the step to reprocess the spent fuel. While it was known in the beginning that the organization had a domestic reactor, there was no evidence that they had actually made strides towards actually separating the plutonium out of the fuel.

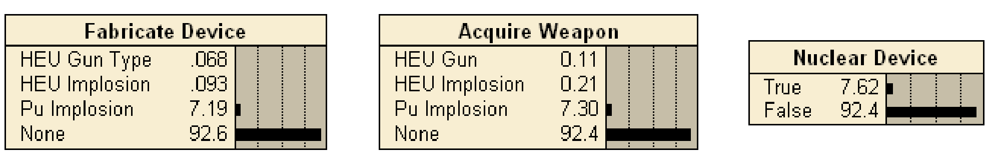


Fig. 41. Results for Case 2 with reprocessing gases added

Sensitivity Analysis

The final thing that will be demonstrated in this case is a sensitivity analysis. As mentioned in Chapter II, Netica allows the user to select a node in the network and calculate what node has the largest impact on its value. This calculation includes the evidence that is already added to the network. In order to do a sensitivity analysis, the user needs to highlight which node to analyze and then highlight the nodes that the user wishes to test by holding the control key down and clicking on different nodes. Next the user selects "Sensitivity to Findings" in the "Network" tab at the top of the program.

If the user only highlights the node that the sensitivity analysis is desired on and then runs the analysis, Netica will calculate the sensitivity for every node in the network. This is not overly useful since the network contains many nodes, such as prior nodes and inverted nodes, that serve a specific function. There are also several regular nodes, such as steal or purchase a completed device, that are not helpful to analyze either. Since stealing or purchasing a completed device automatically makes the weapons program successful, making any one of these nodes true will always have the biggest impact. Thus it is beneficial for the user to select the nodes that should be analyzed to avoid generating a list that is cumbersome to weed through to get the information that is desired.

Another type of node that may or may not be important to consider is the nodes where pathways fork. A node that represents the culmination of its constituent pathway will always be more important than any of its single components. For example, the node for a machined pusher is always going to be more important to the final result than pusher materials or precision machining capabilities. This is because for a machined pusher to be true, both machining capabilities and pusher materials had to be true. Thus a comparison of the three is unfair. A fair comparison would be only between the pusher material and the machining capability; it would also be fair to compare the machined pusher against the machined reflector or machined tamper. Depending on the detail that the user wishes to analyze, it may be preferable to only consider the nodes at the end of various branches, or only nodes that are one step in from the end of the branch, and so on. Either way, when looking at the calculated sensitivity values it is important to consider whether apples are being compared to apples.

When a sensitivity analysis is performed, Netica creates a report that displays how much the probability distribution of the node analyzed is influenced by making other nodes true. Netica creates a report that first lists each node and how much several different sensitivity measures impact the node in question. The second part of the report displays a summary table that compares the findings for each node with two columns of numbers. Netica recommends that the first column, which compares the amount of mutual information the two nodes share in the network, should be looked at if the user wants a single value that best describes the degree of sensitivity. The list generated in the report is arranged from the node that has the greatest impact to the node that has the least impact according to the number in the first column. This is the number that is used for sensitivity analysis purposes in this work. For complete details about the functions used in the sensitivity analysis, the user can contact *Norsys*, the creator of Netica. Fig. 42 gives the results of the summary section of the sensitivity analysis performed on Case 2.

```
-------------------------------------------------------------------------

Sensitivity of 'Nuclear_Device' due to a finding at another node:

Node                 Mutual      Variance of
----                 Info        Beliefs
SNM_Machine          0.08451     0.0072788
HighPr_Mach          0.05747     0.0044282
Lenses               0.04586     0.0041558
Electronics_Pk       0.03727     0.0036936
DTGen                0.02412     0.0027542
PoBe                 0.01234     0.0014823
```

Fig. 42. Sensitivity analysis run on Case 2 to compare select nodes in the weaponization section and the ability to machine SNM

Fig. 42 shows that the ability to machine SNM will give the organization the biggest gain toward their nuclear weapon program. This is not surprising considering that the organization already has a very high chance of obtaining SNM. Removing the obstacle of manufacturing a usable pit leaves only the weaponization to prevent the organization from producing nuclear weapons.

Case 3: International Extremist Group with National Sponsorship

This case examines an international extremist group that has many sympathizers positioned throughout the populace and in the government of a rogue nation, which has a covert weapons program. The advantage the terrorist group gains from having help from the rogue nation is treated as if the terrorist organization is given the resources of the state. While complete access to a nation’s resources is not a conceivable situation and offers an unfair advantage, this scenario is invented to show the use of the methodology, not to model a specific organization. The input for this organization is given in Fig. 43 and the motivation and resource values used are seen in Table III.

Table III
Motivations and resources used in Case 3

Case 3			
Motivations		**Resources**	
Prestige of Capabilities (Non-Peaceful)	1	International Networking	Great
Manipulate Adversaries	2	Technical Capability	Good
Psychological Warfare (Intended Use)	1	Available Infrastructure	Good
War on Another Nation (Extremist)	3		

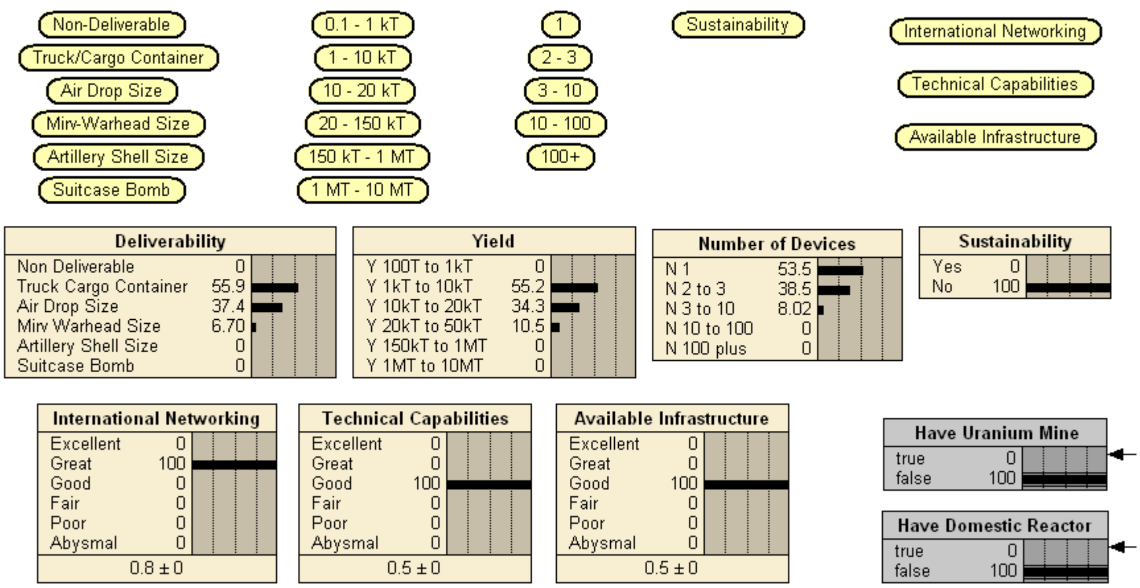


Fig. 43. Input display for Case 3

To examine the likelihood of different pathways that this organization will take, a different approach will be used than in the previous cases. In this scenario, evidence is given that the organization has successfully developed a nuclear weapon. The probability distributions that are created in this scenario are not the probabilities that the organization has a particular component or will successfully complete a particular step. Instead, since success is a given, the probability distributions for each node represent the likelihood that the organization will require a particular component or will attempt to take a particular step.

This is helpful because it is important for the user to question how much faith can be placed in the accuracy of the final value given. Very few nations have successfully developed nuclear weapons and to date, no terrorist group has either. Thus, there is not an abundance of data to draw statistical conclusions about the probabilities of success. Examining a case by making success a given eliminates that aspect and allows the user to compare the likelihood of various pathways.

The probability distributions for completed nuclear weapons are given in Fig. 44. On the left side the node labeled *Fabricated Device* shows that there is a 77.8% percent chance that the organization would attempt to weaponize machined SNM. On the *Fabricated Device* node the two HEU weapon types are the most likely to be produced. This is a result of which SNM they are likely to pursue, seen in Fig. 45.

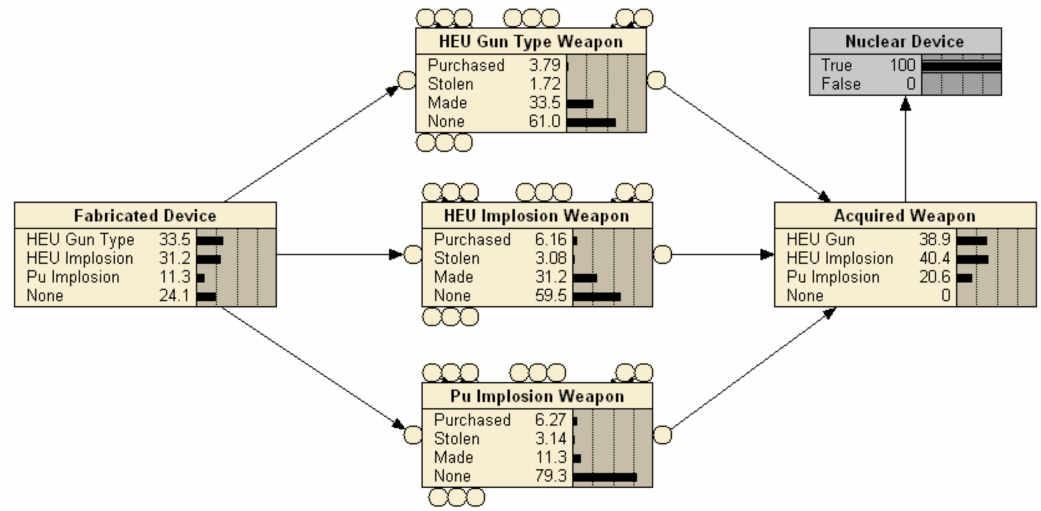


Fig. 44. Output of Case 3 showing evidence that the organization has acquired a nuclear weapon

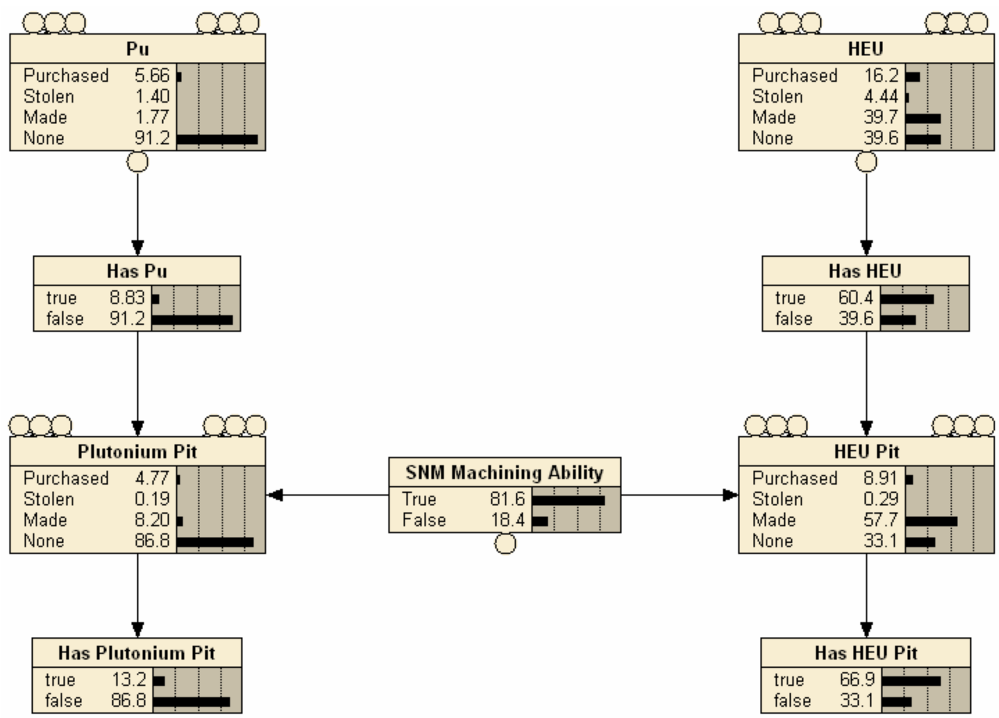


Fig. 45. SNM section of the network for Case 3

The SNM section of the network reveals that the organization has almost a 70% chance of attempting to produce an HEU pit and only about a 13% chance of using Pu. There is almost a 10% chance that the organization would attempt to steal the HEU pit and avoid machining it themselves. For obtaining HEU there is almost a 20% chance that the organization would attempt to purchase or steal it, and a little over 40% chance that they will attempt to produce it on their own.

Making HEU requires the organization to obtain some source of uranium feed along with the ability to enrich it. Since the organization has no mining source of uranium, they would be required to procure uranium through theft or purchase of natural, depleted, or low enriched uranium. With the intended number of devices so low for this organization, acquiring uranium feed material becomes feasible, if only slightly. The important nodes for uranium enrichment are given in Fig. 46. Gaseous centrifuge is the most likely enrichment method used, followed by EMIS and aerodynamic separation.

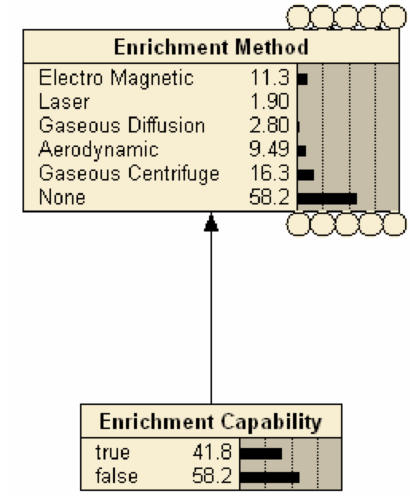


Fig. 46. Uranium enrichment nodes from the network for Case 3

Effect of Evidence Against Weapons Package

Evidence is added to the network in the same manner as the other scenarios. For instance, making the weapons package pathway false forces the implosion pathway to become essentially zero. Fig. 47 shows the updated probabilities when this evidence is added. As expected, without a weapons package the only feasible pathway for indigenously fabricating a weapon is the gun type design. The probability of theft or purchase of a weapon increased, from a total of 22.2% to 34.6%, since the pathway to producing an implosion device was essentially removed.

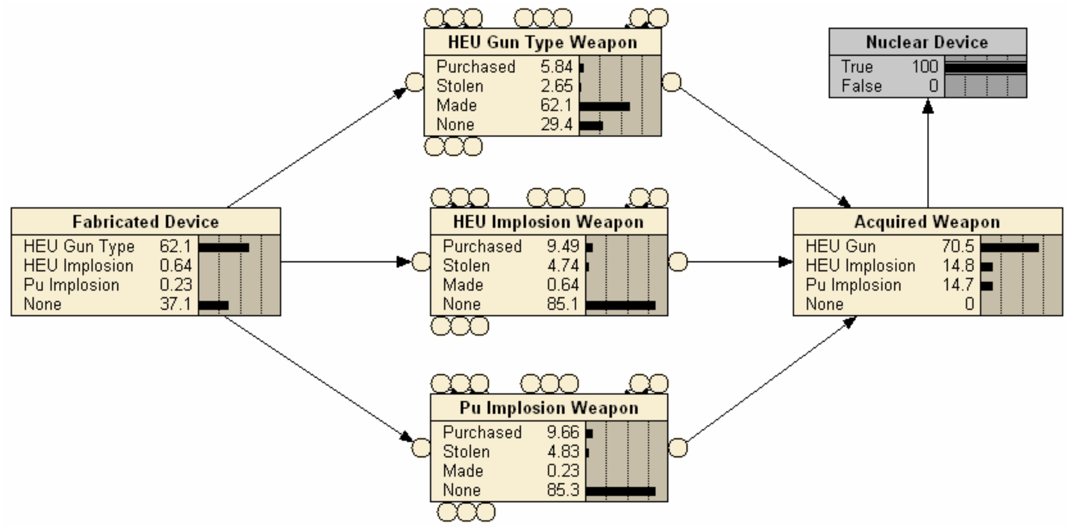


Fig. 47. Results for Case 3 after the weapons package node is made false

Case 4: Developed Nation

In the final scenario, a first world nation that has a fully developed civilian nuclear program is examined. The nation for this scenario enriches its own fuel for its fleet of domestic reactors with a large gaseous centrifuge plant. Furthermore, the nation is on a closed fuel cycle and reprocesses its spent fuel. The large industrial base of the nation already has high precision machining capabilities, as well as the ability to machine SNM. No perceived military scenario requires nuclear weapons; however, popular opinion is evolving to believe that indigenous nuclear weapons are necessary as a matter of pride. The input for this organization is given in Fig. 48 and the motivation and resource values used are seen in Table IV.

Table IV
Motivations and resources used in Case 4

Case 4			
Motivations		**Resources**	
Increase Domestic Morale	1	International Networking	Poor
		Technical Capability	Excellent
		Available Infrastructure	Excellent

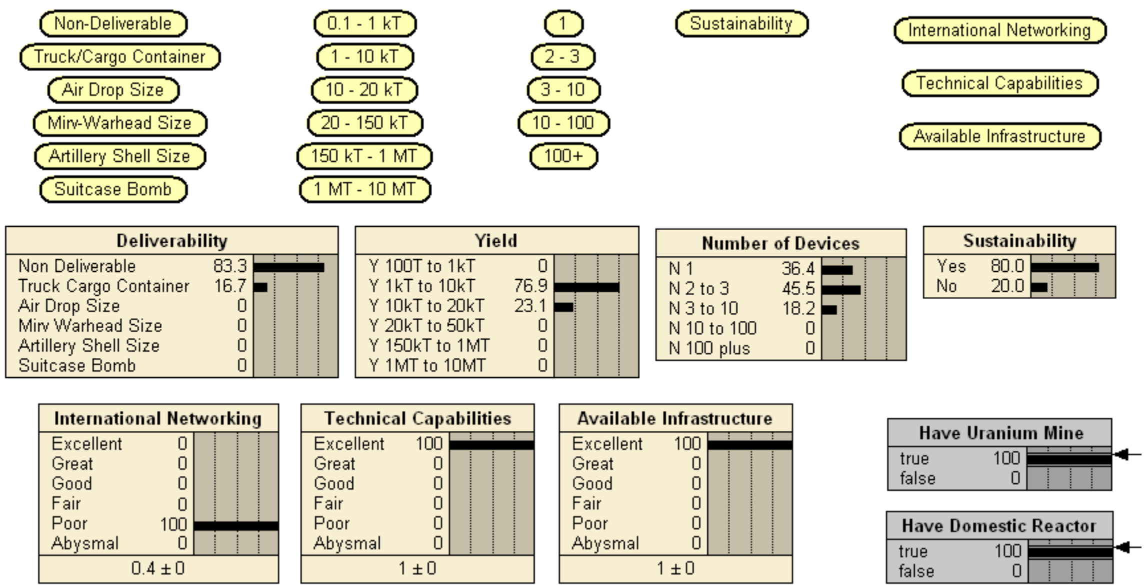


Fig. 48. Input for Case 4

Evidence is given in the network that the nation possesses precision machining as well as SNM machining capabilities. Evidence is also given for compressors, uranium hexafluoride, high strength rotors, and the other components of a gaseous centrifuge plant. Evidence is also added regarding their reprocessing plant. The nation's research institutions have deuterium-tritium (D-T) generators and possess the skills to produce any of the components in a nuclear weapons package. Finally, their industrial base is capable of providing any materials desired to use in the weapons construction, particularly materials for a tamper, reflector, and pusher. After entering all of the evidence above, the results produced are given in Fig. 49.

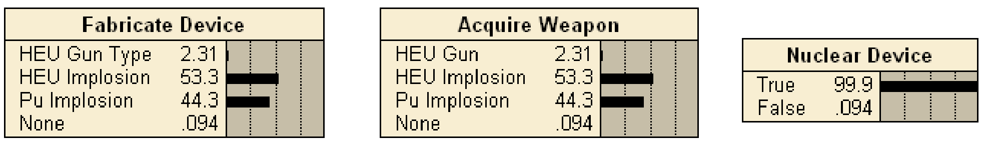


Fig. 49. Results for Case 4

The chance for success in this scenario is 99.9% and all of it is contributed to indigenously fabricating the nuclear weapons. The extremely high probability for success should be no surprise since evidence was given that each obstacle faced in producing a nuclear weapon covered in this network would be overcome.

The motivations given in this case produce intentions that don't demand an implosion device. Therefore, the user might expect to again see the gun type device as the most likely. However, the gun type design is drastically less likely than an implosion design. This is because (1) all of the pieces were given for the weapons package of an implosion device, (2) the evidence for precision machining along with having various materials that may be used for a pusher result in a high likelihood of a machined pusher, and (3) the high technical capability resource imparts a slight bias toward implosion over gun type.

The second reason exposes a shortcoming of the network. The network infers that if an organization is capable of doing something, they will. Thus, with evidence added that the nation possesses machining capabilities and pusher materials, the nation has a machined pusher. Therefore, the network is unable to account for acts of deception.

Importance of Evidence Compared to Resources and Intentions

Suppose the nation's motivations change to motivations that require a more robust weapon program. The resource and evidence is all the same, but the motivations change to the following list and the new input into the network is given in Fig. 50.

Motivations used for second part of Case 4:

- Deter Attack from Nuclear Adversary: 1
- Seek Military Superiority: 2

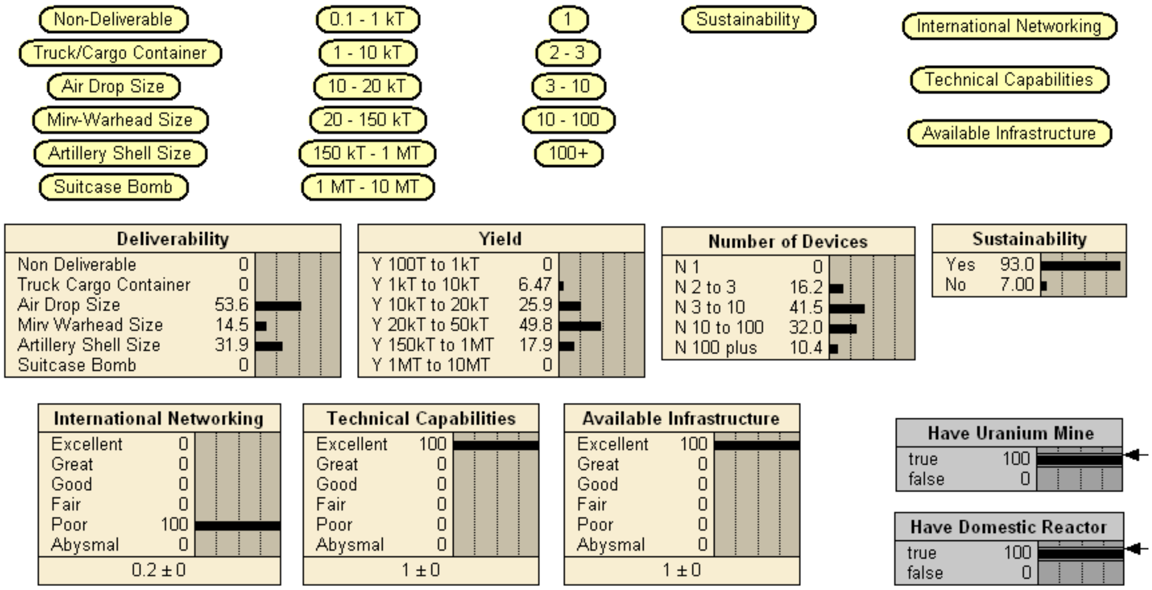


Fig. 50. New inputs used for Case 4

The devices desired now need greater deliverability and higher yields. Furthermore, the number of devices desired increased dramatically and a sustainable program is needed. The probability of success remains extremely high at 99.7% as seen in Fig. 51.

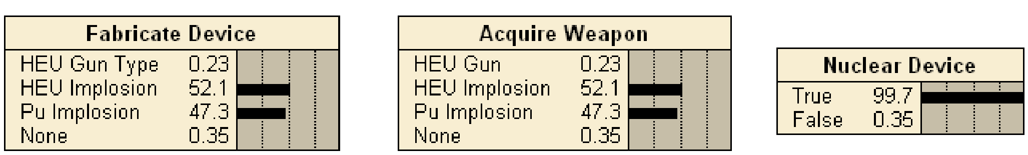


Fig. 51. Results for Case 4 using new motivations

Next, leaving everything else the same, the resources are changed. The nation was given high values for resources, suppose this advantage is removed. All three resources are set to "Abysmal" and the results are given in Fig. 52.

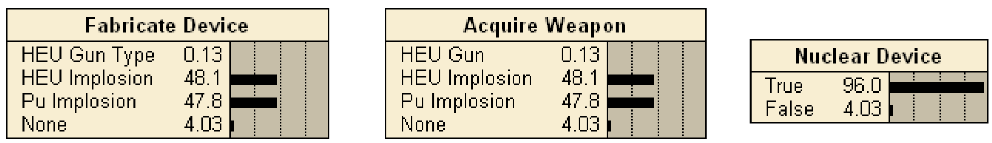


Fig. 52. Results for Case 4 with all resources set to "Abysmal"

As one might expect, the chance of success did decrease as all of the organization's resources were removed. However, the chance of success (96%) did not decrease by any appreciable amount and reveals an underlying aspect of Bayesian statistics. Considering the three results given in this case, it would seem that intentions and resources have no significant impact on the results. This is in fact true, but only in a case such as this one where much of the evidence is known.

The reason that the intentions and resources fail to hinder the chance of success is that the evidence given is enough to define the majority of the system. The resources and intentions are used to calculate the subjectively defined priors of the network, which state the *belief* that an event is true without knowledge that any other events have occurred. These priors represent the uncertainty in the system. But as evidence is added, this uncertainty in the system is removed. Therefore, when all of the evidence is known, there is no uncertainty left and the priors play no role in defining the probability distributions of the system. The actual truth of each event is known, and there is no longer a need for a *belief* that it is true.

Scenario Conclusions

The scenarios in this chapter demonstrate the network's ability to make inferences that agree with intuition and highlight the strengths and limitations of the model. The first case shows that an organization with limited resources has a minimal chance of success. The most likely pathway predicted in that scenario was theft or purchase of an assembled device. The second scenario demonstrated how increasing resources increased the probability of success. Furthermore, the second case showed that an organization desiring a large number of devices and a sustainable program will be unlikely to purchase or steal SNM or an assembled device. Also, these two cases highlight how an organization whose intentions need higher yields and deliverability are more likely to pursue implosion devices over gun type devices. Case 3 demonstrated a scenario where evidence was given that an organization already had a nuclear weapon, which showed how the Bayesian network can work backwards to predict the most likely path the organization would have taken to obtain that weapon. Finally, in Case 4 it was seen that an organization that can obtain SNM, machine it into a usable pit, and weaponize the pit has a very high chance of success, which is expected.

CHAPTER V

CONCLUSIONS

The purpose of the work presented in this paper was to create a methodology to analyze pathways of nuclear weapons development, incorporating an organization's motivations and any pertinent evidence. The methodology makes predictions about the most likely path that an organization will take. Furthermore, the tool could be used to evaluate how applicable evidence impacts the likelihood of these pathways and as a means to assess the relative threat that different organizations pose to nuclear proliferation.

This methodology was implemented in a Bayesian Network developed using the Netica software package. The motivations and critical resources were incorporated through the use of the priors. The difficulty of determining how a particular motivation affects the network pathways was addressed by the use of intentions as an intermediary. Several cases were examined to show how evidence impacts the pathways and demonstrate the methodology's capabilities. These cases were also used to validate the model's capability to produce decision results that agree with intuition.

For example, an organization that is not particular regarding the yield and deliverability of their nuclear weapon is predicted to choose a gun type design over an implosion design. Motivations that desired a larger number of devices or a sustainable program were unlikely to steal or purchase nuclear weapons. Furthermore, the cases demonstrated that organizations with greater resources were more likely to succeed, and that sub national organizations, such as terrorist groups, had almost no chance of success. Finally, it was demonstrated that evidence supporting (or rejecting) a pathway increases (or decreases) the probabilities along the pathway. It was seen that the motivations biased the various pathways more than resources, however, resources had a greater impact on an organization's overall chance of success.

The scenarios discussed in Chapter IV highlight a few limitations of the methodology. First, the model assumes that if an organization is capable of doing something, they will. Thus, any acts of deception can not be accounted for in the model. Next, many nodes in the model contain an underlying assumption that only one choice out of many will be made. Therefore, weapon programs where many pathways are taken in parallel are not properly modeled. Finally, as with any decision analysis tool, the accuracy of the output can only be as good as the input.

Several endeavors can be pursued to improve upon the methodology created here.

1. Expert elicitation could be used to obtain more correct input values and even their corresponding statistical uncertainty.
2. A more accurate and complete model can be produced if both the number of pathways and the level of their detail are increased.
3. The deliverability aspect could be improved by having a branch for missile technologies and capabilities

4. Demotivating factors for nuclear proliferation should also be considered, allowing motivations a similar ability to impact the overall success as resources do.
5. Additional organization resource development used in the priors should be considered.

Including resources was not part of the initial scope of this project. The three used were deemed necessary to allow the network to differentiate between certain scenarios that logically had very different outcomes, which could not be accomplished by the motivations alone. The resources of an organization can be systematically broken down into their base components, similar to how the motivations and intentions were dissected, and a system developed to implement them into the network. Pertinent resources that also might be considered for integration in to the model could include time, money, available work force, land availability, and special forces availability.

This work developed first, published, quantitative methodology for predicting nuclear proliferation with consideration for how an organization's motivations impact their pathway probabilities. The methodology produced and presented in this paper has limitations, but it will serve as a valuable tool and will aid in the fight to combat nuclear proliferation.

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APPENDIX A

VALUES OF v_i^m USED FOR DELIVERABILITY INTENTIONS

The figures in appendix A give all of the values of v_i^m that are used to calculate the deliverability intentions for each motivation considered in this work.

Deliverability	v_i^m
Non-Deliverable	0.8
Truck/Cargo Container	1
Air Drop	0.2
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

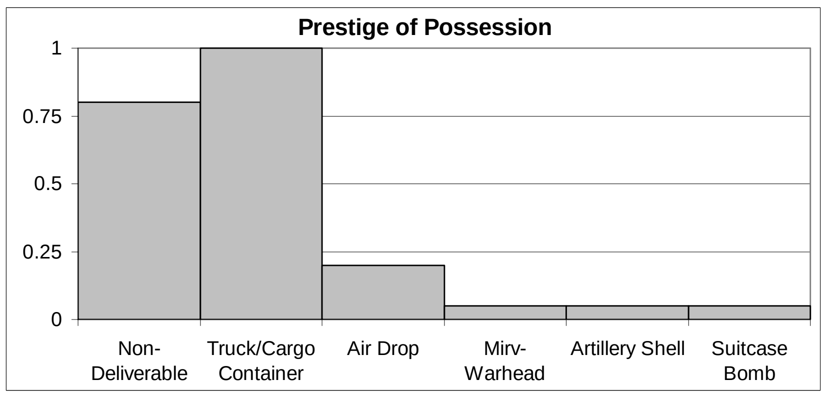

Fig. A-1. Values of v_i^m used for prestige of possession

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.8
Air Drop	1
Mirv-Warhead	0.1
Artillery Shell	0.05
Suitcase Bomb	0.05

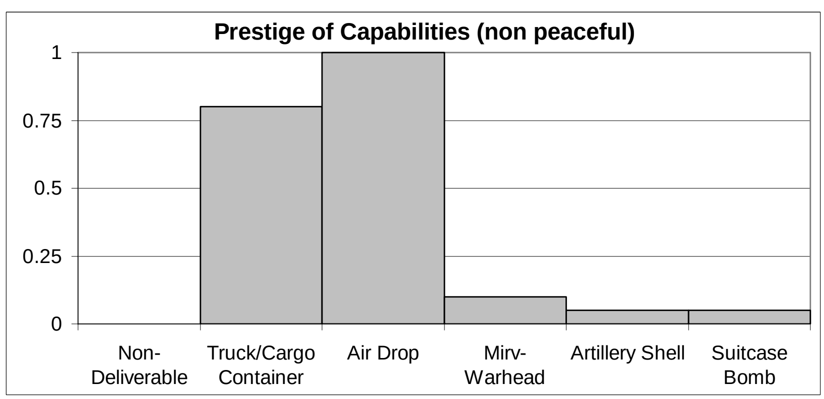

Fig. A-2. Values of v_i^m used for prestige of capabilities (non peaceful)

Deliverability	v_i^m
Non-Deliverable	1
Truck/Cargo Container	0.8
Air Drop	0.2
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

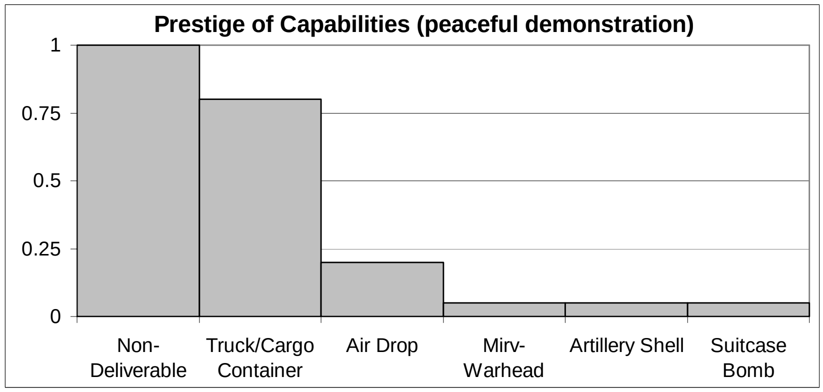

Fig. A-3. Values of v_i^m used for prestige of capabilities (peaceful demonstration)

Deliverability	v_i^m
Non-Deliverable	0.05
Truck/Cargo Container	0.4
Air Drop	1
Mirv-Warhead	0.4
Artillery Shell	0.05
Suitcase Bomb	0.05

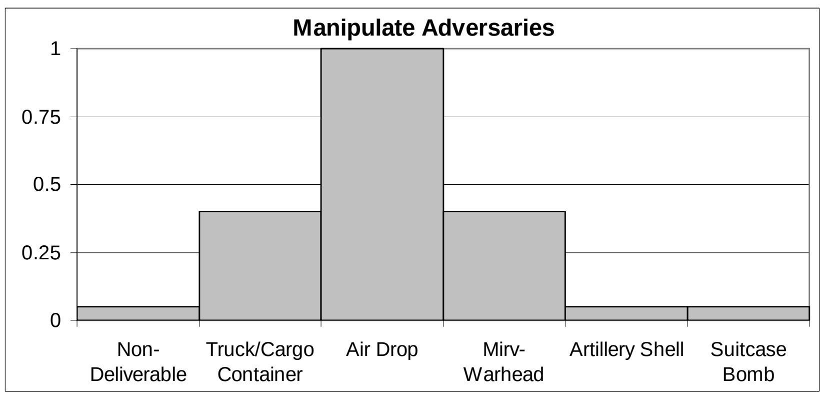

Fig. A-4. Values of v_i^m used for manipulate adversaries

Deliverability	v_i^m
Non-Deliverable	0.2
Truck/Cargo Container	1
Air Drop	0.3
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

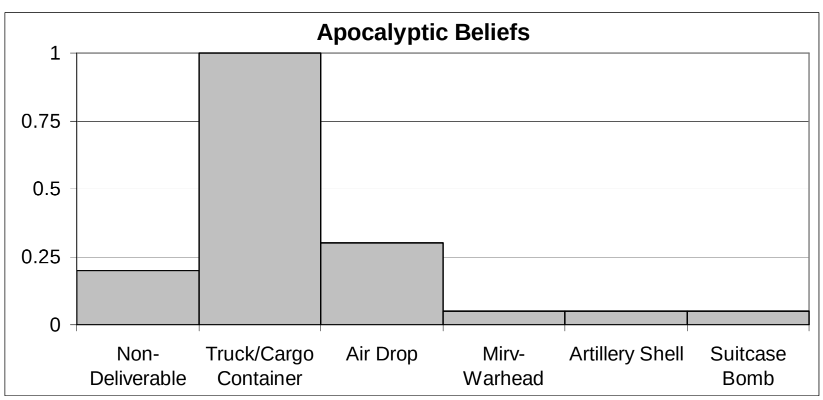

Fig. A-5. Values of v_i^m used for apocalyptic beliefs

Deliverability	v_i^m
Non-Deliverable	0.3
Truck/Cargo Container	1
Air Drop	0.05
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

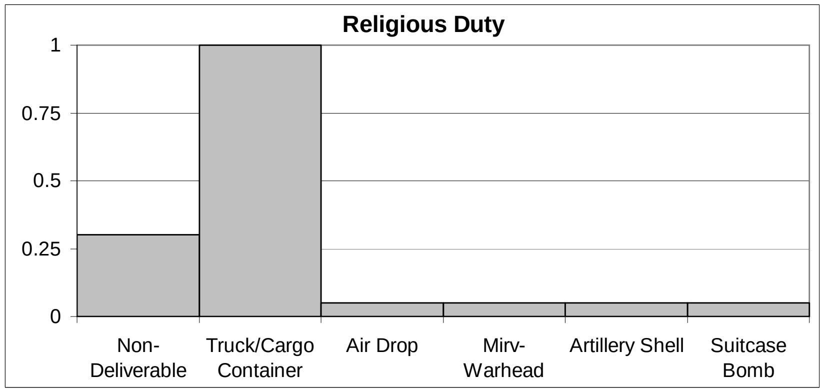

Fig. A-6. Values of v_i^m used for religious duty

Deliverability	v_i^m
Non-Deliverable	0.5
Truck/Cargo Container	7
Air Drop	0.2
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

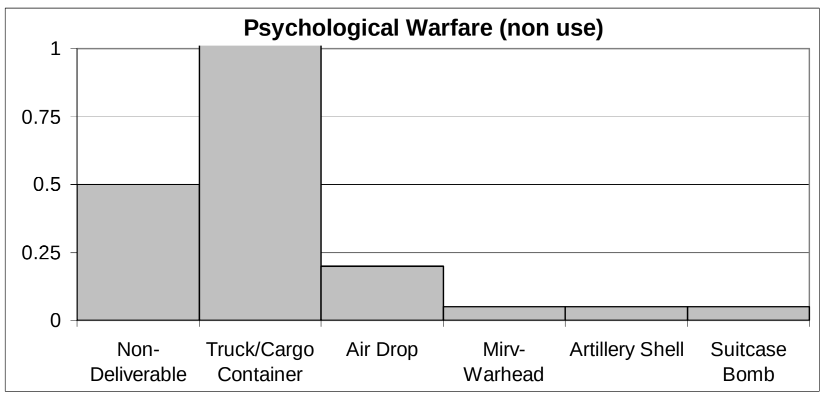

Fig. A-7. Values of v_i^m used for psychological warfare (non use)

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	1
Air Drop	0.6
Mirv-Warhead	0.2
Artillery Shell	0.05
Suitcase Bomb	0.05

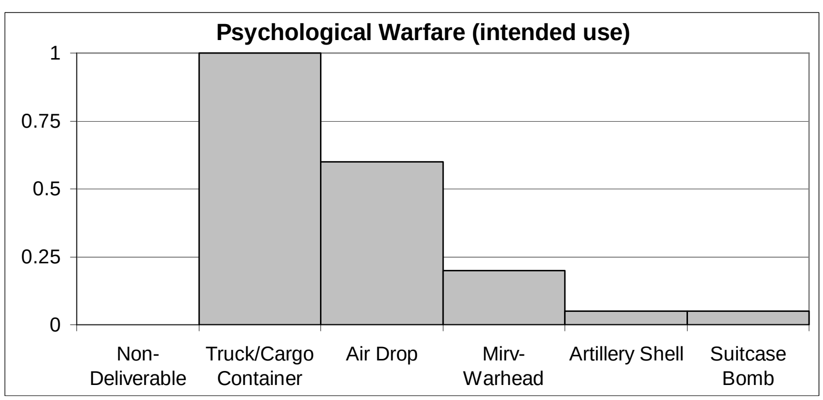

Fig. A-8. Values of v_i^m used for psychological warfare (intended use)

Deliverability	v_i^m
Non-Deliverable	0.05
Truck/Cargo Container	1
Air Drop	0.4
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

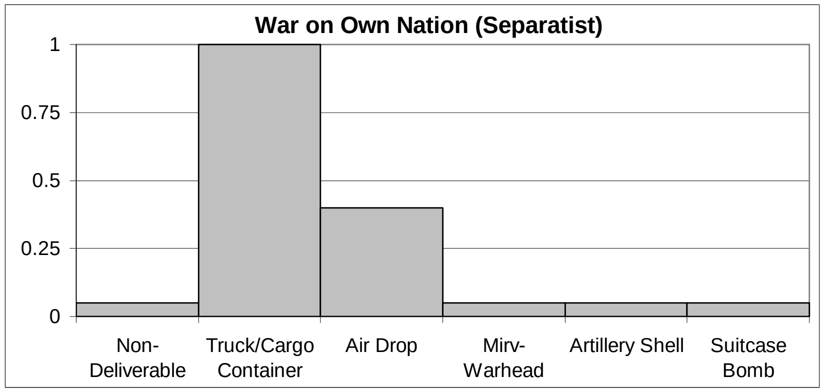

Fig. A-9. Values of v_i^m used for war on own nation (Separatist)

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	1
Air Drop	0.8
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

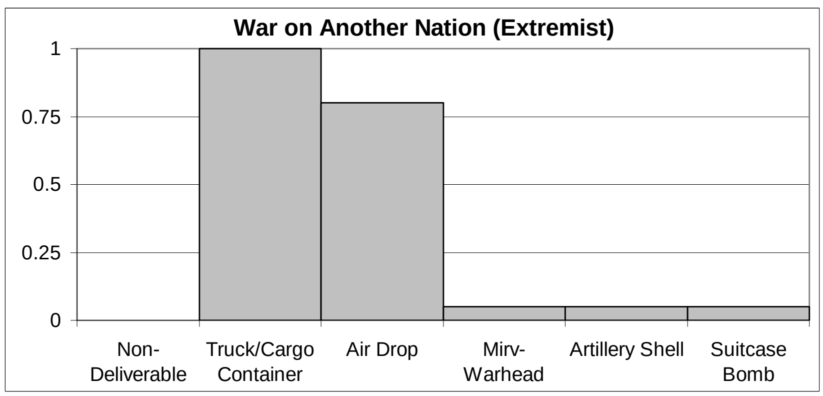

Fig. A-10. Values of v_i^m used for war on another nation (Extremist)

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.2
Air Drop	1
Mirv-Warhead	0.8
Artillery Shell	0.05
Suitcase Bomb	0.05

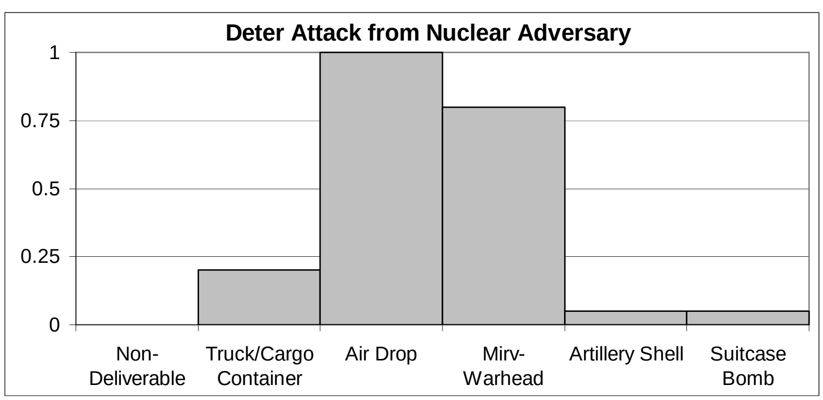

Fig. A-11. Values of v_i^m used for deter attack from nuclear adversary

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0
Air Drop	0.2
Mirv-Warhead	1
Artillery Shell	0.4
Suitcase Bomb	0.05

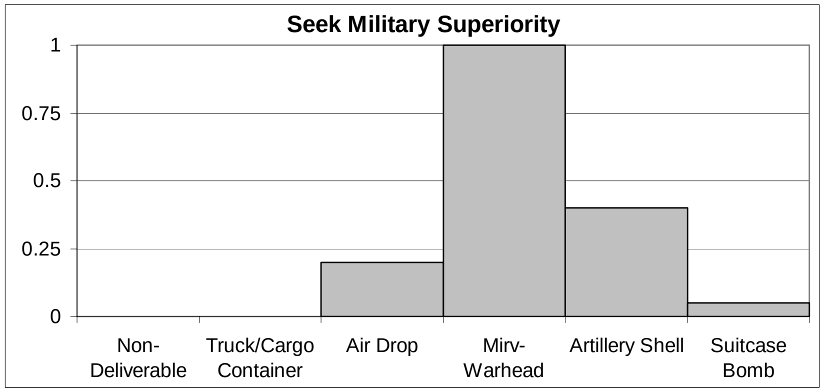

Fig. A-12. Values of v_i^m used for seek military superiority

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.05
Air Drop	0.8
Mirv-Warhead	1
Artillery Shell	0.2
Suitcase Bomb	0.05

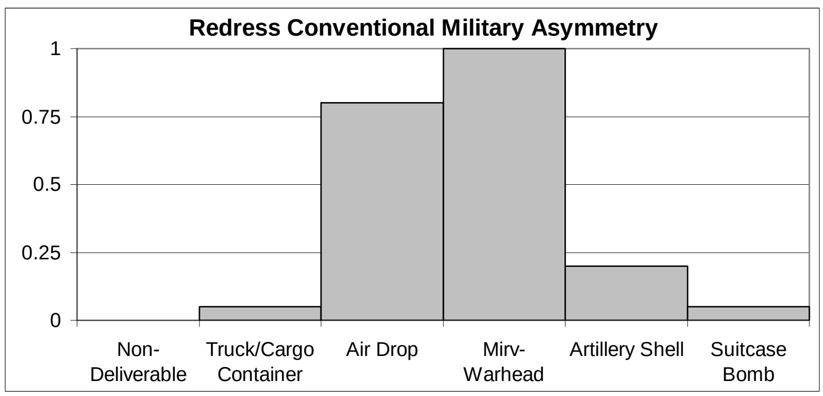

Fig. A-13. Values of v_i^m used for redress conventional military asymmetry

Deliverability	v_i^m
Non-Deliverable	1
Truck/Cargo Container	0.2
Air Drop	0.05
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

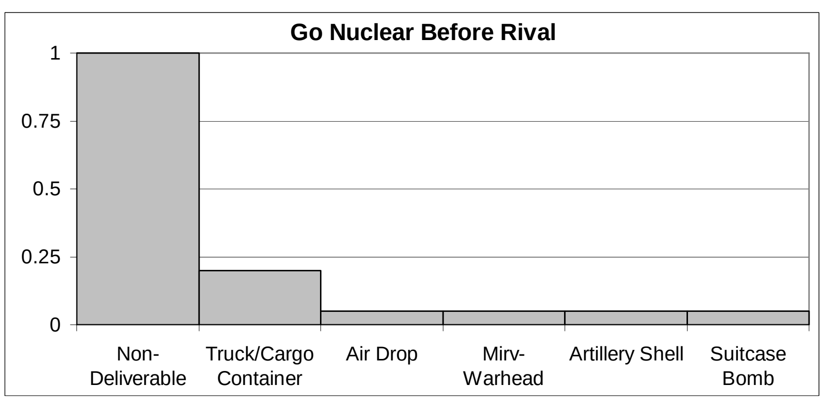

Fig. A-14. Values of v_i^m used for go nuclear before rival

Deliverability	v_i^m
Non-Deliverable	0.2
Truck/Cargo Container	0.6
Air Drop	1
Mirv-Warhead	0.2
Artillery Shell	0.05
Suitcase Bomb	0.05

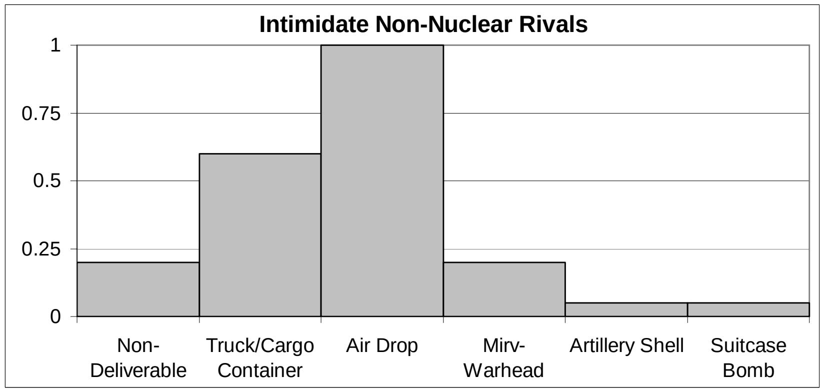

Fig. A-15. Values of v_i^m used for intimidate non-nuclear rivals

Deliverability	v_i^m
Non-Deliverable	0.5
Truck/Cargo Container	1
Air Drop	1
Mirv-Warhead	0.2
Artillery Shell	0.05
Suitcase Bomb	0.05

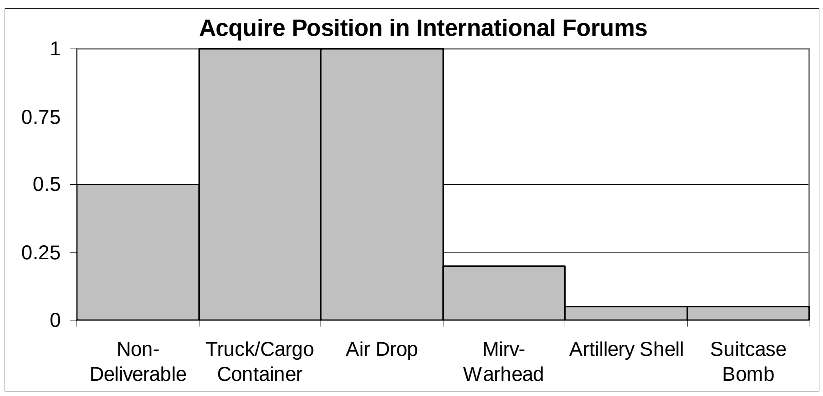

Fig. A-16. Values of v_i^m used for acquire position in international forums

Deliverability	v_i^m
Non-Deliverable	0.05
Truck/Cargo Container	0.05
Air Drop	0.8
Mirv-Warhead	1
Artillery Shell	0.4
Suitcase Bomb	0.05

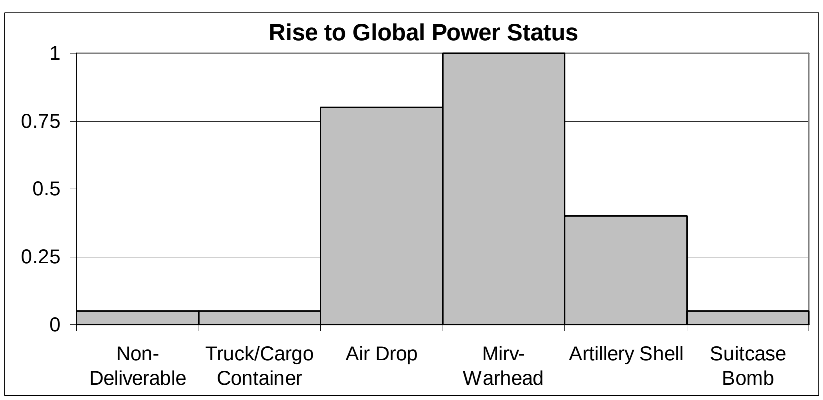

Fig. A-17. Values of v_i^m used for rise to global power status

Deliverability	v_i^m
Non-Deliverable	0.2
Truck/Cargo Container	0.6
Air Drop	1
Mirv-Warhead	0.4
Artillery Shell	0.05
Suitcase Bomb	0.05

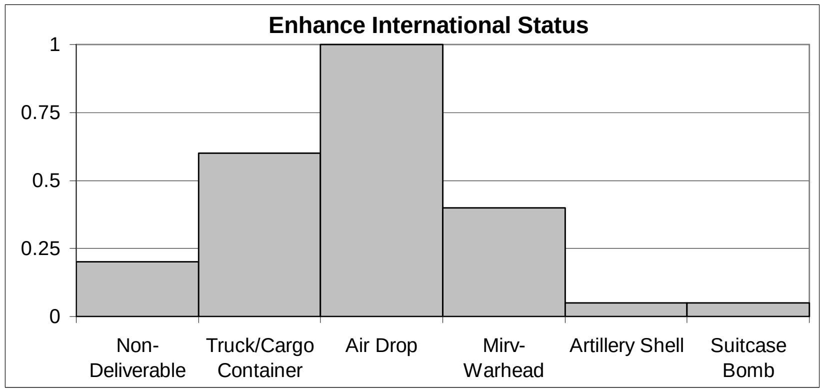

Fig. A-18. Values of v_i^m used for enhance international status

Deliverability	v_i^m
Non-Deliverable	0.5
Truck/Cargo Container	1
Air Drop	0.4
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

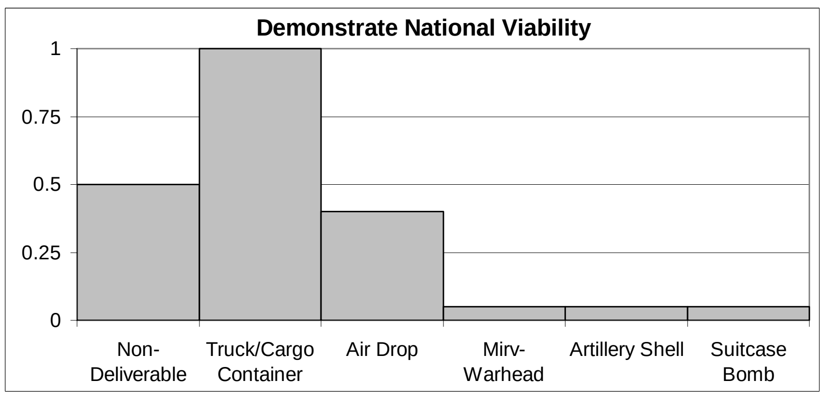

Fig. A-19. Values of v_i^m used for demonstrate national viability

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.4
Air Drop	1
Mirv-Warhead	0.2
Artillery Shell	0.05
Suitcase Bomb	0.05

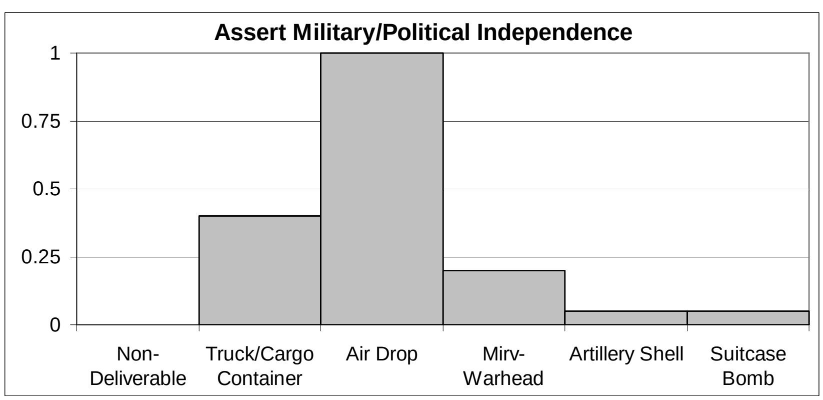

Fig. A-20. Values of v_i^m used for assert military/political independence

Deliverability	v_i^m
Non-Deliverable	1
Truck/Cargo Container	0.05
Air Drop	0.05
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

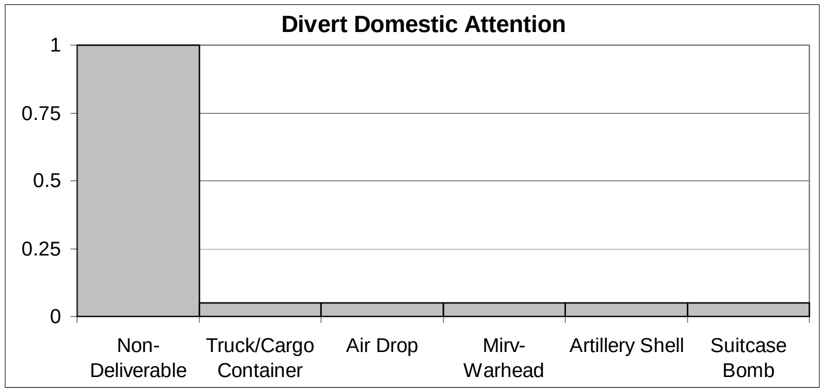

Fig. A-21. Values of v_i^m used for divert domestic attention

Deliverability	v_i^m
Non-Deliverable	0.05
Truck/Cargo Container	0.4
Air Drop	0.8
Mirv-Warhead	1
Artillery Shell	0.2
Suitcase Bomb	0.05

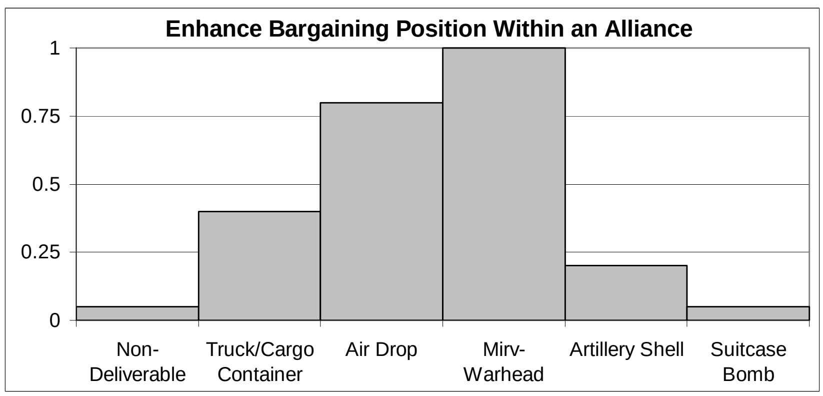

Fig. A-22. Values of v_i^m used enhance bargaining position within an alliance

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.2
Air Drop	1
Mirv-Warhead	0.6
Artillery Shell	0.05
Suitcase Bomb	0.05

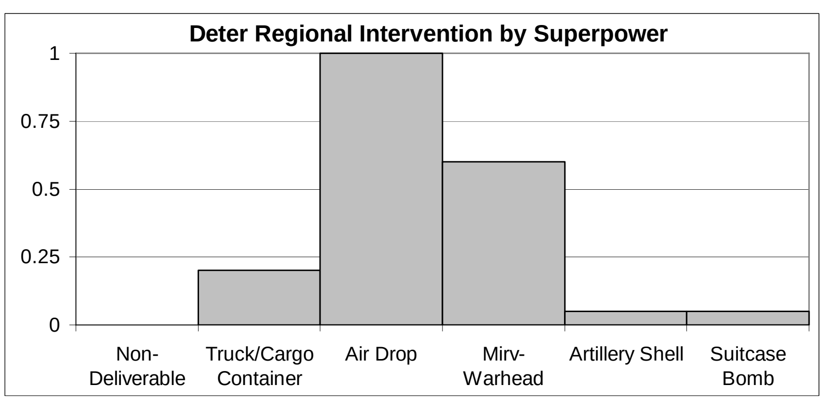

Fig. A-23. Values of v_i^m used deter regional intervention by superpower

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.05
Air Drop	0.2
Mirv-Warhead	1
Artillery Shell	0.6
Suitcase Bomb	0.05

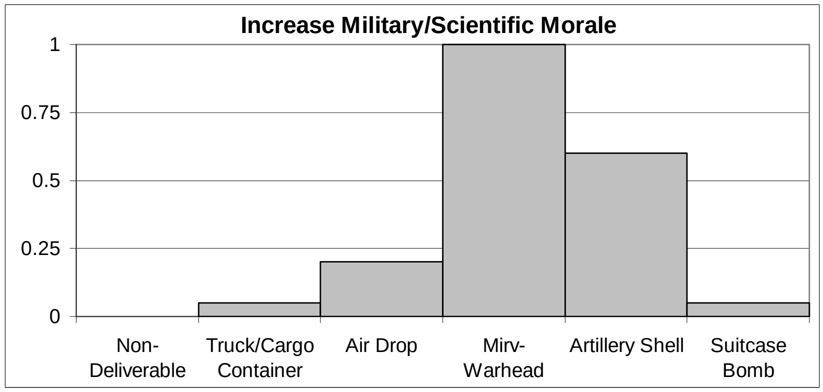

Fig. A-24. Values of v_i^m used for increase military/scientific morale

Deliverability	v_i^m
Non-Deliverable	1
Truck/Cargo Container	0.2
Air Drop	0.05
Mirv-Warhead	0.05
Artillery Shell	0.05
Suitcase Bomb	0.05

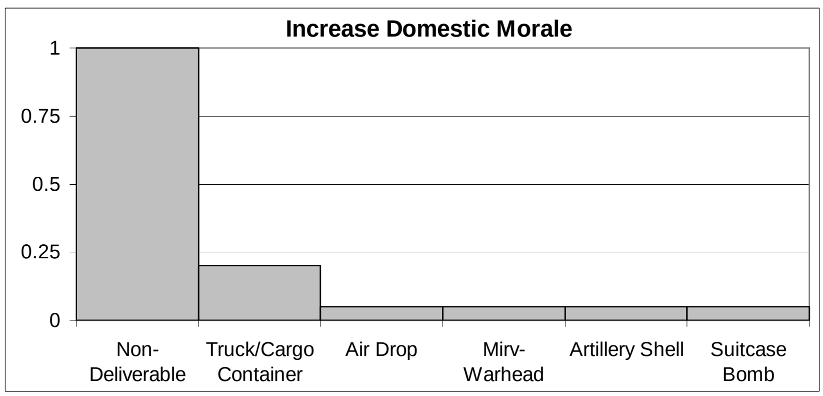

Fig. A-25. Values of v_i^m used for increase domestic morale

Deliverability	v_i^m
Non-Deliverable	0
Truck/Cargo Container	0.05
Air Drop	0.8
Mirv-Warhead	1
Artillery Shell	0.2
Suitcase Bomb	0.05

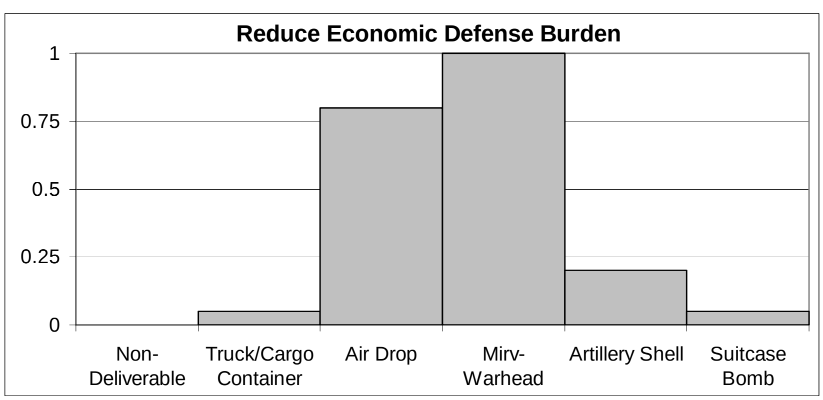

Fig. A-26. Values of v_i^m used for reduce economic defense burden

APPENDIX B

VALUES OF v_i^m USED FOR YIELD INTENTIONS

The figures in appendix B give all of the values of v_i^m that are used to calculate the yield intentions for each motivation considered in this work.

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.2
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

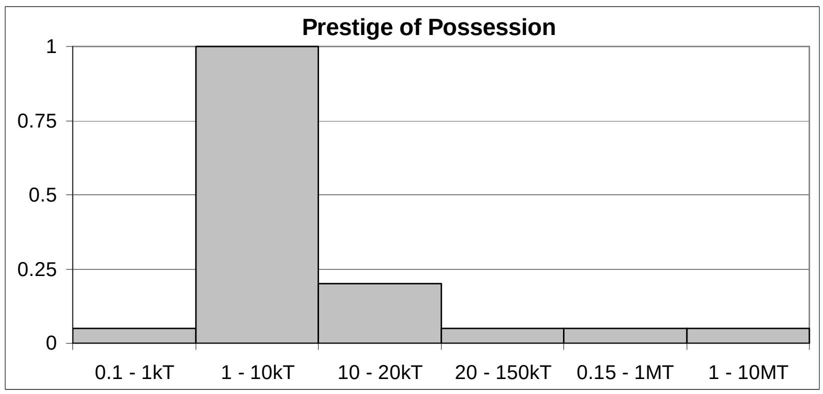

Fig. B-1. Values of v_i^m used for prestige of possession

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.3
10 - 20kT	1
20 - 150kT	0.2
0.15 - 1MT	0.05
1 - 10MT	0.05

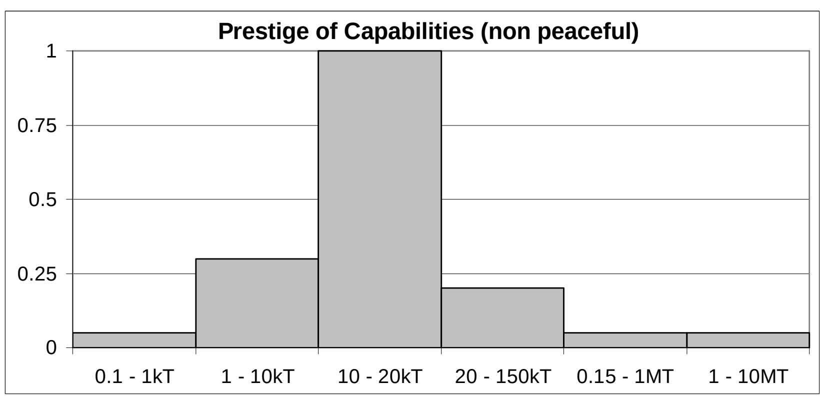

Fig. B-2. Values of v_i^m used for prestige of capabilities (non peaceful)

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.6
20 - 150kT	0.05
0.15 - 1MT	0
1 - 10MT	0

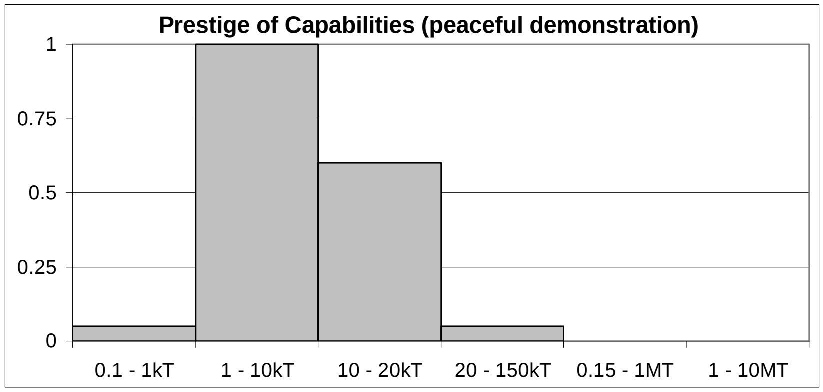

Fig. B-3. Values of v_i^m used for prestige of capabilities (peaceful demonstration)

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.3
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

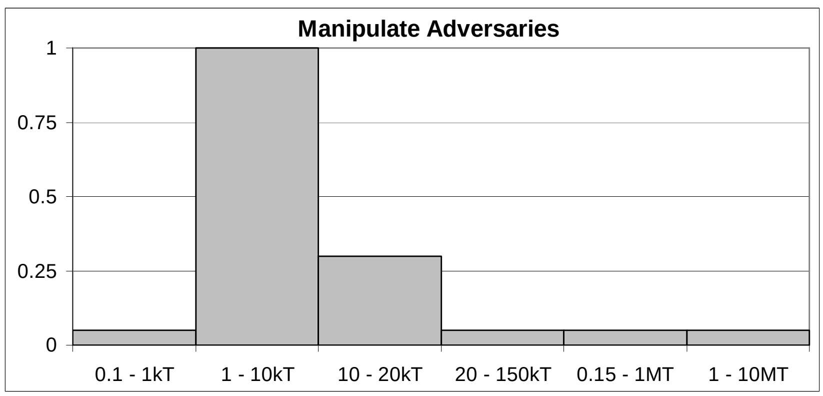

Fig. B-4. Values of v_i^m used for manipulate adversaries

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.05
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

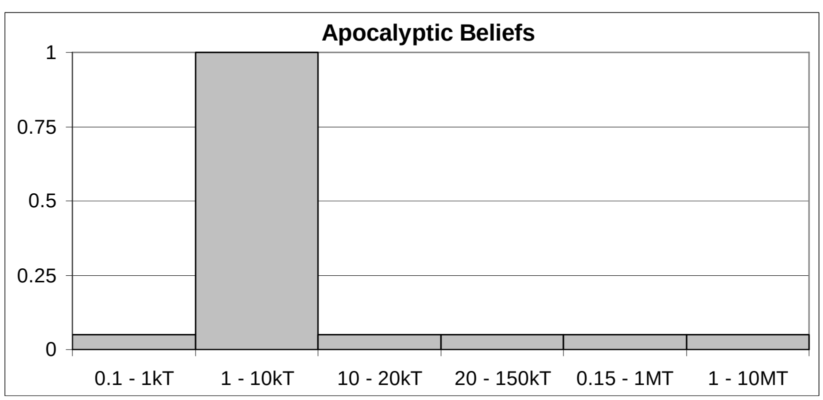

Fig. B-5. Values of v_i^m used for apocalyptic beliefs

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.05
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

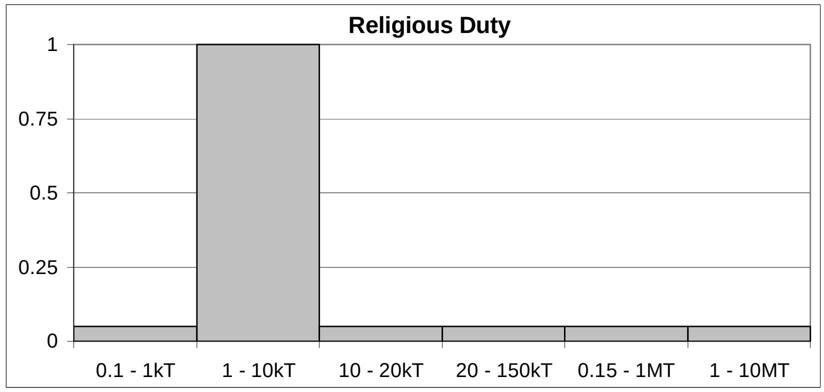

Fig. B-6. Values of v_i^m used for religious duty

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.4
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

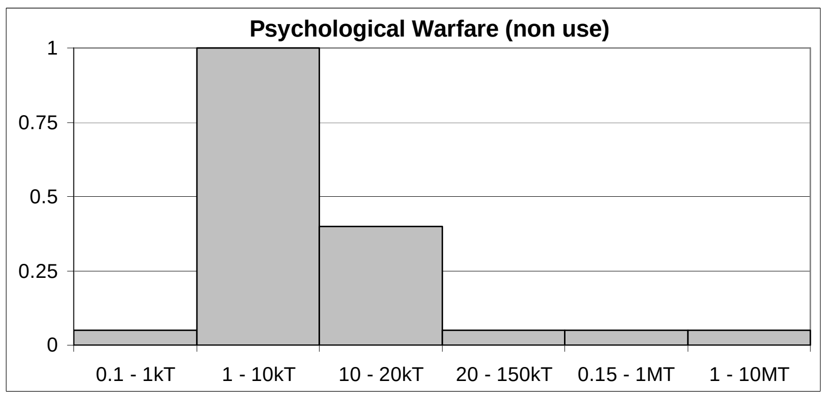

Fig. B-7. Values of v_i^m used for psychological warfare (non use)

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.7
10 - 20kT	1
20 - 150kT	0.4
0.15 - 1MT	0.05
1 - 10MT	0.05

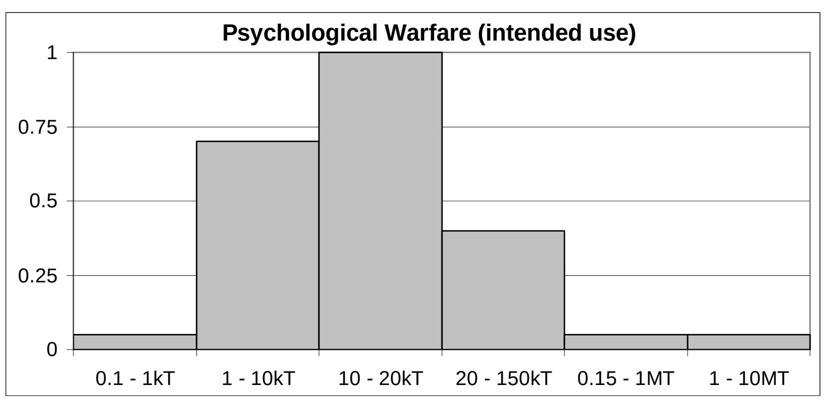

Fig. B-8. Values of v_i^m used for psychological warfare (intended use)

Yield	v_i^m
0.1 - 1kT	1
1 - 10kT	0.6
10 - 20kT	0.05
20 - 150kT	0.05
0.15 - 1MT	0
1 - 10MT	0

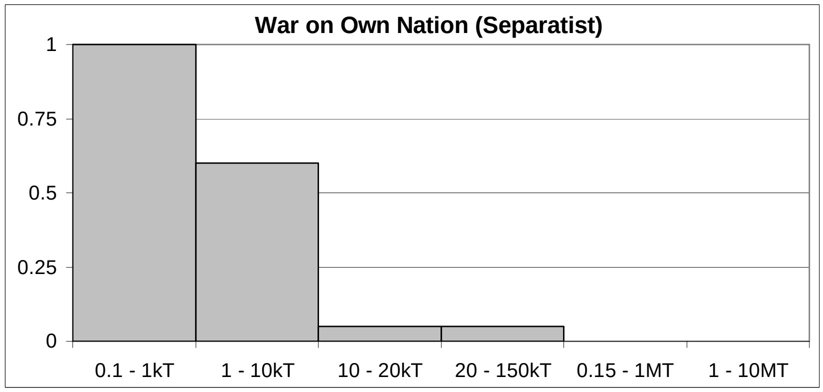

Fig. B-9. Values of v_i^m used for war on own nation (Separatist)

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.7
10 - 20kT	1
20 - 150kT	0.4
0.15 - 1MT	0.05
1 - 10MT	0.05

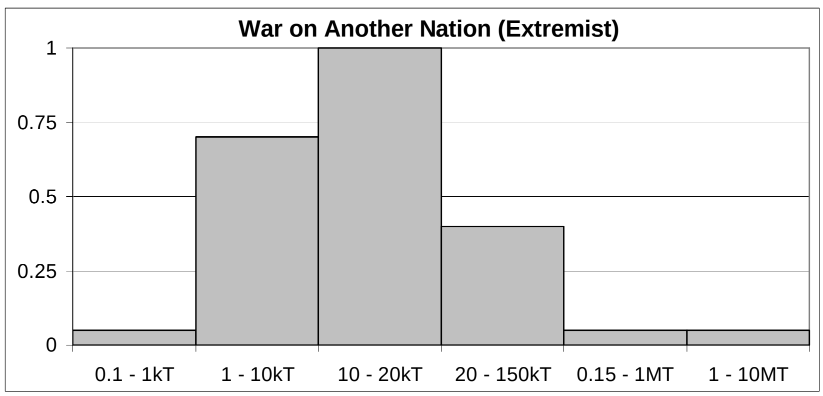

Fig. B-10. Values of v_i^m used for war on another nation (Extremist)

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.05
10 - 20kT	0.4
20 - 150kT	1
0.15 - 1MT	0.3
1 - 10MT	0.05

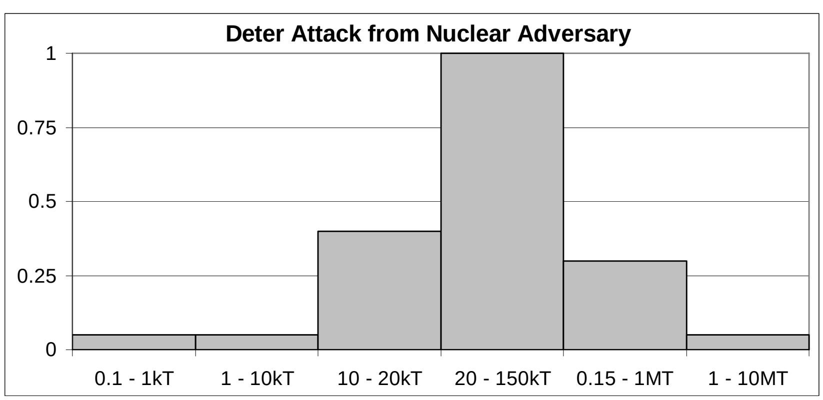

Fig. B-11. Values of v_i^m used for deter attack from nuclear adversary

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.2
10 - 20kT	0.6
20 - 150kT	1
0.15 - 1MT	0.4
1 - 10MT	0.05

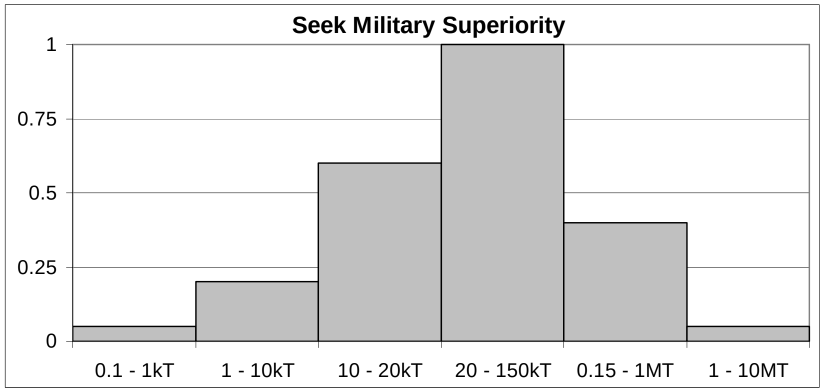

Fig. B-12. Values of v_i^m used for seek military superiority

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.6
20 - 150kT	0.2
0.15 - 1MT	0.05
1 - 10MT	0.05

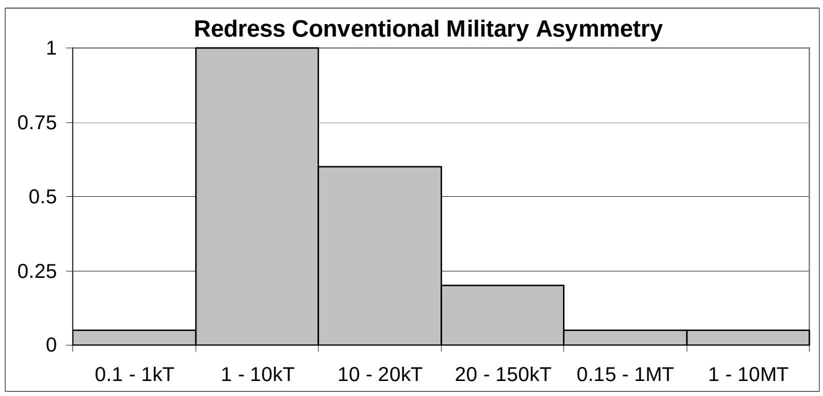

Fig. B-13. Values of v_i^m used for redress conventional military asymmetry

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.05
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

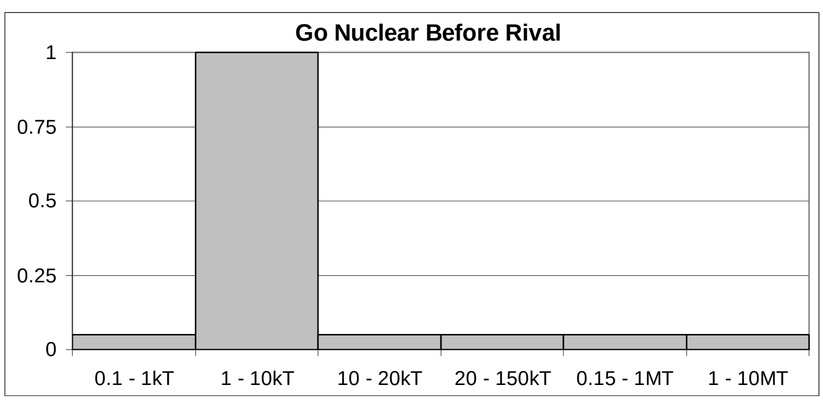

Fig. B-14. Values of v_i^m used for go nuclear before rival

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.4
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

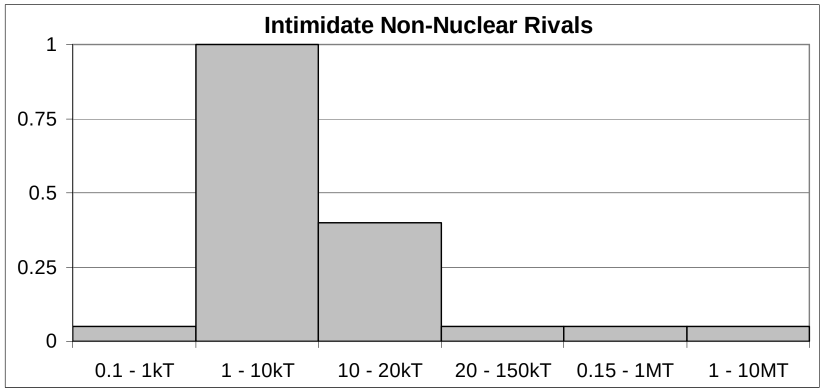

Fig. B-15. Values of v_i^m used for intimidate non-nuclear rivals

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.6
10 - 20kT	1
20 - 150kT	0.3
0.15 - 1MT	0.05
1 - 10MT	0.05

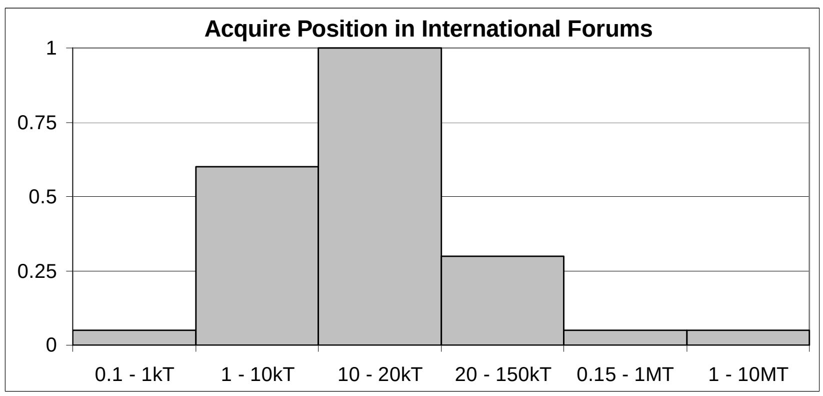

Fig. B-16. Values of v_i^m used for acquire position in international forums

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.05
10 - 20kT	0.6
20 - 150kT	1
0.15 - 1MT	0.5
1 - 10MT	0.05

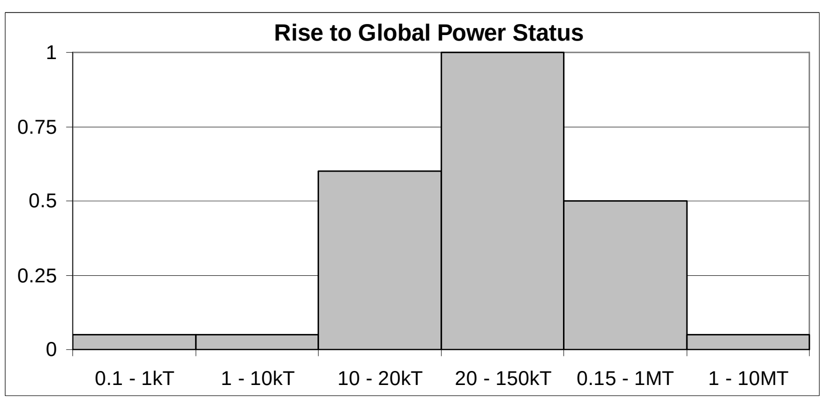

Fig. B-17. Values of v_i^m used for rise to global power status

Yield	v_i^m
0.1 - 1kT	0.6
1 - 10kT	0.05
10 - 20kT	0.4
20 - 150kT	1
0.15 - 1MT	0.3
1 - 10MT	0.05

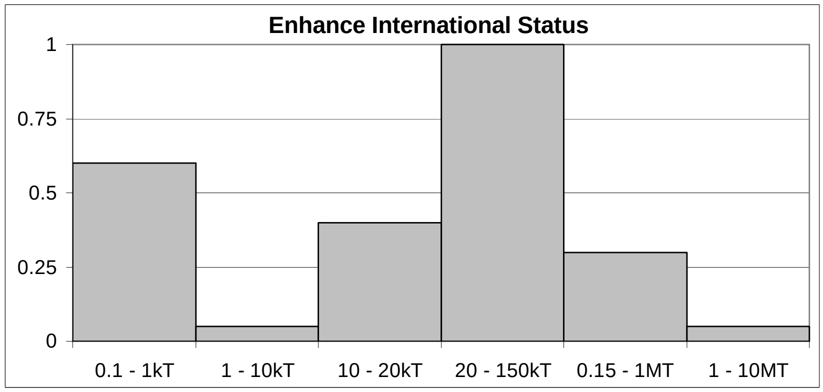

Fig. B-18. Values of v_i^m used for enhance international status

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.8
10 - 20kT	1
20 - 150kT	0.2
0.15 - 1MT	0.05
1 - 10MT	0.05

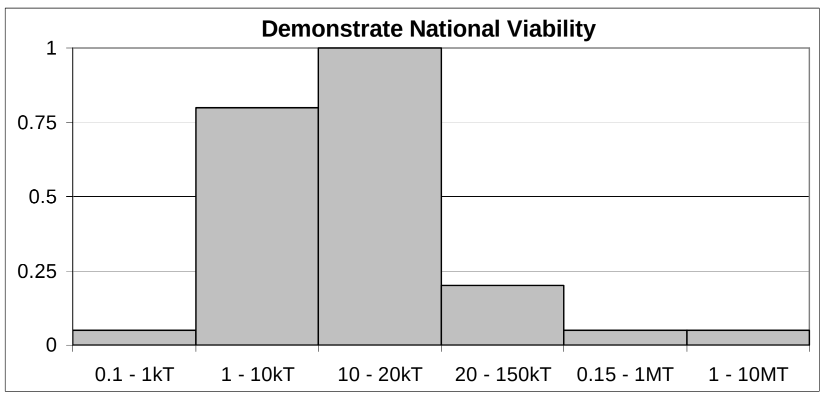

Fig. B-19. Values of v_i^m used for demonstrate national viability

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.6
10 - 20kT	1
20 - 150kT	0.3
0.15 - 1MT	0.05
1 - 10MT	0.05

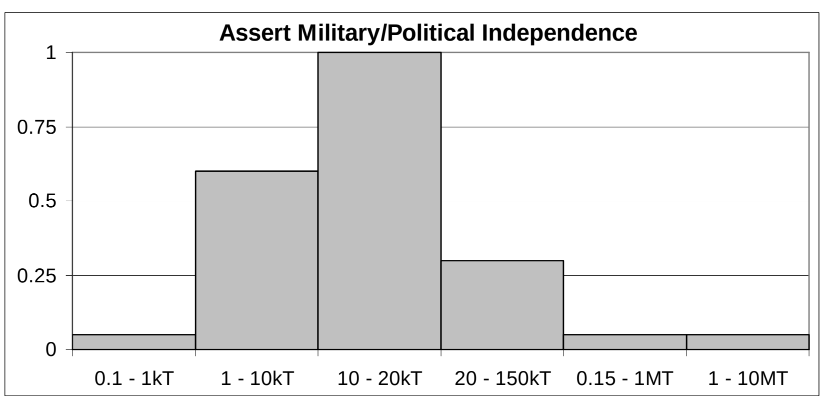

Fig. B-20. Values of v_i^m used for assert military/political independence

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.05
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

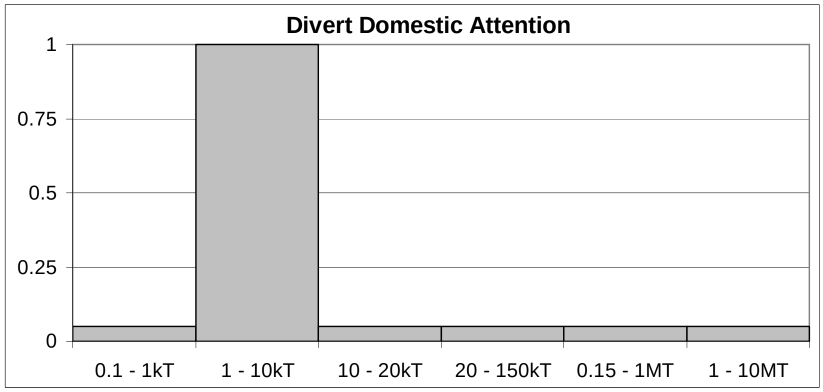

Fig. B-21. Values of v_i^m used for divert domestic attention

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.3
10 - 20kT	0.6
20 - 150kT	1
0.15 - 1MT	0.4
1 - 10MT	0.05

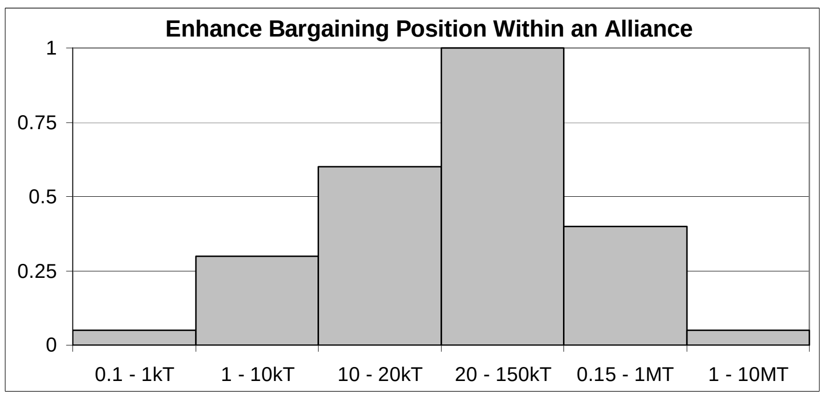

Fig. B-22. Values of v_i^m used enhance bargaining position within an alliance

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.4
10 - 20kT	1
20 - 150kT	0.2
0.15 - 1MT	0.05
1 - 10MT	0.05

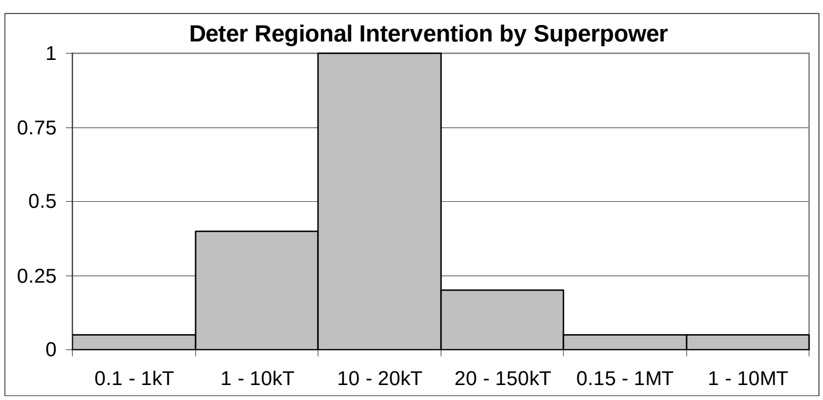

Fig. B-23. Values of v_i^m used deter regional intervention by superpower

Yield	v_i^m
0.1 - 1kT	1
1 - 10kT	0.05
10 - 20kT	0.05
20 - 150kT	1
0.15 - 1MT	0.6
1 - 10MT	0.2

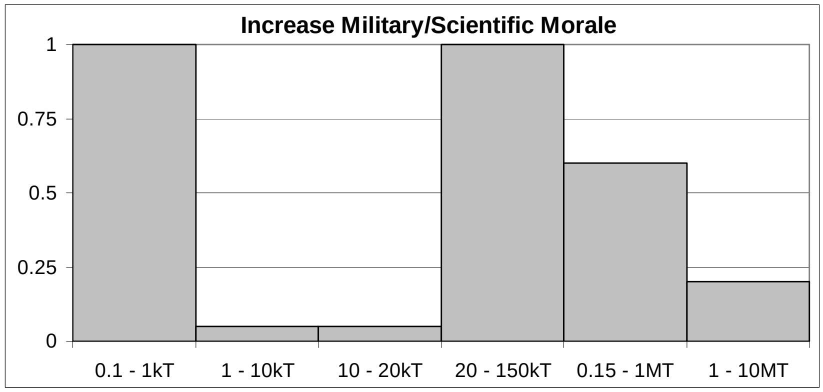

Fig. B-24. Values of v_i^m used for increase military/scientific morale

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	1
10 - 20kT	0.3
20 - 150kT	0.05
0.15 - 1MT	0.05
1 - 10MT	0.05

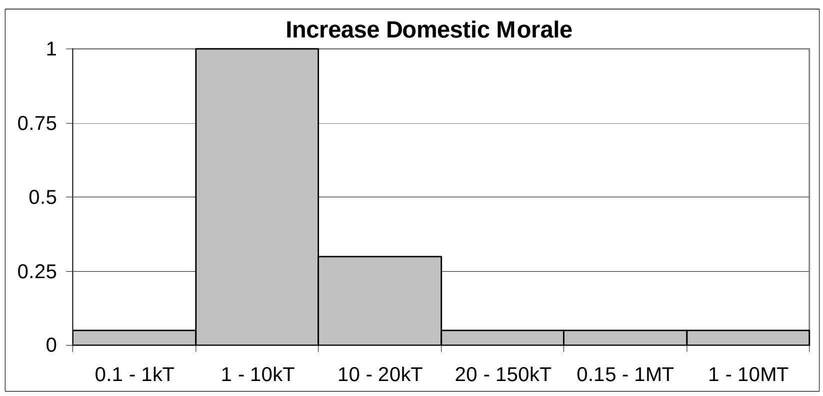

Fig. B-25. Values of v_i^m used for increase domestic morale

Yield	v_i^m
0.1 - 1kT	0.05
1 - 10kT	0.6
10 - 20kT	1
20 - 150kT	0.4
0.15 - 1MT	0.05
1 - 10MT	0.05

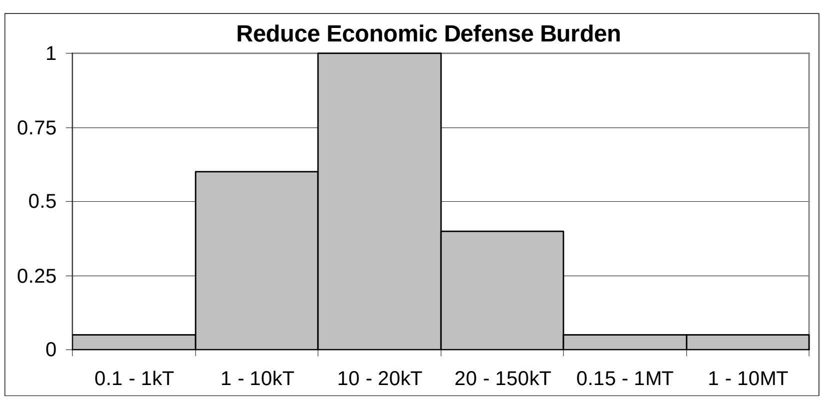

Fig. B-26. Values of v_i^m used for reduce economic defense burden

APPENDIX C

VALUES OF ν_i^m USED FOR NUMBER OF INTENDED DEVICES INTENTIONS

The figures in appendix C give all of the values of ν_i^m that are used to calculate the number of intended devices intentions for each motivation considered in this work.

Intended # of Devices	ν_i^m
1	1
2 - 3	0.8
3 - 10	0.3
10 - 100	0.05
100 +	0.05

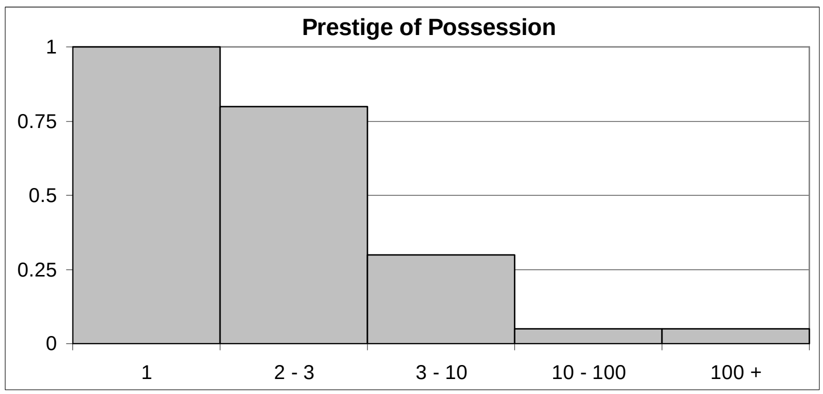

Fig. C-1. Values of ν_i^m used for prestige of possession

Intended # of Devices	ν_i^m
1	0.8
2 - 3	1
3 - 10	0.5
10 - 100	0.05
100 +	0.05

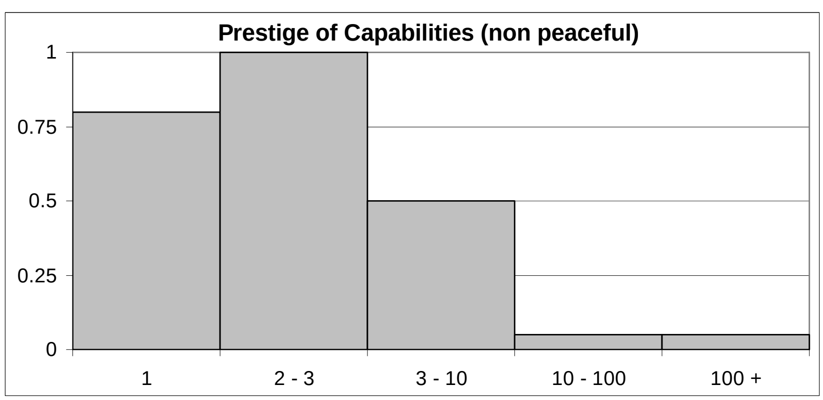

Fig. C-2. Values of ν_i^m used for prestige of capabilities (non peaceful)

Intended # of Devices	v_i^m
1	1
2 - 3	0.4
3 - 10	0.05
10 - 100	0.05
100 +	0.05

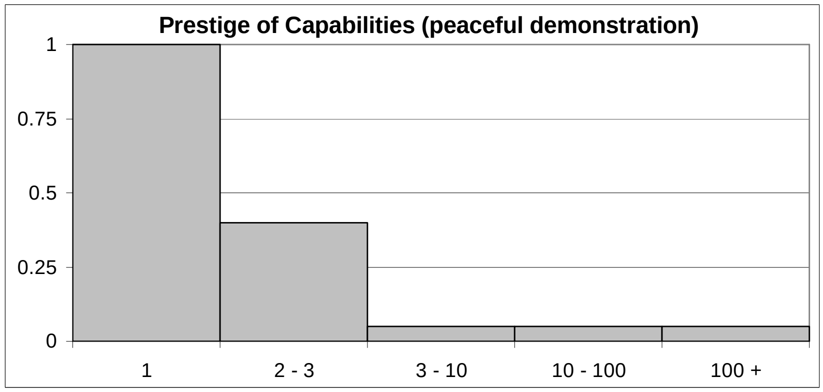

Fig. C-3. Values of v_i^m used for prestige of capabilities (peaceful demonstration)

Intended # of Devices	v_i^m
1	1
2 - 3	0.7
3 - 10	0.2
10 - 100	0.05
100 +	0.05

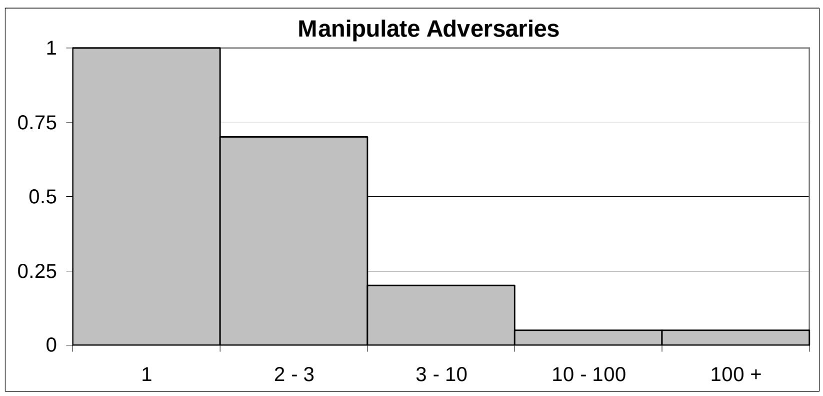

Fig. C-4. Values of v_i^m used for manipulate adversaries

Intended # of Devices	v_i^m
1	1
2 - 3	0.5
3 - 10	0.05
10 - 100	0.05
100 +	0.05

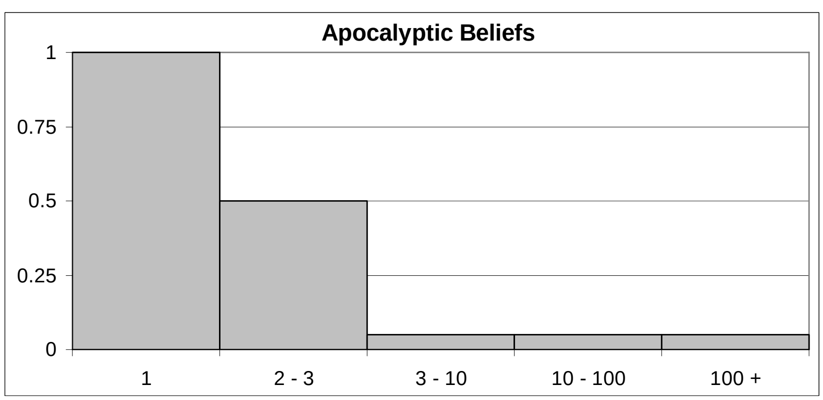

Fig. C-5. Values of v_i^m used for apocalyptic beliefs

Intended # of Devices	v_i^m
1	1
2 - 3	0.05
3 - 10	0.05
10 - 100	0.05
100 +	0.05

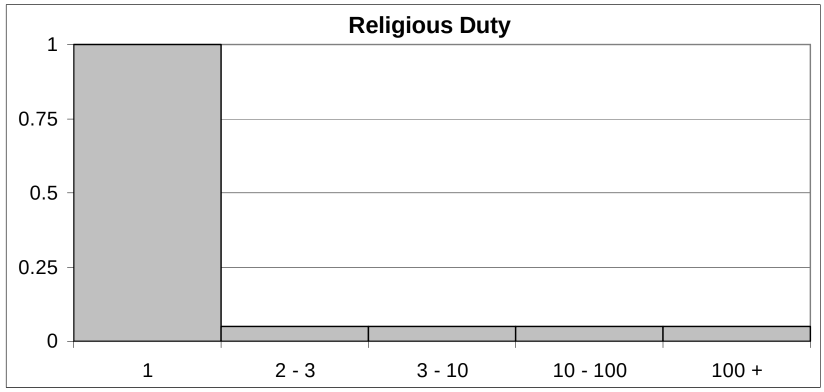

Fig. C-6. Values of v_i^m used for religious duty

Intended # of Devices	v_i^m
1	0.8
2 - 3	1
3 - 10	0.3
10 - 100	0.05
100 +	0.05

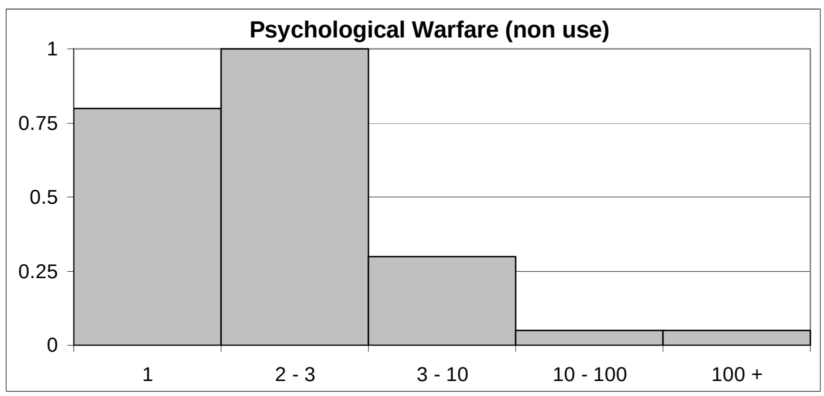

Fig. C-7. Values of v_i^m used for psychological warfare (non use)

Intended # of Devices	v_i^m
1	0.5
2 - 3	1
3 - 10	0.4
10 - 100	0.05
100 +	0.05

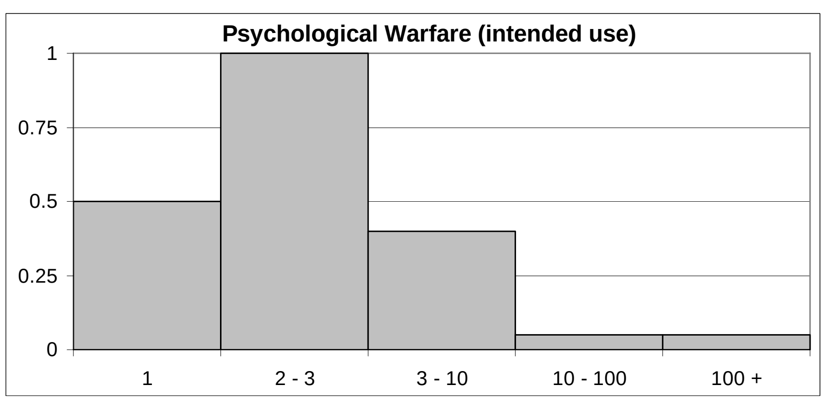

Fig. C-8. Values of v_i^m used for psychological warfare (intended use)

Intended # of Devices	v_i^m
1	1
2 - 3	0.6
3 - 10	0.2
10 - 100	0.05
100 +	0.05

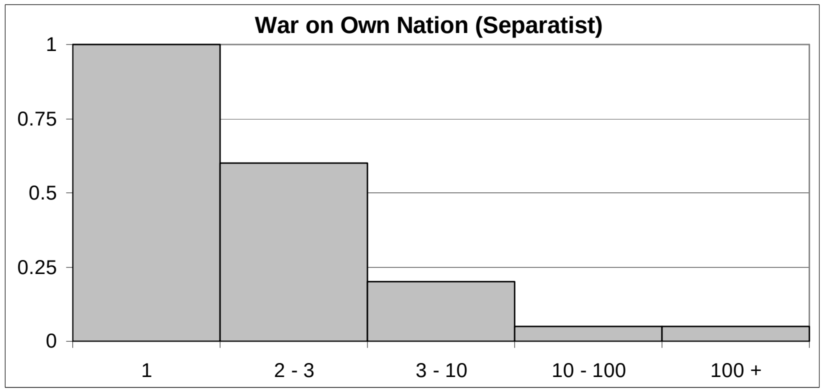

Fig. C-9. Values of v_i^m used for war on own nation (Separatist)

Intended # of Devices	v_i^m
1	1
2 - 3	0.8
3 - 10	0.3
10 - 100	0.05
100 +	0.05

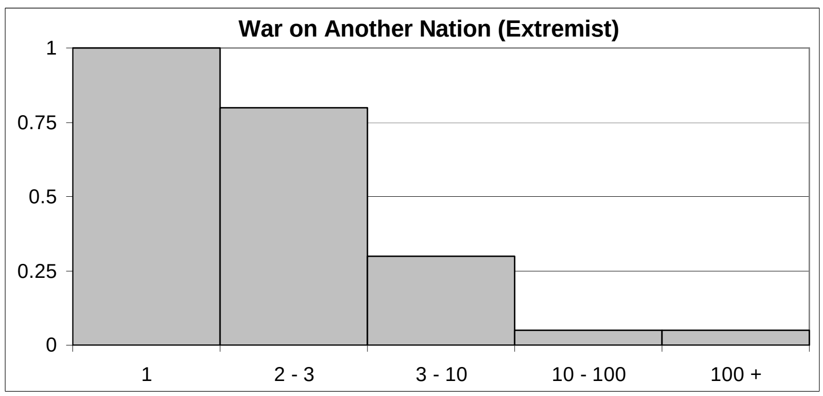

Fig. C-10. Values of v_i^m used for war on another nation (Extremist)

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.3
3 - 10	0.8
10 - 100	1
100 +	0.3

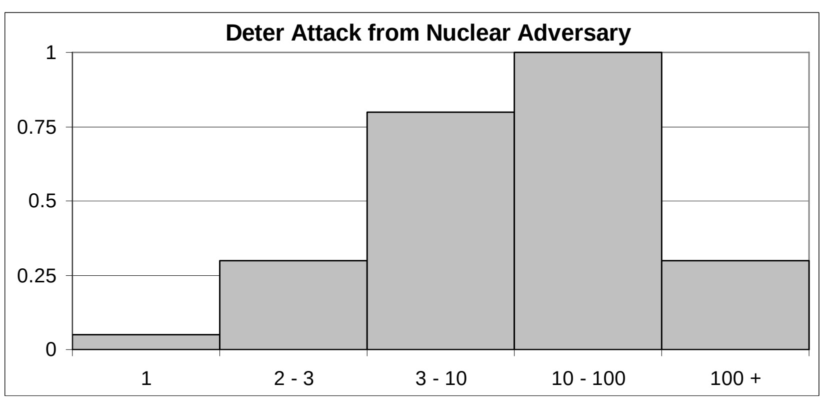

Fig. C-11. Values of v_i^m used for deter attack from nuclear adversary

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.4
3 - 10	1
10 - 100	0.6
100 +	0.2

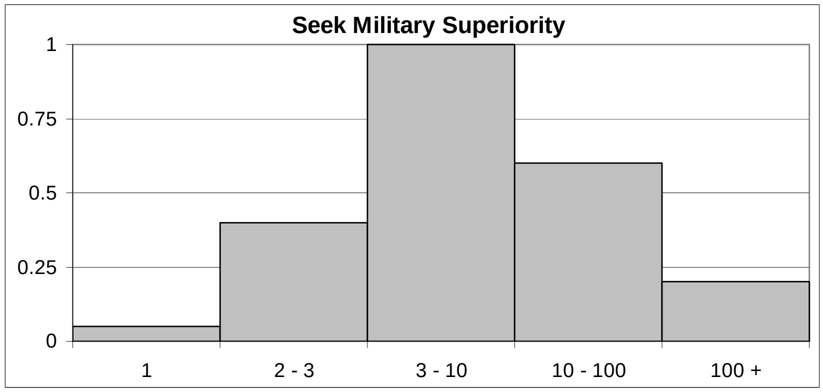

Fig. C-12. Values of v_i^m used for seek military superiority

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.3
3 - 10	0.8
10 - 100	1
100 +	0.3

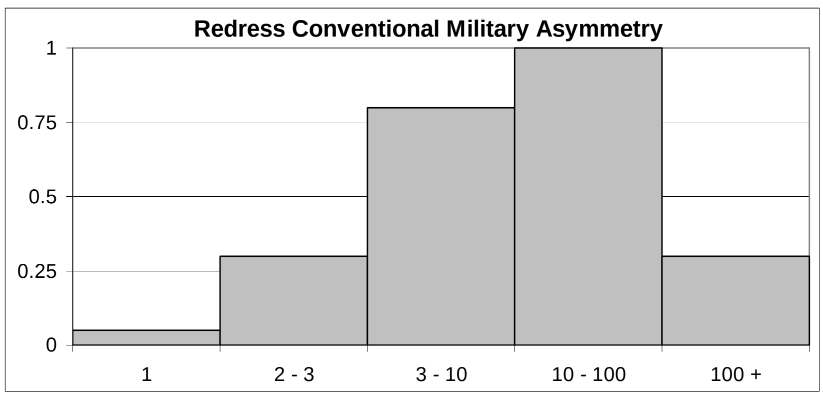

Fig. C-13. Values of v_i^m used for redress conventional military asymmetry

Intended # of Devices	v_i^m
1	1
2 - 3	0.05
3 - 10	0.05
10 - 100	0.05
100 +	0.05

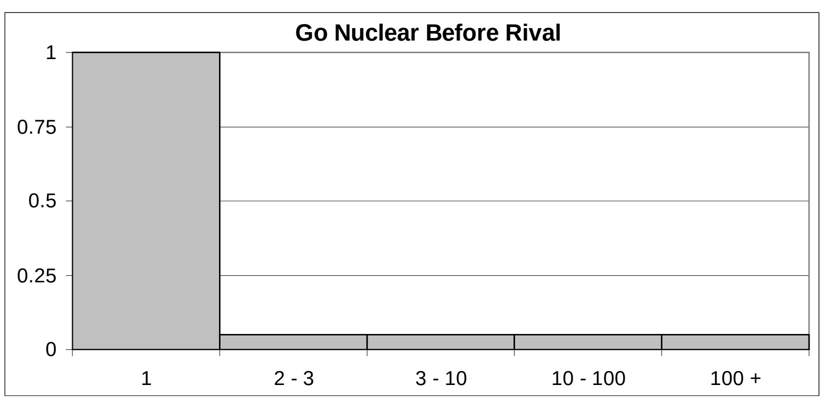

Fig. C-14. Values of v_i^m used for go nuclear before rival

Intended # of Devices	v_i^m
1	0.4
2 - 3	1
3 - 10	0.8
10 - 100	0.3
100 +	0.05

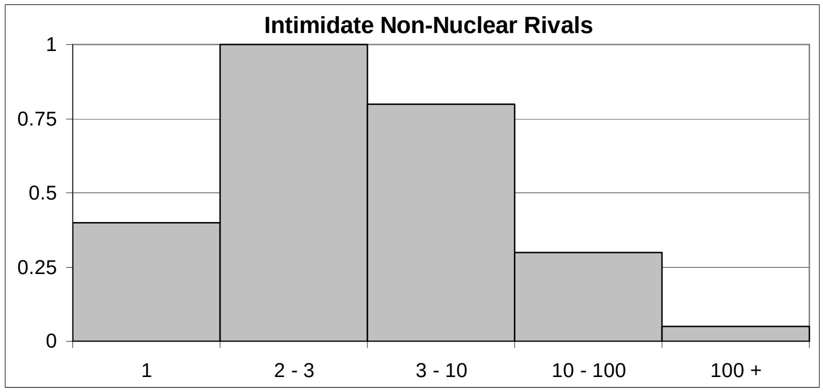

Fig. C-15. Values of v_i^m used for intimidate non-nuclear rivals

Intended # of Devices	v_i^m
1	0.2
2 - 3	0.6
3 - 10	1
10 - 100	0.8
100 +	0.3

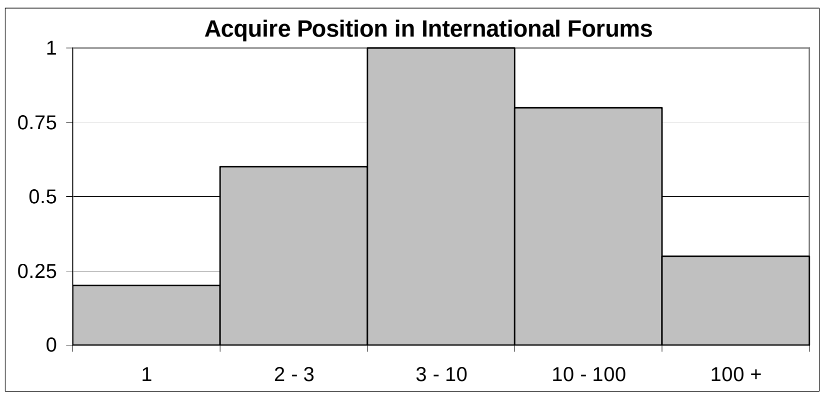

Fig. C-16. Values of v_i^m used for acquire position in international forums

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.3
3 - 10	0.8
10 - 100	1
100 +	0.2

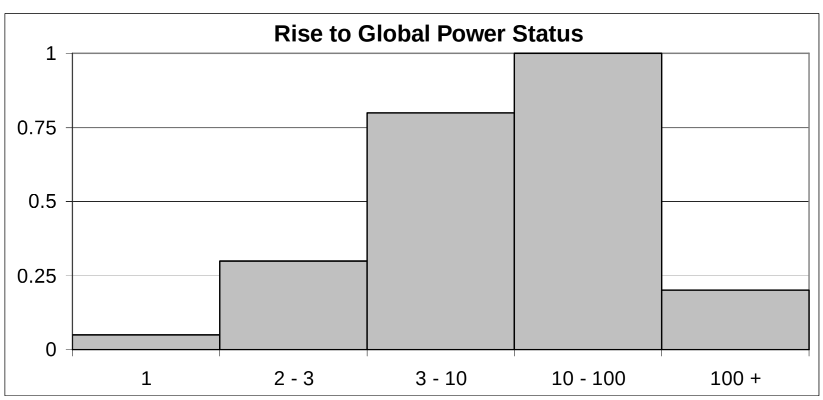

Fig. C-17. Values of v_i^m used for rise to global power status

Intended # of Devices	v_i^m
1	0.4
2 - 3	0.8
3 - 10	1
10 - 100	0.4
100 +	0.05

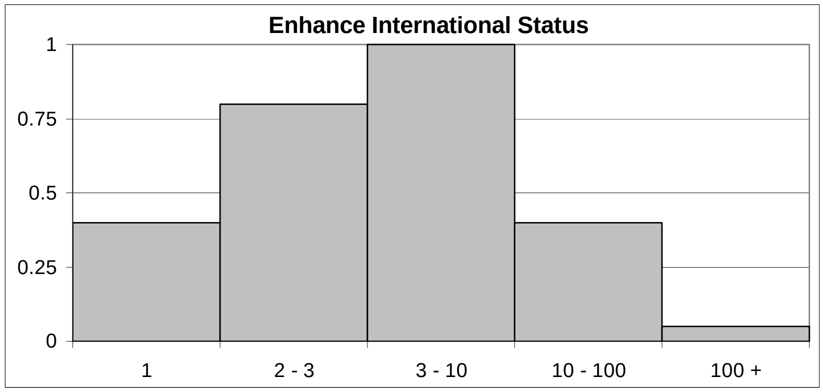

Fig. C-18. Values of v_i^m used for enhance international status

Intended # of Devices	v_i^m
1	0.6
2 - 3	1
3 - 10	0.4
10 - 100	0.05
100 +	0.05

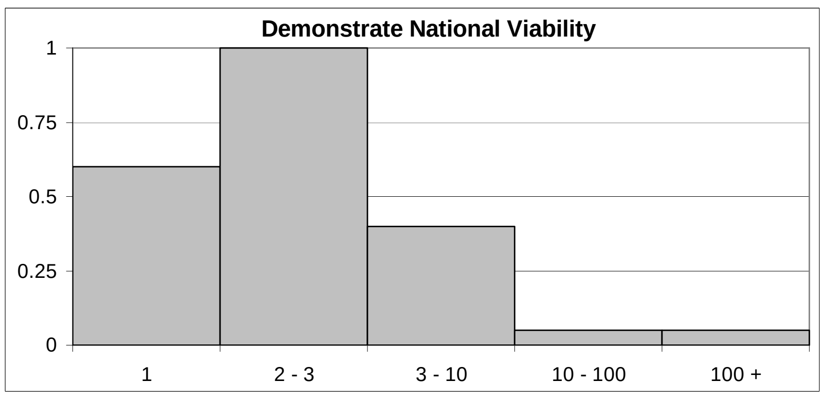

Fig. C-19. Values of v_i^m used for demonstrate national viability

Intended # of Devices	v_i^m
1	0.4
2 - 3	0.8
3 - 10	1
10 - 100	0.4
100 +	0.05

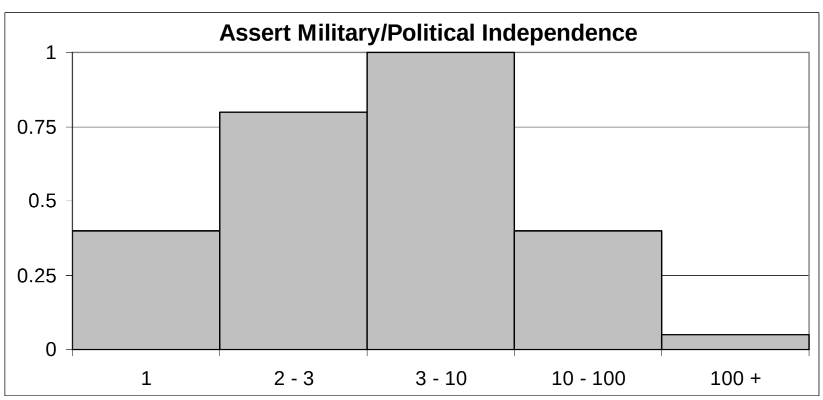

Fig. C-20. Values of v_i^m used for assert military/political independence

Intended # of Devices	v_i^m
1	1
2 - 3	0.3
3 - 10	0.05
10 - 100	0.05
100 +	0.05

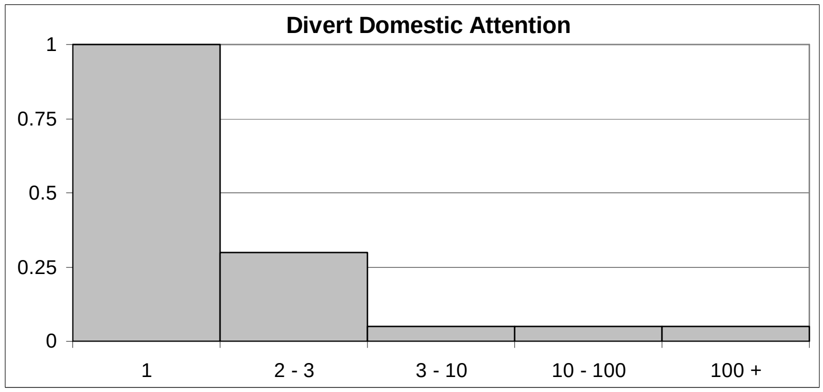

Fig. C-21. Values of v_i^m used for divert domestic attention

Intended # of Devices	v_i^m
1	0.3
2 - 3	0.8
3 - 10	1
10 - 100	0.3
100 +	0.05

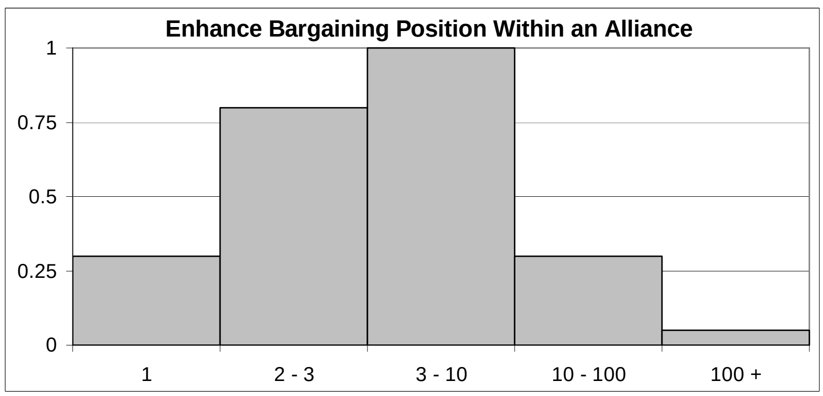

Fig. C-22. Values of v_i^m used enhance bargaining position within an alliance

Intended # of Devices	v_i^m
1	0.6
2 - 3	1
3 - 10	0.6
10 - 100	0.05
100 +	0.05

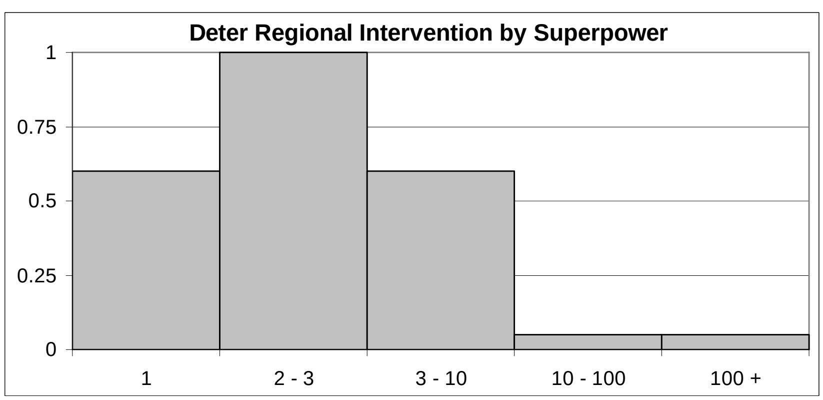

Fig. C-23. Values of v_i^m used deter regional intervention by superpower

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.05
3 - 10	0.6
10 - 100	1
100 +	0.2

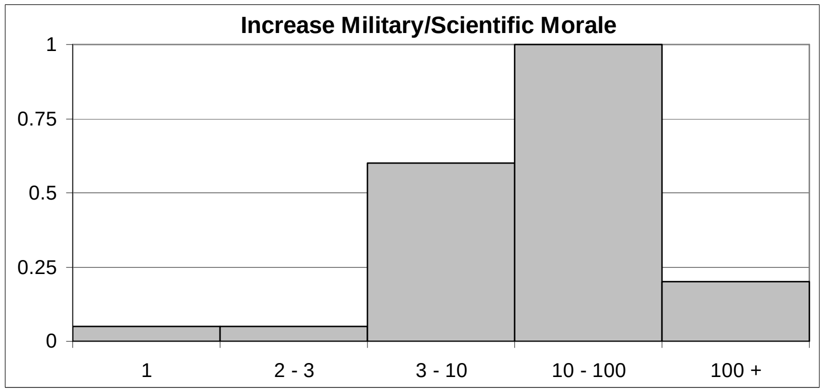

Fig. C-24. Values of v_i^m used for increase military/scientific morale

Intended # of Devices	v_i^m
1	0.8
2 - 3	1
3 - 10	0.4
10 - 100	0.05
100 +	0.05

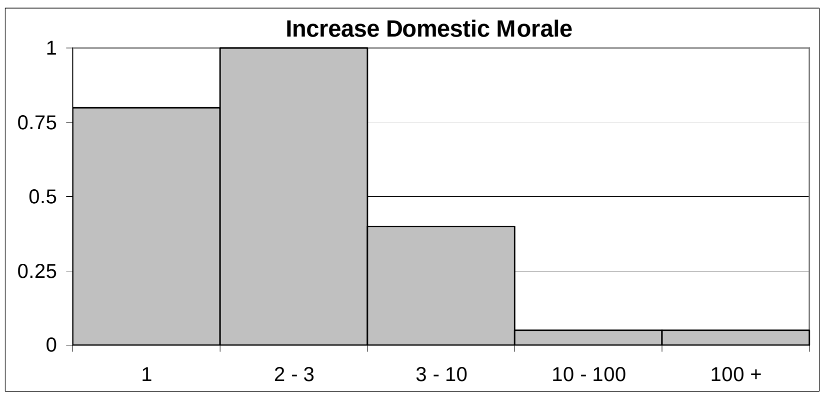

Fig. C-25. Values of v_i^m used for increase domestic morale

Intended # of Devices	v_i^m
1	0.05
2 - 3	0.05
3 - 10	0.4
10 - 100	1
100 +	0.4

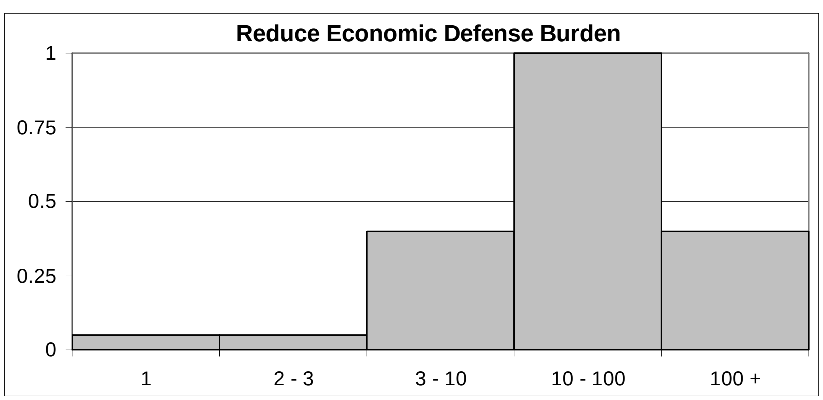

Fig. C-26. Values of v_i^m used for reduce economic defense burden

APPENDIX D

VALUES OF v_i^m USED FOR SUSTAINABILITY INTENTION

The table in appendix D gives all of the values of v_i^m that are used to calculate the sustainability intention for each motivation considered in this work.

TABLE D-I
Values of v_i^m for sustainability

Sustainability	v_i^m
Prestige of Possession	0.05
Prestige of Capabilities (non peaceful)	0.3
Prestige of Capabilities (peaceful demonstration)	0.3
Manipulate Adversaries	0.05
Apocalyptic Beliefs	0.05
Religious Duty	0.05
Psychological Warfare (non use)	0.05
Psychological Warfare (intended use)	0.05
War on Own Nation (Separatist)	0.05
War on Another Nation (Extremist)	0.05
Deter Attack from Nuclear Adversary	0.8
Seek Military Superiority	1
Redress Conventional Military Asymmetry	0.8
Go Nuclear Before Rival	0.1
Intimidate Non-Nuclear Rivals	0.1
Acquire Position in International Forums	0.7
Rise to Global Power Status	0.9
Enhance International Status	0.8
Demonstrate National Viability	0.6
Assert Military/Political Independence	0.4
Divert Domestic Attention	0.1
Enhance Bargaining Position Within an Alliance	0.5
Deter Regional Intervention by Superpower	0.3
Increase Military/Scientific Morale	1
Increase Domestic Morale	0.8
Reduce Economic Defense Burden	1

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