# Development of a Bayesian Network to Monitor the Probability of Nuclear Proliferation

by

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B.S. in Chemistry, United States Military Academy, (1998)

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## Abstract

Nuclear Proliferation is a complex problem that has plagued national security strategists since the advent of the first nuclear weapons. As the cost to produce nuclear weapons has continued to decline and the availability of nuclear material has become more widespread, the threat of proliferation has increased. The spread of technology and the globalization of the information age has made the threat not only more likely, but also more difficult to detect. Proliferation experts do not agree on the universal factors which cause nations to want to proliferate or the methods to prevent countries from successfully developing nuclear weapons. Historical evidence also indicates that the current nuclear powers pursued their nuclear programs for different reasons and under different conditions. This disparity presents a problem to decision makers who are tasked with preventing further nuclear proliferation.

Bayesian Inference is a tool of quantitative analysis that is rapidly gaining interest in numerous fields of scientific study that have previously been limited to purely statistical methods. The Bayesian approach removes the statistical limitations of large-n data sets and strictly numerical types of data. It allows researchers to include sparse and rich data as well as qualitative data based on the opinions of subject matter experts. Bayesian inference allows the inclusion of both the quantitative data and subjective judgments in the determination of predictions about a theory of interest. This means that contrary to classic statistical methods, we can now make accurate predictions with reduced information and apply this probabilistic method to problems in social science.

The problem of nuclear proliferation is one that lends itself to a Bayesian analysis. The data set is relatively small and the data is far from consistent from country to country. There is however, a wide body of literature that seeks to explain proliferation factors and capabilities through both quantitative and qualitative means. This varied field can be brought together in a coherent method using Bayesian inference and specifically Bayesian Networks which graphically represent the various causal linkages. This work presents the development of a Bayesian Network describing the various causes, factors, and capabilities leading to proliferation. This network is constructed with conditional probabilities using theoretical insights and expert opinion. Bayesian inference using historical and real time events within the structure of the network is then used to give a decision maker an informed prediction of the proliferation danger of a specific country and inferences about which factors are causing it.

# Acknowledgements

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I would also like to express my gratitude to my thesis reader Professor Choucri, for her valuable advice and constructive input. She made measurable improvements in the thesis and helped me clarify a difficult subject. She was a diligent, involved reader and also a great instructor.

For his repeated efforts on my behalf and his willingness to let me try to fit two degrees into the space required for one, I would like to thank Professor Barry Posen. I have benefited greatly from his instruction and his example. Due to my experience with the Security Studies Program these past two years, I am now determined to make security studies a lifetime pursuit.

I would like to thank the Idaho National Laboratory and the Center for Advanced Nuclear Energy Systems at the MIT Department of Nuclear Science and Engineering which both provided funding that allowed me to complete this project.

Finally, I would like to thank my family and friends for their support during my time at MIT; I wouldn't have made it without them. I would also like to specifically dedicate this thesis to my wife Jeonga, who has endured countless lonely hours over the past two years; I love you honey.

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# I INTRODUCTION

Nuclear proliferation has been a top security concern of the United States since Einstein first advised President Roosevelt to dedicate the resources to master the technology before Nazi Germany did in 1939. Since then, nuclear weapons have become the most destructive tool in the global arsenal. Their use in Japan and the threat of use during the Cold War have only heightened the importance of these weapons in the calculus of war and peace. Despite this central role, efforts to combat the spread of these devastating weapons have been erratic. In some cases, US efforts have even contributed to proliferation. The result is only mixed success at combating the most important challenge to US national security.

One of the major challenges to countering proliferation is the early detection of the development of a weapons program. Early detection is essential if deterrent action or other intervention against the offending nation is to have any chance of working. Participation in the Nuclear Non-Proliferation Treaty (NPT) affords some protection due to the safeguards and inspection schedule, but it is not perfect. There are many ways that nations can operate within the NPT with the intention to proliferate. Therefore it is important for us not only to consider the probability that they have the capacity to proliferate, but those nations' intentions as well. By considering a state's intentions, capability, and actions we have a better chance of making the early warning required for the international community to take action. This information would just be anecdotal without a method to organize and understand it however. The method that allows us to model the intentions, capabilities, and actions of a specific country in this study is Bayesian Inference.

## 1.1 Motivations and goals

Determining the risk of proliferation is a vital national security interest for the United States. The intelligence community produces estimates based on vast amounts of gathered information and the best guesses of their expert analysts. The Intelligence Estimates produced then influence the course of the foreign policy of the nation. These estimates are vulnerable to a number of errors and judgment calls and depend on subjective human biases to compile the diverse information and produce coherent probabilities. The motivations behind this work are both the limitations of this existing system at predicting proliferation activities and the possible applications of Bayesian inference to other social science problems. The goal of this work is to develop an analytical system that integrates disparate information about a nation to provide a real time unbiased probability of the risk of proliferation and to determine the factors driving proliferation in the country of interest.

## 1.2 Work scope

There are numerous studies that seek to explain nuclear proliferation. Most studies use theories of International Relations as a basis for desire of a state to pursue nuclear weapons. There have also been studies that quantitatively seek to explore the determinants leading to proliferation. Collectively these studies can identify some of the factors which may lead countries to proliferate, but all contain exceptions and examples that are unexplained by their models. This work seeks to go beyond listing the reasons why states proliferate and concede that these previous studies have gotten it right. Starting from their conclusions, we can move on to trying to determine which of these factors is actually operating in a particular country and estimating the effect of that particular factor on the overall risk of proliferation.

Proliferation has been defined in many ways through the course of these previous studies. Some differentiate between stages of proliferation such as the development of a latent capacity to proliferate, the decision to proliferate, the actions taken to proliferate, and the actual acquisition of weapons. Our main effort however, is to predict the probability that the country of interest is **acting on a decision to proliferate** in order to provide early warning to a decision maker. Our definition of proliferation therefore contains this threshold quality. Proliferation is complete when a country has a tested, viable nuclear weapon contained in a delivery system capable of employment.

The limitation of the previous studies is either their strict theoretical framework in the case of qualitative works or the lack of a large data set in the quantitative ones. Each approach left some proliferation or non-proliferation cases unexplained. These types of analysis are suited to explain a subset of proliferation vulnerable countries and to identify possible causes and conditions leading to proliferation but fail to apply universally. However, their conclusions are still useful to us as foundation material for this study as well as evidentiary input to our analytical model. This study develops a network that integrates both the qualitative and quantitative approaches; using subjective and objective data to eliminate the explanatory outliers. The analytical tool that allows us to use Bayesian inference to accomplish this feat is known as a Bayesian Network (BN).

Bayesian Networks are graphical representations of complex causal relationships which rely on Bayesian inference allow the inclusion of a variety of evidence types and organize them in a manner that allows further analysis. The structure of the network allows causal factors to be weighted appropriately for the particular situation in the country of interest and for quantitative facts as well as actual events to serve as evidentiary input. This makes the BN a more flexible and superior tool than previous qualitative or quantitative models on their own.

The Bayesian Network also provides advantages over previous efforts by integrating the effects of numerous causal factors. By consulting experts, intelligence agencies and proliferation literature, we can identify the most important factors leading to proliferation based on historical examples of proliferation and of countries that have renounced nuclear weapons. These factors form the structure of our network and define the types of contributory evidence we will consider.

I will use the examples of India and Iran to show how the network can integrate evidence over time and provide realistic probabilities that the nation of interest is in fact pursuing nuclear weapons. These case studies reinforce the construct of the model and the BN, but also can be analyzed for sensitivity to illustrate which factors impacted the decision to proliferate most. These factors can then be the focus of non proliferation efforts versus less important ones. After examining the case studies, I will perform a hypothetical analysis of new evidence to show how the proliferation risk changes based on possible future events.

This will demonstrate the utility of using the network in a predictive manner to aid in contingency planning. In essence, by observing the network under various future scenarios, we can plan national priorities and direct efforts more efficiently. The conclusions and implications will summarize both the utility of the network and its possible applications in countering proliferation pressures.

### 1.3 Overview and contributions of the work

I begin the study by reviewing the basic concepts and theory behind Bayesian Inference and explain how it can be applied to a social science problem such as proliferation. Chapter II covers both of these concepts. Chapter III presents a survey of previous proliferation studies as well as approaches to the problem of proliferation using theoretical insights. The purpose of the literature review is to derive a list of determinants that contribute to proliferation. This set of determinants forms the evidentiary nodes for the Bayesian Network. Chapter IV describes the methodology behind creating a working Bayesian Network using the set of determinants from Chapter III and the Bayesian concepts from Chapter II. Chapter V examines two case studies. The first case, India, is used to validate and make corrections to the structure of our model. The second case, Iran, is used to illustrate the application of the methodology to a real world proliferation problem. This application not only quantifies probabilistic values for the proliferation risk of Iran, but also shows which factors are most likely driving Iran's nuclear ambitions. Chapter VI reviews the results obtained from the Iran study and shows how the results can be used to make predictions about the proliferation intentions of Iran as well as to aid in contingency planning for a decision maker.

The contributions of this work are the analytical methodology for integrating the disparate theories and models of proliferation into a single framework that allows real time monitoring of proliferation activity, and the use of this framework to identify the most significant factors driving the country to proliferate. Using this method, I can not only identify that proliferation risk factors are present, but quantify them in a way that is helpful to estimate a real-time risk of proliferation. The results can then be used to determine which counter proliferation methods will be most appropriate and effective in mitigating that proliferation threat.

# II BAYESIAN INFERENCE

Analysts make predictions about how close to developing a weapon a country is or what proliferations activities they think a country is pursuing. They use a variety of information and sources to arrive at that belief. The purpose of this study is to represent those beliefs in a more analytical way that can reveal additional useful information to the decision maker. One tool that provides this sort of analysis and representational utility is a Bayesian Network. In this Chapter I will cover the basics of BNs and why it is appropriate to apply this modeling technique to our problem. The explanation covers the theory behind Bayesian Networks, how to structure a BN, and how to obtain useful results from the network. This application of Bayesian Networks to the problem of proliferation is the major methodological contribution of this work.

## 2.1 The Benefits of Bayesian Networks

The current methods of predicting proliferation either rely on applications of a wide range of theoretical concepts to real world events and conditions, or on empirical correlations of multiple independent variables. Both methods provide only limited explanatory power and usually handicap their conclusions with the exceptions that their method fails to explain. In most cases the theoretical applications are ad hoc attempts to explain a specific action or decision using broader theories meant for other purposes. The empirical methods suffer from a sparse database and the complexities of identifying the multiple independent and possibly non-linear causal chains. An analyst using these methods to analyze data or evidence in order develop a reasonable belief about the proliferation status of a country would be limited by these weaknesses. In addition, weighing the impact of all the possible causes and motivations, comparing it against historical data, and applying the various theories are tasks too difficult for a human to perform reliably or efficiently. It is possible to attempt, but in the end the beliefs will be based on educated guesses and general impressions.

The method of using Bayesian inference allows us to organize that same information and develop a structure for analyzing it. Bayesian networks can represent complex problem domains in a consistent way without oversimplifying the complexities. Bayesian Networks are useful because of the efficiency of the calculations and the intuitive representation of a model of causal or contributory influence. This structure not only clarifies and quantifies our judgments about the relative weights and validity of the data, but allows us to integrate new information without the cognitive biases that are so common in normal human reasoning such as recency (new information is subconsciously given greater weight than older). By creating this analytical structure that models the complex relationships and has rules for integrating the data, I can consider all the possible causes of proliferation, integrate all the historical data, and reduce the subjective impact that human biases have on decision making.

## 2.2 The Theory Behind Bayesian Networks[1]

**Conditional probability:** The basic concept in Bayesian treatment of uncertainties in causal networks is *conditional probability*. It represents the probability of an event, *A*, given that the event *B* is true and everything else known is irrelevant for A. The notation for this statement is P(A|B) and is defined by

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \qquad (2\text{-}1)$$

**Fundamental rule:** The fundamental rule for probability calculus is

$$\begin{aligned} P(A|B)P(B) &= P(A,B), \\ P(B|A)P(A) &= P(A,B), \end{aligned} \qquad (2\text{-}2)$$

where $P(A,B)$ is the probability of the joint event $A \cap B$.

**Bayes' Rule, Theorem:** From Equation 2-2 it follows that

[1] Finn V. Jensen and Thomas D. Nielsen, Bayesian Networks and Decision Graphs, Springer Verlag, 2007.

$$P(A|B)P(B) = P(B|A)P(A)$$
$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \quad (2\text{-}3)$$

which is known as *Bayes' Theorem*. In the Bayesian interpretation, the probability of a certain hypothesis A being true, P(A), represents the degree of belief in that hypothesis. After new evidence B is received, which may reinforce or weaken that hypothesis, this degree of belief becomes P(A|B) and can be formally updated according to the Bayes' Rule.

**Conditional probability calculus for variables:**

If A is a variable with states $a_1,\ldots, a_n$ then:
P(A) = $(x_1,\ldots,x_n)$ is a probability distribution with $\sum_{i=1}^{n} x_i = 1$
And P(A|B) is a *n* x *m* table containing entries for all combinations of states for each variable. The tabulated values are $P(a_i|b_j)$, as shown below:

| | | B | | |
|---|---|---|---|---|
| | | $b_1$ | $b_2$ | $b_3$ |
| A | $a_1$ | 0.5 | 0.4 | 0.7 |
| | $a_2$ | 0.5 | 0.6 | 0.3 |

-note that for each $b_j$, $\sum_A P(A|b_j) = 1$

**Fundamental rule for variables:**

$P(A|B)P(B) = P(A,B)$ using variables becomes $P(a_i|b_j)P(b_j) = P(a_i, b_j)$ and again is easily seen in tabulated form as:

| | $b_1$ | $b_2$ | $b_3$ |
|---|---|---|---|
| $a_1$ | 0.5 | 0.4 | 0.7 |
| $a_2$ | 0.5 | 0.6 | 0.3 |

*P(A|B)*

X

| $b_1$ | $b_2$ | $b_3$ |
|---|---|---|
| 0.3 | 0.5 | 0.2 |

*P(B)*

=

| | $b_1$ | $b_2$ | $b_3$ |
|---|---|---|---|
| $a_1$ | 0.15 | 0.2 | 0.14 |
| $a_2$ | 0.15 | 0.3 | 0.06 |

*P(A,B)*

-note again $\sum_A P(A|b_j) = 1$, $\sum_B P(B) = 1$, and $\sum_{A,B} P(A,B) = 1$

## 2.3 Explaining the Structure of a Bayesian Network

A Bayesian Network is a graphical representation of a multivariate statistical distribution function. A BN encodes the probability density function governing a set of random variables $X_i=\{X_1, \ldots, X_n\}$ by specifying a set of conditional probability functions. More specifically, a

BN consists of a qualitative part, a directed acyclic graph where the nodes mirror the random variables $X_i$, and a quantitative part, the set of conditional probability functions.[2] The directed acyclic graph is simply the visual representation of the causal relationships between the nodes (variables) in our model (See Fig 2.1). This graph represents the functional hierarchy of the variables in the network. Without assigning any values, it shows the logical structure of the model.

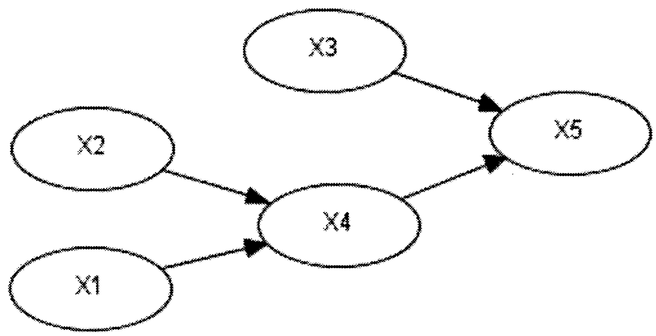


Figure 2.1: Illustrative Directed Acyclic Graph

The quantitative part of the network is the set of conditional probability functions that define the relationships between the nodes. Each node without parents (i.e. X1, X2, X3) has a fixed prior probability distribution among its various states. These nodes have a marginal probability table (MPT) which indicates the probability distribution across each state of that particular node independent of other nodes. This probability does not depend on any others (i.e. P(X1), P(X2), P(X3)), but reflects the spread of probability across the possible states that the node could be in. The sum of the probabilities in each MPT is of course equal to unity.

| Node | State | Probability |
|---|---|---|
| X1 | $x1_1$ | 0.2 |
| | $x1_2$ | 0.4 |
| | $x1_3$ | 0.4 |

| Node | State | Probability |
|---|---|---|
| X2 | $x2_1$ | 0.3 |
| | $x2_2$ | 0.1 |
| | $x2_3$ | 0.6 |

| Node | State | Probability |
|---|---|---|
| X3 | $x3_1$ | 0.5 |
| | $x3_2$ | 0.3 |
| | $x3_3$ | 0.2 |

[2] Helge Langseth, "Bayesian Networks in Reliability: Some Recent Developments", http://www.idi.ntnu.no/~helgel/papers/MMR04.pdf, accessed 02 April, 2008.

Each node with parents (i.e. X4, X5) has a conditional probability function based on the conditional probability relationship between daughter and parent nodes. These relationships may be recorded in tabular form for each daughter node as described in Section 2.2 above and are called conditional probability tables (CPT). For example, the CPT below represents the probability states of the daughter variable X4 ($x_1$, $x_2$) given the evidence from the parent variables X1 and X2 ($x_1$, $x_2$, $x_3$). The tabulated values represent P(X4|X1,X2) including each combination of states for parent and daughter variables $P(x4_i|x1_j,x2_k)$.

| | | (X1,X2) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $x2_1$ | | | $x2_2$ | | | $x2_3$ | | |
| | | $x1_1$ | $x1_2$ | $x1_3$ | $x1_1$ | $x1_2$ | $x1_3$ | $x1_1$ | $x1_2$ | $x1_3$ |
| X4 | $x4_1$ | 1 | 0.8 | 0.6 | 0.7 | 0.5 | 0.3 | 0.4 | 0.2 | 0 |
| | $x4_2$ | 0 | 0.2 | 0.4 | 0.3 | 0.5 | 0.7 | 0.6 | 0.8 | 1 |

The matrix is defined by the number of states each variable can be in as well as the number of parent variables. A single parent variable with 3-states and a single daughter with 3-states requires a 3x3 matrix. Two 3-state parent variables with one 2-state daughter requires a 9x2 matrix as seen above. As the number of parent nodes (variables) increase, the size of the table increases exponentially. The values in the CPTs are usually established using statistical databases if information is abundant and available, or from subjective expert opinion if information is sparse.

Once the qualitative and quantitative aspects of the BN are fixed, it represents our best knowledge about the current state of our model. We can trace and quantify the causal relationships and derive probability distributions for any of the variables that make up the network. We can then integrate any new data we gather into the network to see its effect on our model. If the new data affects one variable, then the probability distribution for that variable may change (or the new data may confirm our previous value). This change then propagates through the network by following the structural rules established by the causal linkages and the CPTs. We can use the variables with known or observable values and the linkages in the network to reveal information about other variables with unknown values by using Bayesian Inference.

## 2.4 Obtaining Results Using Bayesian Inference

Given the state of one or more of the variables, one can infer information about the others. If this inference is used to deduce an effect from a given cause, it is called *prediction*. If it is used to find a cause, given an effect, it is called *diagnosis*. It involves drawing possible inferences rather than a certain one. Both directions of information flow can be inferred in a Bayesian Network. As I show in Chapter V, this allows us to not only infer our belief about the proliferation state of a country based on the available evidence, but also allow us to infer our belief about the primary cause should proliferation occur.

This utility allows us to use the base case for the model established in the last section to represent our current beliefs about the overall system. We can then use the network to make predictions about the effects of particular hypothetical events. We simply enter the hypothetical effect of the event as a change in the marginal probability table of one of our variable nodes and then observe the changes in the rest of the network variables. By using hypothetical data instead of actual events, we can predict what effect those events will have on our model and make appropriate decisions to mitigate any undesired effects.

The other purpose of using inference is to diagnose a cause when a specified effect has already been observed. By entering the observed event as evidence in the marginal probability table of the appropriate daughter node, the structure and the conditional probability tables in the network determine the new probability values of the causal variables. The results of this inference will tell us which variables most likely caused the observed effect.

The propagation of the new probabilities follows the rules described in Section 2.2 above. The difficulty and complexity of the calculations increases as the numbers of variables in the network increases. These computational requirements therefore mandate the use of software to make the numerous calculations. In order to handle the complex calculations required for a model of useful size, we must use software specifically designed for Bayesian Belief Networks. The software has to be able to represent the various states of evidence nodes and the relative relationships between them, as well as to do the required Bayesian calculations. The software used in this work is a Bayesian network tool which is part of the commercial HUGIN expert system shell.[3]

## 2.5 Application to the Problem of Proliferation

Bayesian Networks have been used in the past to diagnose and predict disease, to map out failure modes in nuclear power plants, and even to predict which books will interest you at your favorite online bookstore. Applied to the problem of proliferation, the BN has the potential to be just as useful and informative. This application of Bayesian Networks to the problem of proliferation is the main contribution of this work.

We want to find the probability of our hypothesis that Country X is proliferating, Prob(P). We surmise through our search of the literature that there are a number of causal conditions that lead a country to want to proliferate, and if we can capture all of the causal linkages then we can construct a Bayesian Network to represent the logical structure of the model of proliferation.

[3] HUGIN. HUGIN Researcher ver. 6.7, 2006, www.hugin.com.

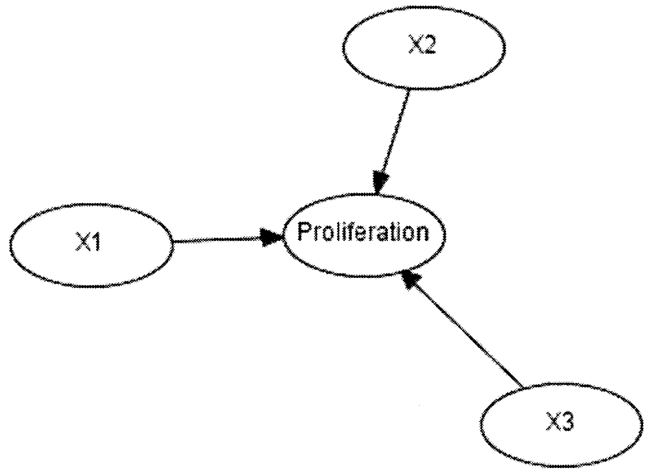


Figure 2.2: Example Proliferation Network

We can use the broad theoretical literature and subjective expert opinion to determine which variables lead to proliferation and to build the conditional probability tables that will form the quantitative structure of the network. The conditional probability tables reflect how the influence of each variable causes or contributes to our belief concerning the proliferation status of the country P(P|X1,X2,X3).

We can determine the values of the marginal probability tables for each of the variables P(X1), P(X2), P(X3), from the historical evidence available about the country of interest. The historical data can give us good starting values for what we expect the probability distribution across the various states to be for each variable. Once all the marginal and conditional probability tables are set, we can use the resulting marginal probability table for the center node 'Proliferation' P(P), as a measure of our belief that Country X is proliferating.

Once this network is up and running, it can provide us a snapshot value for our belief that Country X is proliferating. We can also use the network over time to monitor the probability that the country will proliferate. To explain how this is accomplished I will use the example of the nuclear power plant.

If our network were a fault detection system in a nuclear power plant, our center variable would be a catastrophic failure of the entire plant. The sensors in our power plant would monitor different system components to measure their status and to give us a probability that the component will fail. If the component fails, then it could lead to a failure of the entire plant. The variables in our network would represent the various components in the systems, the sensors which monitor the components, and possibly intervening variables that are present in the different failure modes of the plant. The components each have a probability distribution of their failure time, and the sensors would use their measurements of the components to inform their marginal distribution functions which then tell us the probability that the component is close to failure.

In our scenario, a failure of the entire system is the successful proliferation by Country X. Our components are the causes and conditions which lead to proliferation. I don't have data from a component manufacturer to tell us the Mean Time to Failure of our components, so it is very important that our sensors work well. The sensors in our scenario are the analysts that watch the events in Country X and determine if one of the variables associated with proliferation is increasing in importance, i.e. that the component is close to failure.

The links in our network are causal because they cause us to change our beliefs about the proliferation status of the country. Changes in the variables don't necessarily cause proliferation; they cause a change in beliefs. The analyst believes that the events are relevant to the proliferation status of the country because the theories of proliferation, the authors of journal articles, and proliferation experts have convinced them, and their knowledge was built into the CPTs. The variables allow the analysts to identify key events in Country X.

If that variable is security concerns, then the analyst would consider events in the country such as conflicts with neighbors or bellicose rhetoric from a longtime rival to increase the importance of that variable in Country X's thinking about proliferation. The analyst can assign a probability value to each particular event and therefore change the marginal probability table of the 'security concerns' variable. This change of course will propagate through the network and will give us a new belief about the overall probability that Country X is proliferating.

The analyst now has a real time monitor that can integrate new events in a structure that captures all the complexity of the problem of proliferation and can truly put that event into context for a decisionmaker. The analyst can now report with confidence the real impact of the day's events in a measurable way that accounts for the specific historical data from the country and factors in the complex causal relationships of all the variables which lead to proliferation.

If we are interested in using a Bayesian Network as described above to determine our belief about the proliferation status of a country of interest, we need to use statistical evidence derived from large databases, subjective expert opinion, or theoretical insight to determine its qualitative structure. All three are readily available in the proliferation literature in the form of quantitative studies, various published expert opinions, and extensive theoretical work on proliferation in various fields such as International Relations, decision making, and cognitive psychology. A survey of this literature with the purpose of informing the structure of the BN is the subject of Chapter III.

# III THEORIES AND MODELS OF PROLIFERATION

Political scientists, statesmen, sociologists and even physicists have written about nuclear proliferation since the beginning of the Manhattan Project in the early 1940s. There are many perspectives about the issue and even disagreement about whether it is a problem or not. There are different explanations about the causes of proliferation, the capabilities needed to proliferate. There are even competing opinions that proliferation is caused by the persistent directed efforts of a few powerful individuals, or that certain apolitical economic and technical factors make proliferation inevitable. Regardless of the source or the opinion, it is clear that there is no single coherent theory explaining why states proliferate, and that many of them have some degree of explanatory power. Recognizing that different theories have merit is essential to developing a predictive methodology that has universal application. In addition, only considering one theoretical framework necessarily limits the counter-proliferation policy options available to an eventual decision maker.

For every theory there is an exception to the rule. In fact the one point that all these authors agree on is that the problem is complex. This study does not seek to prove any of these authors right or wrong, but merely to acknowledge that any theory that has a reasonable explanatory power has merit and should be considered when evaluating the proliferation risk of a potential nuclear power. A survey of the studies and papers in the literature show a few general categories of proliferation theories. They fall roughly in line with the typical levels of analysis seen in the International Relations world. They explain proliferation from either the perspective of international pressures that cause states to act, organizational pressures from within causing the state to act, or pressures on individuals which lead the state to act. Some theories will fall neatly into one category, while others may span two or even all three.

In order to expand the breadth of theories, I have also included some comprehensive studies and surveys of the proliferation literature. These studies range from purely qualitative to surprisingly quantitative in their approach to identifying the determinants of proliferation. These studies don't replace the individual theories, they complement and support them. They can help to determine the conditions where a certain theory operates and not another, or even refute a theory altogether based on the evidence. These studies can not only help us critically evaluate which determinants are important, but will give us an indication of which theory is operating in a particular case of interest. I do not conduct a systemic evaluation of any of the theories here as these surveys are widely available.[4] My purpose is to catalogue the determinants of proliferation that have reasonable explanatory merit with the supposition that absent a unifying theory of proliferation, each may have some validity given certain conditions. This set of determinants then forms the set of input nodes of the Bayesian Belief Network in the following Chapter.

## 3.1 Proliferation due to External Sources

A large body of proliferation literature focuses on the external factors that cause states to try to develop nuclear weapons. A nuclear weapons program is not something that can be taken on by any nation. It involves years of research and technical mastery. The economic requirements require dedication of enormous resources over an extended period. Anything that convinces a state to commit to such a program must be significant. Traditionally, commitments

[4] See Zachary S. Davis and Benjamin Frankel Eds., The Proliferation Puzzle: Why Nuclear Weapons Spread (and What Results), Security Studies 2 (Spring/Summer 1993) , T. Ogilvie-White, "Is there a theory of nuclear proliferation?", The Nonproliferation Review 4(Fall 1996): 43-60, and Mitchell Reiss, Without the Bomb: The Politics of Nuclear Non-proliferation, Columbia University Press, New York, 1988.

of this nature only came after threats to the sovereignty or very survival of the state. The only major state activity comparable is warfare or ambitious scientific programs like the Space Race.

It is for this reason that many of the theories in the International Relations field that concentrate on the causes of war have been appropriated to explain the causes of nuclear proliferation. One framework that concentrates almost exclusively on the external determinants of war and proliferation is Realism. The various incarnations of theory in this approach to proliferation focus on the state as the primary actor in an anarchic international system. The relative balance of power or the distribution of capabilities within that system then defines how each state will respond to its neighbors or competitors. Many theories within this framework couple the intentions of the states to these capabilities to increase their explanatory power.

Realists dominated the early proliferation literature primarily because of a lack of information about other motivators during the Cold War and because the theories had a great deal of explanatory power. At the most basic level, if one state acquired nuclear weapons, the balance of power would be upset, and competitor states would feel threatened. They would then seek to acquire weapons as well. States will try to enhance their security by shifting that balance of power in their favor, or restore a balance of power that was previously stable. The basic realist or neo-realist approach does not necessarily predict that a state will proliferate, just that the state will be motivated to respond to a threat or power differential.

One neo-realist theory which takes this basic explanation further is Rational Deterrence Theory which describes deterrence as a motivator to acquire nuclear weapons. The theory predicts that the balance of power will not be restored until both competitor states not only have nuclear weapons, but also have invulnerable second strike capabilities and the command and control capabilities to employ them.[5] Only at this point does a confrontation between the two states become unwinnable, thus restoring stability. The primary determinant here is that a state feels threatened by another and is motivated by these security concerns to proliferate.

Structural realism explains state behavior in terms of its relative position in the structure of the international system. This theory ties tendencies to proliferate to the structure of the international system and the security guarantees of other nuclear powers. In a bipolar world, states are not as likely to proliferate because of an alignment with one or the other superpower. This is considered a very stable structure. If this structure changes to multipolar due to changes in the distribution of power, then states that had the latent capability to develop nuclear weapons may now decide to do so. They may no longer be able to rely on the credibility of the nuclear umbrella provided by their previous patrons. Since the nature of the international system is self-help, these states may now feel compelled to develop their own nuclear programs.[6] This theory underscores the driving force of security concerns behind proliferation, and the effect of credible security guarantees at preventing it. It also predicts that disarmament by the nuclear superpowers would increase the proliferation tendencies of non-nuclear powers that depend on that large arsenal for their own security.

Other realists contend that the pursuit of security may lead states to take paths other than proliferation. While nuclear weapons may help balance against one state, the repercussions in other states may in effect reduce security. Participation in the non-proliferation regime is another response to security threats that states may take if they feel nuclear weapons will not contribute

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[5] Kenneth Waltz makes this claim while explaining why proliferation may be beneficial to stability in the world, Scott D. Sagan and Kenneth N. Waltz, The Spread of Nuclear Weapons: A Debate Renewed, 2d ed., W.W. Norton & Company, New York, 2003, pg 20.

[6] Benjamin Frankel, "The Brooding Shadow: Systemic Incentives and Nuclear Proliferation," Security Studies 2 (Spring/Summer 1993), p. 60.

to their security. By this logic, participation in international or bilateral security agreements should be a disincentive to proliferate.[7]

The Realist tradition also has room for other explanations for proliferation. There are some states that may be emerging regional powers that are not dominated by a global superpower. Because of this, security concerns are not paramount and in the desire for regional hegemony a nuclear capability makes sense. They have the latent capability to proliferate and are not dissuaded by superpower involvement. To these emerging states, prestige and status are fundamental motives in the pursuit of nuclear weapons.[8]

Neo-liberal Institutionalist Theory allows the external determinants of the realists to be affected by the political systems of the actors. This theory explains the international structure as a group of core states and states on the periphery. The core states are dominated by liberal democracies that have little incentive towards conflict with each other and therefore little incentive to proliferate.[9] As states on the periphery become more democratic, they should also reject proliferation. This theory explains another subset of cases, but continues to hold security concerns as the motivating factor. The other additional motivation is that states use the decision to proliferate or not as leverage to gain admittance in to the core and to secure economic and political benefits. This motivation of political leverage or a desire for national prestige is also present in other studies discussed below.

A study by Stephen Meyer viewed the proliferation problem as traversing external determinants and domestic governmental decisions. A government had to make a capability

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[7] Zachary S. Davis, "The Realist Nuclear Regime," Security Studies 2 (Spring/Summer 1993), p 79.
[8] This motive was asserted in a 1977 paper by Richard Betts and figured prominently in explaining states without a strong involvement in the East-West conflict at the time. Now that the restraining influence of a superpower is even less prevalent, this motive should be even more apparent. Richard K. Betts, "Paranoids, Pygmies, Pariahs and Non-proliferation Revisited," Security Studies 2 (Spring/Summer 1993), p 107.
[9] Glenn Chaftez, "The End of the Cold War and the Future of Nuclear Nonproliferation: An Alternative to the Neo-realist Perspective, "Security Studies 2 (Spring/Summer 1993), p 128.

decision to develop a latent nuclear capability and a politico-military decision to proliferate.[10] Meyer uses a Bayesian analysis to address the decision of interest here, the proliferation decision. His used a different application of the Bayesian techniques to take quantitative inputs into a model to shows correlations between his indicators and the likelihood a country would proliferate. He conducted a study using three sets of motive indicators; domestic political incentives, military/security incentives, and political power/prestige incentives.[11] Using the term 'nuclear propensity' he showed how all of these factors contribute to the likelihood that a country will proliferate. We have seen from the previous theories the importance of security and prestige, but this study also reinforces the idea of domestic determinants. He also identified a number of motive factors that had a dissuasive effect on this nuclear propensity. These include factors such as international alliances, legal commitments, or threats from other nations.[12]

Criticisms of these externally oriented theories center on the exclusion of domestic and organizational factors in explaining the behavior of states. In fact, many attempts to modify traditional neo-realist theories have implicitly included domestic factors. Theories that consider purely external factors fail to explain many empirical events in the history of nuclear proliferation. In order to capture the determinants that can explain these exceptions we also must consider theories that examine internal domestic pressures that can lead to proliferation.

### 3.2 Proliferation due to Domestic Pressures

Many theorists contend that domestic determinants are the most important to consider when evaluating a country's risk of proliferating. Proliferation does not happen overnight. It is a complex process which requires years of dedicated research and economic resources. It also requires dedicated individuals and organizations to marshal those resources and to conduct the

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[10] Stephen M. Meyer, The Dynamics of Nuclear Proliferation, The University of Chicago Press, Chicago, 1984, p 5.
[11] Ibid, 46.
[12] Ibid, 68.

research. This process cannot begin without a decision to act. The decision to proliferate may be driven by the external factors describe above, but the actors and decision makers will be organizations and individuals within the domestic structure. These actors are subject to an entirely separate set of internal pressures which some theorists argue have an even greater effect on the likelihood of proliferation.

One study that tried to explain the behavior of non-proliferators rather than proliferators highlights these domestic determinants. While acknowledging the importance of technical and economic capability in enabling a successful nuclear weapons program, Mitchell Reiss also focuses on the need for political will for a country to proliferate.[13] He examines nations that met this necessary but not sufficient requirement for proliferation, yet did not. By the time France joined the nuclear club in 1960, every nation that had the capacity to proliferate had done so. Reiss examines why this trend ended after the first five nuclear states, and determines that the answer lies in four factors; domestic pressures, bilateral agreements, international non-proliferation agreements, and world public opinion.[14]

The domestic pressures he identified were a function of competing views of political parties (Sweden), public aversion to nuclear technology (Japan), and economic concerns about the enormous cost of a nuclear program (India). These particular pressures did not affect the other countries in his study however (South Korea, Israel, and South Africa), they were instead restrained by the other three factors listed above. The remaining three factors belong in the first section as external determinants. In the context of this study, they are different from the factors discussed thus far in that they have a negative effect on proliferation risk rather than a positive one. These three factors are restraints on proliferation rather than enablers. The other major

[13] Mitchell Reiss, Without the Bomb: The Politics of Nuclear Non-proliferation, Columbia University Press, New York, 1988, p 247.
[14] Ibid, 265.

insight we gain from this study is that these factors operate differently in each country. Once domestic factors are considered, the simple billiard ball approach of the Realists no longer fits.

One quantitative study used hazard models and multinomial logit models that examined the different correlates of proliferation. The authors identified a strong link between domestic capabilities and the tendency to proliferate. The per capita GDP in 1996 US dollars of countries was found to have strong effects on their likelihood to proliferate. The authors found that the likelihood of proliferation increased non-linearly up to about $7700, then declined. In addition, technological factors such as thresholds in domestic steel production and energy generation also increased the likelihood of proliferation.[15] This study not only outlined the importance of these domestic determinants, but also confirmed the correlations to enduring rivalries and security concerns described in the earlier section.

Organizational Theory explains state behavior by considering the influence of powerful groups or agencies within the state. All complex organizations function using some form of division of labor to accomplish larger goals that simple collections of sub-units cannot, and states are no different. This division of labor may lead to competing interests within the same organization, or competing ideas about how to achieve the national interests. Proponents of this approach argue that the behavior and competing interests created by the organization of the state apparatus will contribute to the decision to proliferate and must be considered. Scott Sagan uses this approach when he focuses on the consequences of proliferation using organizational theory vs. rational deterrence theory.[16] With regard to the causes of proliferation, the same organizational forces are at play. The realist assumption of rational actors requires that the sub-units of the state are acting in unison. In fact, the different operational focus of each group may

[15] Sonali Singh and Christopher R. Way, "The Correlates of Nuclear Proliferation: A Quantitative Test," Journal of Conflict Resolution 48 (Dec 2004), p. 876.
[16] Sagan and Waltz, pg 49.

cause a disproportionate influence on the overall decision to proliferate.[17] This tendency is also a hallmark of bureaucratic politics models.

Decisions can be a result of miscues or imbalances between these groups or agencies, or even a result of political bargaining. Graham Allison describes this interaction as a model of decision making that takes into account not only the bureaucracies at the heart of government, but their leaders as well.[18] In explaining this model using the events of the Cuban Missile crisis, we see that these seemingly petty interactions can affect even the most important decisions of a state. In order to take into account these possible processes, we must consider domestic influences of different agencies, departments, and organizations in government as well as their leaders.

A final theory of how organizations can affect decisions to proliferate is the social construction of technology theory (SCOT) or large technological systems theory (LTS), which argues that human action shapes technology and its uses. So to understand how a country decides to develop and use nuclear weapons we must look to the social context.[19] While this theory actually traverses all three of our levels of analysis, the application to proliferation has most in common with bureaucratic models. In the case of proliferation, some argue that various alliances between groups of scientists, corporations, and the military led to proliferation in India and South Africa as well as explaining that subsequent nonproliferation in these countries was a result of the failure of these alliances.[20] This approach brings in the importance of technical and economic capability, but relies on how these things drive decision making in different groups.

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[17] Ogilvie-White uses the examples of South Africa and North Korea to illustrate this point. Ogilvie-White, p 51.
[18] Graham Allison, The Essence of Decision, Little, Brown and Company, Boston, 1971, p 144.
[19] Used to examine a different, but related technology, see Donald MacKenzie, Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance, MIT Press, Cambridge, 1990, p 9.
[20] Steven Flank, "Exploding the Black Box: The Historical Sociology of Nuclear Proliferation", Security Studies 3 (Winter 1993/1994).

Economists may not want nuclear weapons because of the expense, military strategist may focus on their benefits to national security, and subcontractors may just want the new business that a nuclear industry would entail. The social context in which proliferation decisions are made and the influence of technology directs us to include the domestic social context as well as technical and economic factors in our set of determinants.

3.3 Proliferation due to Influential Individuals

Considering domestic influences is important, but if we continue the same logic, then we find that individuals make up the state sub-units or organizations. There are always leaders and followers, but some individuals will have an influence over decisions to proliferate. This concept forms the basis of the model of Nuclear Mythmakers.[21]

Lavoy argues that groups of elites influence the foreign policy of their countries, particularly regarding nuclear weapons. These elites drive the motivations described above. If a state proliferates due to security concerns, it is because a group of influential individuals believed that the weapons would improve their security and convinced policymakers to acquire them. The content of the myth is as important as the influence of the mythmaker. If the myth can tell the story of the strategic benefits of having nuclear weapons, then national officials may be convinced that proliferation is the correct path. There are many arguments that nuclear weapons allow states to adopt a national security strategy of deterrence rather than worry about offense/defense balances.[22] The integration of nuclear weapons into a national security strategy is not a trivial matter however, and requires that the state develop a tactical nuclear capability to employ its weapons.

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[21] Peter R. Lavoy, "Nuclear Myths and the Causes of Nuclear Proliferation," Security Studies 2 (Spring/Summer 1993).

[22] For an explanation of how states are motivated to proliferate once they recognize this transformation see Avery Goldstein," Understanding Nuclear Proliferation: Theoretical Explanation and China's National Experience," Security Studies 2 (Spring/Summer 1993), p 222.

These elites can influence the decision making process in other ways as well. Nuclear experts can convince recalcitrant officials that a development program will cost far less than expected, or that the technical challenges will be easily overcome. In the same way, they can convince policy makers that the price is too high and not worth the effort. By influencing the beliefs of country officials about the utility of nuclear weapons, these nuclear mythmakers can individually shape the proliferation risk of a state. Acceptance of the nuclear myth in the halls of national power is the most important determinant of proliferation under the mythmaker model.[23] As we try to establish a set of determinants, we must consider the influence of these mythmakers which can be either positive or negative.

Another examination of how individuals can influence major nuclear decisions comes from extensions of studies of the psychological reasons behind why leaders make decisions. Robert Jervis argues that the psychological factors involved in the perceptions of state leaders and signals they send can cause a number of illogical effects such as states not taking advantage of adversaries or being unreasonably aggressive.[24] These actions which were intended to increase state security end up having the opposite effect. Standard explanations of deterrence and spiral theory don't account for instances when leaders behave differently than they should. Their emotions, perceptions, and calculations play a role in their decisions. Applying this logic to proliferation, it follows that we should consider the leaders' calculations about how nuclear weapons will deter an adversary, or what signal they are trying to send by not proliferating.

So called 'learning models' are also useful in explaining why political leaders are susceptible to nuclear myths or to other sources of information. If groups of scientists or academics can convince political officials to change their stances on the use of nuclear weapons,

[23] Peter R. Lavoy, "Nuclear Proliferation Over the Next Decade: Causes, Warning Signs, and Policy Responses," Nonproliferation Review, 13 (Nov 2006), p 447.
[24] Robert Jervis., Psychology and Deterrence, The Johns Hopkins University Press, Baltimore, 1985, p 6.

then it forms a clear picture of the influence of individuals. One example of this phenomenon is the process by which the Americans and Soviets agreed to the 1972 antiballistic missile arms control treaty (ABM). This was a clear example of scientists challenging the long held notions of decision makers and through education, convincing them to change course. They were not only able to bring their ideas into reality in the US, but to diffuse these ideas to the Soviets and stabilize the nuclear balance.[25] Similar changes in stance such as the rejection of nuclear weapons by the former Soviet republics can be partially explained using the same ideas. It is also speculated that Gorbachev 'learned' that the Soviet Union needed to undergo drastic change and that his new foreign policy resulted in the end of the Cold War.[26] If the political officials are convinced by academics or intellectuals that nuclear weapons will not contribute to security, they will likely adopt policies that reflect this. Once again we see that it is important to identify individuals as domestic sources of, or restraints to, nuclear proliferation.

3.4 Generating the Set of Determinants

The theories and models above suggest a wide range of explanations and drivers behind the proliferation decisions of states. If our Bayesian Belief Network is to benefit from these insights, we must construct a set of determinants that captures them all. I began our set by acknowledging two broad groups of factors that enable proliferation; motivations and capabilities. Mitchell Reiss explained that:

> *Nuclear proliferation is a function of two variables: technological capability and political motivation. Both must be present for a country to acquire nuclear weapons. The capability without the motivation is innocuous. The motivation without the capability is futile.*[27]

[25] Emanuel Adler, "The Emergence of Cooperation: National Epistemic Communities and the International Evolution of the Idea of Nuclear Arms Control", International Organization, 46 (Winter 1992), p. 102.
[26] Janice Gross Stein, "Political Learning by Doing: Gorbachev as Uncommitted Thinker and Motivated Learner", International Organization 48 (Spring 1994).
[27] Reiss, 247.

The qualitative works focus mainly on motivations and intentions behind proliferation. The quantitative studies confirm the importance of both intentions and capabilities (i.e. $7700 threshold value or domestic steel production). The factors that motivate countries to proliferate or that change their intentions can reasonably be treated as causal, but theories of technological determinism failed to convince some authors.[28] The correlations identified between certain capabilities and proliferation do not necessarily equate to causation. Capabilities must be included in our set of determinants because they present the necessary (but insufficient) condition for the motivations to lead to action. In essence, the presence of a capability may not cause proliferation, but it causes a change in our belief about the proliferation status of a country.

The theories above also generate a varied list of determinants within these groups. Certainly the Realist theories hold security to be the primary motivation behind this and all other state decisions, and most other theorists agree. There is little dispute on this point, security must be included as a determinant of proliferation. The other major external determinant came from studies that considered domestic factors. A desire for international political power or national prestige operates externally, but may be generated by internal domestic forces.

The second section highlights our need to include organizational determinants in our set. The explanatory power of sub-unit motives in organizational theory, the undue influence of elites, as well as the possibly restraining properties of public opinion are all present in our studies. Another minor determinant related to both prestige and domestic influence is the desire for scientific or technical achievement. Though technological determinism was not seen as a major motive factor, there may be times when this factor has influenced proliferation. Statements by Manhattan Project physicists indicate that it did play a part. There was always the threat of a

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[28] Meyer, p 90.

Nazi bomb, but also the imperative to build it 'because we could'. We can't totally discount the possibility that this motivation may surface again.

Many theories included motivators that dissuaded states from proliferation rather than encouraging them. A common thread through many of them was that the presence of bilateral security arrangements reduced the desire to proliferate. Participation in the non-proliferation regime of treaties and agreements also correlated with a reduced occurrence of proliferation. Meyer concluded that the threat of attack or of seizure of nuclear materials were additional causes of restraint.[29] The presence of IAEA controls and safeguards makes this a definite reality for NPT signatories. These determinants should also be included in our set as general International Agreements and Safeguards.

Capabilities are considered implicitly in most of the theories and studies discussed above. We must include both the technical capability to develop the weapons and the economic capability to support the program. These should be treated separately as any given state would be unable to proliferate unless it had both capabilities. The nuclear myth model also led to idea of tactical capability. A country with a known nuclear weapon and no means to employ it is not nearly as threatening as a full nuclear state. A tactical capability therefore, would include not only military hardware such as delivery systems, but also a strategic plan to integrate the nuclear weapons to further the national interests. We should be interested in all three capabilities in our set of determinants.

This set of determinants based on all the theories considered above encompasses a large segment of the proliferation literature. A summary of the complete set and the theories is included in Table 3.1 below. Each one of the theories had some explanatory power and usually a few cases it couldn't explain. The survey of the different theories confirmed one of our

[29] Meyer, 102.

suspicions, that each country must be treated differently. Based on the conditions present, the determinants in our set will change in importance. This not only holds for differences between states, but also changes within each country over time. Our BN must include the ability to tailor our approach to fit the country of interest by allowing the analyst to weight the determinants appropriately. By including all the determinants and by allowing for each to have a variable impact on the overall proliferation risk, we can be reasonably assured that our methodology will be applicable to all cases.

| Theory or Model of Proliferation | | National Security/ External Threats | Scientific/ Technical Achievement | National Prestige/ Political Leverage | Domestic Opinion/ Policy | Technical Capability | Economic Capability | Tactical Capability | International Agreements | Controls/ Safeguards |
|---|---|---|---|---|---|---|---|---|---|---|
| International | Rational Deterrence Waltz | X | | | | X | | X | | |
| | Structural Realism Frankel | X | | | | X | X | X | X | |
| | Davis, Betts (pg. 27) | X | | X | | | | | X | |
| | NeoLiberal Institiutionalist | X | | X | | | X | | X | X |
| | Meyer (pg. 27-28) | X | | X | X | | | | X | X |
| Domestic | Reiss (pg. 29) | | | | X | X | X | | X | |
| | Singh & Way (pg. 30) | X | | | | X | X | | | |
| | Organizational Theory Sagan | | X | | X | | | X | | |
| | Bureaucratic Theory Allison | X | X | X | X | | | | | |
| Individual | Misperception Jervis | X | | X | X | X | | X | | |
| | Nuclear Mythmaking Lavoy | | | | X | | | | | |
| | Learning Models | X | X | | X | | | | X | X |
| Sociological | Social Construction of Technology Theory | | X | | X | X | | | | |

Table 3.1 Matrix of the Literature Survey of Proliferation Determinants

# IV METHODOLOGY

The Methodological Contribution of this work is to use the Bayesian principles described in Chapter II along with the Theories of Proliferation in Chapter III to construct a Bayesian Belief Network that will enable us to answer the question, 'What is the likelihood that a country is proliferating?' In order to create the network, we need to determine what types of evidence are important to consider when trying to assess a country's likelihood of proliferating, how that evidence should be organized within the network, what relative importance should be assigned to each type of evidence, and what criteria are reasonable to categorize the impact of that evidence. By laying down these ground rules, we can then integrate evidence in an orderly fashion while minimizing the biases present in the human analytical mind.

The theories examined in Chapter III provide a good survey of the determinants of proliferation. Each theory has merits and some degree of explanatory power under certain conditions. A single theory of proliferation may be adequate to explain the behavior of a certain country, but motivations and situations change over time. As time passes leaders change, wars are fought, and trade builds new partners. In order to represent adequately all the reasons why countries want to proliferate and the capabilities required to do so in the network, I used the determinants from Chapter III to form the set of contributing factors which encompass all the theories.

It is possible that considering such a large set of contributing factors would just complicate matters. At different times and in different countries, some factors will matter more than others. To take this variability in to account we must organize the set of contributing factors in a structure that is internally consistent. By gathering the factors into separate factor groups or types of evidence, we can handle similar evidence types collectively. This allows us to assign relative weights to each type of evidence and creates flexibility in the network. This flexibility can allow us to utilize the network in a variety of situations and tailor the structure for each particular country of interest.

Another vital part of organizing the network is establishing the initial values of the variables. As in any Bayesian analysis, we must establish a prior probability, our best guess, as to the proliferation status of the country of interest. To do this we must not only determine what the initial states of each contributing factor are, but we must establish the relative weights of each type of evidence. This network initialization will be different for every case and is usually accomplished through an assessment of the country of interest and the input of subject matter experts. Once we establish the BN, we can then use the software to track the impact of any new evidence on the overall probability that a nation is proliferating.

Before this new evidence can be considered however, we must establish rules and criteria for the input of new data into the network. Much of the data used in a network of this type will be qualitative in nature and will require analyst interpretation before they can serve as input. We must determine not only which Contributing Factor is affected by the evidence, but also how much that evidence affects the state of that factor. By using these specified criteria, we ensure that the evidence is handled in a consistent manner. Once the network structure is established, and the criteria for integrating new data is set, we can use the network to determine the effects of each new piece of evidence on the overall proliferation probability.

While this updated probability of proliferation is useful, we can use the results to provide even more information to a decision maker. We can compare the new probabilities with previous network runs to track proliferation probability changes over time. We can also use the Bayesian relationship between the probabilities of the event and the likelihood of the evidence to conduct an analysis of which contributing factor was the most significant in changing the overall proliferation probability. This Chapter explains the methodology, and Chapter V examines two case studies to illustrate its application.

## 4.1 Defining the Factors Contributing to Proliferation

The wide body of literature that we see in Chapter III spans the realms of International Relations theory, to sociology, and various cognitive models to describe why states pursue nuclear weapons. Table 3.1 summarized the factors that each theory considers important to determine if a state will attempt to proliferate. In order to build our network, I included each of those determinants as Contributing Factors in an attempt to capture the explanatory power from all of the perspectives.

The list of factors is a bit long for a set of independent variables, but they lend themselves to further organization which will allow us to treat similar factors as a group. In general, the factors listed in Table 3.1 are either motivations for proliferating that explain a state's Intention to proliferate, or Capabilities which allow the states to proliferate. The group of motivations also includes determinants that can primarily dissuade states from proliferating (International Agreements and Safeguards). Since our intention is to group these determinants according to their broad effects upon the overall proliferation probability, I held these separate in a third factor group, Restraints. By grouping our contributing factors into these three factor groups, we can lend further clarity and flexibility to the network. However a problem still remains.

These factors can offer explanations as to why a state would proliferate, and if they have the capability to do so, but none of them cover the actual behavior of the state. As a final factor group, I considered the Actions of the state. This factor group can provide complementary evidence which can help confirm the predictions of the other factor groups and will give empirical evidence of proliferation rather than just predictive. This allows us to increase the precision of our assessments of the probability of proliferation.

4.1.1 Intentions

Our National Intelligence Services have also dedicated themselves to the task of predicting proliferation probabilities based on motivations.[30] Regardless of the approach, the central question is the same; what factors explain why states choose to proliferate? The factors most often cited are National Security Concerns, reasons of National Prestige or Political Leverage in the global community, a desire for Scientific or Technical Achievement, the Domestic Opinion of the public and the Official Policy of the elites. Other studies have tried to answer the question of not only why, but how states proliferate.

4.1.1.1 National Security and External Threats

Threats to a nation's sovereignty or survival are usually sufficient to warrant paying any price and overcoming moral qualms about nuclear weapons. These motivations are present in all nations, weak and strong; and once a nation decides that these weapons are critical to their security, nothing short of force is likely to deter them. Concerns about security are universal, but are highly dependant on the threatening conditions in the country and the region. For instance, even though Russia and China had vast nuclear arsenals, Pakistan only began nuclear research in earnest once India acquired the technology. Both qualitative and quantitative studies have cited external threats in some for as a major contributing factor in any country's decision to pursue a nuclear weapons program. In the same way, any reduction in the perceive threat to a nation should lower their desire to proliferate. Security agreements with nuclear superpowers can

[30] National Intelligence Estimates have been using certain parameters to predict proliferation probabilities from the beginning of the Nuclear Era. The 1966 report includes a section titled 'Decisions to Acquire Nuclear Weapons'. The report details a list of definable factors that lead to a decision to proliferate.

negate a need for nuclear arsenals if the agreement is credible and enforceable. This dynamic can explain why nations such as Germany or Japan, who have every reason and capability to proliferate, have declined to do so. These security guarantees are not an absolute cure however. They will only deter a country from developing weapons if they are believable. The Chinese developed nuclear weapons in part because of a lack of confidence in Soviet security guarantees, and France pursued their program despite the explicit and strong wording of the NATO agreement.

Indicators of threat should be easy to measure and will allow the analyst to make appropriate changes to the probability values of this contributing factor in the network. They can be an overpowering conventional advantage in a neighboring rival, a latent or actual nuclear capability in a rival, or any other situational threat to sovereignty that nuclear weapons could conceivably solve. The analyst can also use quantitative measures instead of binary variables. The literature provides examples of comparative indicators such as enduring rivalries, number of conflicts in the past three years, or other metrics to determine how threatened a country is. The analyst may also choose to use expert opinion or specific occurrences of speech by country officials describing the threats they face. While the relative threats to any nation may be vastly different, it is certain that every nation considers external threats in their proliferation calculus.

#### 4.1.1.2 National Prestige/Political Leverage

Linked to the concern about external threats is the desire of countries to have political leverage and freedom of action in the global community. Even conventionally strong nations lose this leverage without the accompanying nuclear deterrent. With even a minor arsenal, a nation is assured that they will be considered 'important' and will be given the requisite respect of a nuclear nation. Nuclear proliferation in France is a prime example of this motivation at work. Although they had no hope or desire to compete with the USSR, they were able to muster a credible deterrent through the development of a nuclear weapons program. This also ensured that they had a hand in charting any international agreements in nuclear matters. This motivation, to 'be in the club', is a powerful one among the developing world and is often seen as a shortcut to respectability and geopolitical power. International sanctions play directly into this motivation to proliferate as they usually include some form of benefit for compliance. A nation can forego development of a nuclear program or dismantle an existing program in order to gain concessions from other nations. An occurrence of sanctions would have a negative effect on the proliferation risk due to this factor as the nation would reduce its proliferation activities in an exchange of political leverage for concessions. States may also pursue a weapons program in the absence of a significant threat for this same reason. The analysts can use these types of indicators to determine the correct probability values for this contributing factor in the network.

4.1.1.3 Scientific/Technical Imperative

One motivation considered in the 1966 NIE was a universal desire of nations to keep pace in technological achievement and scientific study. Another hypothesis is that as a nation develops and gains expertise in areas like chemical, electrical, and mechanical engineering, it will eventually posses the latent capability to build a nuclear weapon. Once this capability exists, the momentum of technological advancement will inevitably lead to the development of a nuclear program.[31] A corollary motivation is the desire to prevent a lesser nation with the latent capacity from acquiring the technology first, i.e. an effort to maintain status.

Early proliferators may have felt this pressure. In a famous letter to President Roosevelt, Albert Einstein wrote of the scientific possibility of atomic weapons and that Germany was

[31] Stephen Meyer tests technological determinism in his survey of the nuclear proliferation literature and shows quantitatively that it plays little role in the efforts of modern countries to proliferate (1984, p 9).

already working on the problem.[32] Once the possibility of these weapons was accepted, there was no doubt that the President saw the necessity of developing them first. Once the US succeeded and demonstrated the effectiveness of atomic weapons, the Soviets then felt the need to follow suit.[33] While this wasn't necessarily a response to an overt threat since the US and USSR were recent allies, the sense of an impending adversarial competition was already present. Certainly for some American scientists, the development of the bomb in the US was in some part 'because we could'. While in today's world it is hard to find examples of proliferation efforts based on this motivation, it has some explanatory power in considering single events and their contribution to the overall proliferation risk. While it certainly won't affect each country equally, it may play some role.

4.1.1.4 Domestic Policy/Public Opinion

This factor includes the sum of internal pressures either to proliferate or to refrain discussed in Chapter III. Domestic opinion can be a powerful influence in some countries, liberal democracies in particular. Policy plays a similar role in that it is the official opinion of the elites in power and reflects the official course charted by the government. Much of this opinion is influenced by the norms and values of the population. The country's elites also play a role in establishing the policy by influencing political officials as organizational leaders and intellectuals. They form the collective story of why the development of nuclear weapons is important and then convince the rest of the population; they drive the nuclear myth.[34]

Lavoy lists five specific activities that indicate an attempt to create a nuclear myth. In an attempt to influence decisionmakers, the elites will:

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[32] Albert Einstein, Letter to President Roosevelt, August 2, 1939.
[33] David Holloway, Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939-1956, Yale University Press, New Haven, 1994, pg 166.
[34] Peter Lavoy, "NUCLEAR PROLIFERATION OVER THE NEXT DECADE: Causes, Warning Signs, and Policy Responses", Nonproliferation Review 13 (Nov 2006).

> (1) emphasize their country's insecurity or its poor international standing; (2) portray this strategy as the best corrective for these problems; (3) articulate the political, economic, and technical feasibility of acquiring nuclear weapons; (4) successfully associate these beliefs and arguments (nuclear myths) with existing cultural norms and political priorities; and finally (5) convince senior decisionmakers to accept and act on these views.[35]

The result of an effective nuclear myth is that domestic opinion shift towards support of proliferation and decision makers implement official policy to pursue nuclear weapons. If evidence of these nuclear mythmaking activities is found, it can have either a positive or negative effect on the overall proliferation risk depending on the particular story driving public opinion and policy at the time.

Examples of evidence that will change the probability values of this contributing factor can include events such as public statements, policy debates, and even appointments of mythmaking elites to key positions in government. The analyst can consider the psychological or cognitive processes behind the decision making of the country's leaders, or the effects of political competition between different political parties. Disputes between governmental agencies regarding the utility of nuclear weapons, or even disagreements about the norms and values that define the national identity can be included as well. The analyst must include any evidence that alters the effects that domestic pressures have on the probability that the country will proliferate.

### 4.1.2 Capabilities

Nuclear proliferation is an inherently technical and extremely difficult project to undertake, and currently only sovereign nations have successfully demonstrated the capability. There are quantitative studies in the literature that attempt to identify the critical factors that make a state capable of successful proliferation. It is not enough to have the motivation to create

[35] Lavoy, p 435.

a nuclear weapon, and these studies illustrate the enormous economic investment and technical know how required for a successful program. Tactical Capability is included as an additional factor as weapons deployment and delivery capabilities are often developed concurrently with the weapons themselves. Regardless of their motivations, a state is only capable of developing nuclear weapons if it has the economic, technical and tactical means to do so.

4.1.2.1 Economic Capability

The economic burdens of a nuclear development program are well known. The economic capability of a country takes into account the purely monetary ability to support development of a nuclear program. This factor is slightly complicated by the requirement for prolonged investment in research, training of scientists and engineers, and nuclear infrastructure development. A country may have the threshold capability at one point but then can experience an economic downturn which makes a nuclear program untenable. Either of these events can be entered as evidence into the BN, the former as a positive contributor to proliferation risk, the latter as a negative.

While individual events have an effect on the capability to develop nuclear weapons, quantitative studies have shown a strong correlation between economic indicators and the likelihood of proliferation. As a country develops economic capability, they can fulfill their latent proliferation aspirations. In general, as the GDP per capita of a nation increases, they will be more likely to pursue a weapons program. However, beyond a certain threshold level of $7700 in 1996 US dollars, an increase in GDP per capita actually reduces the likelihood of proliferation.[36] While the authors don't seek to explain this phenomenon, the effect is attributed to a lack of motivation. If a country hasn't decided to pursue nuclear weapons before the

[36] Sonali Singh and Christopher R. Way, "The Correlates of Nuclear Proliferation: A Quantitative Test", Journal of Conflict Resolution 48 (Dec 2004), p 872.

threshold, any further rise in GDP has no effect on the opportunity cost of a weapons program. In effect, after the threshold, they can easily afford a program, they just don't want one.

Economic indicators of this type can be used in the BN as evidence through this contributing factor. The analyst may also include specific events that speak to a country's economic capability. Budgets for nuclear research, specific allocation for facilities, or other forms of economic evidence can all be included when assigning probability values for this contributing factor.

4.1.2.2 Technical Capability

The development of a nuclear weapon requires an enormous amount of technical experience and knowledge. The ability of national scientists and engineers to design and build the required systems, structures, components, and to maintain the program takes time to develop. The movement of these scientists and engineers can be tracked as they receive training either at school or in a helpful foreign country. Construction of research facilities or other parts of the vast nuclear infrastructure can also be monitored and analyzed. Agreements between nations on nuclear cooperation can also indicate an imminent increase of that state's technical capability. All events of this type can be included in the BN with a positive effect on the proliferation risk, while events such as the cessation of a bilateral nuclear cooperation agreement could have a negative effect on a state's technical capability.

In the same way that economic indicators provide quantitative evidence to the overall likelihood of proliferation, the same study cited above identifies industrial capacity as a major indicator as well. The study correlates domestic steel production and electricity generation into an overall measure of industrial capability.[37] It found that the likelihood of exploring a nuclear weapons program increased by 563% once a country developed domestic steel production

[37] Singh, Way, p 868.

facilities and installed electric-generation of 5,000 MW, and that the likelihood of actually acquiring weapons increased by 2340%.[38] Other studies have done an exhaustive analysis of the technical requirements to produce an indigenous nuclear weapon.[39] An analyst could also track improvements in these industries as evidence of an increasing technical ability. Indicators of this type can serve as evidence in the BN and provide a probability input for this contributing factor.

4.1.2.3 Tactical Capability

The development of delivery systems such as strategic bombers, submarines, or long-range missiles also play a part in indicating that a nation intends to equip these delivery systems with potential nuclear payloads. The ability of the nation to combine warheads and delivery systems and to deploy a nuclear force should be of great interest to a decision maker and merits separate consideration from technical capability. The events which indicate an increase in tactical capability are less ambiguous in their connotation than those that modify technical capability and will have a different effect on the overall risk of proliferation.

The delivery systems are not the only requirement to deploy an effective nuclear weapons arsenal. The country must develop strategic plans that integrate these weapons into its overall national security strategy. This strategy is only useful if a country can achieve its aims through the use of nuclear weapons to destroy or threaten to destroy a particular target. There is little utility in a nuclear weapon without an appropriate target. The integration of a nuclear arsenal into a nation's security strategy is a complex process and evidence of modifications to a country's national strategic strategy may be available. In fact, leaders may articulate a nuclear strategy as part of an effort to achieve a deterrent effect or to send a signal to potential

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[38] Ibid, 876.

[39] See the technical model described in Meyer, Appendix B, p 173-193.

adversaries. The analyst can include evidence of a nuclear strategy, or development of delivery systems, etc. as evidence to assign probability values to this contributing factor in the network.

4.1.3 Restraints

In order to make a complete study of proliferation risk, we must include all the factors of Intention and Capability derived from Chapter III. Relying solely on capabilities would completely miss states that attempt to acquire nuclear weapons through theft or purchase rather than indigenous development. Some outlier states that have the capability and justification for developing weapons don't and some nations that don't fit the mold of a proliferator pursue a weapons program anyway. Thus, it is important to recognize that there are also Restraints to proliferation. As we saw in Chapter III, some theories include factors such as participation in the non-proliferation regime to explain the behavior of some states. So by including Restraints with Intentions and Capabilities we can cover all the determinants from Chapter III.

4.1.3.1 Safeguards

Safeguards are voluntary measures that countries agree to in order to receive some form of nuclear assistance from an international partner; usually in the form of inspections or monitoring equipment. They can take the form of unrestricted inspections of a research reactor supplied by another country, IAEA seals placed on prohibited areas, or even cameras and sensors in their facilities. They are controls placed to reduce the risk of proliferation, but are also a way for countries to show that their nuclear program is for strictly peaceful purposes. Agreeing to safeguards should have a negative effect on overall belief of proliferation risk while rejecting them would have a positive one. The analyst can consider both of these type of indicators when assigning probability values for this contributing factor.

#### 4.1.3.2 International Agreements

International Agreements are formal arrangements that restrict or prohibit a certain set of behaviors, or require certain actions to be performed. These agreements, along with safeguards, are considered by the IAEA to be a vital part of the non-proliferation effort. They can take the form of treaties such as the Nuclear Non-Proliferation Treaty, participation in a nuclear sharing program, or agreements to return all spent waste products from fuel rods supplied by a member of the Nuclear Suppliers Group. They set rules and expectations that are usually designed to reduce the risk of proliferation. Security arrangements or other bilateral agreements may also have a direct effect on the likelihood that a country will proliferate. The analyst must consider the effects of all these types of indicators as events in this category can have a positive or negative effect on proliferation risk.

### 4.1.4 Actions

In order to increase the precision of proliferation predictions, it is important to include not only broad predictive factors like enduring rivalries or economic investment in nuclear research, but also on a continuous collection of hard facts and monitored metrics. In this way, we can take into account the factors that are necessary for proliferation, and complement them with evidence that may be sufficient to give a more concrete picture of proliferation activities. By utilizing the BN, we can integrate the broad predictive factors with new data as it happens and provide decision makers with early warning of possible proliferation. Previously, these same warnings may have taken the form of an analyst's report of subjective judgments about the implications of world events. The BN allows the inclusion of new evidence in an analytic framework tailored for the country that avoids many of the pitfalls of subjective reports.

These complementary factors consist of a variety of information gathering tools that can confirm or infirm the effects of the predictive factors and can provide valuable information about actual proliferation activities. These factors can include reports on the actions of the country of interest by US or international agencies, or even the media. These factors have no place in predictive theories about why a state proliferates, but they have an obvious effect on our confidence that proliferation is actually taking place. In the BN these complementary factors take the form of sources of gathered information; Covert Reports, US or International Agency Reports, Media, and information relayed through Diplomatic Channels. Integrating this type of real-time information allows us to not only say whether or not a state may be proliferating, but also to state with some confidence that they actually are.

4.1.4.1 Covert Reports

This information takes the form of classified intelligence data gathered through US national assets. It is assumed that the information is already vetted for credibility and importance. These reports would include critical hard evidence that either reinforces or refutes predictions based on other contributing factors. While it was important to know that India had the capability to develop nuclear weapons in the mid-60s and that China's explosion of a weapon gave them a definite motivation to do so, the US was still surprised by India's nuclear test in 1974. The missing piece was information that could identify indicators such as test site preparation, unusual movement of nuclear scientists and engineers, or purchase of specialized sensors and computers. Evidence of this sort can alert the analyst to imminent proliferation activities and trigger an early warning to decisionmakers. The analyst does not even necessarily have to know the contents of the report if the source is familiar with the structure of the BN. They can just take the input as a strict probability value. For instance, if a covert report concludes that it is 40% likely that Iran is conducting proliferation activities, then that value can be used as the percentage probability for the Covert Reports factor.

4.1.4.2 US and International Agency Reports

These are reports from trusted sources that are not necessarily classified in nature and require the analyst to make a judgment as to their effect on proliferation risk. If the reports are specific enough to give an estimated probability, then that can be entered directly, but it will more than likely include data such as a summary of conditions at a nuclear site, the relative compliance of a country with safeguards, or the results of an inspection. Various agencies make frequent reports concerning a wide range of proliferation activities including the IAEA, the UN, the US State Department, and many others. The analyst will have to make the judgment on the reliability of the source and the impact of the reports and decide if the evidence has a positive or negative impact on the overall proliferation risk.

4.1.4.3 News Media

News Media reports as a source of information includes a wide gamut of open source information that may be relevant. It can include radio or television broadcasts, Internet traffic, print articles, etc. and have a lesser degree of credibility than official reports. These sources must be carefully considered for reliability and impact, but can still serve as inputs to the overall proliferation risk.

4.1.4.4 Diplomatic Channels

Diplomatic Channels include information gathered through official government communications either from the country of interest or a third country. This category of data should be considered separately because of the unique purpose of these official channels as a form of direct communication between governments. They need further analysis to identify motives and credibility beyond the content of the messages. This may be the vehicle by which a country responds to sanctions, demands incentives, or communicates its intentions.

4.2 Organizing the Evidence in the Network

In organizing this model, I have chosen to group the contributing factors into the four factor groups based on their collective effect upon the overall proliferation risk; Intentions to proliferate, Capability to proliferate, voluntary Restraints, and information on state Actions or behavior (Figure 1). This allows the analyst to gauge the importance of each factor group separately based upon the particular situation in the country of interest. As described in Section 2.3, pg. 16, the analyst must assign marginal probability values to each contributing factor that reflects the current state of that factor in the country of interest.

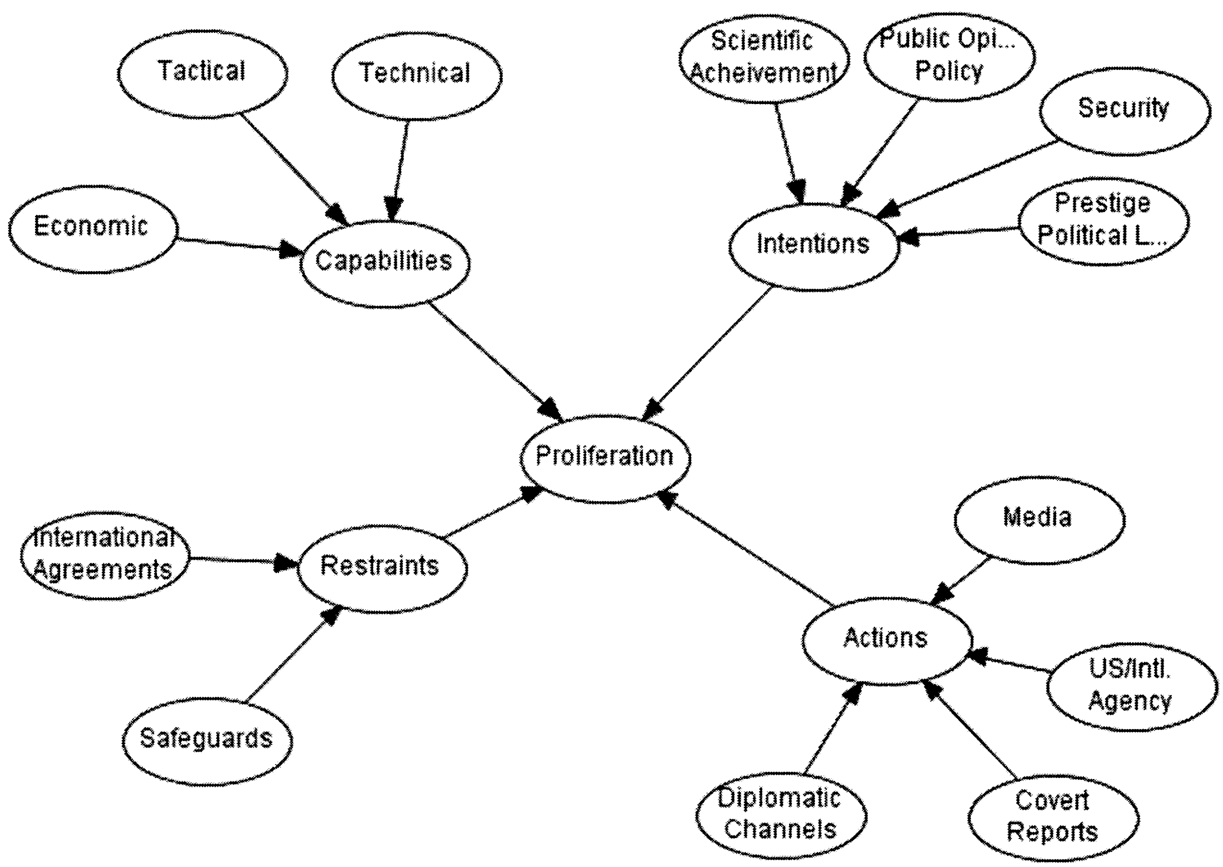


Figure 4.1: Proliferation Influence Network Structure

Each factor group is also assigned a relative weight based upon how much it affects the overall probability of proliferation. These values are determined a priori based upon expert opinion about the particular country or historical evidence of significant events that shape the country's desire to proliferate. As described in Chapter II, the tool used to apply the appropriate weights and relative importance of each factor and factor group is the conditional probability table (CPT).

Conditional probability tables represent the knowledge base from domain experts as well as providing a way to update the network structure based on situational changes. i.e. significant events. The conditional probabilities represent the beliefs that an factor group variable is in a particular state, given that the state of the evidence node is known(see Table 4.1); and in the belief that the overall proliferation variable is in a particular state given that the states of these factor groups is known. For example, if given that security concerns are in state X, then the Intentions factor group node will be in state Y.

Ideally we would want our evidence nodes to be in a single state, but due to the subjective nature of the evidence, I used three states in the marginal probability tables (MPT) to reflect our belief about the effect of each event on the contributing factor. The probability values assigned to each evidence node reflect the analyst's beliefs about how much that factor plays in the country's decision to proliferate.

| Factor Group (G)-States | Evidence Node (E)- States | | |
|---|---|---|---|
| | Not Contributing (n) | Possibly Contributing (p) | Definitely Contributing (d) |
| Not Contributing (N) | P(N\|n) | P(N\|p) | P(N\|d) |
| Possibly Contributing (P) | P(P\|n) | P(P\|p) | P(P\|d) |
| Definitely Contributing (D) | P(D\|n) | P(D\|p) | P(D\|d) |

Table 4.1: Conditional probability table for linking one three-state evidence node to one three-state factor group node, in terms of P(G|E)

### 4.2.1 Determining the Initial Values of the Network

The initial values entered into the network represent the a priori knowledge in Bayesian Inference. They reflect the best available information from subject matter experts, facts gathered by analysts, or may even reflect a lack of knowledge. They are the starting points from which the BN will begin to integrate new data and refine the overall proliferation risk. The values are entered in the network for each contributing factor node in the form of probabilities. These values reflect the current state of each contributing factor in the country of interest. The values give a snapshot for each factor to show how much it is currently contributing to the overall proliferation risk. If the country of interest has no enemies and no external threats, then an example initial probability distribution for the National Security node is: 99% that the factor is Not Contributing (N), 0.9% that the factor is Possibly Contributing (P), and 0.1% that the factor is Definitely Contributing (D)[40]. For each node, the analyst must split the probability between the three states of evidence, with the total equaling 100%. For our contributing factors, the initial values of the evidence nodes follow the logic described above. They are be assumed to be in the least threatening state to start; 99% N, 0.9% P, and 0.1% D. The exception is the Restraint factor group which starts with the reverse probability spread due to the negative effect of having no international controls in effect.

Once each node has the appropriate initial probability distributions fixed, the relationship between the evidence nodes must be established. The initial relative weights of each contributing factor within its group and the weights of the factor groups in the overall proliferation risk are equal. The values will change based on the particular situation in the country of interest as described in the next section. In order to integrate these relative weights

[40] Note that due to the Bayesian algorithm, a proliferation state having a nil probability will remain at that value regardless of future evidence, so we use negligible values instead of 0%.

into the software program, they are compiled into tables that reflect every possible combination of states that the evidence nodes can be in. The sum of the weights is normalized to unity to reflect 100% probability and then the probability values are split according to the various combinations of states. An example of a conditional probability table for the Restraints factor group, which has two inputs, is shown in Table 4.2.

| | Contributing Factors (weighted) | Input State of Evidence Node Combinations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Inputs | International Agreements (3) | N | N | N | P | P | P | D | D | D |
| | Safeguards (2) | N | P | D | N | P | D | N | P | D |
| Outputs | Output State N | 1.000 | 0.600 | 0.600 | 0.400 | 0.000 | 0.000 | 0.400 | 0.000 | 0.000 |
| | Output State P | 0.000 | 0.400 | 0.000 | 0.600 | 1.000 | 0.600 | 0.000 | 0.400 | 0.000 |
| | Output State D | 0.000 | 0.000 | 0.400 | 0.000 | 0.000 | 0.400 | 0.600 | 0.600 | 1.000 |

Table 4.2: Conditional Probability Table for Restraint Factor Group

### 4.2.2 Determining the Values of the Conditional Probability Tables

Like the initial values for the evidence nodes, the Conditional Probability Tables may also be constructed based on expert opinion. They form the underpinnings of the BN and serve as the lens through which the new evidence is considered. Their relative weights reflect how important the experts believe each contributing factor is to the overall proliferation risk. For instance, in one scenario, the country may have had the latent capability to proliferate for several years but has refrained from doing so. The analyst may want to weight the 'Intention to Proliferate' group of evidence nodes more heavily as this will have more of an effect upon a proliferation decision. They may also choose to focus on 'Actions' to confirm any deviations from their peaceful stance. In the same way, if the country of interest does not currently have the capability to proliferate but has regional enemies, then the 'Capability' group may be the most important one to monitor. These same considerations must be made when placing weights on the individual contributing factors within each category group.

The analyst can also look to the theories described in Chapter III for guidance. For instance, external factors may be important motivators in a regionally weak country, while democratic states might be highly influenced by domestic factors. Proliferation in highly autocratic states might be completely controlled by the psychological or behavioral factors of a single individual. The analyst must consider the operative conditions in the country of interest in order to correctly set the relative weights of the contributing factors and the factor groups.

In Table 4.2 above, International Agreements has been given a weight of 3 while Safeguards has been given a weight of 2. This means the analyst believes International Agreements has more importance in determining the overall proliferation risk. The CPT then reflects the probabilities that the Restraints node will use when new data is fed into the network. For the purposes of the initial BN demonstration in Chapter V, the conditional probability values were set to reflect equal values between the individual contributing evidence nodes and between the larger category groups. The second run reflects changes in the CPTs to show the effect that correctly setting the relative weights beforehand can have on the network accuracy.

4.2.3 Soliciting Expert Opinion

In order to generate initial values for the evidence node and conditional probability tables in a coherent manner, the subject matter experts must be consistent in how they view the contributing factors. We can ensure consistency by conducting surveys using pair-wise comparisons and analyzing the results for opinions that don't make sense logically, i.e. results such as A>B>C>A. This can be done by providing feedback to experts based on what others said. The experts can then revise their opinions or provide arguments for their reasoning. Once each contributing expert is internally consistent, then the opinions of various experts can be combined to derive a group expert set of conditional probabilities. In addition, particular experts can be given priority based on their area of specialty or concentration. One expert may be a country expert while another may have the best knowledge about technical or economic effects. When combining expert opinions all of these factors must be carefully considered. After this process is complete, the values in the conditional probability tables should reflect as closely as possible the best elicitation of the consensus expert opinion. Once these tables are established, the BN can then receive inputs and begin to use new evidence to provide relevant proliferation probabilities.

### 4.3 Method of Categorizing and Entering Event Data

Any event or evidence of proliferation relevance can be entered into the BN for inclusion in the overall proliferation risk. The method that the analyst chooses to integrate the evidence must be considered carefully and followed with consistency in order to reduce bias or uncertainty in the model. For each piece of evidence, the analyst must decide which contributing factor or factors the evidence impacts, and to what degree the evidence contributes to or detracts from the proliferation risk.

#### 4.3.1 Criteria for Determining the Contributing Factors Impacted

Each piece of evidence or event considered for inclusion into the BN will alter the probability distribution in one or more contributing factor nodes. The analyst must decide which factors to change, and by how much. Once the new information is input into the network, the BN can apply the appropriate conditional probability based on the weights setup in the initial tables. This helps to ensure that all evidence is considered in a consistent manner and has the appropriate impact on the overall proliferation risk established a priori.

As long as the analyst is consistent in the method of categorizing each piece of evidence, and has set the conditional probability tables to reflect the relative importance of the different contributing factors, there should be relatively little ambiguity in the actual data entry. Events such as increased conflicts or border skirmishes will effect a country's perception of the external threat. Events such as alliances and security agreements will as well, but we expect the state of evidence to reflect a negative effect on the overall proliferation risk rather than a positive one.

The input will be straightforward for the traditional Motivations/Capabilities type contributing factors such as those suggested in the literature, but will be less so when considering facts collected from Intelligence or Media reports. The analyst must take into account the reliability of the source and determine whether it corroborates other evidence already considered in the network. The basics of reliability of information can be built into the conditional probability tables as suggested above. For instance, there should be a greater weight given to US Intelligence reports that ostensibly have already been vetted or have their own reliability assessment than to evidence taken from Media broadcasts in the country of interest. The evidence presented in the broadcast can and should be considered, but rarely given the same weight as a trusted US Intel report.

### 4.3.2 Criteria for Determining the State of Evidence

Once the analyst[41] determines which contributing factor is affected by the particular event or piece of evidence, they must decide upon the new marginal probability values for the evidence node. As described in Chapter II, each evidence node has a marginal probability table that describes the analyst's belief about that particular node. When a new event takes place, the analyst quantifies its impact by altering the values in this table. Some evidence may not affect the probability values of the particular evidence node, while others may require changes.

Each one of the evidence nodes represents a spectrum of probability for each contributing factor and each event is considered new evidence that may change the values in the marginal probability tables for that node. A particular event may have multiple interpretations or

[41] References to the analyst refer to the person or people constructing, maintaining, and interpreting the BN. This can be a single individual, or a group of people such as a panel of experts.

explanations, so it is difficult to assign a precise proliferation probability. The US Office of the Director of National Intelligence (ODNI) uses a method to handle the spectrum of probabilities by discretizing evidence into seven different states to assign a degree of importance to each piece of evidence.[42] I have used a similar technique using a simplified set of three states in each MPT that the evidence can take based on how much they increase the probability that the subject is proliferating. The three states included in each MPT are Not contributing to proliferation (N), Possibly contributing to proliferation (P), and Definitely contributing to proliferation (D).

As each piece of evidence is considered, the analyst must ask numerous questions about the meaning of the evidence. Criteria can be established through familiarization with the process and by using input from experts so that the analyst can apply consistent rules when categorizing each new event or piece of evidence. (See Appendix A for an example of general criteria that can be used to evaluate qualitative event data) Generally, if the evidence reduces the probability or has a neutral contribution, then it increases the probability that the evidence node is Not Contributing (N). If the evidence weakly contributes to the probability of proliferation or has multiple explanations, it increases the probability of Possibly Contributing (P). Finally if the evidence directly increases the probability of proliferation or has no alternate explanation, then it increases the probability of Definitely Contributing (D). This general categorization has different meanings for each contributing factor, so I established a set of criteria to guide the process. Establishing these criteria before considering any evidence both increases the precision of the grouping and ensures consistency over time.

[42] This method of using estimative language to describe probabilistic assessments and judgments is described in the 2007 National Intelligence Estimate. National Intelligence Council, 'Iran: Nuclear Intentions and Capabilities', November 2007, p 5.

### 4.3.3 Assessing the Effect of the New Data

Once the analyst has determined the effect of the new evidence, they input the new marginal probability values into the MPT of the appropriate evidence node. This new input will then generate a new overall proliferation risk through the network structure. This new risk is an accumulation of all the previous inputs to the network including the initial values. The results of integrating new evidence may be only a slight change in the overall proliferation risk, but the results will be consistent with the a priori values established when creating the network.

The results will allow an analyst to give a decision maker a more logically consistent assessment of the meaning of an event. Where previously, a recent or significant event might be given a disproportionate amount of weight by a decision maker, the BN will allow them to see the event in the context of all the other available evidence in a more objective way.

## 4.4 Deriving Results from the Network

Once we have established the network, set the initial values, and begun to enter evidence, our overall probability of proliferation will begin to change. This can give us current probability values for the country's proliferation risk, but there are even more important results that can be derived from the BN. We can show the effects of events over time and we can determine which contributing factors were most significant in changing the proliferation risk.

### 4.4.1 Compiling Network, Establishing/Interpreting Trendlines

Compiling the network for the first time will generate a baseline proliferation risk for the country. This can be done using the initial probability values described in Section 4.2.1 (circa 1946), or those obtained at a particular time in the country's history. The analyst must set the appropriate marginal probability values correctly for each contributing factor based on the conditions at the time of interest. Again, a good resource for this can be subject matter experts.

Once the analyst begins to enter data, the overall probability values provided by the network will reflect the new evidence. If the analyst tracks these changes over time, they can establish a trendline which shows the dynamic nature of the proliferation risk. The analyst can then tie the proliferation probability levels to significant events and make inferences about their effects. The analyst can record new data points for each new event entry, or consolidate events and track only daily changes. In the case studies in Chapter V, I tracked the changes in yearly increments. If this network was used for real time proliferation monitoring, then the output would be constantly tracked for changes.

4.4.2 Bayesian Analysis to Determine Most Significant Contributing Factors

Another major advantage of this trendline analysis is that analysts can use the Bayesian relationship between event probabilities and the likelihood of proliferation to determine which factor is contributing most to that probability. As described in Chapter II, this is using the network to diagnose, rather than predict. By setting the overall proliferation risk to 100% Definitely Proliferating (D) instead of the probability spread, I used the inference algorithm in the network to work backwards and calculate the most significant contributing factor. This is in essence answering the question, 'If this country had developed nuclear weapons at this time, what most likely made them do it?'

In the same way, we can set the probability to 100% Not Proliferating (N) and determine which factors were most effective in preventing proliferation in that country. Both of these calculations are based upon the probability values entered in the evidence nodes and the relative weights set in the conditional probability tables, so the analyst must choose a particular data point or time in history at which to conduct this analysis.

In order to validate this methodology and to show the explanatory power of the BN, I examined two case studies in Chapter V. I established a BN for India and Iran, and used historical events to simulate the population of the network with new evidence over time. The results of the inputs give me a measure of the proliferation risk over time and allowed me to compare the results of the network to proliferation events as they actually transpired. The results also tell me which contributing factors had the most impact on their proliferation decisions.

# V CASE STUDIES

The purpose of using case studies is to validate the method, but also to determine the extent of its utility. I want to know that my method produces plausible results, but also that those results can be useful to a potential decision maker. In order to test the validity of the Bayesian approach, the first country I investigated was India. I chose India as the test case because over its nuclear history, it has chosen to both proliferate (twice) and to reject proliferation. I use historical data as evidence in the network to track the rise and fall of the probability of proliferation by India. I then assess the how well the model's predictions match with the actual proliferation events. If the model's predictions correspond to the observed events, then the method is validated and it can be applied to other countries with increased confidence. The logical choice was to then use the validated model on our primary case; a country that has not yet succeeded in developing nuclear weapons but that has generated significant political interest, Iran.

The construction of the BN as an analytical tool in Chapter IV was only the first step in answering the question of the proliferation likelihood of a particular country. We must also tailor the structure of the network for the particular county of interest and then find data relevant to the country. In order for the network to provide meaningful information, the events and evidence related to the development of a nuclear weapons program in the country of interest must be used as data. One particularly useful source of data regarding the nuclear history of various nations is the Nuclear Threat Initiative's (NTI) website, which contains various country profiles and nuclear chronology databases.[43] While this website provides a wealth of

[43] NTI tracks and collects information from a wide variety of sources and maintains the results online. The events they include in the database are individually referenced. The biases of the organization are present in that they

information, other relevant sources of qualitative evidence can be included as well. In Chapter IV, I included quantitative information, like the correlation between per capita GDP and the economic capability to maintain a weapons program, in the model. When considering evidence for a particular country, it is important to include quantitative data such as historical economic indicators as well. Once we integrate all of these data into the network, we can get results for the predicted proliferation probability.

Using the power of the Bayesian relationship between the likelihood of evidence and the events themselves, we can also show the relative contributions of each factor to the overall proliferation event. This answers the question, 'If country X were to successfully proliferate, what would be the likely driving cause?' and the next logical question for the decision maker, 'What can we do to prevent it?'. These questions are addressed in the following chapter which covers how to make use of the results of the analysis.

5.1 India

India is a country of over 1.1 billion people that has two nuclear armed neighbors that have both been enemies at various times. It was one of the first countries to benefit from the US Atoms for Peace program, but has received nuclear assistance from Russia as well.[44] They have an extremely capable indigenous nuclear scientist and engineer corps and the economic base required to maintain a nuclear program. They hold the distinction of being one of the few nations to have not signed the NPT. Over the past 60 years, India has both developed and renounced a nuclear weapons program, and has twice tested actual nuclear devices. Due to its lack of restraining treaties or safeguards, India should provide a good study for tracking the

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oppose proliferation, but that serves our purposes well as information of value and relevance is unlikely to be left out. http://www.nti.org/

[44] Catherine Collins and Douglas Frantz, "How you helped build Pakistan's bomb," Asia Times, 29 November 2007.

effects of intentions and capabilities. In addition, the two data points corresponding to the two nuclear explosions provide a good opportunity to test the validity of the methodology.

The initial conditions in 1945 for India in the network follow those established in Chapter IV. They were not yet capable of attempting a nuclear program, and had not accepted any voluntary restrictions. I will also hold the values of the relative weights between the factor groups constant throughout the analysis in order to not bias the analysis with hindsight. As the case of India was run on an earlier version of the network to test the methodology, it also does not include the Actions factor group which was added later. After setting the initial values, the NTI database provides a chronological summary of relevant nuclear events. I analyzed the events during each calendar year between 1946 and 2000 and updated the marginal probability tables of the evidence nodes for each year. The spreadsheet of all the probability values can be found in Appendix B.

I then ran the network using these values to determine the overall proliferation risk for each year. The results in Figure 5.1 show two important things, that the overall trend in proliferation probability corresponds to the evidence in the NTI database, and that local peaks are observed around the 1974 and 1998 tests. This means that the network accurately represents the historical trends seen in the literature and that the model is working properly. During this test case however, the relative weights between the contributing factors and the factor groups were kept constant. While the general accuracy of the trendline validates the methodology, the equal weighting of the factors reduces the utility of the results and prohibits us from conducting the analysis of the most significant contributing factors. We are in essence increasing the signal-to-noise ratio of the data by not taking into account the relative weights of each contributing factor and factor group. We can say that India did proliferate, but we are unable to say why.

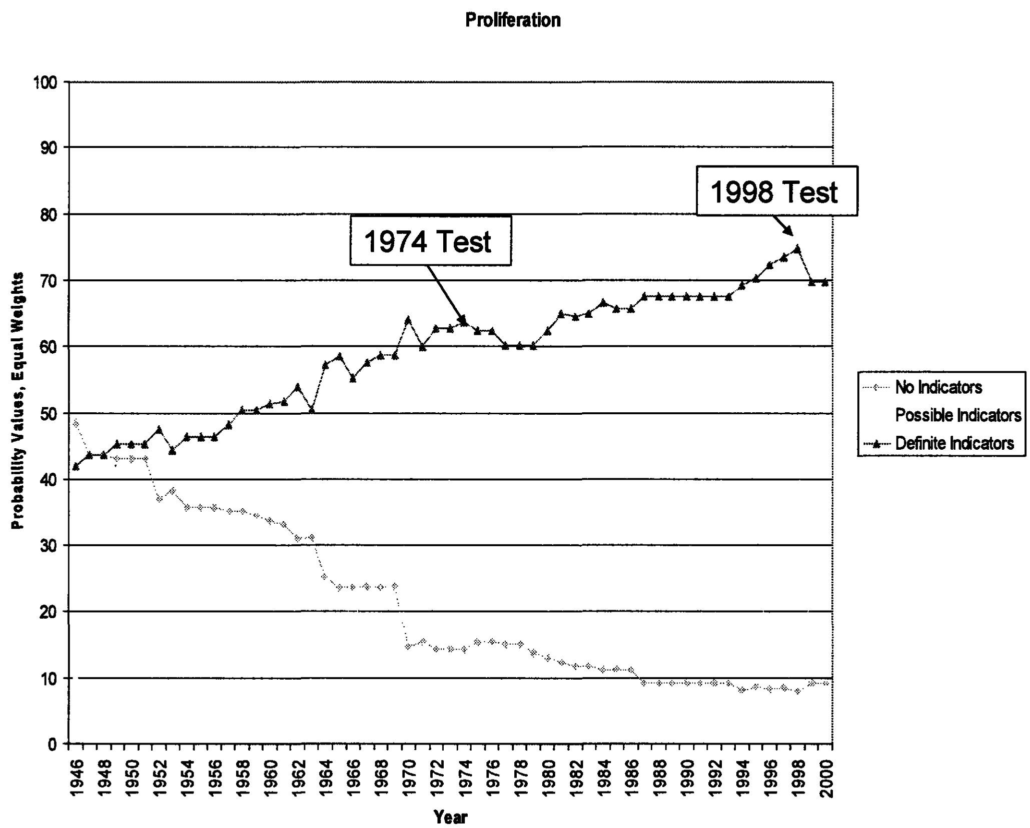


Figure 5.1. Proliferation Trendline in India with Equal Weighting

In order to achieve more precise results, we must tailor the structure of the network to match India's unique situation. We must take into account significant events or particular characteristics of the country that affect how important various contributing factors are at different times. The significant events included in this analysis are the 1962 war with China, the various conflicts with Pakistan, and their domestic and international debate over the NPT. Figure 5.2 shows the results when the conditional probability tables reflect the weighting of the factor groups to account for the influence of significant events. These results show more distinct peaks around both nuclear tests and a more significant drop after the 1974 test. This also shows that between the 1974 and 1998 tests, that the proliferation probability remained relatively flat instead of increasing as in Figure 5.1. The use of relative weights is the proper application of the methodology and provides a better reflection of the historical data from India's nuclear program such as the large opposition to a weapons program after the 1974 test, the subsequent general attitude against further proliferation, followed by the second proliferation event in 1998.

Differentiating the weights also allows us to say something about which factors were most significant in contributing to the overall probability. This illustrates the need to tailor the structure of the network for each country to account for unique characteristics. We can be more precise in our analysis by taking into account the effects of significant events on the relative weight each contributing factor and factor group have in that particular country. In addition, for the case of Iran I have added the factor group 'Actions', which allows the element of real time information and behavior to be included into the probability calculations. While the relative weights will increase the precision of the results, the addition of behavior will increase the accuracy. The following case of Iran explains in more detail how this is done.

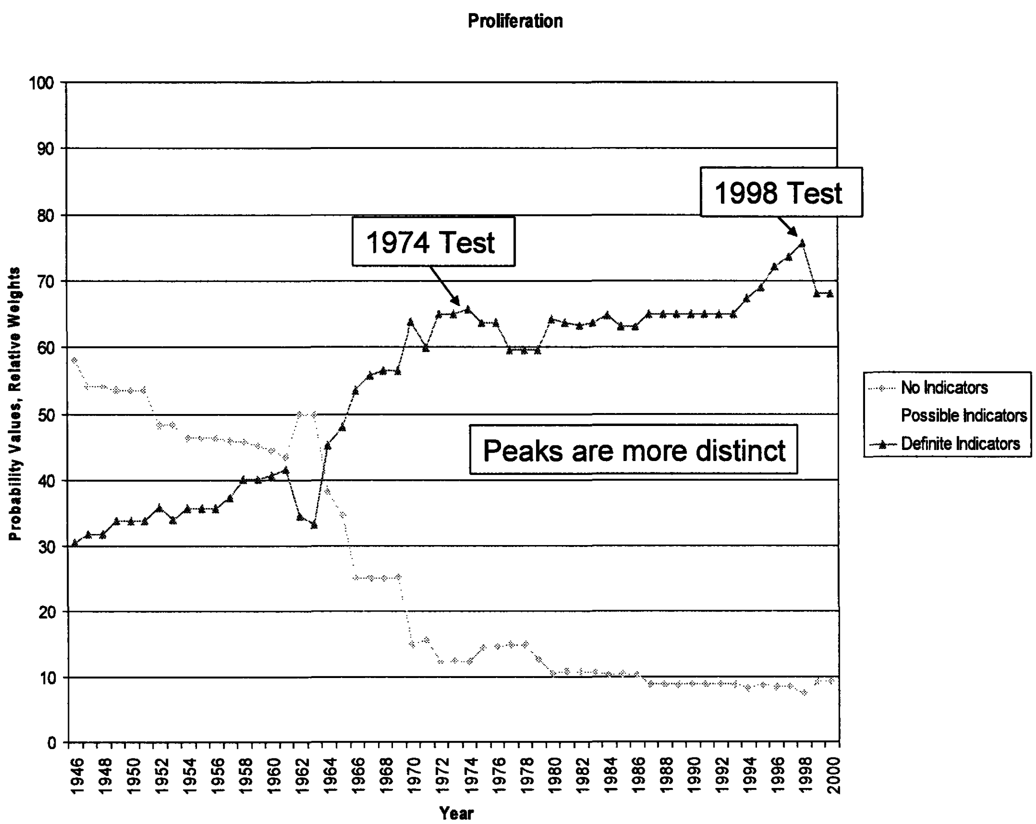


Figure 5.2. Proliferation Trendline in India with Relative Weighting

## 5.2 Iran

I chose Iran as the primary case study due to the highly politicized nature of their nuclear program. The program has been a huge source of conflict and tension within the international community and any insights revealed by this method would not only be useful for the thesis but might be important from a larger perspective. There is general agreement that Iran has pursued or is pursuing nuclear weapons, but has not yet succeeded. This presents a good case to study because there is a large amount of information available, and the results can be used to suggest possible courses of action.

I first looked to Iranian history for any significant events between 1946 and 2007 that may alter the structure of the network from the initial values described in Chapter 4. Once the network structure has been tailored in this way to the Iranian situation, I then analyzed the data presented for Iran in the NTI database, historic economic indicators for Iran, as well as various other relevant data to develop yearly values for each of the observable evidence nodes. After establishing the values of the evidence nodes, I then ran the Bayesian Inference engine to determine the overall probability of proliferation for each year. By tracking these probabilities over the course of the study, we can see trend lines in the likelihood of proliferation by Iran, and can tie them to significant events. The Bayesian Network also allows us to show which contributing factors were most significant at various periods of time in influencing the proliferation probability in Iran. The implications of these results are revealed with further analysis in Chapter VI.

### 5.2.1 Initialization of the Iranian Network

Each country's history plays a significant role in how important each of the elements that make up the BN are to the overall risk of proliferation in that country. Countries with historically neutral positions in the international structure will not weigh external threats too heavily when considering whether to develop nuclear weapons. Likewise, covert reports are likely to be of less value when investigating closed societies like North Korea. Once the history of a particular country is taken into account, we can modify the structure of the network to reflect these unique characteristics. This can help to give a more accurate representation of the effects of the evidence once we begin to enter data into the network. In the case of Iran, I start with a brief timeline of important nuclear related events and then explain how these events shaped the unique Iranian Network.

5.2.1.1 Timeline

1957 US signs civil nuclear cooperation agreement as part of Atoms for Peace Program.

1967 Tehran Nuclear Research Center established. US-provided 5 MW research reactor using highly enriched Uranium goes online.

1970 Iran ratifies NPT.

1970s mark era of cooperation between the West and the Shah's government. Iran reached agreements with the US, France, and Germany to build reactors and bought a stake in a French uranium enrichment plant.[45] MIT began training the first cadre of Iranian nuclear engineers.[46]

1979 Islamic revolution. Initial rejection of nuclear technology, followed in the mid-1980s by a complete restart of the program.

1982-1988 Iran-Iraq War. Establishes an enduring rivalry that among other things reinforces the idea among the Iranian leadership that having a deterrent capability is a necessity for protection. The Iraqi use of chemical weapons and more sophisticated missile technology evened the field against the more powerful Iran because they could not respond in kind. This psychological scar may have affected decision making in their wish to develop a nuclear deterrent.[47]

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[45]Permanent Mission of the Islamic Republic of Iran to the Agency (IAEA), "Iranian Nuclear Policy and Activities – Complementary Information to the Report of the Director General (GOV/2005/67)," IAEA Information Circular, INFCIRC/657, 15 September 2005.
[46] Farah Stockman, "Iran's Nuclear Vision Initially Glimpsed at Institute," The Boston Globe, 13 March 2007.
[47] This line of logic is put forward by Gawdat Bahgat, "Nuclear Proliferation: The Islamic Republic of Iran," Iranian Studies, 39 (Sep 2006), p 311.

1983-present US starts directed effort to prevent IAEA from helping Iran enrich fuel. Iran reaches out to various countries for help in nuclear technology.[48]

1987-1989 Pakistan, through AQ Khan, begins transfer of technology to Iran. This marks the first significant progress made by Iran to secure enrichment technology and assistance. It had to be conducted secretly due to US pressure on most other available partners. This assistance came not only in the transfer of old Pakistani centrifuges, but also of blueprints for newer versions. The Iranians reportedly made significant improvements based upon these designs although the technology remained dated.[49]

1990 Unable to find a western partner to aid in nuclear technology, Iran turns to the Soviet Union and China for assistance. The US and other EU nations continue to exert pressure on these countries to prevent nuclear cooperation, specifically in the area of enrichment and weapons technology.

1995 Although the US has established sanctions in the past against Iran, they were usually directed at oil exports or other political issues. The Clinton Administration affects the first in a series of sanctions against Iran directly related to their nuclear activities.[50] The pressure of US and UN sanctions continue to affect Iran today.

5.2.1.2 Network Initialization

The history of nuclear technology in Iran provides us some insight into how the BN should be structured in order to reflect an accurate picture of the influences that Intentions, Capabilities, Restraints, and Actions played in the development of their program. By determining the appropriate relative weights, we can build the conditional probability tables that represent Iran's particular history for use in the BN. During the first period examined (between 1946 and 1956), the probability of an Iranian weapons program was exceedingly remote, leading to an almost equal relative weight among these factors before 1957.

After the US-Iran nuclear cooperation agreement in 1957 as part of Atoms for Peace, the probability of a nuclear weapons program realistically existed for the first time. Iran was now in possession of enriched Uranium and had the technical support of other nuclear weapons nations.

[48] Mark Hibbs, "U.S. in 1983 stopped IAEA from helping Iran make UF6," Nuclear Fuel 28 (Aug 2003).
[49] This assessment can be found on Globalsecurity at http://www.globalsecurity.org/wmd/world/iran/khan-iran.htm
[50] Kenneth Katzman, "The Iran-Libya Sanctions Act (ILSA)," CRS Report for Congress, Order Code RS20871, Updated 31 July 2003.

The Intentions and Capabilities of Iran during this period became more significant contributors to their likelihood of proliferating. The Shah himself said that Iran will have nuclear weapons, "without a doubt and sooner than one would think."[51]

Once the Shah was overthrown in 1979, much of the western support for the Iranian nuclear program disappeared. The new regime became increasingly isolated and tensions in the region led to the war with Iraq. During this time, the motivations for developing weapons increased in importance.

After years of isolation and US efforts to thwart advances in nuclear technology, Iran was finally successful in securing technical assistance from the underground network of AQ Kahn. This assistance along with their indigenous domestic base of scientists and engineers allowed significant progress in Iran's nuclear program. The capability of Iran to produce a weapon increased in relative importance during this period.

Voluntary restraints on nuclear weapons development did not play a significant role in the overall probability that Iran would proliferate before 1995. The dual use loop holes and relative immaturity of the Iranian program allowed them to comply fully with International Agreements and IAEA safeguards while still developing nuclear technology. After the severe sanctions starting in 1995, the regime began to respond by using the little political leverage they had. Iran began to selectively deny access to international inspectors and began to retreat from portions of their non-proliferation agreements. They variously started and stopped enrichment activities, used appeals, and filed administrative complaints through the Non-Proliferation Regime in order to stall or eliminate further sanctions.[52] During this period, the Iranian

[51] John K. Cooley, "More Fingers on Nuclear Trigger?," Christian Science Monitor, 25 June 1974.
[52] Hosein Musavian, "Chief Iranian Nuclear Affairs Negotiator Hosein Musavian: The Negotiations with Europe Bought Us Time to Complete the Esfahan UCF Project and the Work on the Centrifuges in Natanz ," Interviewer

acceptance of voluntary Restraints increases in importance in determining their overall proliferation probability. The changes to the relative importance of these groups of contributing factors along with the values used in the BN are summarized in Table 5.1. These changes are reflected in the structure of the network through changes to the conditional probability tables of the central proliferation node. The full CPTs can be found as Appendix E.

| | Intentions | Capabilities | Restraints | Actions |
|---|---|---|---|---|
| 1946-1956 | 2 | 2 | 1 | 2 |
| 1957-1978 | 5 | 3 | 1 | 2 |
| 1979-1987 | 6 | 3 | 1 | 2 |
| 1988-1995 | 6 | 4 | 1 | 2 |
| 1996-2007 | 6 | 4 | 2 | 2 |

Table 5.1: Changes Over Time in Relative Weights of Contributing Factor Groups for Iran

In addition to changes in the relative weights of the groups of contributing factors, particular events changed the relative values of the contributing factors within each factor group. The Iran/Iraq War had a profound affect on how the country viewed itself in the international structure and its perception of national security threats. The motivations to develop a nuclear weapon were then driven more by concerns about neighboring enemies. Ideas about Scientific Achievement became less important than preserving the sovereignty of the nation. The war exposed the vulnerability of Iran and its relative lack of tactical capability, particularly in the quality of its missile program. Development of a tactical missile program goes hand in hand with the development of a nuclear weapons program. The Iraq war focused the priorities of the regime and the increased attention on tactical missile capability meant that this particular contributing factor increased in importance during this time as well.

unk. Aired on Iranian Channel 2 on 4 August 2005, Middle East Media Research Institute, Special Dispatch Series – No. 957, 12 August 2005.

Another phenomenon that changed the relative values of the contributing factors within a factor group was a decrease in US intelligence gathering ability. There are multiple explanations for this event, but it seems to have occurred as a result of the further isolation of Iran during the mid-90s. The US put extreme pressure on any country willing to deal with Iran, and used its considerable influence to make it unprofitable for any country that tried. During this time the only countries with enough economic independence and ability to resist such pressure were Russia and China, and even they complied with US demands more often than not. The normal pathways of intelligence gathering were thus denied to the US because they had prevented diplomats, businessmen, and even students from interacting with the Iranian regime. On the few occasions where they did present intelligence gleaned from the remaining sources, the Russian and Iranian governments quickly moved to remove the sources of the leaks. The structure of the network during this period thus reflects a decrease in the importance of Covert Reports in determining proliferation risk and an increase in the reliance on Diplomatic Channels as the source of information on Iranian Actions. The changes to the relative importance of these contributing factors along with the values used in the BN are summarized in Table 5.2. These changes are also implemented in the network as changes to the CPTs of their respective nodes.

| | National Security | Scientific Achievement | Tactical Capability | Covert Reports | Diplomatic Channels |
|---|---|---|---|---|---|
| Initial Values | 7 | 5 | 1 | 9 | 7 |
| Iran/Iraq War | 8 | 3 | 4 | 9 | 7 |
| Mid-90s Isolation | 8 | 3 | 4 | 7 | 8 |

Table 5.2: Changes Over Time in Relative Weights of Contributing Factors for Iran

### 5.2.2 Inclusion and Analysis of the Iranian Data

After initializing the network to reflect Iran's particular history, I began entering data into the model. I began by running the historical per capita GDP number through the algorithm described in Chapter IV. Iran reached the peak risk according to the correlation by surpassing

$7700 US per capita GDP in 2004. This serves to provide baseline Economic Capability numbers for every year. I also made note of the years when Iran developed indigenous steel production (1972) and 5000 MWe power generation (1974). Other quantitative information can be entered in the same way; however these represent the limits of such inclusion in this study.

After entering the quantitative data, I considered the qualitative evidence available. There are numerous studies and reports on Iran, but the most comprehensive collection of nuclear related events is the Iran Nuclear Chronology database maintained by the Nuclear Threat Initiative. The database for Iran includes over 3000 entries and each entry is individually cited. The information derived from the database is qualitative in nature and requires analysis of each entry to determine its effect on the evidence nodes of the network. I chose to update the network on a yearly basis, considering the entire year's worth of events when I change the values of the evidence nodes. As described in Chapter IV, I used the general criteria in Appendix A to determine the effects of the events in a consistent manner. Although this is a useful guide, it does not cover every situation; it is up to the analyst to make a reasonable, educated assessment of the impact of each event. Many events have no effect on the evidence nodes while others may create significant changes.

The following are a sample of the events from the NTI database considered during my evaluation. Following each event is my assessment of the relevant contributing factor affected along with the marginal probability table for the evidence node. The values reflect my changes to the probability values based on the event.

### Example Event 1- 11 January 1995

In response to speculations in the Western media that Israel is considering an attack on Iran's Bushehr nuclear plant, Iran warns Israel that such an attack would be a "blunder." According to the Iran News, Iranian Parliament Speaker Ali Akbar Nateq Nuri's responds to rumors of an Israeli strike by saying, "Should Israel commit such a blunder, we will teach her a lesson not to ever attempt another aggression against Iran." Iran cautions Israel for the second time not to attack the Bushehr nuclear power plant.
—Ralph Joseph, "Iran Warns Israel Not To Attack," UPI, 11 January 1995; in Executive News Service, 11 January 1995.

| National Security External Threats | | |
|---|---|---|
| N | P | D |
| 20 | 35 | 45 |
| 18 | 37 | 45 |

**National Security and External Threats-**This event showed a response to a potential threat from Israel. The response was non-specific, but the meaning is clear. This slightly increased the probability (35→37) that this external threat is Possibly Contributing (P) to proliferation while reducing Not Contributing (N) an equal amount (20→18).

## Example Event 2- May 1979

During the Iranian Revolution, a Khomeini adviser tells energy specialist Dr. Fereydun Fesharaki, "It is your duty to build the atomic bomb for the Islamic Republican Party."
—Leonard S. Spector with Jacqueline R. Smith, Nuclear Ambitions: The Spread of Nuclear Weapons, 1989-1990 (Boulder: Westview Press, 1990), p. 208.

| National Prestige/ Political Leverage | | |
|---|---|---|
| N | P | D |
| 99 | 0.9 | 0.1 |
| 65 | 20 | 15 |

**National Prestige/ Political Leverage-**This event reflects a desire to maintain or attain respected status in world community and it has a definite political component. This is the first time we see this motivation mentioned for pursuit of nuclear weapons, so the values change from the initial probability, to values that show that this motivation is present and is contributing to proliferation.

## Example Event 3- Mid 1980s

An estimated 15,000-17,000 Iranian students are sent abroad for nuclear-related training. Some return to teach at Sharif Technical University, which is also established at this time "to serve as a pool of trained technicians for the nuclear weapons program."
—Kenneth R. Timmerman, Weapons of Mass Destruction: The Cases of Iran, Syria and Libya (Los Angeles: Simon Wiesenthal Center, 1992), p. 43.

## 1985

China supplies Iran with a subcritical research facility, also referred to as a "training reactor," for the Isfahan nuclear research center.
—Mark Hibbs And Neel Patri, "U.S. To Ask New Delhi To Back Off On Research Reactor Offer To Iran," Nucleonics Week, 21 November 1991, Vol. 32, No. 47, pp. 2-3; in Lexis-Nexis, <http://www.lexis-nexis.com>; "Iran's Nuclear Weapons Program: Iranian Procurement Fronts," Mednews, 8 June 1992, p. 3.

| Technical Capability | | |
|---|---|---|
| N | P | D |
| 33 | 37 | 30 |
| 30 | 40 | 30 |

**Technical Capability-** These two events illustrate two of the many ways in which a country increases its technical ability; through training of scientist/engineers and by partnering with other countries to gain assistance. They only indirectly increase the probability of proliferation as they can be explained by a peaceful nuclear program, so the probability values increase in the (P) state and decrease in (N).

## Example Event 4- 27 July 1994

In an effort to "remain committed" to the regulations promulgated by the International Atomic Energy Agency on nuclear nonproliferation, Iran says it will accept the Agency's supervision of the construction of the Bushehr nuclear power plant.
—"Iran Agrees to Bring Nuclear Plant Under IAEA Supervision," Agence France Presse, 27 July 1994; in Lexis-Nexis, <http://www.lexis-nexis.com/>.

| Controls/ Safeguards | | |
|---|---|---|
| N | P | D |
| 50 | 20 | 30 |
| 60 | 20 | 20 |

**Controls/Safeguards**- This event shows a willingness to submit voluntarily to inspections and oversight by the IAEA. This shows a net negative effect on the probability of proliferation based on this contributing factor. The probability value in the (N) state is increased while the (D) state decreases.

**Example Event 5- September 1991**

US satellite photographs show major construction on a plutonium production plant and a large number of Chinese technicians at Isfahan.

—"Nuclear Facilities," Middle East Defense News, 8 June 1992; in Lexis-Nexis, <http://www.lexis-nexis.com/>.

| Covert Reports | | |
|---|---|---|
| N | P | D |
| 50 | 32 | 18 |
| 20 | 45 | 35 |

**Covert Reports**- This event is one example of the evidence included for 1991. Other events that fall into this contributing factor could include any classified information that intelligence agencies gather about a country's actions, or even analysis of those actions. In this case, I increased the probability values in both the (P) and (D) states while decreasing (N).

**Example Event 6- April 1989-October 1990**

Two Iranian nationals, Ray Amiri and Dan Danesh, illegally export Tektronix oscilloscopes to Iran from the United States. The oscilloscopes are used to process nuclear weapons test data. Amiri and Danesh also export logic analyzers, pulse generators, and other electronic equipment that could be used to develop nuclear weapons.

—James V. Grimaldi and David Greenwald, Orange County Register, 30 August 1991; Cristina Lee, Los Angeles Times, 13 September 1991, p. D2.

| Media Print Journals Open Source Events | | |
|---|---|---|
| N | P | D |
| 53 | 27 | 20 |
| 51 | 28 | 21 |

**Media/Other External (non-vetted) Sources**- This event was reported in a local newspaper. Similar events can be found reported in the foreign press on radio broadcasts, or even on the Internet. They must be evaluated based on the reliability of the sources. Based on this and other media evidence in 1990, the probability values decreased in the (N) state and increased slightly in (P) and (D).

The preceding are some examples of changes I made to the evidence nodes based on events from the NTI database. For a more comprehensive study, the analyst can include not just events from a single database, but from any source, as long as it has relevance to one of the network's contributing factors. Over a single calendar year some events increased the probability values and some decreased them. The values used for this study reflect the cumulative effect of all the events within that calendar year. The yearly probability values of each evidence node based on my reading of the database are included in Appendix C.

5.2.3 Results of the Bayesian Analysis

After establishing the structure of the Iran-specific network and compiling the evidence based probability values in Appendix C, we can use the BN to calculate the overall proliferation probability for each year. The software program utilizes the probability values entered for each evidence node and applied the conditional probability tables to determine the final likelihood of proliferation. Since I compiled the input data for each calendar year, the output returns the overall proliferation probability for each year as well. An example of the network output for 2005 is shown in Fig. 5.3.

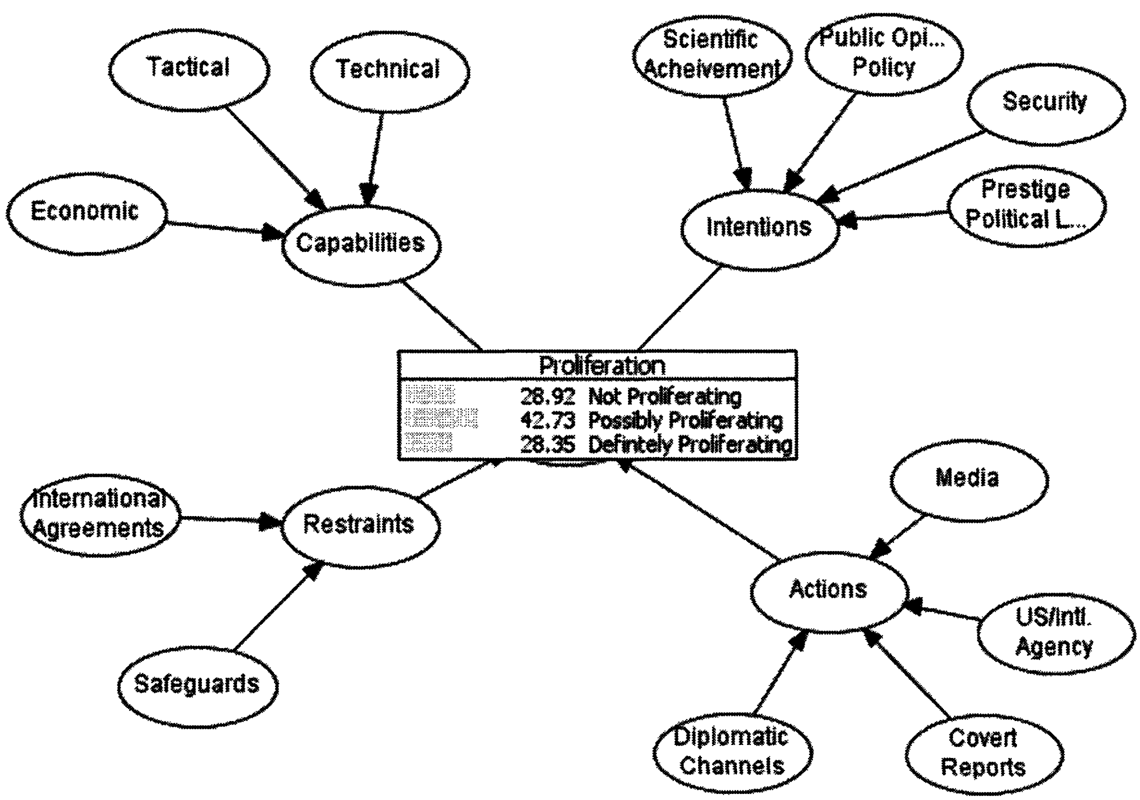


Figure 5.3. Output proliferation probability values for 2005.

5.2.3.1 Evaluating the Trendline

By plotting the probability values over the years from 1946 to 2007, we can trace the trends in the likelihood that Iran was engaged in proliferation activities (See Figure 5.4). This pictorial representation also allows us to more easily relate large increases or decreases in probability to significant events. An analyst could track the effects of other historical events such as wars, sanctions, or peace talks and see if they had the desired effect on proliferation, or if they were detrimental. This information can provide a coarse grained analysis of how these events contributed to the overall proliferation risk. The same methodology can give finer resolutions by simply decreasing the time periods used in the analysis, including gauging the effects of a single event.

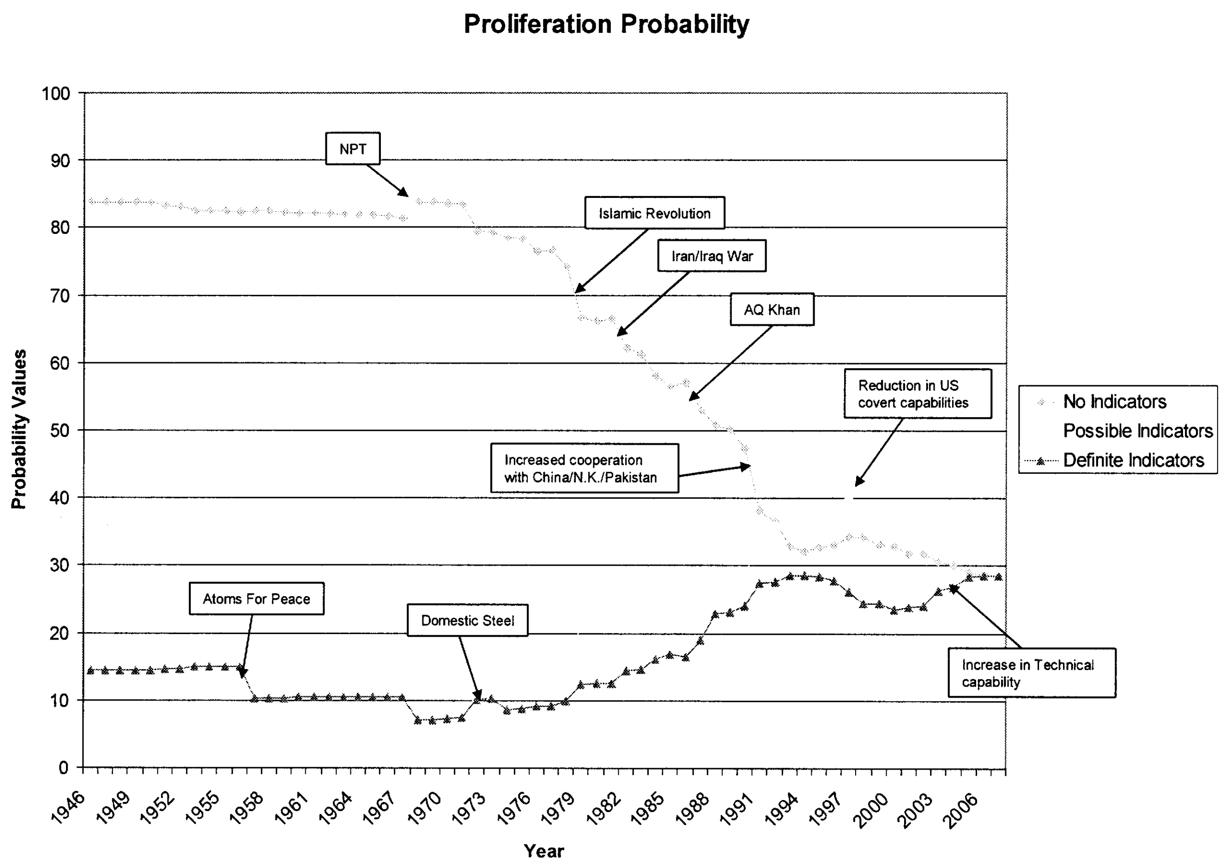


Figure 5.4. Iran proliferation probability tracking 1946-2007

Other methods of using the trendline analysis can be useful to the decision maker. For instance, if they are interested is in a worst case probability, then the decision maker may want to know the values of the combination of the possible and definite states. For Iran, these results are included as Figure 5.5.

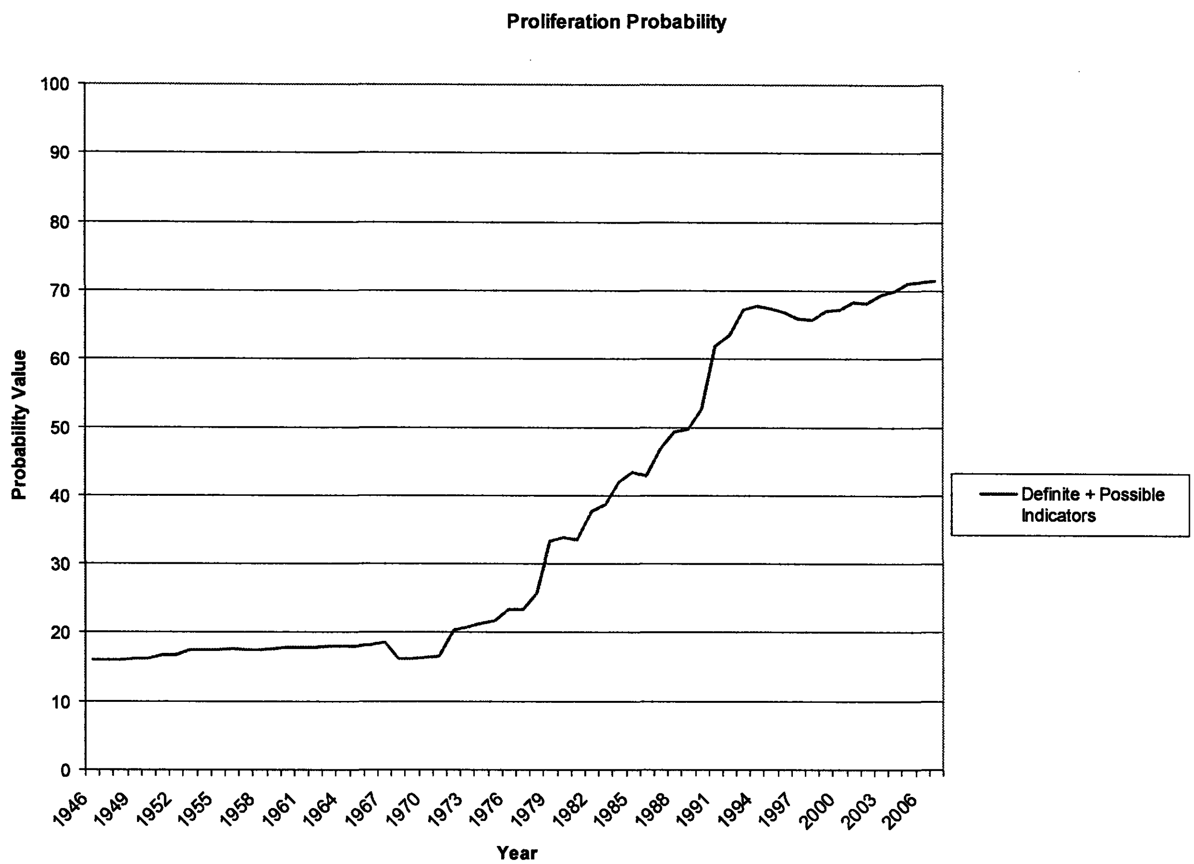


Figure 5.5: Iran worst case proliferation probability tracking 1946-2007

Another way to represent the information is by using the middle state of possible proliferation to denote uncertainty with the expected value being the average between the worst case (definite + possible) and the best case (only definite) scenarios. For Iran, these results are included as Figure 5.6.

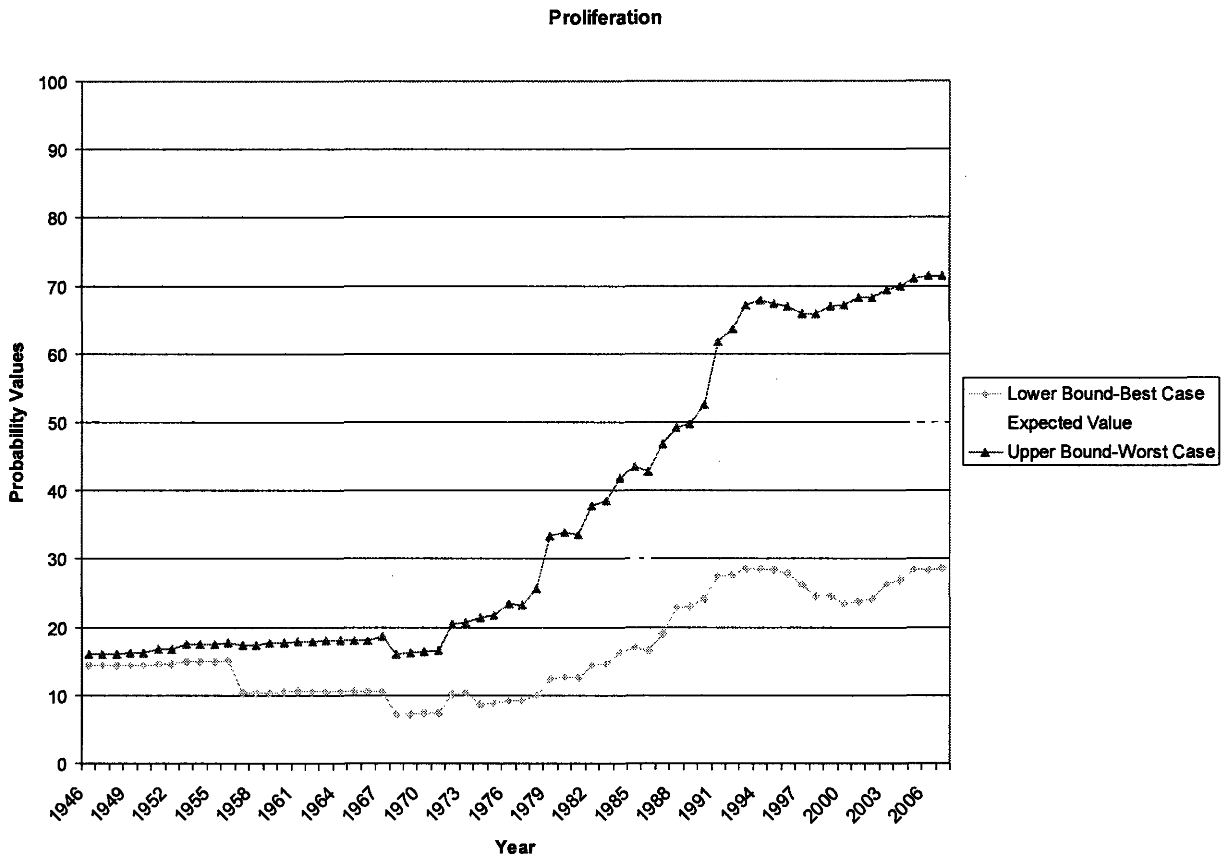


Figure 5.6: Iran expected value proliferation probability tracking 1946-2007

5.2.3.2.Evaluating the Most Significant Contributing Factors

Knowledge of the overall probability risk is useful information, but it is only the beginning of what we can learn from the BN. The more interesting information is hidden in the contributing factors that drive the overall probability. Using the BN, we can backtrack to determine which factors were most significant in affecting the overall proliferation probability. In order to do this, I utilized the properties of Bayes' Theorem which allow us to assume a proliferation event has occurred and trace back the most likely cause based on our input probability values and conditional probability tables. This is accomplished by artificially setting the proliferation probability to unity for any year of interest by running the network model with the overall probability of proliferation forced to 100%. This is in essence answering the question, 'Had Iran succeeded in developing a nuclear weapon in a particular year, and based upon the evidence that we had, what were the most significant contributing factors?' The original probability values for the event evidence for that year and the conditional probability tables are still relevant and now reflect the relative importance that each contributing factor played in the hypothetical proliferation event. The qualitative results of this analysis are shown in Table 5.3 and the actual values are included in Appendix D.

| | National Security vs. External Threats | Scientific/ Technical Achvmnt. | National Prestige/ Political Leverage | Domestic Opinion/ Policy | Technical Capability | Economic Capability | Tactical Capability | International Agreements | Controls/ Safeguards | Covert Reports | US/Intl. Agency Reports | Media Print Journals Open Source Events | Diplomatic Channels 3d Country Officials |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 | | | | | | | | X | X | | | | |
| 1955 | | | | | | | | X | X | | | | |
| 1960 | | | | | | | | X | X | | | | |
| 1965 | | | | | | | | X | X | | | | |
| 1970 | | | | | | | | | X | | | | |
| 1975 | | | | | X | | | | X | | | | |
| 1980 | | | | | X | X | | | X | | | | |
| 1985 | X | | | | X | X | | | X | | | | |
| 1990 | X | | | X | X | | | | | | | | |
| 1995 | X | | | | | | | | | | | | |
| 2000 | X | | | | | | | | | | | | |
| 2005 | X | | | | | | | | | | | | |

Table 5.3. Most Significant Contributing Factors Given a Known Proliferation Event

Determining the significant contributing factors can tell us a lot about the processes that are occurring in our country of interest. As Table 5.3 shows, there are definite changes over time in the factors that were most important to Iran. During the early years when proliferation was impossible for all intents and purposes, the greatest danger was the fact that Iran had signed no treaties to prevent proliferation. They did not have the capability or motivation to begin a program, so those factor groups did not impact the results as much. This changed however during the middle years.

During the middle years, Iran began cooperating with other countries to build technical expertise and was growing sufficiently economically to be able to support a nuclear development program. They also signed the NPT, reducing the danger posed by the Restraints factor group.

In the most recent years, the impact of Iran's security concerns come to the forefront. The war with Iraq and the general isolation from the West cause this factor to lead all others in contributing to the probability that Iran will proliferate.

These results are likely to be the first step in a decision making process regarding the consequences of an increase in the probability of proliferation, and concerning possible means to deter or deny a country from succeeding in developing nuclear weapons. The next Chapter covers ways in which these results can be used by an analyst or contingency planner to help a decision maker determine which courses of action are likely to have the most success in reducing the proliferation threat.

# VI RESULTS AND IMPLICATIONS

The case studies of India and Iran have shown that the method of using BNs to predict the probability of proliferation gives reasonable results that are based on observable phenomenon. However this is far from an explicitly predictive tool. The results indicate the probability that the country is proliferating along with the associated uncertainties about the result. Particularly for Iran in 2007, the probability spread of 30/40/30 in the N/P/D states does not seem particularly useful at first. These results do indicate the current state of knowledge about Iran, but that is not the only useful information this method provides to the decision maker.

The Bayesian relationship between the proliferation event and the likelihood of the evidence allowed us to analyze the results further. By entering the proliferation event as a hypothetical 'known occurrence' instead of a probability, I traced the contributing factors to see which ones played the most significant part in the event. Once these factors are identified, the decision maker can direct an operational organization to develop scenarios that address or reduce the impact of that contributing factor. The analyst can then test each scenario to determine its effect on the overall proliferation probability. (The following use of the results of the Bayesian analysis is beyond the scope of this paper but can be explained in order to outline possible future utility of this methodology.)

The practice of using hypothetical scenarios to develop plans for a variety of possible future outcomes is known as contingency planning. It is a useful tool for planners to determine if they have the required assets or training to meet the range of possible future demands. This practice is vital because it allows decision makers to stay ahead of the decision-making cycle and to focus on preventative measures rather than corrective ones after the fact. This is particularly important in the case of proliferation as it is extremely difficult to deny a country the ability to produce weapons after it has already been achieved. The costs and effort associated with preventing the proliferation in the first place will invariably be much lower. The BN allows the analyst to predict the reduction in the proliferation probability due to these plans. The decision maker can then use the expected costs and proliferation reduction probabilities for each scenario to conduct a comparison between alternatives. The results of this decision-making analysis will help guide difficult decisions and maximize the effectiveness of effort in high consequence situations.

Over time this methodology can be improved and informed with more precise variable inputs, expert opinion, and structural modifications based upon historical data. As the precision of the methodology improves, it can also be applied to more countries. If the methodology is precise enough, an analysis of these results may yield some universal correlations regarding how major proliferation decisions are made. For instance, if a correlation can be found between a certain threshold probability value for the proliferation probability and the incidence of a proliferation decision, then we have found some universal trigger point to monitor. The Bayesian analysis should also eventually reveal threshold values for certain contributing factors as well. This analysis will provide vital information about what conditions lead to proliferation activities. This will not only provide targets for intelligence gathering, but for policy interventions as well. The decision maker will be able to direct scare resources against the particular contributing factors that matter most and that are approaching the threshold values.

## 6.1 Contingency Planning

If a proliferation crisis occurs, a decision maker will have to make informed choices about how to deal with the problem, and may have little time to act. Contingency planning allows for the same types of decisions to be made in non-crisis situations using hypothetical problems. The information gained from the Bayesian analysis can be used to recommend possible approaches to these problems of proliferation in the country of interest.

After the analysis, we know what the probability is that the state is proliferating, as well as which contributing factors are playing the most significant role in determining that likelihood. Once the most significant factors are determined, the analyst can consult the literature for the theory of proliferation (Chapter III) that is most applicable. Once this is determined, solutions can be developed that fit the theoretical framework that best explains the problem situation. Once the operational scenario is developed to target the specific contributing factors, the expected outcomes can be framed probabilistically. The scenario can then be used as an additional input into the BN to determine the range of expected effects on the overall proliferation probability; in essence, to what degree the proposed solution fixes the problem.

Should these contingency plans ever be put into use, the analyst can conduct a post evidence analysis to see if the predicted consequences in fact occurred. The analyst can compare the post-event evidence to the expected outcomes derived from the contingency planning and determine if there were faults in the assumptions or if the analysis was flawed. The analyst can use the comparison to determine why the network-predicted outcomes were different and how to improve the analysis.

### 6.1.1 Theory-Based Solutions

Determining which solutions will work for a particular country require both the knowledge provided by the Bayesian analysis and a firm grounding in the theories of proliferation in Chapter III. As I described in that chapter, there are numerous perspectives in the International Relations realm, but no single theory or model is able to explain the proliferation tendencies of all countries. This lack of a universal theory of proliferation requires a tailored approach to each situation. In most instances, there will be more than one significant contributing factor that is driving proliferation. Any contingency plan to mitigate the risk in that country will need to address them all. In some instances, this will require solutions using a combination of approaches and even application of different schools of thought at different levels of analysis.

For instance, if National Security is the sole leading contributing factor, then the problem may be examined using a strictly realist approach. Possible solutions could be bilateral security agreements or regional disarmament initiatives which reduce the threat felt by the country in danger of proliferating. If the most significant cause is a group of elites or a particular leader, then the social theories may yield better results. Intense diplomatic efforts to educate the country's elites about the difficulties and dangers of maintaining a nuclear weapons program may help to destroy the myths about the benefits they envision. In actuality, proliferation is such a complex problem that a mixed approach will probably be required. The Bayesian analysis will help to inform the operational planners which factors matter most, and which solutions form the appropriate balance for the situation.

6.1.2 Determining the Effectiveness of the Solutions

Any scenario developed to prevent or reduce the probability of proliferation will be complex and will contain some uncertainty in its effectiveness. Operational plans will contain an expected chance of success or failure, and may even contain benchmarks for 'partial successes'. As part of the planning process each scenario should include a range of likely outcomes with probabilities for each. The analysts can use these contingency plans to form an input into the BN and measure its influence on the outcome of proliferation probability.

As with the Evidence inputs, the probabilities developed by the operational planners reflecting the expected outcome of the plan can be translated into Influence Node inputs. The operational plan's most likely and least likely outcomes can be used to build the probability values for the influence node. An example influence node is shown with a portion of the BN in Figure 6.1. In this example, an analyst determines that an external rivalry is the most significant contributing factor leading to proliferation. In order to mitigate this factor, operational planners determine that a brokered peace negotiation between the two rival countries is the best way to help reduce the impact of this rivalry. The operation plan is developed and the analyst uses the information to assign probability values to the influence node. When the node is inserted into the BN, the expected effect on the overall probability can be measured.

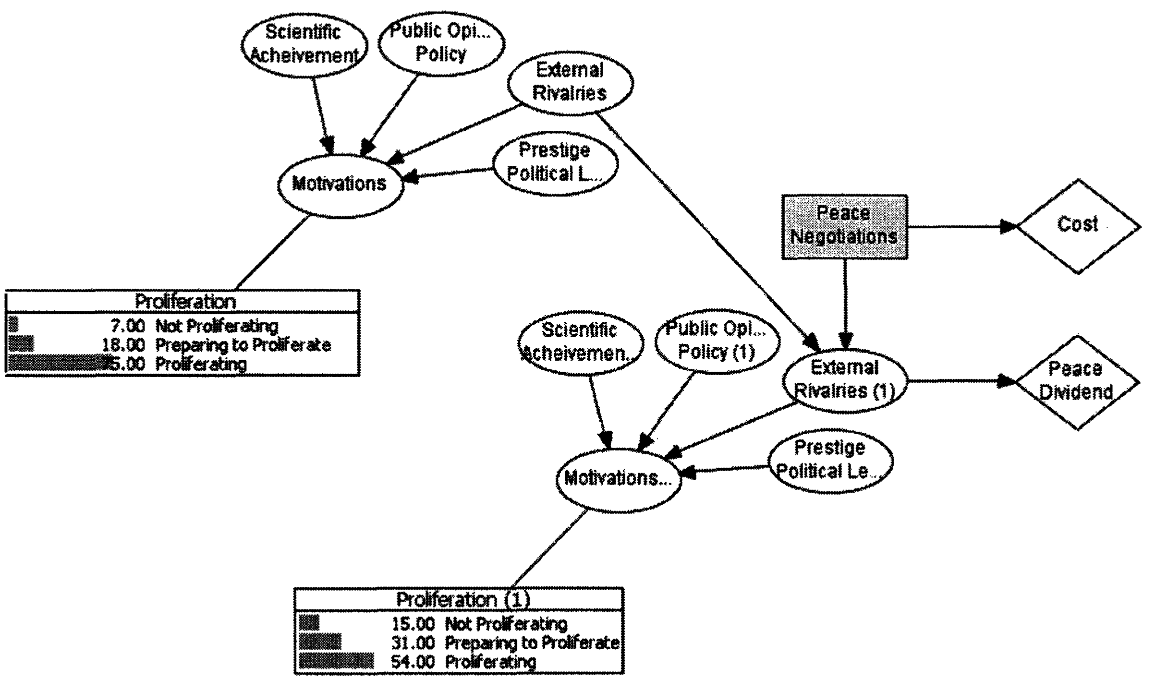


Figure 6.1 Single Influence Node Input into BN

As stated above however, solutions will rarely be this simple. They will probably include multiple influence nodes acting on multiple contributing factors. This complicates the planning process, but is relatively simple to integrate in to the BN. Further complications arise however, when the analyst must account for second or third order effects of the solutions. Unanticipated negative externalities are a consequence of any complex process. Mapping these effects in a situation as politically charged and vitally important as nonproliferation becomes essential to evaluating the true effectiveness of an operational plan. For example, if the Bayesian analysis determines that a country's economic and technical capacity are the main factors allowing it to pursue a weapons program, then sanctions will have a positive effect by reducing that capacity. They will put a strain on the economy, requiring resources to be directed to sectors other than the nuclear program and may reduce the availability of vital technical components and training.

These are only the simple first order effects of sanctions however. There are other consequences that may actually increase the likelihood of proliferation. As we saw in the case of Iran, sanctions did reduce their capacity to pursue a weapons program, but it also increased their isolation from the world community. This resulted in a decrease in our intelligence gathering capability, and heightened Iran's concerns about security. The end result was an increase in the probability that they were pursuing a nuclear weapons program.

In order to map these second and third order effects, the influence nodes included for each operation plan should link not only to their primary contributing factor, but to all factors that they will affect. This will serve to increase the complexity of the BN, but will give much more accurate results of the overall effect on proliferation. An example network with multiple influence nodes is shown in Figure 6.2.

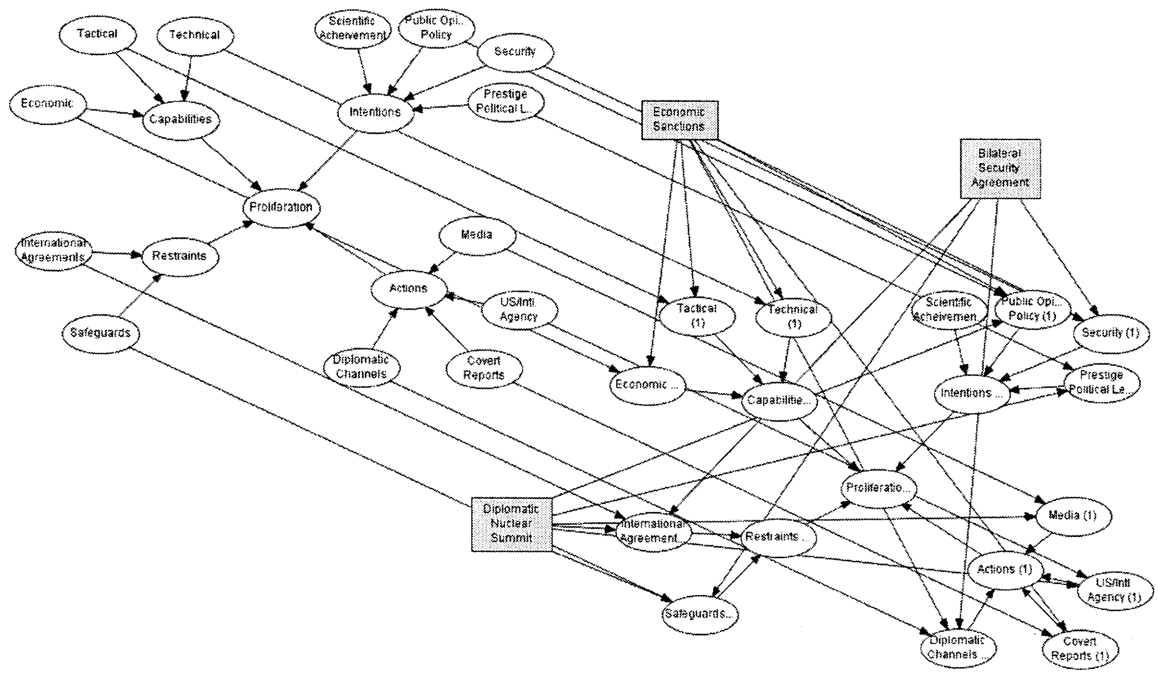


Figure 6.2 BN with Multiple Influence Nodes

## 6.2 Decision Making

As we have just seen, when the solutions don't match up correctly with the contributing factors, a decision maker may make the problem worse. Preventative wars may temporarily destroy a country's nuclear infrastructure and technical capacity, but will inevitably heighten security concerns. We have also seen in North Korea how an obstinate elite can let their population starve while continuing to pour resources into a nuclear program. Once the analyst has determined the expected effects of an operational scenario using the BN, the results can be utilized to compare the scenario against other plans to determine which provides the most effective results for the least cost in blood and treasure. Should there be competing plans, each can be entered separately into the BN to determine which would be more effective. This allows the decision maker to take the results from the BN and use them as inputs to various decision making tools.

This analysis can be accomplished as a part of contingency planning well before any crisis develops. This has the benefit of reducing the time needed to make quick decisions in pressure situations and makes sure that as many factors as possible are taken in to account. This results in informed decisions, which have the highest probability of returning positive results. The decision maker can utilize the information gained from these results to provide inputs to a larger decision making analysis. There are a number of decision making tools available to compare potential solutions. Some examples are Cost-Benefit Analysis, Decision Analysis, or Probabilistic Risk Assessments.

# VII CONCLUSION

The immediate goal of this work was to develop an analytical system that integrates disparate information about a nation to provide a real time unbiased probability of the risk of proliferation and to determine the factors driving proliferation in the country of interest with the ultimate goal of providing decision makers with a tool to prevent or mitigate the consequences of proliferation. In this respect, this immediate goal was successfully satisfied. The network was created from the causal linkages described in proliferation literature, forming a solid theoretical basis for the structure. The historical evidence used to establish the probability tables in the networks ensured that they were tailored to study the particular country. The results derived from this study indicate that Bayesian Networks are a useful tool to monitor the probability of proliferation in a particular country and to provide decision makers with information regarding the factors contributing to proliferation decisions. The networks provide a means to aggregate and organize a variety of information in a consistent manner. This is particularly useful when applied to a problem like proliferation due to the complexity and the multitude of causal chains.

The results obtained from the Bayesian analysis show the possible utility of the method, but also indicate that it can be improved. The study was limited by my limited expertise and by my lack of access to non-open source information. The relative weights formed the quantitative structure of the network, but were assigned based on my reading of the significant historic events that affected the case study countries. I also interpreted the NTI database based on a set of criteria that was informed by the literature review, but not created by an established expert in proliferation.

If the study had the benefit of more time and funding, I could have conducted surveys of subject matter experts in the numerous fields that informed the network. This could include country specialists, IAEA inspectors, historians, economists, and nuclear scientists, as well as experts in proliferation from the IR, foreign policy, and cognitive psychology fields. Most aspects of the structure of the network and the criteria for interpreting the event data could be improved through inclusion of this expert experience. The constraint of remaining in the public domain also necessitates a limited scope. If this methodology was applied in a setting without limits regarding the classification of information, the results would be more accurate. The end result is that the network works as intended, but is only as good as the inputs. Further work in this area should focus on these easy methods of improvement.

I expect with further applications of the methodology, some changes to the network will be warranted. This may take the form of reevaluating the list of contributing factors, or even adding or deleting factor groups. For instance Scientific/Technical Achievement contributing factor may be a relic of only the original nuclear powers and not have any use in evaluating potential proliferators in the modern era. Likewise, the burgeoning fields of political psychology may lead to a disaggregation of the domestic opinion/ public policy factor into nodes that consider psychological factors, bureaucratic factors, public norms and values, etc.

The value of the network is that is forms a consistent and cohesive tool to formulate recommendations to a decision maker. The probabilities returned are consistent with expert recommendations but can account for a much larger quantity and type of evidence than conventional methods. The network also permits analysis of a wide variety of contingency planning that will be invaluable to policy planners and counter proliferation officials. When the network is improved with the input of the appropriate experts, it can make a large contribution to efforts to prevent proliferation.

APPENDIX A: Event Categorization Criteria

The Bayesian network requires the input of subjective analyses of qualitative data to help determine the overall proliferation risk of a particular country. The analyst must use a set of criteria or rules to integrate new events in order to keep the data entry consistent and to eliminate or reduce bias over time. The criteria must remain somewhat general in order to remain applicable to the wide range of possible event that may occur. They should serve as guidelines for the analyst so that they can remain internally consistent in how they treat new data. In the end, the analyst must make a judgment as to how the particular event affects the values of the marginal probability table. The network is designed to reflect the cumulative effect of these small judgments to produce an overall belief in the proliferation status of the country. The following is an example of a checklist or guideline an analyst may follow when entering new events into the Bayesian network. The analyst can determine which state in the marginal probability table will increase in probability based on the answer to the questions (i.e. N/P/D). This document should be created for each network and may grow in sophistication over time. If significant changes are made however, the network will have to be reinitialized to reflect the changes and to ensure the data is treated consistently.

Does the Event-

-Directly enhance the ability of the country to reprocess or enrich fuel without safeguards?

| | |
|---|---|
| - Purchase of single use prohibited equipment | D |
| - Purchase of dual use prohibited equipment | D |
| - Construction of enrichment or reprocessing facility | D |
| - Assistance in construction of an enrichment or reprocessing facility | D |

-Indirectly enhance the ability of the country to reprocess or enrich fuel without safeguards?

| | |
|---|---|
| - Training of scientists and engineers | P |
| - Purchase or production of unsafeguarded fuel | P |
| - Purchase or production of Heavy Water | P |
| - Economically unnecessary pursuit of nuclear power program | P |
| - Construction or assistance in constructing proliferation friendly power plants | P |

- Reflect a desire to not enrich or reprocess fuel?

| | |
|---|---|
| - Construction or assistance in construction of proliferation resistant power plants | N |
| - Use of strongly safeguarded fuel | N |
| - Participation in fuel buy-back program, etc. | N |

## APPENDIX A: Event Categorization Criteria

- Make a public statement of a nation's intentions?

| | |
|---|---|
| - Agreement to participate in international non proliferation agreements | N |
| - Government official statements of desire to proliferate | D |
| - Public statements of government officials against proliferation | N |
| - Government policy against proliferation | N |

- Reflect a change in the global or regional political balance?

| | |
|---|---|
| - A regional neighbor threatens attack | D |
| - A regional competitor proliferates | D |
| - A nation seeks to gain prestige or political leverage | P |
| - A nation seeks to gain prestige or political leverage through proliferation | D |
| - A nation seeks to gain or maintain scientific or technical superiority | P |
| - A nation seeks to gain or maintain scientific or technical superiority through proliferation activities | D |
| - A regional competitor gains an economic/political/military advantage | P |
| - A regional competitor disarms or signs peace agreements | N |
| - A nation modifies its behavior based on sanctions other pressure | N |

- Reflect direct reports about a nation's intentions or capabilities?

| | |
|---|---|
| - A reliable US agency reports proliferation activities | D |
| - A reliable US agency reports dual explanation activities | P |
| - A reliable diplomatic source reports proliferation act. | D |
| - A diplomatic source reports proliferation activities | P |
| - Media reports proliferation activities | D/P/N |
| - Other external agencies report proliferation activities | D/P/N |

- Reflect a nation's capability to fund a nuclear proliferation program?

| | |
|---|---|
| - A nation commits threshold funds for a nuclear program | P |
| - A nation budgets money in excess of that required for nuclear power or research program | D |
| - A nation scales back spending or has budget cuts in nuclear program | N |

APPENDIX B: Yearly Evidence Node Probability Values India

This appendix is the summary of the yearly marginal probability tables for the analysis of India. They reflect the changes made over time based on the events from the NTI database. The last two columns are the results of the network runs for each year reflecting the overall proliferation probability based on the values in each of the MPTs for each node and the CPTs for the rest of the network nodes. The two columns show the difference with the evidence nodes weighted equally (i.e. neutral CPTs) and with the appropriate relative weights entered (i.e. CPTs tailored for India).

# APPENDIX B: Yearly Evidence Node Probability Values India

| | National Security vs. External Threats | | | Scientific/ Technical Achievement | | | National Prestige/ Political Leverage | | | Domestic Opinion/ Policy | | | Technical Capability | | | Economic Capability | | | Tactical Capability | | | International Agreements | | | Controls/ Safeguards | | | Proiliferation Equal Weights | | | Proiliferation Relative Weights | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| 1946 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 48.48 | 9.59 | 41.93 | 58.15 | 11.33 | 30.52 |
| 1947 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 43.57 | 12.85 | 43.59 | 54.21 | 13.94 | 31.85 |
| 1948 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 43.57 | 12.85 | 43.59 | 54.21 | 13.94 | 31.85 |
| 1949 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 25 | 35 | 40 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 43.01 | 11.74 | 45.26 | 53.54 | 12.61 | 33.85 |
| 1950 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 25 | 35 | 40 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 43.01 | 11.74 | 45.26 | 53.54 | 12.61 | 33.85 |
| 1951 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 25 | 35 | 40 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 43.01 | 11.74 | 45.26 | 53.54 | 12.61 | 33.85 |
| 1952 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 40 | 40 | 20 | 99 | 0.9 | 0.1 | 15 | 40 | 45 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 36.98 | 15.55 | 47.47 | 48.28 | 15.88 | 35.84 |
| 1953 | 99 | 0.9 | 0.1 | 40 | 40 | 20 | 40 | 40 | 20 | 95 | 4 | 1 | 15 | 40 | 45 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 38.29 | 17.32 | 44.38 | 48.47 | 17.41 | 34.12 |
| 1954 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 20 | 40 | 40 | 95 | 4 | 1 | 15 | 40 | 45 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 35.79 | 17.74 | 46.47 | 46.47 | 17.74 | 35.79 |
| 1955 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 20 | 40 | 40 | 95 | 4 | 1 | 15 | 40 | 45 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 35.79 | 17.74 | 46.47 | 46.47 | 17.74 | 35.79 |
| 1956 | 99 | 0.9 | 0.1 | 30 | 45 | 25 | 20 | 40 | 40 | 95 | 4 | 1 | 15 | 40 | 45 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 35.79 | 17.74 | 46.47 | 46.47 | 17.74 | 35.79 |
| 1957 | 99 | 0.9 | 0.1 | 30 | 30 | 40 | 20 | 40 | 40 | 95 | 4 | 1 | 10 | 40 | 50 | 10 | 35 | 55 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 35.24 | 16.49 | 48.27 | 45.8 | 16.74 | 37.46 |
| 1958 | 99 | 0.9 | 0.1 | 30 | 30 | 40 | 20 | 40 | 40 | 95 | 4 | 1 | 10 | 40 | 50 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 35.23 | 14.27 | 50.5 | 45.8 | 14.07 | 40.13 |
| 1959 | 89.9 | 10 | 0.1 | 30 | 30 | 40 | 20 | 40 | 40 | 95 | 4 | 1 | 10 | 40 | 50 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 34.48 | 15.03 | 50.5 | 45.2 | 14.68 | 40.13 |
| 1960 | 89.9 | 10 | 0.1 | 30 | 30 | 40 | 10 | 40 | 50 | 95 | 4 | 1 | 10 | 40 | 50 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 33.64 | 15.02 | 51.33 | 44.53 | 14.68 | 40.79 |
| 1961 | 89.9 | 10 | 0.1 | 30 | 30 | 40 | 10 | 40 | 50 | 90 | 5 | 5 | 10 | 40 | 50 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 33.23 | 15.11 | 51.67 | 43.53 | 14.88 | 41.59 |
| 1962 | 65 | 20 | 15 | 30 | 30 | 40 | 10 | 35 | 55 | 90 | 5 | 5 | 10 | 35 | 55 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 10 | 80 | 0.1 | 0.9 | 99 | 31.15 | 14.97 | 53.88 | 49.82 | 15.64 | 34.54 |
| 1963 | 65 | 20 | 15 | 30 | 30 | 40 | 10 | 35 | 55 | 90 | 5 | 5 | 10 | 35 | 55 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 30 | 60 | 0.1 | 0.9 | 99 | 31.15 | 18.3 | 50.55 | 49.82 | 16.89 | 33.29 |
| 1964 | 35 | 25 | 40 | 10 | 25 | 65 | 10 | 25 | 65 | 75 | 5 | 20 | 5 | 35 | 60 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 30 | 60 | 0.1 | 0.9 | 99 | 25.17 | 17.47 | 57.36 | 38.25 | 16.44 | 45.3 |
| 1965 | 15 | 30 | 55 | 10 | 25 | 65 | 10 | 25 | 65 | 75 | 5 | 20 | 5 | 35 | 60 | 10 | 15 | 75 | 99 | 0.9 | 0.1 | 10 | 30 | 60 | 0.1 | 0.9 | 99 | 23.51 | 17.88 | 58.61 | 34.68 | 17.34 | 47.98 |
| 1966 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 55 | 15 | 30 | 5 | 35 | 60 | 20 | 15 | 65 | 99 | 0.9 | 0.1 | 10 | 30 | 60 | 10 | 15 | 75 | 23.77 | 21.07 | 55.16 | 25.2 | 21.22 | 53.59 |
| 1967 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 55 | 15 | 30 | 5 | 35 | 60 | 20 | 15 | 65 | 99 | 0.9 | 0.1 | 10 | 15 | 75 | 10 | 15 | 75 | 23.77 | 18.57 | 57.66 | 25.2 | 18.97 | 55.84 |
| 1968 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 55 | 15 | 30 | 5 | 25 | 70 | 20 | 15 | 65 | 99 | 0.9 | 0.1 | 10 | 15 | 75 | 10 | 15 | 75 | 23.77 | 17.46 | 58.77 | 25.2 | 18.3 | 56.5 |
| 1969 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 55 | 15 | 30 | 5 | 25 | 70 | 20 | 15 | 65 | 99 | 0.9 | 0.1 | 10 | 15 | 75 | 10 | 15 | 75 | 23.77 | 17.46 | 58.77 | 25.2 | 18.3 | 56.5 |
| 1970 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 25 | 20 | 55 | 5 | 25 | 70 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 10 | 15 | 75 | 14.71 | 21.1 | 64.18 | 14.83 | 21.31 | 63.85 |
| 1971 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 25 | 20 | 55 | 5 | 25 | 70 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 15.55 | 24.44 | 60.01 | 15.58 | 24.31 | 60.1 |
| 1972 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 10 | 15 | 75 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 14.3 | 22.91 | 62.79 | 12.37 | 22.57 | 65.06 |
| 1973 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 25 | 65 | 10 | 15 | 75 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 14.3 | 22.91 | 62.79 | 12.37 | 22.57 | 65.06 |
| 1974 | 5 | 30 | 65 | 10 | 25 | 65 | 10 | 15 | 75 | 10 | 15 | 75 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 14.3 | 22.08 | 63.63 | 12.37 | 21.86 | 65.77 |
| 1975 | 20 | 30 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 10 | 15 | 75 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 15.55 | 22.08 | 62.38 | 14.51 | 21.86 | 63.63 |
| 1976 | 20 | 30 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 10 | 15 | 75 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 15 | 35 | 50 | 15.55 | 22.08 | 62.38 | 14.51 | 21.86 | 63.63 |
| 1977 | 20 | 30 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 15 | 25 | 60 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 10 | 45 | 45 | 15.13 | 24.58 | 60.29 | 14.83 | 25.5 | 59.66 |
| 1978 | 20 | 30 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 15 | 25 | 60 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 10 | 45 | 45 | 15.13 | 24.58 | 60.29 | 14.83 | 25.5 | 59.66 |
| 1979 | 5 | 45 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 15 | 25 | 60 | 5 | 15 | 80 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 10 | 45 | 45 | 13.88 | 25.83 | 60.29 | 12.69 | 27.65 | 59.66 |
| 1980 | 5 | 45 | 50 | 10 | 25 | 65 | 10 | 15 | 75 | 5 | 15 | 80 | 5 | 10 | 85 | 10 | 15 | 75 | 50 | 30 | 20 | 10 | 15 | 75 | 10 | 45 | 45 | 13.05 | 24.44 | 62.52 | 10.55 | 25.17 | 64.28 |
| 1981 | 5 | 35 | 60 | 10 | 20 | 70 | 10 | 15 | 75 | 10 | 30 | 60 | 5 | 7 | 88 | 5 | 10 | 85 | 45 | 30 | 25 | 10 | 10 | 80 | 10 | 45 | 45 | 12.35 | 22.71 | 64.93 | 10.95 | 25.31 | 63.73 |
| 1982 | 5 | 35 | 60 | 10 | 20 | 70 | 10 | 15 | 75 | 10 | 30 | 60 | 5 | 7 | 88 | 5 | 10 | 85 | 40 | 30 | 30 | 10 | 10 | 80 | 10 | 50 | 40 | 11.8 | 23.55 | 64.66 | 10.62 | 26.06 | 63.32 |
| 1983 | 5 | 35 | 60 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 30 | 60 | 5 | 7 | 88 | 5 | 10 | 85 | 40 | 30 | 30 | 10 | 10 | 80 | 10 | 50 | 40 | 11.8 | 23.13 | 65.07 | 10.62 | 25.71 | 63.67 |
| 1984 | 5 | 35 | 60 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 30 | 60 | 5 | 5 | 90 | 5 | 10 | 85 | 35 | 30 | 35 | 10 | 10 | 80 | 10 | 45 | 45 | 11.24 | 22.07 | 66.68 | 10.29 | 24.82 | 64.89 |
| 1985 | 5 | 30 | 65 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 35 | 30 | 35 | 10 | 10 | 80 | 10 | 45 | 45 | 11.24 | 23.05 | 65.71 | 10.29 | 26.58 | 63.13 |
| 1986 | 5 | 30 | 65 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 35 | 30 | 35 | 10 | 10 | 80 | 10 | 45 | 45 | 11.24 | 23.05 | 65.71 | 10.29 | 26.58 | 63.13 |
| 1987 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1988 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1989 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1990 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1991 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1992 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1993 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 40 | 50 | 5 | 5 | 90 | 5 | 15 | 80 | 25 | 35 | 40 | 5 | 10 | 85 | 10 | 45 | 45 | 9.3 | 23.18 | 67.52 | 8.87 | 26.2 | 64.93 |
| 1994 | 5 | 25 | 70 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 30 | 60 | 5 | 5 | 90 | 5 | 15 | 80 | 15 | 30 | 55 | 5 | 10 | 85 | 10 | 50 | 40 | 8.19 | 22.63 | 69.18 | 8.2 | 24.48 | 67.32 |
| 1995 | 5 | 20 | 75 | 10 | 20 | 70 | 10 | 10 | 80 | 10 | 25 | 65 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 5 | 10 | 85 | 15 | 50 | 35 | 8.69 | 21.02 | 70.29 | 8.75 | 22.23 | 69.02 |
| 1996 | 5 | 20 | 75 | 10 | 20 | 70 | 5 | 10 | 85 | 10 | 15 | 75 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 5 | 5 | 90 | 15 | 50 | 35 | 8.27 | 19.35 | 72.38 | 8.4 | 19.33 | 72.27 |
| 1997 | 5 | 15 | 80 | 10 | 15 | 75 | 5 | 10 | 85 | 10 | 15 | 75 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 5 | 5 | 90 | 15 | 45 | 35 | 8.4 | 18.08 | 73.52 | 8.51 | 17.87 | 73.62 |
| 1998 | 5 | 10 | 85 | 10 | 15 | 75 | 5 | 5 | 90 | 5 | 15 | 80 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 5 | 5 | 90 | 15 | 45 | 35 | 7.99 | 17.25 | 74.77 | 7.44 | 16.8 | 75.76 |
| 1999 | 5 | 25 | 70 | 10 | 15 | 75 | 5 | 5 | 90 | 10 | 25 | 65 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 10 | 15 | 75 | 15 | 45 | 35 | 9.24 | 21 | 69.77 | 9.26 | 22.58 | 68.15 |
| 2000 | 5 | 25 | 70 | 10 | 15 | 75 | 5 | 5 | 90 | 10 | 25 | 65 | 2 | 3 | 95 | 5 | 15 | 80 | 15 | 25 | 60 | 10 | 15 | 75 | 15 | 45 | 35 | 9.24 | 21 | 69.77 | 9.26 | 22.58 | 68.15 |

APPENDIX C: Yearly Evidence Node Probability Values Iran

This appendix is the summary of the yearly marginal probability tables for the analysis of Iran. They reflect the changes made over time based on the events from the NTI database. Figure 5.4 shows the trendline results of the network runs for each year reflecting the overall proliferation probability based on the values in each of the MPTs for each node and the CPTs for the rest of the network nodes.

APPENDIX C: Yearly Evidence Node Probability Values Iran

| | National Security vs. External Threats | | | Scientific/ Technical Acheivement | | | National Prestige/ Political Leverage | | | Domestic Opinion/ Policy | | | Technical Capability | | | Economic Capability | | | Tactical Capability | | | International Agreements | | | Controls/ Safeguards | | | Covert Reports | | | US/Intl. Agency Reports | | | Media Print Journals Open Source Events | | | Diplomatic Channels 3d Country Officials | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| 1946 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 91 | 7 | 2 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1947 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 91 | 7 | 2 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1948 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 91 | 7 | 2 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1949 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 89 | 8 | 3 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1950 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 89 | 8 | 3 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1951 | 93 | 5 | 2 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 89 | 8 | 3 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1952 | 93 | 5 | 2 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 89 | 8 | 3 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1953 | 90 | 7 | 3 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 87 | 9 | 4 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1954 | 90 | 7 | 3 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 87 | 9 | 4 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1955 | 90 | 7 | 3 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 87 | 9 | 4 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1956 | 90 | 7 | 3 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 85 | 10 | 5 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1957 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 70 | 29 | 1 | 85 | 10 | 5 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1958 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 70 | 29 | 1 | 85 | 10 | 5 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1959 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 70 | 29 | 1 | 84 | 11 | 5 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1960 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 70 | 29 | 1 | 83 | 11 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1961 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 83 | 11 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1962 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 83 | 11 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1963 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 82 | 12 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1964 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 82 | 12 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1965 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 82 | 12 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1966 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 69 | 30 | 1 | 81 | 13 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1967 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 65 | 32 | 3 | 81 | 13 | 6 | 99 | 0.9 | 0.1 | 0.1 | 0.9 | 99 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1968 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 65 | 32 | 3 | 80 | 13 | 7 | 99 | 0.9 | 0.1 | 70 | 25 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1969 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 65 | 32 | 3 | 79 | 14 | 7 | 99 | 0.9 | 0.1 | 70 | 25 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1970 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 65 | 32 | 3 | 77 | 15 | 8 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1971 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 97 | 2 | 1 | 65 | 32 | 3 | 74 | 17 | 9 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1972 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 90 | 9 | 1 | 45 | 35 | 20 | 72 | 19 | 9 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1973 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 90 | 9 | 1 | 45 | 35 | 20 | 69 | 21 | 10 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 0.1 | 0.9 | 99 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1974 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 80 | 15 | 5 | 32 | 38 | 30 | 62 | 25 | 13 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1975 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 82 | 15 | 3 | 30 | 38 | 32 | 61 | 26 | 13 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 99 | 0.9 | 0.1 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1976 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 82 | 15 | 3 | 30 | 38 | 32 | 46 | 37 | 17 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 99 | 0.9 | 0.1 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1977 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 82 | 15 | 3 | 30 | 38 | 32 | 47 | 36 | 17 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 99 | 0.9 | 0.1 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1978 | 90 | 7 | 3 | 97 | 2 | 1 | 99 | 0.9 | 0.1 | 85 | 12 | 3 | 28 | 40 | 32 | 50 | 34 | 16 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 55 | 30 | 15 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1979 | 60 | 30 | 10 | 97 | 2 | 1 | 65 | 20 | 15 | 85 | 12 | 3 | 35 | 35 | 30 | 44 | 38 | 18 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 55 | 30 | 15 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1980 | 60 | 30 | 10 | 97 | 2 | 1 | 65 | 20 | 15 | 80 | 15 | 5 | 35 | 35 | 30 | 45 | 37 | 18 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1981 | 60 | 30 | 10 | 97 | 2 | 1 | 65 | 20 | 15 | 80 | 15 | 5 | 35 | 35 | 30 | 48 | 35 | 17 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1982 | 40 | 40 | 20 | 97 | 2 | 1 | 65 | 20 | 15 | 80 | 15 | 5 | 35 | 35 | 30 | 44 | 38 | 18 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1983 | 40 | 40 | 20 | 97 | 2 | 1 | 65 | 20 | 15 | 80 | 15 | 5 | 35 | 35 | 30 | 35 | 44 | 21 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 99 | 0.9 | 0.1 | 99 | 0.9 | 0.1 |
| 1984 | 30 | 45 | 25 | 97 | 2 | 1 | 65 | 20 | 15 | 80 | 15 | 5 | 33 | 37 | 30 | 33 | 45 | 22 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 60 | 25 | 15 | 99 | 0.9 | 0.1 |
| 1985 | 30 | 45 | 25 | 97 | 2 | 1 | 65 | 20 | 15 | 65 | 20 | 15 | 30 | 40 | 30 | 35 | 44 | 21 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 60 | 25 | 15 | 99 | 0.9 | 0.1 |
| 1986 | 30 | 45 | 25 | 97 | 2 | 1 | 65 | 20 | 15 | 65 | 20 | 15 | 28 | 42 | 30 | 45 | 38 | 18 | 99 | 0.9 | 0.1 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 98 | 1 | 1 | 60 | 25 | 15 | 99 | 0.9 | 0.1 |
| 1987 | 30 | 45 | 25 | 97 | 2 | 1 | 65 | 20 | 15 | 50 | 20 | 30 | 25 | 44 | 31 | 46 | 37 | 17 | 50 | 30 | 20 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 90 | 5 | 5 | 54 | 26 | 20 | 99 | 0.9 | 0.1 |
| 1988 | 30 | 30 | 40 | 97 | 2 | 1 | 65 | 20 | 15 | 30 | 30 | 40 | 23 | 46 | 31 | 52 | 33 | 15 | 50 | 30 | 20 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 90 | 5 | 5 | 53 | 27 | 20 | 99 | 0.9 | 0.1 |
| 1989 | 30 | 30 | 40 | 97 | 2 | 1 | 65 | 20 | 15 | 30 | 30 | 40 | 20 | 48 | 32 | 51 | 33 | 16 | 50 | 30 | 20 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 90 | 5 | 5 | 53 | 27 | 20 | 99 | 0.9 | 0.1 |
| 1990 | 30 | 30 | 40 | 97 | 2 | 1 | 65 | 20 | 15 | 30 | 30 | 40 | 18 | 50 | 32 | 44 | 38 | 18 | 45 | 35 | 20 | 75 | 20 | 5 | 50 | 20 | 30 | 50 | 32 | 18 | 55 | 20 | 25 | 51 | 28 | 21 | 99 | 0.9 | 0.1 |
| 1991 | 30 | 30 | 40 | 45 | 40 | 15 | 65 | 20 | 15 | 30 | 30 | 40 | 16 | 52 | 32 | 35 | 43 | 22 | 35 | 40 | 25 | 75 | 20 | 5 | 50 | 20 | 30 | 20 | 45 | 35 | 40 | 35 | 25 | 35 | 33 | 32 | 70 | 20 | 10 |
| 1992 | 30 | 30 | 40 | 45 | 40 | 15 | 55 | 25 | 20 | 40 | 30 | 30 | 15 | 53 | 32 | 29 | 47 | 24 | 30 | 40 | 30 | 75 | 20 | 5 | 50 | 20 | 30 | 17 | 48 | 35 | 42 | 38 | 20 | 32 | 33 | 35 | 70 | 20 | 10 |
| 1993 | 20 | 35 | 45 | 45 | 40 | 15 | 55 | 25 | 20 | 40 | 35 | 25 | 14 | 54 | 32 | 22 | 52 | 26 | 30 | 40 | 30 | 75 | 20 | 5 | 50 | 20 | 30 | 16 | 49 | 35 | 42 | 42 | 16 | 29 | 33 | 38 | 55 | 30 | 15 |
| 1994 | 20 | 35 | 45 | 45 | 40 | 15 | 55 | 25 | 20 | 40 | 35 | 25 | 10 | 56 | 34 | 21 | 53 | 26 | 28 | 42 | 30 | 75 | 20 | 5 | 60 | 20 | 20 | 15 | 50 | 35 | 40 | 42 | 18 | 29 | 33 | 38 | 50 | 35 | 15 |
| 1995 | 18 | 37 | 45 | 45 | 40 | 15 | 55 | 25 | 20 | 45 | 35 | 20 | 10 | 55 | 35 | 24 | 50 | 26 | 28 | 42 | 30 | 75 | 20 | 5 | 60 | 20 | 20 | 13 | 50 | 37 | 42 | 40 | 18 | 29 | 33 | 38 | 55 | 30 | 15 |
| 1996 | 18 | 37 | 45 | 40 | 45 | 15 | 55 | 25 | 20 | 45 | 35 | 20 | 9 | 56 | 35 | 21 | 52 | 27 | 25 | 45 | 30 | 79 | 18 | 3 | 45 | 30 | 25 | 13 | 48 | 39 | 45 | 38 | 17 | 25 | 35 | 40 | 55 | 30 | 15 |
| 1997 | 18 | 39 | 43 | 40 | 45 | 15 | 53 | 27 | 20 | 45 | 40 | 15 | 15 | 57 | 28 | 23 | 51 | 26 | 25 | 47 | 28 | 79 | 18 | 3 | 50 | 30 | 20 | 13 | 48 | 39 | 50 | 35 | 15 | 25 | 37 | 38 | 50 | 35 | 15 |
| 1998 | 16 | 40 | 44 | 40 | 45 | 15 | 53 | 27 | 20 | 45 | 45 | 10 | 15 | 60 | 25 | 23 | 51 | 26 | 24 | 50 | 26 | 79 | 18 | 3 | 50 | 30 | 20 | 13 | 48 | 39 | 50 | 40 | 10 | 24 | 38 | 38 | 51 | 34 | 15 |
| 1999 | 16 | 40 | 44 | 37 | 48 | 15 | 53 | 27 | 20 | 45 | 45 | 10 | 14 | 62 | 24 | 16 | 55 | 29 | 22 | 52 | 26 | 79 | 18 | 3 | 50 | 30 | 20 | 13 | 48 | 39 | 50 | 40 | 10 | 24 | 40 | 36 | 51 | 34 | 15 |
| 2000 | 15 | 45 | 40 | 37 | 48 | 15 | 53 | 27 | 20 | 45 | 45 | 10 | 18 | 60 | 22 | 12 | 58 | 30 | 22 | 52 | 26 | 79 | 18 | 3 | 50 | 30 | 20 | 10 | 55 | 35 | 50 | 40 | 10 | 24 | 42 | 34 | 51 | 34 | 15 |
| 2001 | 15 | 45 | 40 | 35 | 50 | 15 | 53 | 27 | 20 | 45 | 45 | 10 | 18 | 60 | 22 | 11 | 59 | 30 | 22 | 50 | 28 | 65 | 30 | 5 | 50 | 30 | 20 | 10 | 52 | 38 | 48 | 42 | 10 | 24 | 40 | 36 | 51 | 34 | 15 |
| 2002 | 15 | 43 | 42 | 35 | 50 | 15 | 53 | 27 | 20 | 45 | 45 | 10 | 22 | 56 | 22 | 5 | 63 | 32 | 22 | 50 | 28 | 65 | 30 | 5 | 55 | 30 | 15 | 10 | 52 | 38 | 45 | 45 | 10 | 24 | 41 | 35 | 48 | 35 | 17 |
| 2003 | 15 | 40 | 45 | 35 | 50 | 15 | 50 | 30 | 20 | 50 | 40 | 10 | 20 | 55 | 25 | 3 | 64 | 33 | 20 | 50 | 30 | 65 | 25 | 10 | 55 | 30 | 15 | 10 | 50 | 40 | 40 | 40 | 20 | 23 | 42 | 35 | 40 | 35 | 25 |
| 2004 | 15 | 40 | 45 | 35 | 50 | 15 | 50 | 30 | 20 | 45 | 45 | 10 | 20 | 52 | 28 | 2 | 65 | 33 | 20 | 50 | 30 | 63 | 27 | 10 | 55 | 33 | 12 | 10 | 45 | 45 | 38 | 42 | 20 | 23 | 40 | 37 | 40 | 30 | 30 |
| 2005 | 15 | 35 | 50 | 35 | 45 | 20 | 47 | 33 | 20 | 35 | 55 | 10 | 20 | 51 | 29 | 5 | 63 | 32 | 20 | 50 | 30 | 60 | 25 | 15 | 50 | 35 | 15 | 20 | 45 | 35 | 40 | 40 | 20 | 21 | 42 | 37 | 35 | 35 | 30 |
| 2006 | 15 | 35 | 50 | 35 | 50 | 15 | 47 | 33 | 20 | 35 | 55 | 10 | 20 | 50 | 30 | 7 | 62 | 31 | 20 | 50 | 30 | 60 | 25 | 15 | 45 | 40 | 15 | 20 | 40 | 40 | 40 | 35 | 25 | 20 | 40 | 40 | 35 | 35 | 30 |
| 2007 | 15 | 35 | 50 | 35 | 50 | 15 | 47 | 33 | 20 | 35 | 55 | 10 | 20 | 45 | 35 | 8 | 61 | 31 | 20 | 50 | 30 | 55 | 30 | 15 | 48 | 37 | 15 | 20 | 50 | 30 | 35 | 40 | 25 | 20 | 45 | 35 | 35 | 35 | 30 |

## APPENDIX D: Significant Contributing Factors

This appendix is a summary of the results of the analysis of the most significant factors contributing to the proliferation status of Iran in 5-year increments form 1946-2005. This reflects the analysis done by artificially setting the overall probability of proliferation to 100% as if a significant proliferation event had occurred such as a nuclear test. The upper half of the table shows the absolute results of the analysis. The marginal probability table for each contributing factor shows what the probability distribution is as a result of the proliferation event. The lower half of the table is a simple normalization of the probability distributions among the factors in the D state to highlight which factor was relatively most significant in its contribution to the overall result.

APPENDIX D: Significant Contributing Factors

| | National Security vs. External Threats | | | Scientific/ Technical Achievement | | | National Prestige/ Political Leverage | | | Domestic Opinion/ Policy | | | Technical Capability | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| 1950 | 98.93 | 0.90 | 0.17 | 98.95 | 0.90 | 0.15 | 98.95 | 0.90 | 0.15 | 98.97 | 0.90 | 0.13 | 98.90 | 0.90 | 0.20 |
| 1955 | 88.20 | 6.86 | 4.94 | 98.95 | 0.90 | 0.15 | 98.95 | 0.90 | 0.15 | 98.97 | 0.90 | 0.13 | 98.90 | 0.90 | 0.20 |
| 1960 | 85.93 | 6.68 | 7.39 | 95.95 | 1.98 | 2.07 | 98.89 | 0.90 | 0.21 | 96.37 | 1.99 | 1.64 | 69.05 | 28.60 | 2.35 |
| 1965 | 85.93 | 6.68 | 7.39 | 95.95 | 1.98 | 2.07 | 98.89 | 0.90 | 0.21 | 96.37 | 1.99 | 1.64 | 68.06 | 29.59 | 2.35 |
| 1970 | 84.37 | 6.56 | 9.07 | 95.56 | 1.97 | 2.47 | 98.85 | 0.90 | 0.25 | 96.13 | 1.98 | 1.88 | 61.33 | 30.19 | 8.48 |
| 1975 | 85.11 | 6.62 | 8.27 | 95.74 | 1.97 | 2.28 | 98.87 | 0.90 | 0.23 | 80.09 | 14.65 | 5.26 | 14.30 | 18.11 | 67.60 |
| 1980 | 51.72 | 25.86 | 22.42 | 96.04 | 1.98 | 1.98 | 55.39 | 17.04 | 27.57 | 77.63 | 14.56 | 7.81 | 24.11 | 24.11 | 51.78 |
| 1985 | 20.66 | 30.99 | 48.35 | 96.55 | 1.99 | 1.46 | 57.41 | 17.67 | 24.92 | 60.44 | 18.60 | 20.96 | 23.95 | 31.93 | 44.12 |
| 1990 | 20.34 | 20.34 | 59.32 | 96.71 | 1.99 | 1.30 | 60.10 | 18.49 | 21.41 | 26.38 | 26.38 | 47.25 | 14.66 | 40.72 | 44.61 |
| 1995 | 12.45 | 25.60 | 61.95 | 43.27 | 38.46 | 18.28 | 50.30 | 22.86 | 26.84 | 42.69 | 33.20 | 24.11 | 8.27 | 45.51 | 46.22 |
| 2000 | 10.40 | 31.20 | 58.40 | 35.40 | 45.93 | 18.67 | 47.92 | 24.41 | 27.67 | 43.70 | 43.70 | 12.59 | 15.81 | 52.71 | 31.48 |
| 2005 | 10.23 | 23.87 | 65.90 | 33.33 | 42.85 | 23.82 | 43.26 | 30.38 | 26.36 | 34.16 | 53.69 | 12.15 | 17.34 | 44.22 | 38.43 |

| | Economic Capability | | | Tactical Capability | | | International Agreements | | | Controls/ Safeguards | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | D | N | P | D | N | P | D | N | P | D |
| 1950 | 86.80 | 7.80 | 5.40 | 98.99 | 0.90 | 0.11 | 0.06 | 0.55 | 99.39 | 0.04 | 0.38 | 99.58 |
| 1955 | 84.21 | 8.71 | 7.08 | 98.99 | 0.90 | 0.11 | 0.06 | 0.55 | 99.39 | 0.04 | 0.38 | 99.58 |
| 1960 | 77.57 | 10.28 | 12.15 | 98.99 | 0.90 | 0.11 | 0.07 | 0.59 | 99.34 | 0.05 | 0.44 | 99.51 |
| 1965 | 76.63 | 11.21 | 12.15 | 98.99 | 0.90 | 0.11 | 0.07 | 0.59 | 99.34 | 0.05 | 0.44 | 99.51 |
| 1970 | 67.72 | 13.19 | 19.09 | 98.98 | 0.90 | 0.12 | 73.21 | 19.52 | 7.27 | 0.03 | 0.26 | 99.71 |
| 1975 | 50.62 | 21.57 | 27.81 | 98.98 | 0.90 | 0.12 | 73.45 | 19.59 | 6.97 | 40.67 | 16.27 | 43.06 |
| 1980 | 38.27 | 31.47 | 30.25 | 98.99 | 0.90 | 0.11 | 74.02 | 19.74 | 6.24 | 44.11 | 17.64 | 38.25 |
| 1985 | 31.05 | 39.03 | 29.92 | 98.97 | 0.90 | 0.13 | 74.26 | 19.80 | 5.93 | 45.58 | 18.23 | 36.19 |
| 1990 | 40.33 | 34.83 | 24.84 | 42.92 | 33.38 | 23.71 | 74.52 | 19.87 | 5.60 | 47.14 | 18.85 | 34.01 |
| 1995 | 21.54 | 44.87 | 33.59 | 26.34 | 39.52 | 34.14 | 74.59 | 19.89 | 5.51 | 58.05 | 19.35 | 22.60 |
| 2000 | 10.41 | 50.31 | 39.28 | 20.74 | 49.02 | 30.25 | 78.42 | 17.87 | 3.71 | 46.36 | 27.81 | 25.83 |
| 2005 | 4.41 | 55.61 | 39.97 | 18.90 | 47.26 | 33.84 | 58.19 | 24.24 | 17.57 | 47.73 | 33.41 | 18.85 |

| | Covert Reports | | | US/Intl. Agency Reports | | | Media Print Journals Open Source Events | | | Diplomatic Channels 3d Country Officials | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | D | N | P | D | N | P | D | N | P | D |
| 1950 | 98.94 | 0.90 | 0.16 | 98.95 | 0.90 | 0.15 | 98.97 | 0.90 | 0.13 | 98.95 | 0.90 | 0.15 |
| 1955 | 98.94 | 0.90 | 0.16 | 98.95 | 0.90 | 0.15 | 98.97 | 0.90 | 0.13 | 98.95 | 0.90 | 0.15 |
| 1960 | 98.94 | 0.90 | 0.16 | 98.96 | 0.90 | 0.14 | 98.97 | 0.90 | 0.13 | 98.96 | 0.90 | 0.14 |
| 1965 | 98.94 | 0.90 | 0.16 | 98.96 | 0.90 | 0.14 | 98.97 | 0.90 | 0.13 | 98.96 | 0.90 | 0.14 |
| 1970 | 98.92 | 0.90 | 0.18 | 98.94 | 0.90 | 0.16 | 98.97 | 0.90 | 0.13 | 98.94 | 0.90 | 0.16 |
| 1975 | 98.93 | 0.90 | 0.17 | 97.47 | 0.99 | 1.53 | 98.97 | 0.90 | 0.13 | 98.95 | 0.90 | 0.15 |
| 1980 | 46.05 | 29.47 | 24.48 | 97.67 | 1.00 | 1.34 | 98.98 | 0.90 | 0.12 | 98.97 | 0.90 | 0.13 |
| 1985 | 47.04 | 30.10 | 22.86 | 97.75 | 1.00 | 1.25 | 58.68 | 24.45 | 16.86 | 98.97 | 0.90 | 0.13 |
| 1990 | 48.09 | 30.78 | 21.14 | 52.73 | 19.17 | 28.10 | 49.99 | 27.45 | 22.56 | 98.98 | 0.90 | 0.12 |
| 1995 | 12.13 | 46.66 | 41.21 | 40.94 | 38.99 | 20.08 | 28.12 | 31.99 | 39.89 | 53.84 | 29.37 | 16.79 |
| 2000 | 9.43 | 51.86 | 38.72 | 49.18 | 39.35 | 11.47 | 23.24 | 40.66 | 36.10 | 49.57 | 33.05 | 17.39 |
| 2005 | 19.05 | 42.87 | 38.08 | 38.92 | 38.92 | 22.17 | 20.40 | 40.79 | 38.81 | 33.37 | 33.37 | 33.26 |

Normalized Values for D

| | National Security vs. External Threats | Scientific/ Technical Achievement | National Prestige/ Political Leverage | Domestic Opinion/ Policy | Technical Capability | Economic Capability | Tactical Capability | International Agreements | Controls/ Safeguards | Covert Reports | US/Intl. Agency Reports | Media Print Journals Open Source Events | Diplomatic Channels 3d Country Officials |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.48 | 0.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1955 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.47 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1960 | 0.03 | 0.01 | 0.00 | 0.01 | 0.01 | 0.05 | 0.00 | 0.44 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1965 | 0.03 | 0.01 | 0.00 | 0.01 | 0.01 | 0.05 | 0.00 | 0.44 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1970 | 0.06 | 0.02 | 0.00 | 0.01 | 0.06 | 0.13 | 0.00 | 0.05 | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1975 | 0.05 | 0.01 | 0.00 | 0.03 | 0.41 | 0.17 | 0.00 | 0.04 | 0.26 | 0.00 | 0.01 | 0.00 | 0.00 |
| 1980 | 0.11 | 0.01 | 0.13 | 0.04 | 0.24 | 0.14 | 0.00 | 0.03 | 0.18 | 0.12 | 0.01 | 0.00 | 0.00 |
| 1985 | 0.19 | 0.01 | 0.10 | 0.08 | 0.17 | 0.12 | 0.00 | 0.02 | 0.14 | 0.09 | 0.00 | 0.07 | 0.00 |
| 1990 | 0.18 | 0.00 | 0.06 | 0.14 | 0.13 | 0.07 | 0.07 | 0.02 | 0.10 | 0.06 | 0.08 | 0.07 | 0.00 |
| 1995 | 0.16 | 0.05 | 0.07 | 0.06 | 0.12 | 0.09 | 0.09 | 0.01 | 0.06 | 0.11 | 0.05 | 0.10 | 0.04 |
| 2000 | 0.17 | 0.05 | 0.08 | 0.04 | 0.09 | 0.11 | 0.09 | 0.01 | 0.07 | 0.11 | 0.03 | 0.10 | 0.05 |
| 2005 | 0.16 | 0.06 | 0.06 | 0.03 | 0.09 | 0.10 | 0.08 | 0.04 | 0.05 | 0.09 | 0.05 | 0.09 | 0.08 |

APPENDIX E: Conditional Probability Tables

This appendix shows the values entered into the conditional probability table for the overall probability of proliferation node in the center of the network. The values represent the results of a probability distribution based on the relative weights of each of the factor groups in contributing to the overall proliferation probability. These values changed over time as shown in Table 5.1 and each page in the appendix reflects the relative weights of the factor groups for each time period. Since there are four parent nodes with three possible states contributing to this table, along with three possible states for the overall central node, the CPT is a 3 by $3^4$ matrix reflecting all the possible combinations of the parent nodes. The values in this case were determined simply by the decisions about relative weighting. They can be further tailored by a subject matter expert if the appropriate information is available, but individually assigning the 243 matrix values would be extremely difficult.

## APPENDIX E: Conditional Probability Tables

### CPT for Proliferation Node 1946-1956

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | Base | 1P0D | 0P1D | 1P0D | 2P0D | 1P1D | 0P1D | 1P1D | 0P2D | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D |
| Not Proliferating | 1.000 | 0.714 | 0.714 | 0.857 | 0.571 | 0.571 | 0.857 | 0.571 | 0.571 | 0.714 | 0.429 | 0.429 | 0.571 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.714 | 0.429 | 0.429 | 0.571 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 |
| Possibly Proliferating | 0.000 | 0.286 | 0.000 | 0.143 | 0.429 | 0.143 | 0.000 | 0.286 | 0.000 | 0.286 | 0.571 | 0.286 | 0.429 | 0.714 | 0.429 | 0.286 | 0.571 | 0.286 | 0.000 | 0.286 | 0.000 | 0.143 | 0.429 | 0.143 | 0.000 | 0.286 | 0.000 |
| Definitely Proliferating | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.429 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.429 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.571 | 0.429 | 0.429 | 0.714 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 2P0D | 3P0D | 2P1D | 3P0D | 4P0D | 3P1D | 2P1D | 3P1D | 2P2D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D |
| Not Proliferating | 0.714 | 0.429 | 0.429 | 0.571 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.429 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.429 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 |
| Possibly Proliferating | 0.286 | 0.571 | 0.286 | 0.429 | 0.714 | 0.429 | 0.286 | 0.571 | 0.286 | 0.571 | 0.857 | 0.571 | 0.714 | 1.000 | 0.714 | 0.571 | 0.857 | 0.571 | 0.286 | 0.571 | 0.286 | 0.429 | 0.714 | 0.429 | 0.286 | 0.571 | 0.286 |
| Definitely Proliferating | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.429 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.429 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.571 | 0.429 | 0.429 | 0.714 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D | 0P2D | 1P2D | 0P3D | 1P2D | 2P2D | 1P3D | 0P3D | 1P3D | 0P4D |
| Not Proliferating | 0.714 | 0.429 | 0.429 | 0.571 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.429 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 | 0.429 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.286 | 0.000 | 0.000 |
| Possibly Proliferating | 0.000 | 0.286 | 0.000 | 0.143 | 0.429 | 0.143 | 0.000 | 0.286 | 0.000 | 0.286 | 0.571 | 0.286 | 0.429 | 0.714 | 0.429 | 0.286 | 0.571 | 0.286 | 0.000 | 0.286 | 0.000 | 0.143 | 0.429 | 0.143 | 0.000 | 0.286 | 0.000 |
| Definitely Proliferating | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.571 | 0.429 | 0.429 | 0.714 | 0.286 | 0.286 | 0.571 | 0.286 | 0.286 | 0.571 | 0.429 | 0.429 | 0.714 | 0.571 | 0.571 | 0.857 | 0.571 | 0.571 | 0.857 | 0.714 | 0.714 | 1.000 |

## APPENDIX E: Conditional Probability Tables

### CPT for Proliferation Node 1957-1978

| Intentions | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | Base | 1P0D | 0P1D | 1P0D | 2P0D | 1P1D | 0P1D | 1P1D | 0P2D | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D |
| Not Proliferating | 1.000 | 0.818 | 0.818 | 0.909 | 0.727 | 0.727 | 0.909 | 0.727 | 0.727 | 0.545 | 0.364 | 0.364 | 0.455 | 0.273 | 0.273 | 0.455 | 0.273 | 0.273 | 0.545 | 0.364 | 0.364 | 0.455 | 0.273 | 0.273 | 0.455 | 0.273 | 0.273 |
| Possibly Proliferating | 0.000 | 0.182 | 0.000 | 0.091 | 0.273 | 0.091 | 0.000 | 0.182 | 0.000 | 0.455 | 0.636 | 0.455 | 0.545 | 0.727 | 0.545 | 0.455 | 0.636 | 0.455 | 0.000 | 0.182 | 0.000 | 0.091 | 0.273 | 0.091 | 0.000 | 0.182 | 0.000 |
| Definitely Proliferating | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.182 | 0.091 | 0.091 | 0.273 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.182 | 0.091 | 0.091 | 0.273 | 0.455 | 0.455 | 0.636 | 0.455 | 0.455 | 0.636 | 0.545 | 0.545 | 0.727 |

| Intentions | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 2P0D | 3P0D | 2P1D | 3P0D | 4P0D | 3P1D | 2P1D | 3P1D | 2P2D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D |
| Not Proliferating | 0.727 | 0.545 | 0.545 | 0.636 | 0.455 | 0.455 | 0.636 | 0.455 | 0.455 | 0.273 | 0.091 | 0.091 | 0.182 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.273 | 0.091 | 0.091 | 0.182 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 |
| Possibly Proliferating | 0.273 | 0.455 | 0.273 | 0.364 | 0.545 | 0.364 | 0.273 | 0.455 | 0.273 | 0.727 | 0.909 | 0.727 | 0.818 | 1.000 | 0.818 | 0.727 | 0.909 | 0.727 | 0.273 | 0.455 | 0.273 | 0.364 | 0.545 | 0.364 | 0.273 | 0.455 | 0.273 |
| Definitely Proliferating | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.182 | 0.091 | 0.091 | 0.273 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.182 | 0.091 | 0.091 | 0.273 | 0.455 | 0.455 | 0.636 | 0.455 | 0.455 | 0.636 | 0.545 | 0.545 | 0.727 |

| Intentions | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D | 0P2D | 1P2D | 0P3D | 1P2D | 2P2D | 1P3D | 0P3D | 1P3D | 0P4D |
| Not Proliferating | 0.727 | 0.545 | 0.545 | 0.636 | 0.455 | 0.455 | 0.636 | 0.455 | 0.455 | 0.273 | 0.091 | 0.091 | 0.182 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 | 0.273 | 0.091 | 0.091 | 0.182 | 0.000 | 0.000 | 0.182 | 0.000 | 0.000 |
| Possibly Proliferating | 0.000 | 0.182 | 0.000 | 0.091 | 0.273 | 0.091 | 0.000 | 0.182 | 0.000 | 0.455 | 0.636 | 0.455 | 0.545 | 0.727 | 0.545 | 0.455 | 0.636 | 0.455 | 0.000 | 0.182 | 0.000 | 0.091 | 0.273 | 0.091 | 0.000 | 0.182 | 0.000 |
| Definitely Proliferating | 0.273 | 0.273 | 0.455 | 0.273 | 0.273 | 0.455 | 0.364 | 0.364 | 0.545 | 0.273 | 0.273 | 0.455 | 0.273 | 0.273 | 0.455 | 0.364 | 0.364 | 0.545 | 0.727 | 0.727 | 0.909 | 0.727 | 0.727 | 0.909 | 0.818 | 0.818 | 1.000 |

APPENDIX E: Conditional Probability Tables

## CPT for Proliferation Node 1979-1987

| Intentions | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | Base | 1P0D | 0P1D | 1P0D | 2P0D | 1P1D | 0P1D | 1P1D | 0P2D | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D |
| Not Proliferating | 1.000 | 0.833 | 0.833 | 0.917 | 0.750 | 0.750 | 0.917 | 0.750 | 0.750 | 0.500 | 0.333 | 0.333 | 0.417 | 0.250 | 0.250 | 0.417 | 0.250 | 0.250 | 0.500 | 0.333 | 0.333 | 0.417 | 0.250 | 0.250 | 0.417 | 0.250 | 0.250 |
| Possibly Proliferating | 0.000 | 0.167 | 0.000 | 0.083 | 0.250 | 0.083 | 0.000 | 0.167 | 0.000 | 0.500 | 0.667 | 0.500 | 0.583 | 0.750 | 0.583 | 0.500 | 0.667 | 0.500 | 0.000 | 0.167 | 0.000 | 0.083 | 0.250 | 0.083 | 0.000 | 0.167 | 0.000 |
| Definitely Proliferating | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.167 | 0.083 | 0.083 | 0.250 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.167 | 0.083 | 0.083 | 0.250 | 0.500 | 0.500 | 0.667 | 0.500 | 0.500 | 0.667 | 0.583 | 0.583 | 0.750 |

| Intentions | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 2P0D | 3P0D | 2P1D | 3P0D | 4P0D | 3P1D | 2P1D | 3P1D | 2P2D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D |
| Not Proliferating | 0.750 | 0.583 | 0.583 | 0.667 | 0.500 | 0.500 | 0.667 | 0.500 | 0.500 | 0.250 | 0.083 | 0.083 | 0.167 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.250 | 0.083 | 0.083 | 0.167 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 |
| Possibly Proliferating | 0.250 | 0.417 | 0.250 | 0.333 | 0.500 | 0.333 | 0.250 | 0.417 | 0.250 | 0.750 | 0.917 | 0.750 | 0.833 | 1.000 | 0.833 | 0.750 | 0.917 | 0.750 | 0.250 | 0.417 | 0.250 | 0.333 | 0.500 | 0.333 | 0.250 | 0.417 | 0.250 |
| Definitely Proliferating | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.167 | 0.083 | 0.083 | 0.250 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.167 | 0.083 | 0.083 | 0.250 | 0.500 | 0.500 | 0.667 | 0.500 | 0.500 | 0.667 | 0.583 | 0.583 | 0.750 |

| Intentions | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D | 0P2D | 1P2D | 0P3D | 1P2D | 2P2D | 1P3D | 0P3D | 1P3D | 0P4D |
| Not Proliferating | 0.750 | 0.583 | 0.583 | 0.667 | 0.500 | 0.500 | 0.667 | 0.500 | 0.500 | 0.250 | 0.083 | 0.083 | 0.167 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.250 | 0.083 | 0.083 | 0.167 | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 |
| Possibly Proliferating | 0.000 | 0.167 | 0.000 | 0.083 | 0.250 | 0.083 | 0.000 | 0.167 | 0.000 | 0.500 | 0.667 | 0.500 | 0.583 | 0.750 | 0.583 | 0.500 | 0.667 | 0.500 | 0.000 | 0.167 | 0.000 | 0.083 | 0.250 | 0.083 | 0.000 | 0.167 | 0.000 |
| Definitely Proliferating | 0.250 | 0.250 | 0.417 | 0.250 | 0.250 | 0.417 | 0.333 | 0.333 | 0.500 | 0.250 | 0.250 | 0.417 | 0.250 | 0.250 | 0.417 | 0.333 | 0.333 | 0.500 | 0.750 | 0.750 | 0.917 | 0.750 | 0.750 | 0.917 | 0.833 | 0.833 | 1.000 |

APPENDIX E: Conditional Probability Tables

## CPT for Proliferation Node 1988-1995

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | Base | 1P0D | 0P1D | 1P0D | 2P0D | 1P1D | 0P1D | 1P1D | 0P2D | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D |
| Not Proliferating | 1.000 | 0.846 | 0.846 | 0.923 | 0.769 | 0.769 | 0.923 | 0.769 | 0.769 | 0.538 | 0.385 | 0.385 | 0.462 | 0.308 | 0.308 | 0.462 | 0.308 | 0.308 | 0.538 | 0.385 | 0.385 | 0.462 | 0.308 | 0.308 | 0.462 | 0.308 | 0.308 |
| Possibly Proliferating | 0.000 | 0.154 | 0.000 | 0.077 | 0.231 | 0.077 | 0.000 | 0.154 | 0.000 | 0.462 | 0.615 | 0.462 | 0.538 | 0.692 | 0.538 | 0.462 | 0.615 | 0.462 | 0.000 | 0.154 | 0.000 | 0.077 | 0.231 | 0.077 | 0.000 | 0.154 | 0.000 |
| Definitely Proliferating | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.154 | 0.077 | 0.077 | 0.231 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.154 | 0.077 | 0.077 | 0.231 | 0.462 | 0.462 | 0.615 | 0.462 | 0.462 | 0.615 | 0.538 | 0.538 | 0.692 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 2P0D | 3P0D | 2P1D | 3P0D | 4P0D | 3P1D | 2P1D | 3P1D | 2P2D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D |
| Not Proliferating | 0.692 | 0.538 | 0.538 | 0.615 | 0.462 | 0.462 | 0.615 | 0.462 | 0.462 | 0.231 | 0.077 | 0.077 | 0.154 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.231 | 0.077 | 0.077 | 0.154 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 |
| Possibly Proliferating | 0.308 | 0.462 | 0.308 | 0.385 | 0.538 | 0.385 | 0.308 | 0.462 | 0.308 | 0.769 | 0.923 | 0.769 | 0.846 | 1.000 | 0.846 | 0.769 | 0.923 | 0.769 | 0.308 | 0.462 | 0.308 | 0.385 | 0.538 | 0.385 | 0.308 | 0.462 | 0.308 |
| Definitely Proliferating | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.154 | 0.077 | 0.077 | 0.231 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.154 | 0.077 | 0.077 | 0.231 | 0.462 | 0.462 | 0.615 | 0.462 | 0.462 | 0.615 | 0.538 | 0.538 | 0.692 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D | 0P2D | 1P2D | 0P3D | 1P2D | 2P2D | 1P3D | 0P3D | 1P3D | 0P4D |
| Not Proliferating | 0.692 | 0.538 | 0.538 | 0.615 | 0.462 | 0.462 | 0.615 | 0.462 | 0.462 | 0.231 | 0.077 | 0.077 | 0.154 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 | 0.231 | 0.077 | 0.077 | 0.154 | 0.000 | 0.000 | 0.154 | 0.000 | 0.000 |
| Possibly Proliferating | 0.000 | 0.154 | 0.000 | 0.077 | 0.231 | 0.077 | 0.000 | 0.154 | 0.000 | 0.462 | 0.615 | 0.462 | 0.538 | 0.692 | 0.538 | 0.462 | 0.615 | 0.462 | 0.000 | 0.154 | 0.000 | 0.077 | 0.231 | 0.077 | 0.000 | 0.154 | 0.000 |
| Definitely Proliferating | 0.308 | 0.308 | 0.462 | 0.308 | 0.308 | 0.462 | 0.385 | 0.385 | 0.538 | 0.308 | 0.308 | 0.462 | 0.308 | 0.308 | 0.462 | 0.385 | 0.385 | 0.538 | 0.769 | 0.769 | 0.923 | 0.769 | 0.769 | 0.923 | 0.846 | 0.846 | 1.000 |

APPENDIX E: Conditional Probability Tables

CPT for Proliferation Node 1996-2007

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N | N |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | Base | 1P0D | 0P1D | 1P0D | 2P0D | 1P1D | 0P1D | 1P1D | 0P2D | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D |
| Not Proliferating | 1.000 | 0.857 | 0.857 | 0.857 | 0.714 | 0.714 | 0.857 | 0.714 | 0.714 | 0.571 | 0.429 | 0.429 | 0.429 | 0.286 | 0.286 | 0.429 | 0.286 | 0.286 | 0.571 | 0.429 | 0.429 | 0.429 | 0.286 | 0.286 | 0.429 | 0.286 | 0.286 |
| Possibly Proliferating | 0.000 | 0.143 | 0.000 | 0.143 | 0.286 | 0.143 | 0.000 | 0.143 | 0.000 | 0.429 | 0.571 | 0.429 | 0.571 | 0.714 | 0.571 | 0.429 | 0.571 | 0.429 | 0.000 | 0.143 | 0.000 | 0.143 | 0.286 | 0.143 | 0.000 | 0.143 | 0.000 |
| Definitely Proliferating | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.143 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.143 | 0.143 | 0.143 | 0.286 | 0.429 | 0.429 | 0.571 | 0.429 | 0.429 | 0.571 | 0.571 | 0.571 | 0.714 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 1P0D | 2P0D | 1P1D | 2P0D | 3P0D | 2P1D | 1P1D | 2P1D | 1P2D | 2P0D | 3P0D | 2P1D | 3P0D | 4P0D | 3P1D | 2P1D | 3P1D | 2P2D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D |
| Not Proliferating | 0.714 | 0.571 | 0.571 | 0.571 | 0.429 | 0.429 | 0.571 | 0.429 | 0.429 | 0.286 | 0.143 | 0.143 | 0.143 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.143 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 |
| Possibly Proliferating | 0.286 | 0.429 | 0.286 | 0.429 | 0.571 | 0.429 | 0.286 | 0.429 | 0.286 | 0.714 | 0.857 | 0.714 | 0.857 | 1.000 | 0.857 | 0.714 | 0.857 | 0.714 | 0.286 | 0.429 | 0.286 | 0.429 | 0.571 | 0.429 | 0.286 | 0.429 | 0.286 |
| Definitely Proliferating | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.143 | 0.143 | 0.143 | 0.286 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.143 | 0.143 | 0.143 | 0.286 | 0.429 | 0.429 | 0.571 | 0.429 | 0.429 | 0.571 | 0.571 | 0.571 | 0.714 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intentions | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
| Actions | N | N | N | N | N | N | N | N | N | P | P | P | P | P | P | P | P | P | D | D | D | D | D | D | D | D | D |
| Capabilities | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D | N | N | N | P | P | P | D | D | D |
| Restraints | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D | N | P | D |
| States | 0P1D | 1P1D | 0P2D | 1P1D | 2P1D | 1P2D | 0P2D | 1P2D | 0P3D | 1P1D | 2P1D | 1P2D | 2P1D | 3P1D | 2P2D | 1P2D | 2P2D | 1P3D | 0P2D | 1P2D | 0P3D | 1P2D | 2P2D | 1P3D | 0P3D | 1P3D | 0P4D |
| Not Proliferating | 0.714 | 0.571 | 0.571 | 0.571 | 0.429 | 0.429 | 0.571 | 0.429 | 0.429 | 0.286 | 0.143 | 0.143 | 0.143 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 | 0.286 | 0.143 | 0.143 | 0.143 | 0.000 | 0.000 | 0.143 | 0.000 | 0.000 |
| Possibly Proliferating | 0.000 | 0.143 | 0.000 | 0.143 | 0.286 | 0.143 | 0.000 | 0.143 | 0.000 | 0.429 | 0.571 | 0.429 | 0.571 | 0.714 | 0.571 | 0.429 | 0.571 | 0.429 | 0.000 | 0.143 | 0.000 | 0.143 | 0.286 | 0.143 | 0.000 | 0.143 | 0.000 |
| Definitely Proliferating | 0.286 | 0.286 | 0.429 | 0.286 | 0.286 | 0.429 | 0.429 | 0.429 | 0.571 | 0.286 | 0.286 | 0.429 | 0.286 | 0.286 | 0.429 | 0.429 | 0.429 | 0.571 | 0.714 | 0.714 | 0.857 | 0.714 | 0.714 | 0.857 | 0.857 | 0.857 | 1.000 |

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