Preliminary Sensitivity Analysis on Nuclear Proliferation of Trigger Items Using Bayesian Network

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1. Introduction

In order to prevent the nuclear proliferation, export control of trigger items is being implemented in accordance with international treaties. The export risk assessment is important because the failure of export controls for trigger items can lead to international nuclear proliferation. The nuclear proliferation process was established using the Bayesian network method to evaluate the export risk, and the nuclear proliferation risk according to the factors was pre-analyzed.

2. Methods

2.1 Bayesian Network

A Bayesian network [1] is a probabilistic graphical model that represents a set of variables and their conditional dependencies via a directed acyclic graph. It consists of nodes, arcs, and conditional probability tables. The factors are expressed as nodes, the dependency relationship between nodes is expressed using arcs, and the probability of the dependency is expressed using a conditional probability table. Through this, the posterior probability can be inferred.

2.2 Network Construction

The network was constructed by referring to the Bayesian network model built by C. R. Freeman [2]. The Freeman Network is a Bayesian network that builds the process of acquiring nuclear weapons focused on special nuclear material (SNM) such as high enriched uranium (HEU) and plutonium to predict the path of proliferation of nuclear weapons. The network includes purchasing or stealing. In the Freeman network, 'inverted nodes' were constructed in order to examine the relationship of evidence in a specific pathway. However, in this study, a Bayesian network was constructed with the Freeman network in the forward direction to see the sequential process. The established Bayesian network is composed of seven sections such as reprocessing, enrichment, plutonium, HEU, SNM, weaponization, and nuclear device sections. Netica [3], a commercial program, was used for Bayesian network analysis.

2.3 Conditional Probability Table

In order to calculate the correlation between nodes in a Bayesian network, it is necessary to fill a conditional probability table at each node. For the highest parent node, the probability of true and false is set to 50:50, and the child node is assigned a probability according to the results of the parent nodes. At this time, when the parent nodes are independent, they are given with an equal probability, and when the child node is satisfied even if only one of the parent nodes is satisfied, it is configured so that the sum of true is 100%. It is noted that the conditional probability tables should be determined with detailed information of each node, but in this study, uniform probabilities are applied as the first step of research.

3. Analysis and Results

By setting the conditions of all factors to 'false' and changing the factor to 'true' one by one in each section, the probability change of the final node (Nuclear Device) was confirmed. The results are shown in Table I. The reprocessing section and the enrichment section, which were far away, had no significant effect on proliferation, with a result of less than 1%. In the plutonium section and the highly enriched uranium section, there was generally no significant effect, but if the material was stolen or purchased successfully, it had a significant effect on nuclear proliferation. In the case of stealing or purchasing a nuclear device in the nuclear device section, nuclear proliferation was 100%.

4. Conclusions

A preliminary sensitivity analysis of the nuclear proliferation was performed using a Bayesian network. Because the probability values are equally given in the conditional probability table, nodes in the same path have the same result, and the farther the path from the final node (Nuclear Device), the smaller the probability of nuclear proliferation. A 50% chance of nuclear device does not mean that nuclear proliferation will occur when export controls fail once in two. It merely informs you which factor is numerically more important. The importance of each component can be quantitatively compared if the probability of each factor in the conditional probability table is written by reflecting the opinions of experts.

Acknowledgements

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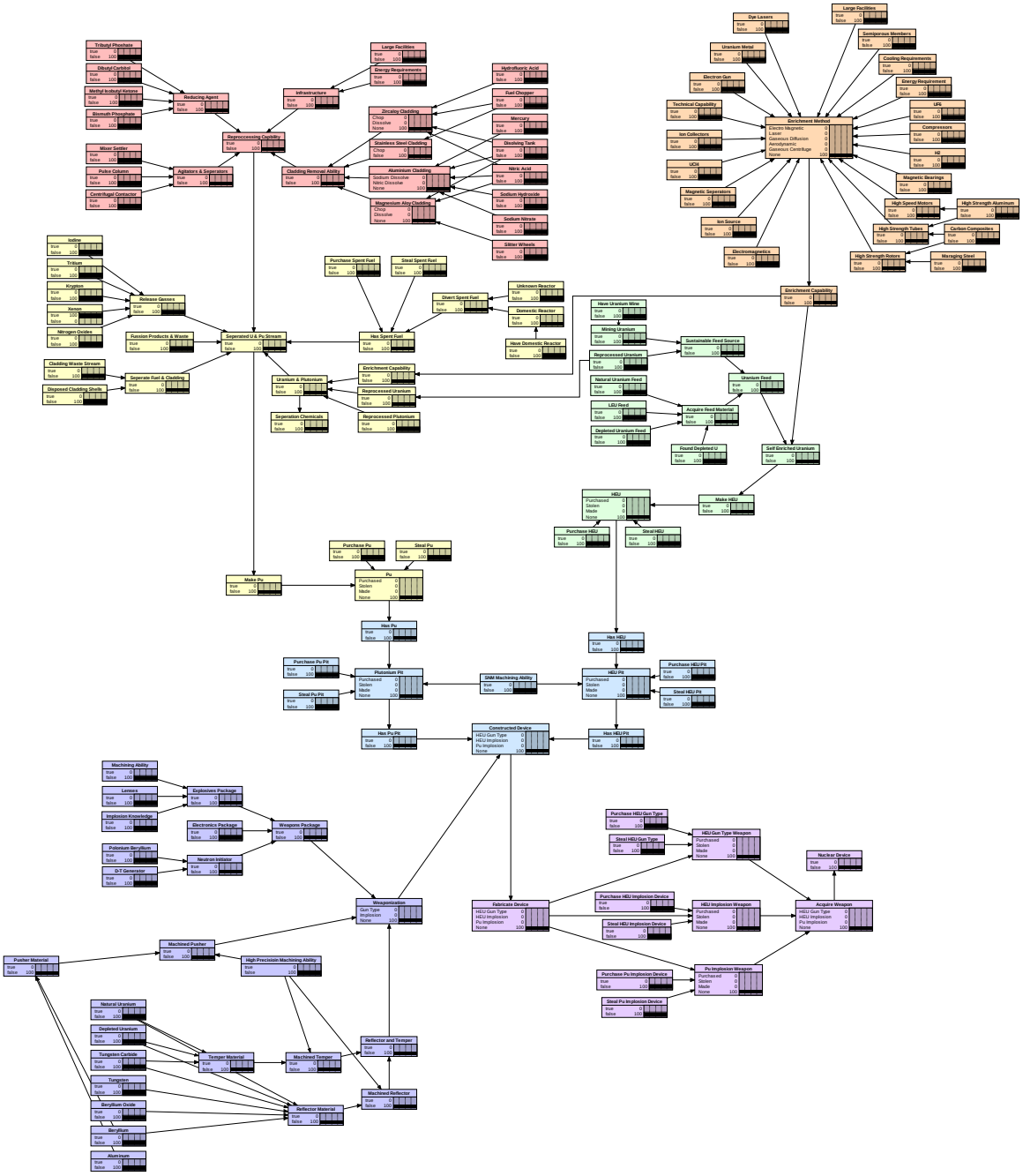

Fig. 1. Nuclear proliferation Bayesian network consisting of seven sections; reprocessing section (red), enrichment section (orange), plutonium section (yellow), high enriched uranium section (green), special nuclear material section (blue), weaponization section (navy), and completed nuclear device section (purple).

Table I: Results of nuclear proliferation probability analysis for each factor

factors	%	factors	%
Reprocessing Section		Enrichment Section	
Tributyl Phosphate	0.087	Dye Lasers	0.35
Dibutyl Carbitol	0.087	Uranium Metal	0.35
Methyl Isobutyl Ketone	0.087	Electron Gun	0.35
Bismuth Phosphate	0.087	Technical Capability	0.35
Mixer Settler	0.12	Ion Collectors	0.7
Pulse Column	0.12	UCl4	0.35
Centrifugal Contactor	0.12	Magnetic Separators	0.35
Large Facilities	0.17	Ion Source	0.35
Energy Requirements	0.17	Electromagnetics	0.35
Hydrofluoric Acid	0.022	Large Facilities	0.29
Fuel Chopper	0.11	Semi-porous Members	0.29
Mercury	0.017	Cooling Requirements	0.65
Dissolving Tank	0.068	Energy Requirement	0.65
Nitric Acid	0.068	UF6	0.94
Sodium Hydroxide	0.017	Compressors	0.94
Sodium Nitrate	0.017	H2	0.35
Slitter wheels	0.029	Magnetic Bearings	0.29
Pu Section		High Strength Aluminum	0.44
Iodine	0.28	Carbon Composites	0.29
Tritium	0.28	Margining Steel	0.15
Krypton	0.28	HEU Section	
Xenon	0.28	Have Uranium Mine	2.08
Nitrogen Oxides	0.28	Reprocessed Uranium	2.55
Fusion Products & Waste	1.39	Natural Uranium Feed	1.04
Cladding Waste Steam	0.69	LEU Feed	1.04
Disposed Cladding Shells	0.69	Depleted Uranium Feed	1.04
Purchase Spent Fuel	1.39	Found Depleted Uranium	1.04
Steal Spent Fuel	1.39	Purchase HEU	16.7
Unknown Reactor	0.69	Steal HEU	16.7
Have Domestic Reactor	0.69	Weaponization Section	
Reprocessed Plutonium	0.46	Machining Ability	0.93
Purchase Pu	8.33	Lenses	0.93
Steal Pu	8.33	Implosion Knowledge	0.93
SNM Section		Electronics Package	2.78
Purchase Pu Pit	16.7	Polonium Beryllium	1.39
Steal Pu Pit	16.7	D-T Generator	1.39
Purchase HEU Pit	33.3	Natural Uranium	1.04
Steal HEU Pit	33.3	Depleted Uranium	1.04
SNM Machining Ability	25	Tungsten Carbide	1.04
Nuclear device Section		Tungsten	0.35
Purchase HEU Gun Type	100	Beryllium Oxide	0.35
Steal HEU Gun Type	100	Beryllium	2.43
Purchase HEU Implosion Device	100	Aluminum	2.08
Steal HEU Implosion Device	100	High Precision Machining Ability	8.33
Purchase Pu Implosion Device	100		
Steal Pu Implosion Device	100		