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INTERDISCIPLINARY MULTICRITERIA ANALYSIS IN THE SIMULATION OF COMPLEX NEGOTIATIONS: A STUDY ON SAFEGUARDS

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ABSTRACT

The article presents the use of the multicriteria method PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) in the simulation of complex negotiations to apply safeguards on nuclear material to be used in the propulsion of submarines of a Non-Nuclear Weapon State (NNWS). Therefore, the article proceeds into four steps. Firstly, it discusses some of the possible variables present in the context of the negotiations of Arrangements between the International Atomic Energy Agency (IAEA) and an NNWS regarding applying safeguards on the nuclear material for the propulsion of submarines. Secondly and thirdly, it presents an overview of the multicriteria methodology and the PROMETHEE method, which incorporates interdisciplinary parameters for robust and exhaustive modeling, presenting its main characteristics in using attributes with which one seeks to identify and measure the preferences of decision-makers. In this way, the method allows the ordering of alternatives for making strategic decisions. Finally, the last section presents the results of simulations carried out with multidisciplinary teams involving Brazilian civilian and military researchers.

Keywords: Negotiation. Nuclear Safeguards. Non-proliferation. Nuclear-Powered Submarines. PROMETHEE Methodology. Simulations.

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INTRODUCTION

Interdisciplinary Multicriteria Decision Analysis (MCDA) plays a pivotal role in addressing the complexities inherent in safeguard studies, particularly in the context of nuclear negotiations. Such studies require a nuanced understanding of diverse factors, including technical feasibility, political considerations, and international regulations. MCDA methodologies, such as the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), offer structured approaches to integrating and evaluating multiple criteria in decision-making processes (BELTON & STEWART, 2002). By leveraging interdisciplinary perspectives, MCDA facilitates the identification of robust safeguards strategies that balance the competing objectives of security, transparency, and cooperation.

One of the key challenges in safeguard studies is the need to navigate complex and often conflicting stakeholder interests. Interdisciplinary MCDA provides a platform for stakeholders from diverse domains, including policymakers, scientists, and industry representatives, to collaboratively evaluate and prioritize safeguard options (MALCZEWSKI, 2006). This participatory approach fosters transparency and consensus-building, enhancing the legitimacy and acceptance of safeguard decisions among stakeholders. Additionally, MCDA enables the incorporation of qualitative and quantitative data, allowing for a comprehensive assessment of the effectiveness and feasibility of different safeguard measures (KEENEY & RAIFFA, 1993).

Simulation modeling serves as a valuable tool in the interdisciplinary MCDA of complex negotiations, offering a dynamic environment to explore the implications of various safeguard strategies over time. Through simulation, decision-makers can assess the resilience of proposed safeguards to evolving threats and uncertainties, thereby enhancing the robustness of decision-making processes (SISKOS & GRIGOROUDIS, 2010). Furthermore, simulation enables the exploration of trade-offs between different criteria and the identification of potential unintended consequences of safeguard decisions.

Two definitions are already necessary in this article: model and simulation. We adopt the definitions of the United States Department of Defense both for model and simulation to resolve this lexical issue:

− A model is "a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process" (U.S. DoD 2018, p. 10).

– A simulation is "a method for implementing a model over time" (U.S. DoD 2018, p. 10).

Having made these initial considerations about what a model and a simulation are, it is now possible to highlight that the interdisciplinary MCDA in safeguard studies extends beyond technical considerations to encompass broader socio-political factors that influence negotiations and implementation. By integrating insights from political science, international relations, and economics, MCDA helps contextualize safeguard decisions within broader geopolitical dynamics and power relations (MACHARIS & SPRINGAEL, 2009). This interdisciplinary perspective is essential for developing safeguards strategies that are not only technically sound but also politically viable and socially acceptable.

This article aims to explore the application of interdisciplinary MCDA in the context of safeguard studies for nuclear materials. Specifically, the research objective is to demonstrate how interdisciplinary MCDA can enhance decision-making processes and improve the effectiveness of safeguard strategies. The methodology involves a review of relevant literature, case studies, and simulation modeling techniques to illustrate the application of interdisciplinary MCDA in safeguard studies.

To achieve the proposed objective, the article was structured in four sections. The first of them discusses some of the possible variables present in the context of the negotiations of Arrangements between the International Atomic Energy Agency (IAEA) and an NNWS regarding applying safeguards on the nuclear material for the propulsion of submarines. The second and third sections present an overview of the multicriteria methodology and the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method, which incorporates interdisciplinary parameters for robust and exhaustive modeling, presenting its main characteristics in the use of attributes with which one seeks to identify and measure the preferences of decision-makers, allowing the ordering of alternatives for strategic decision making. Finally, the last section presents the results of simulations carried out with multidisciplinary and strategic teams.

THE ARRANGEMENT FRAMEWORK AND VARIABLES

A central issue in the negotiations of Arrangement between the IAEA and an NNWS is related to possible ways of ensuring that nuclear material used in a nuclear-powered submarine of an NNWS will not be used for other purposes. This issue implies multiple challenges for an NNWS that aims to acquire or develop this type of weapons system: reconciling the political, legal, and technical issues related to the safeguards without compromising the sensitive and classified characteristics inherent to the development and operation of a nuclear-powered submarine.

The IAEA's normative framework for Comprehensive Safeguards Agreements[2] (CSA) with the NNWS parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is contained in the Information Circular number 153 (INFCIRC/153/Corr − The Structure and Content of Agreements Between the Agency and States Required in Connection with the NPT). Paragraph 14 of INFCIR/153 provides that the State that will use nuclear energy "in a non-proscribed military activity" shall make an Arrangement with IAEA that should contain "the period or circumstances during which safeguards will not be applied" and "the Agency shall be kept informed of the total quantity and composition of such unsafeguarded nuclear material in the State and of any exports of such material" (see IAEA, INFCIRC/153). In other words, if an NNWS decides to use nuclear energy to propel a submarine, it must negotiate an arrangement with the IAEA, as mentioned above.

It is important to note that this negotiation will not be simple mainly because it is presented in broad terms in INFCIRC/153. The directly interested parties – the NNWS and the IAEA – must deal with multiple variables for this Agreement to come to fruition. In this sense, this section discusses some critical and essential variables present in the context of the negotiations of Special Procedures Arrangement between the IAEA and

2 According to article III of the NPT, each NNWS Party to the Treaty must negotiate a safeguards agreement with the IAEA: "Each non-nuclear-weapon State Party to the Treaty undertakes to accept safeguards, as set forth in agreement to be negotiated and concluded with the International Atomic Energy Agency in accordance with the Statute of the International Atomic Energy Agency and the Agency's safeguards system, for the exclusive purpose of verifying the fulfillment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. […]" (see UNODA, NPT, Text of the Treaty).

an NNWS.[3]

The premise considered in this approach is that any proposal of an Arrangement between the IAEA and an NNWS, as provided for in Paragraph 14 of INFCIRC/153, or a CSA based on the INFCIRC/153, shall be made in a way that does not compromise the development and operation of the nuclear-power submarine and, at the same time, provides the ways to the IAEA assures there is no diversion of nuclear material to prohibited activities.

Based on this premise, four variables were identified:

- Preservation of Sensitive/Classified Technologies.

- Preservation of the Submarine's Operational Characteristics.

- Guarantee that there will be no diversion of nuclear material.

- Duration of the Negotiation.

It is worth noting that at the time this article was written, only two NNWS – Brazil and Australia – had programs aimed at developing or acquiring nuclear-powered submarines. The two programs have very different reasons and approaches not discussed in this article. However, it can be assumed that the abovementioned variables will be present in the negotiations between these NNWS and the IAEA.

In this context, regarding the variable "Preservation of Sensitive/Classified Technologies", undoubtedly, the Arrangement must be drafted in such a way as to protect these technologies. In this sense, the NNWS should have previously defined what information on the nuclear material and propulsion should be protected. Thus, the negotiations will develop across a spectrum that ranges from maximum preservation of sensitive/classified technologies to broad flexibility to allow maximum application of safeguards.

Concerning the variable "Preservation of the Submarine's Operational Characteristics", it is essential to highlight the object of the safeguards in the negotiation. The nuclear-powered submarine is not

3 It is worth highlighting that all the ideas expressed here are personal and do not express the position of any official body of the Brazilian State (Authors` note).

the object of safeguards. The nuclear material is the object of safeguards (SILVA, 2022). In this context, this variable refers to the characteristics associated with nuclear-powered submarine operation and maintenance data and profiles, including personnel requirements, operating procedures, software documentation, publications, and maintenance guides.

In this sense, one of the challenges in the negotiation is the determination of the points at which the safeguards – provided for in CSA in force in the NNWS – will no longer be applied to the nuclear material, as well as the point at which the safeguards will be applied again. These definitions will imply the types of IAEA inspections and verifications and, consequently, the eventual observation of the nuclear-powered submarine operating profile and characteristics (SILVA, 2022). Thus, it can be inferred that the negotiations, in aspects related to this variable, will unfold along a spectrum that goes from maximum preservation of the submarine's operational characteristics to total flexibility to allow the maximum application of safeguards.

As for the variable "Guarantee that there will be no diversion of nuclear material", the key concept for the negotiation is Safeguards.

> Safeguards are a set of technical measures applied by the IAEA on nuclear material and activities, through which the Agency seeks to independently verify that nuclear facilities are not misused, and nuclear material not diverted from peaceful uses (see IAEA, Basics of IAEA Safeguards).

The negotiators' perspective must be one of complete understanding that the safeguards aim to assure States parties to the NPT that nuclear material is not being diverted for the manufacture of nuclear weapons or other nuclear explosive devices or any other unknown purposes. Thus, the negotiations, in aspects related to this variable, will unfold along a spectrum that goes from maximum hardness in the application of safeguards to the withdrawal of the application of safeguards, as provided for in paragraph 14 of INFICIRC/153.

Regarding the variable "Duration of the Negotiation", we are referring to the time the negotiation takes to complete. It is pertinent to highlight that the negotiations will be closely watched by the international community and, mainly, by those with direct interests in influencing the future users of nuclear-powered submarines. Therefore, the negotiating parties may receive external pressure to extend or accelerate negotiations on an Agreement. Thus, this variable involves a spectrum that varies from actions for negotiations to "drag on" indefinitely or for them to be concluded satisfactorily for the parties directly involved in the negotiation. T h e point to be highlighted is that these variables will be present in the negotiations between the NNWS and the IAEA. Therefore, developing and employing a model that allows simulating decision makers' preferences at specific points in the negotiation process and, consequently, contributing to decision-making that maximizes the interests of the negotiating parties becomes an advantageous tool in negotiation. With this as a premise, the article sought, as described in the Introduction, to present how the PROMETHEE II method can be used as decision support in negotiations between an NNWS and the IAEA in the case of safeguards to be applied to nuclear material used for propulsion of submarines.

MCDA THEORY

Multicriteria Decision Analysis (MCDA) theory serves as a cornerstone in addressing complex decision-making scenarios across various domains. It provides a systematic framework for evaluating alternatives based on multiple, often conflicting, criteria or objectives. This text aims to delve into the depths of MCDA theory, elucidating its conceptual foundations, methodologies, applications, and recent advancements, supported by relevant scientific literature.

MCDA theory draws upon decision theory, operations research, and multiple-criteria decision-making (MCDM). It builds on seminal works such as von Neumann and Morgenstern's utility theory and Arrow's impossibility theorem, addressing the challenges of aggregating individual preferences into collective decisions. The theory emphasizes the importance of clarifying objectives, alternatives, and uncertainties in decision-making processes (KEENEY & RAIFFA, 1993).

Various methodological approaches exist within the MCDA framework, each offering distinct ways to structure and analyze decision problems. Analytic Hierarchy Process (AHP), developed by Saaty, enables hierarchical structuring of criteria and alternatives, facilitating pairwise comparisons to derive preference weights. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), proposed by Hwang and Yoon, ranks alternatives based on their proximity to the ideal solution and furthest from the negative ideal (SAATY, 1980; HWANG & YOON, 1981).

The MCDA considers different types of criteria, including quantitative, qualitative, and ordinal. Quantitative criteria involve measurable attributes, such as cost or performance metrics, while qualitative criteria capture subjective factors like user satisfaction or environmental impact. Ordinal criteria involve rankings or preferences without precise numerical values, requiring methods such as pairwise comparisons or preference elicitation (BELTON & STEWART, 2002).

MCDA finds applications across diverse domains, including environmental management, healthcare, finance, transportation, and engineering. In environmental management, MCDA aids in site selection for waste disposal or identifying suitable conservation areas by considering ecological, economic, and social criteria. In healthcare, MCDA supports clinical decision-making by integrating patient preferences, efficacy, and cost-effectiveness of treatments (MALCZEWSKI, 2006).

Dealing with uncertainty is a critical aspect of decision-making, and MCDA offers methods to incorporate uncertainty into the analysis. Techniques such as sensitivity analysis, scenario analysis, and probabilistic modeling allow decision-makers to assess the robustness of their decisions under different levels of uncertainty. This integration enhances the reliability and resilience of decision-making processes in uncertain environments (MUNDA, 2004).

Despite its utility, MCDA poses several challenges and limitations. These include the subjective nature of criteria weighting and preference elicitation, which can introduce biases and uncertainties into the decision-making process. Moreover, the complexity of real-world decision problems may render the application of MCDA computationally intensive and prone to model uncertainties. Additionally, interpreting and communicating the results of MCDA analyses to stakeholders with varying levels of expertise can be challenging, requiring effective visualization and communication strategies.

Recent advancements in MCDA theory include the development of hybrid methods that combine different MCDA approaches or integrate machine learning and optimization techniques. These hybrid methods aim to overcome the limitations of individual approaches and provide more robust and flexible decision support tools. Moreover, advancements in computing power and data analytics have enabled the application of

MCDA to increasingly large and complex decision problems, further expanding its potential impact across domains (ZAVADSKAS, TURSKIS, & ANTUCHEVICIENE, 2017).

Therefore, Multicriteria Decision Analysis (MCDA) theory offers a rich and versatile framework for addressing complex decision-making problems across various domains. Grounded in decision theory and multiple-criteria decision-making (MCDM), MCDA encompasses a range of methodologies tailored to specific decision contexts. While it finds widespread application, challenges such as subjective weighting, computational complexity, and stakeholder engagement warrant ongoing research and methodological advancements. Nonetheless, MCDA remains a valuable tool for addressing multifaceted decision problems and fostering informed decision-making processes.

PROMETHEE METHOD

The PROMETHEE methods were designed to treat multicriteria problems of outranking type and their associated evaluation table.

The additional information requested to run PROMETHEE is particularly clear and understandable by both the analysts and the decision-makers. It consists of:

- Information between the criteria; and

- Information within each criterion.

Information between the Criteria

Each criterion – whether a dimension corresponding to stakeholders, or a parameter (variable) considered – receives a weight of relative importance. These weights are non-negative numbers, independent of the measurement, and the higher the weight, the more important the criterion.

In the PROMETHEE software PROMCALC and DECISION LAB, the user is allowed to introduce arbitrary numbers for the weights, making it easier to express the relative importance of the criteria. These numbers are then divided by their sum so that the weights are normed automatically.

Assessing weights to the criteria is not straightforward. It involves the priorities and perceptions of the decision-maker. The selection of the weights is his space of freedom. PROMCALC and DECISION LAB include several sensitivity tools to experience different set of weights in order to help to fix them.

The PROMETHEE method involves comparing alternatives based on multiple criteria. Information intracriteria refers to the data within each criterion, such as the performance or value associated with each alternative. *Limiar* is the threshold or cutoff point used to determine the preference of an alternative within a criterion. These thresholds help in ranking alternatives according to their performance relative to the established criteria.

PROMETHEE METHOD IN SAFEGUARDING NUCLEAR MATERIALS FOR SUBMARINE PROPULSION

One of the key advantages of utilizing PROMETHEE in safeguard studies for submarine propulsion is its ability to handle multiple conflicting criteria. In this context, criteria may include factors such as security, reliability, operational feasibility, and regulatory compliance. PROMETHEE allows decision-makers to systematically compare and rank alternative safeguard measures based on their performance across these criteria, facilitating informed decision-making (BRANS & VINCKE, 1985).

Moreover, PROMETHEE methodology can accommodate both quantitative and qualitative data, making it suitable for assessing diverse aspects of safeguard strategies. For instance, quantitative data such as technical specifications and cost estimates can be integrated with qualitative assessments of political considerations and stakeholder preferences. This comprehensive approach enables decision-makers to consider a wide range of factors influencing safeguard decisions (BRANS & MARESCHAL, 2005).

In the context of submarine propulsion, safeguard measures must not only ensure the security of nuclear materials but also maintain operational readiness and effectiveness. PROMETHEE facilitates the evaluation of safeguard strategies based on their impact on submarine operations, allowing decision-makers to identify measures that strike a balance between security and operational requirements (MARESCHAL & BRANS, 2010).

Furthermore, PROMETHEE can support the analysis of trade-offs between different criteria, helping decision-makers navigate complex decision landscapes. For instance, a safeguard measure that enhances security may incur higher costs or impose operational constraints. PROMETHEE enables decision-makers to quantify and prioritize these trade-offs, guiding the selection of safeguard strategies that best align with overarching objectives (MACHARIS & SPRINGAEL, 2009).

In summary, the PROMETHEE method offers a valuable tool for evaluating and prioritizing safeguard measures for nuclear materials used in submarine propulsion. By providing a structured framework for multicriteria decision analysis, PROMETHEE enables decision-makers to assess alternative strategies based on their performance across multiple criteria. This facilitates the identification of robust and effective safeguard measures that enhance security, safety, and operational readiness in submarine propulsion systems.

PROMETHEE Simulation Analysis

The importance of conducting mathematical simulations for complex decision-making contexts cannot be overstated. Mathematical simulations provide decision-makers with invaluable insights into the potential outcomes and consequences of different courses of action. By modeling complex systems and scenarios, simulations allow for the exploration of various scenarios, the identification of potential risks and opportunities, and the evaluation of alternative strategies. Moreover, simulations enable decision-makers to test hypotheses, refine strategies, and make informed decisions based on evidence rather than intuition or guesswork. In contexts where real-world experimentation is impractical or unethical, mathematical simulations serve as indispensable tools for decision support, helping to mitigate uncertainties and improve the effectiveness of decision-making processes.

We assume that an NNWS negotiating safeguards to be applied to the nuclear fuel of a nuclear-powered submarine developed or acquired by that NNWS would have a team of negotiators representing, at a minimum, the following NNWS bodies or stakeholders: military, diplomatic and technical/regulatory nuclear authority. Thus, the interdisciplinary study included essential dimensions, as shown in Table 1.

Table 1 – Dimensions Adopted.

Analysis dimensions – simulation	Weights
NNWS Military	3,00
NNWS Diplomacy	2,00
NNWS Technical and Regulatory	3,00
IAEA Delegation	1,00

Source: Prepared by the author.

For MCDA studies, weights are fundamental for pairwise analyzes and for building relationships between alternatives. The weights for this simulation were assigned by technical experts and the scale used was from 1 to 3, with 1 being the least important and 3 being the most important.

The parameters used in the simulation were those listed in Table 2 and were stated based on the variables considered essential in negotiation and already described in this article.

Table 2 – Parameters Adopted.

Parameters
Preservation of Sensitive/Classified Technologies
Preservation of the Submarine's Operational Characteristics
Guarantee that there will be no diversion of nuclear material
Duration of the Negotiation

Source: Prepared by the author.

It is worth returning to the weights presented in Table 1 for the respective dimensions considered:

- Weight 3 – Will be assigned to the stakeholder with mastery and expertise in two or more of the four established parameters.

- Weight 2—This will be assigned to the stakeholder who only has "expertise in one of the established parameters" or "central dialogue in the negotiation."

- Weight 1 – Stakeholder considered for a given simulation.

We consider that the simulation will be carried out in two rounds. The first will only involve NNWS stakeholders. In this round, the differentiated weights corresponding to expertise in the parameters considered will allow the NNWS delegation to reach an internal consensual position before negotiating with the IAEA. In the second round, there would be only two dimensions – the NNWS delegation and the IAEA delegation –both with a weight equal to 1.

The Figure 1 presents important information about the parameters versus dimensions, assigned in the Decision Lab software. The scores assigned to each parameter were made by experts, where they used a scale from 0 to 4, with 0 being the lowest impact and 4 being the highest impact.

Figure 1 - Matrix Valuation.

SIMULATION	MILITARY	DIPLOMATIC	TECHNICAL	IAEA
Unit	scale	scale	scale	scale
Cluster/Group				
Preferences				
Min/Max	max	max	max	max
Weight	3,00	2,00	3,00	1,00
Preference Fn.	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a
Statistics				
Minimum	2,0	1,0	1,0	2,0
Maximum	3,0	4,0	3,0	3,0
Average	2,8	2,5	2,0	2,5
Standard Dev.	0,4	1,1	1,0	0,5
Evaluations				
TECNOLOGY	3,0	1,0	1,0	3,0
CHARACTERISTICS	2,0	2,0	1,0	2,0
NUCLEAR MATE...	3,0	4,0	3,0	3,0
NEGOTIATION	3,0	3,0	3,0	2,0

Source: Prepared by the author from the Decision Lab Software.

It is worth noting that this is just an example of using PROMETHEE and does not reflect the actual results obtained from the simulations performed. Just note that this Matrix Valuation did not consider the two previously described rounds. However, the point to be highlighted is the kind of outcomes one can obtain.

Thus, the interdisciplinary simulation 2 included essential dimensions, as shown in Table 3 and Figure 2.

Table 3 – Dimensions Adopted in Simulation 2.

Analysis dimensions – simulation	Weights
NNWS Military	3,00
NNWS Diplomacy	3,00
NNWS Technical and Regulatory	3,00

Source: Prepared by the author

Figure 2 - Matrix Valuation for Simulation 2 – Brazil

SIMULATION BR	DIPLOMATIC	REGULATORY	MILITARY	AIEA	AIEA 1	DIPLOMÁTIC...
Unit	escala	escala	escala	escala	escala	escala
Cluster/Group	◆	◆	◆	◆	◆	◆
Preferences						
Min/Max	max	max	max	max	max	max
Weight	2,00	3,00	3,00	8,00	8,00	2,00
Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a
Statistics						
Minimum	0,0	2,0	0,0	3,0	3,0	0,00
Maximum	4,0	4,0	3,0	4,0	4,0	4,00
Average	2,3	2,8	2,0	3,7	3,7	2,00
Standard Dev.	1,5	0,8	1,2	0,5	0,5	1,63
Evaluations						
TECNOLOGY	0,0	2,0	0,0	4,0	4,0	0,00
CHARACTERISTICS	2,0	2,0	2,0	4,0	4,0	2,00
NUCLEAR MATE...	4,0	4,0	3,0	3,0	3,0	4,00
NEGOTIATION	3,0	3,0	3,0	n/a	n/a	n/a

Source: Prepared by the author from the Decision Lab Software.

Analyzing the Brazilian context is crucial when studying additional safeguards for the nuclear submarine program, considering diplomacy, regulations, and military activities. Brazil's diplomatic stance, both regionally and globally, plays a significant role in how the program is perceived and regulated. Engaging with international partners and adhering to non-proliferation treaties are essential aspects that impact the development and oversight of the nuclear submarine project.

Moreover, Brazil's regulatory framework, including its nuclear safeguards and export control mechanisms, shapes how the country manages its nuclear activities. Understanding these regulations is vital for ensuring compliance with international standards and mitigating proliferation risks associated with the nuclear submarine program.

Additionally, considering Brazil's military activities is crucial for assessing the implications of deploying a nuclear-powered submarine. This involves evaluating the strategic goals of the program, potential security implications for the region, and the broader geopolitical context. Examining the military dimension provides insights into how the submarine program fits within Brazil's national defense strategy and its implications for regional stability.

In summary, analyzing the Brazilian context regarding diplomacy, regulations, and military activities is essential for understanding the broader implications of the nuclear submarine program. It allows for a comprehensive assessment of the program's impact on national security, international relations, and non-proliferation efforts.

GAIA and Graph Results

The GAIA graph, an integral component of the PROMETHEE method, offers a visual representation of decision-making processes, facilitating stakeholders' understanding of complex decision landscapes. This graphical tool maps alternatives based on their performance across multiple criteria, allowing decision-makers to identify trade-offs, dominance relationships, and areas for improvement. By plotting alternatives in a two-dimensional space, with each axis representing a different criterion, the GAIA graph provides a concise yet comprehensive overview of the decision space, empowering decision-makers to prioritize actions and optimize outcomes effectively.

Moreover, the GAIA graph serves as a powerful communication tool, enabling stakeholders to engage in meaningful discussions and consensus-building exercises. Its intuitive visual format allows decision-makers to convey complex information in a clear and accessible manner, fostering transparency and collaboration among stakeholders with diverse expertise and perspectives. By promoting shared understanding and alignment on decision priorities, the GAIA graph enhances the decision-making process's inclusivity and effectiveness, ultimately leading to more informed and robust decisions.

Figure 3 presents a sample of the GAIA Graph utilization in the simulation of the negotiation between the IAEA and BRAZIL. from which we can analyze the following results:

- The decision axis is in the first quartile, characterizing a direction of great impact.

- The dimensions with the greatest impact on the decision are: NNWS Military.

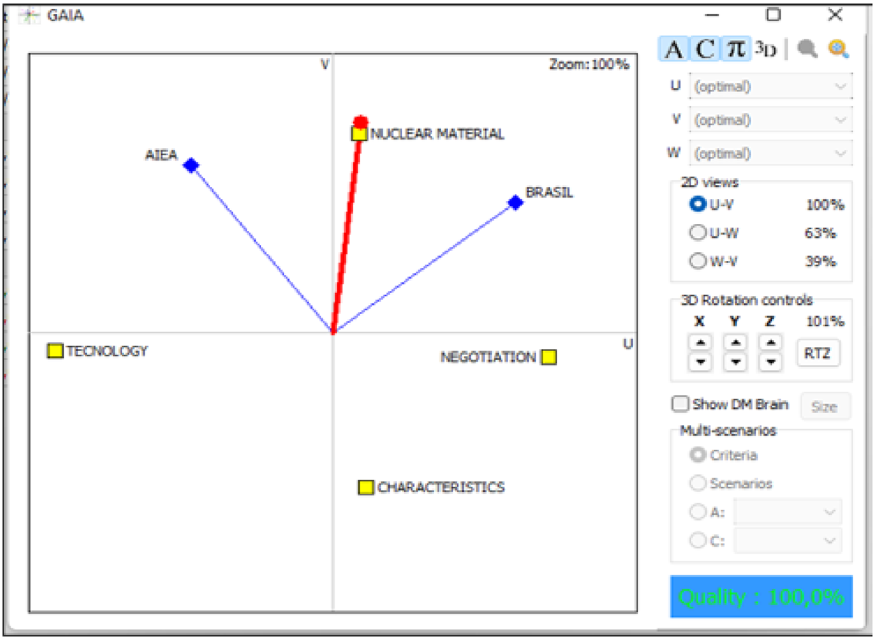
- The Diplomatic and dimensions are important but have lower Phi+ than the others.

-The parameter with the greatest impact on the decision is guarantee that there will be no diversion of nuclear material. This parameter has the same direction as the decision axis and is in the same quartile.

- The Preservation of Sensitive/Classified Technologies and Preservation of the Submarine's Operational Characteristics do not impact the decision, with Phi- greater than the others.

Once again, it is essential to note that this is just an example of using PROMETHEE and does not reflect the actual results obtained from the simulations performed. Just note that this GAIA Graph representation did not consider the two previously described rounds. However, the point to be highlighted is the types of conclusions that can be obtained in the simulation.

Figure 3 – GAIA Graph.



Source: Prepared by the author from the GAIA Graph.

The graphical analysis in the PROMETHEE method holds significant importance in enhancing decision-making processes. Through visual representations such as GAIA graphs or preference ranking maps, PROMETHEE enables decision-makers to gain insights into the relative performance of alternatives across multiple criteria. These graphical tools facilitate the identification of dominance relationships, trade-offs, and areas of compromise, empowering decision-makers to make more informed and effective choices.

Furthermore, the visual nature of graphical analysis in PROMETHEE enhances communication and stakeholder engagement. By presenting complex decision landscapes in a clear and intuitive manner, graphical representations facilitate discussions, consensus-building, and collective decision-making. This fosters transparency, trust, and buy-in among stakeholders, ultimately leading to more robust and sustainable decisions. Thus, the graphical analysis in PROMETHEE not only enhances decision quality but also promotes collaboration and alignment among decision-makers and stakeholders.

FINAL CONSIDERATIONS

Negotiations involving safeguards and their application in the propulsion of nuclear-powered submarines are a current issue on the IAEA agenda. Its unique character lies in the unprecedented nature of these negotiations, given that only two NNWS currently have active programs for the acquisition and/or construction of nuclear-powered submarines: Australia and Brazil. The programs have different contexts and characteristics, but both involve negotiating safeguards with the IAEA considering their respective CSA in force. In the future, other NNWS may pursue acquisition or development projects for this type of weapons system.

The negotiations involve multiple challenges and variables for the negotiating parties. These variables present trade-offs and can generate friction and wear in negotiation and impact the duration of the negotiation process. Therefore, tools that support decisions made in the various phases of this negotiation process become relevant assets.

In this context, interdisciplinary multicriteria analysis plays a crucial role in the simulation of complex negotiations, particularly in safeguard studies. By integrating diverse perspectives, methodologies, and stakeholder inputs, MCDA enables the systematic evaluation and prioritization of safeguard options. Through modeling simulation, decision-makers can assess the resilience and implications of proposed safeguards over time, enhancing safeguard decisions' effectiveness and legitimacy in complex negotiations.

The PROMETHEE showed the possibility of identifying trade-offs between the parameters (variables) adopted and possible friction points (internal and external) between the negotiating parties. Furthermore, the point to be highlighted is that, based on the simulations carried out, it was possible to verify that the proposed model allows negotiators who use it to have the perception of how the prioritization of decision parameters, based on the interests of actors belonging to the dimensions considered, will impact the negotiation of the Arrangement. The cooperative approach, intrinsic to the presented method, enhances consensus-building on sensitive negotiation, as is the case of safeguards to be applied to the nuclear material used in a nuclear-powered submarine of an NNWS.

ANÁLISE MULTICRITÉRIO INTERDISCIPLINAR NA SIMULAÇÃO DE NEGOCIAÇÕES COMPLEXAS: UM ESTUDO SOBRE SALVAGUARDAS

RESUMO

O artigo apresenta a utilização do método multicritério PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) na simulação de negociações complexas para aplicação de salvaguardas sobre o material nuclear para utilizado na propulsão de submarinos de um Estado Não-nuclearmente Armado (NNWS). Para tanto, o artigo está estruturado em quatro partes. Inicialmente são discutidas algumas das possíveis variáveis presentes no contexto das negociações de acordos entre a Agência Internacional de Energia Atômica (AIEA) e um NNWS, no que diz respeito à aplicação de salvaguardas ao material nuclear para a propulsão de submarinos. A segunda e terceira partes têm como foco uma visão geral da metodologia multicritério e do método PROMETHEE, que incorpora parâmetros interdisciplinares para uma modelagem robusta e exaustiva, apresentando suas principais características na utilização de atributos com os quais se busca identificar e medir as preferências dos tomadores de decisão. Dessa forma o método permite a ordenação de alternativas para a tomada de decisões estratégicas. Por fim, a última seção apresenta os resultados de simulações realizadas com equipes multidisciplinares envolvendo pesquisadores, civis e militares, brasileiros.

Palavras-chave: Negociação. Salvaguardas Nucleares. Não-Proliferação. Submarinos de Propulsão Nuclear. Metodologia PROMETHEE. Simulações.

Note for Clarification - copyright

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