



ORIGINAL PAPER

Fuzzy expert system for analyzing the Thucydides Trap in the US–China competition

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Abstract:

In recent decades, researchers in the field of international relations have sought to model competition and conflicts between states using mathematical or computational methods. Models based exclusively on binary logic have often proved insufficient for describing socio-economic and political variables characterised by ambiguity and uncertainty. In this context, fuzzy logic provides a methodological alternative by introducing the concept of degrees of truth, allowing for a nuanced representation of social phenomena.

This paper proposes the development of a fuzzy expert system entitled SECONF (Expert System for Assessing the Possibility and Probability of Conflict Occurrence between States), designed to analyse the likelihood of the emergence of the Thucydides Trap in the relationship between the United States of America and the People's Republic of China. The system is implemented using Matlab Fuzzy Logic Designer and Simulink and integrates nine key variables that capture the geopolitical, economic, and military dimensions of the bilateral relationship. The experimental results indicate a high probability of a Thucydides Trap-type scenario, confirming trends also highlighted by traditional geopolitical analyses.

Keywords: *fuzzy logic, expert systems, Thucydides Trap, geopolitics, international relations, conflict prediction*

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Introduction

Over time, numerous attempts have been made to develop mathematical models of conflicts between states (Omwenga V. O., Singh C. B., Manene M. M., Pokhariyal G. P., 2015; Nickholas Shallcross and Darryl Achner, 2019; Stephen L. Quackenbush and Frank C. Zagare, 2010; Frank C. Zagare, 2007). These models have sought to transform complex social variables into binary variables that can be processed by computers. The approach based on the principle of the excluded middle, rooted in Aristotelian logic, has long dominated Western logical and philosophical thinking.

This principle states that for any proposition, either the proposition or its negation must be true, with no possibility of a third value. While this model has proved effective in the exact sciences, its application to the social sciences has been problematic, as socio-political reality is characterised by ambiguity and gradation.

Fuzzy logic, introduced by Lotfi Zadeh in the 1960s, represents a fundamental paradigm shift. Unlike binary logic, it allows for degrees of truth between 0 and 1, thereby facilitating the modelling of complex phenomena and human perceptions (James. K. Peckol, 2021: 9-10; Hung T. Nguyen, Carol L. Walker, Elbert A. Walker, 2019:2-4). Through the use of fuzzy logic, it becomes possible to analyse socio-economic variables expressed in linguistic terms such as: very low, low, medium, high, and very high.

This approach is particularly useful in analysing competition between great powers (Tshilidzi Marwala, Monica Lagazio, 2004; Huilai Zhi, Jinhai Li, Yinan Li, 2022; Myron S. Karasik, 2023), especially in the case of the relationship between the United States and China, often described in the literature through the concept of the Thucydides Trap. (Graham Allison, 2015; Graham Allison, 2017: 29; Enescu Madalin Ciprian, 2025).

According to Graham Allison the Thucydides Trap is a concept to describe the systemic competition between the hegemon and the rising power inside an international power system. The name came from the competition between Sparta and Athens during the Peloponnesian Wars, when the two power dispute their hegemony to the city-states system in the Ancient Greece. In order to support this theory Graham Allison analyzed 16 cases where the power transition took place, in 12 of these cases the power transition took place after a war, but in four cases the transition was peaceful and the rising power manage to become the new hegemon (Graham Allison, 2017: 30-33).

Computational Systems for Conflict Analysis

In the field of international relations, several software tools have been developed for conflict analysis. Among these are:

- **Violence Early-Warning Systems (VIEWS)**

This system, developed by Uppsala University and the Peace Research Institute Oslo, analyses the probability of the occurrence of armed conflicts using historical databases on political violence. The model focuses primarily on intrastate conflicts and has a predictive capacity of up to approximately 36 months.

The software uses data collected over the period 1990–2020 and focuses particularly on Africa and the Middle East. Although a more recent version, *fatalities002*, has already been released, the system remains largely concentrated on specific types of conflict rather than interstate ones. Nevertheless, its predictive capability can extend to up to 36 months (VIEWS, 2026; The Views Team, 2022:5).

- **International Futures (IFS)**

International Futures is a software tool designed to analyse how certain global trends may generate conflicts or even social crises. It began to be developed during the Cold War period and incorporates several analytical modules, including demography, agriculture, energy, economics, politics, and the environment. Each of these modules employs a set of specific variables in order to generate predictions regarding global trends. To simplify the analysis, countries are grouped into geographical regions, allowing for the observation of the dynamics and interactions among the main variables used by each module, with a predictive horizon extending to the year 2100.

The analysis of interstate conflicts is conducted through the political module, in which the developer of this software has included variables such as fiscal policy, the distribution of state revenues, variables assessing mutual threats between states and the likelihood of their escalation into arms races and potential conflict, as well as variables capturing social changes associated with state development.

However, despite the inclusion of such variables, the software relies heavily on global trends driven by demographic, technological, and economic development and does not directly analyse the underlying causes that may generate interstate conflicts (Barry B. Hughes, 2002: 151-175).

The Proposed Expert System: SECONF

First, it must be clarified whether the classical design of a fuzzy-based expert system (Constantin Virgil Negoita, 1985; Itisha Gupta, Garima Nagpal, 2020: 321-322) still makes sense for analyzing a problem in the context of contemporary ML/LLM/GenAI systems. The specialized literature (Hafsaa Ouifak, Ali Idri, 2025) confirms that it does — but not as a universal solution, and not in the same form in which it was viewed during the classical era of expert systems.

Today, a fuzzy expert system remains particularly relevant when the problem exhibits the following characteristics:

- expert knowledge exists and can be formulated as rules;
- explainability is important;
- data are scarce, noisy, or difficult to label;
- the domain requires predictable and auditable behavior — for example, industrial control, technical diagnosis, risk assessment, or engineering decision support.

Recent literature continues to treat fuzzy logic as a relevant tool precisely because of its interpretability, its ability to handle uncertainty, and its integration with XAI and hybrid ML approaches, rather than as an “obsolete” technology (Hafsaa Ouifak, Ali Idri, 2025).

What has changed is its positioning:

1. it no longer competes directly with deep learning or large language models in tasks where abundant data are available and raw performance is required;
2. it performs favorably in contexts where linguistic rules such as “if temperature is high and vibration is moderate, then risk is high” are needed — that is, where human understanding and the ability to modify the system are essential. Recent reviews highlight exactly this niche: fuzzy logic enhances the interpretability of opaque models but has limitations in terms of scalability and optimization (Hafsaa Ouifak, Ali Idri, 2025).

More specifically, its use is justified when:

- a transparent model is required;

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- the number of variables is relatively small and their relationships can be expressed semantically;
- the domain is stable;
- human experts are able to define meaningful membership functions and rules.

These conditions are met in the case of our problem (a risk assessment): analyzing the probability of the emergence of the Thucydides Trap between the United States and China (Graham Allison, 2015; Graham Allison, 2017: 29; Enescu Madalin Ciprian, 2025). Accordingly, we have developed the SECONF expert system.

The implementation was carried out using MATLAB (Yi Chen, Long Huang, 2024), Fuzzy Logic Designer (The MathWorks Inc, 2023), and Simulink (The MathWorks Inc, 2026). The system employs a set of nine main linguistic variables:

1. Strategic Interests (IntStrat)
2. Ideological Differences (DifId)
3. Cooperation (Colab)
4. Power Competition (ComPu)
5. Cultural Differences (DifCult)
6. Economic Competition (CompEc)
7. Alliances and Treaties (AlTrat)
8. Transnational Challenges (ProvTrans)
9. Military Conflict Potential (PotConflMil)

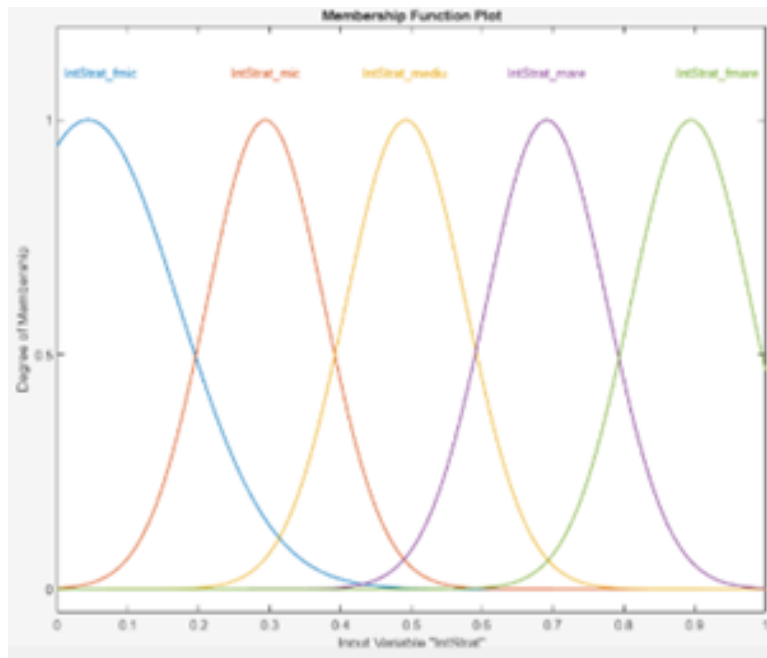
Each variable can take one of the following linguistic values: very low, low, medium, high, and very high. The system's output variable is SECONF, a Mamdani-type fuzzy output expressing the probability of the emergence of the Thucydides Trap.

The simple fuzzy variables are Cooperation (Colab) and Economic Competition (CompEc), while the others are complex composite variables. The complex variables are derived through the combination, via fuzzy subsystems, of secondary variables that are semantically related. Some of these secondary variables, in order to reduce the overall system complexity, are assigned only binary truth values (singleton, Yes or No) as well as linguistic truth values: very low, low, medium, high, and very high.

4. Modelling the Fuzzy Variables

The system variables are of two types: fuzzy and Boolean. A linguistic variable is described by a set of linguistic values, and each linguistic value is associated with a membership function that expresses the degree to which each numerical value of the variable belongs to that linguistic description, as shown in Figure 1.

Figure 1 Representing a variable with multiple degrees of truth through membership functions



- **Strategic Interests**

The IntStrat variable is composed of four primary variables:

1. interest in natural resources;
2. interest in territories;
3. access to maritime routes;
4. geopolitical influence.

The first three variables take binary values (true/false), while geopolitical influence is expressed in fuzzy degrees.

- **Ideological Differences**

This variable is defined through two components:

- divergent ideologies
- incompatibility of political systems

Both components are treated as binary values.

- **Cooperation**

Colab is a binary variable (YES/NO) that measures the extent to which countries engaged in competition are willing to cooperate in order to address bilateral or international issues, or to reduce existing tensions between them.

- **The struggle for power**

The ComPu variable comprises two components:

- competition for expanding the sphere of influence
- competition for maintaining the sphere of influence

Both are expressed in fuzzy degrees.

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- **Cultural differences**

This binary variable refers to the existence of cultural differences between different states. These may include cultural differences generated by language, customs and traditions (*DifCult_Cult*); and religions, superstitions, religious beliefs or religious ethics (*DifCult_Rel*).

- **Economic competition**

Economic competition is modelled using a fuzzy variable with five degrees of truth.

- **Alliances and treaties**

This binary variable refers to the way in which states that are in the Thucydides Trap form or adhere to a series of international alliances or treaties. In this case, it concerns alliances and treaties with military purposes (*AlTrat_Mil*) and security purposes (*AlTrat_Sec*), whether they are offensive or defensive.

- **Transnational challenges**

ProvTrans represents one of the most complex variables in the proposed system. Through this variable, we measure whether countries engage in addressing key international challenges, such as transnational terrorism (*ProvTrans_Ter*), nuclear proliferation (*ProvTrans_PAN*), and climate-related issues that may have an impact on the international system (*ProvEcol*).

- **Military conflict potential**

The **PotConflMil** variable includes:

- nuclear power
- military size
- military budget

Military size is determined by:

- number of ships
- number of personnel
- number of aircraft

The data used are drawn from The Military Balance (2009–2023), which made a comprehensive image regarding the way the US and China military forces and military budgets (The Military Balance 2009-2023). In order to obtain the results of the variables we use the data from the *The Military Balance* and put them in separate categories. Each category was designed using the biggest value from each section, navy, infantry and avion. We also limit the types of the units we used because in the China's case the data were not so relevant in this period of time and it was impossible to compare them with those from the US. Also, there was a shift in the period of 2010-2013 when the Chinese army changed itself from a soviet style army, where the heavy infantry and heavy ships were used to more modern technology, where they use more lighter and fastest ships, build at least three aircraft carrier placed in the north, west and south regions of the Pacific Ocean. On the other hand, the Ukrainian war started in 2022, had showed that a drone war will be more effective than a conventional war in the next years.

Using this data, the results are transformed into fuzzy degrees based on numerical intervals.

a. **Fuzzy System Rules**

The analysis is based on a set of **64 fuzzy** rules, defined in the form: *IF condition1 AND condition2 ... THEN result*

Weights between 0 and 1 are applied to the rules, determining their influence on the final outcome [15].

The fuzzy rule set was carefully constructed, given that the accuracy, realism, and validity of the results depend on it. Obtaining correct outputs from the system is as important as the model's structure. Figure 2 shows the way it is loaded into the system, while Figure 3 illustrates a possible modification after running the model.

Figure 2 The way in which the final rules were entered into the designed system

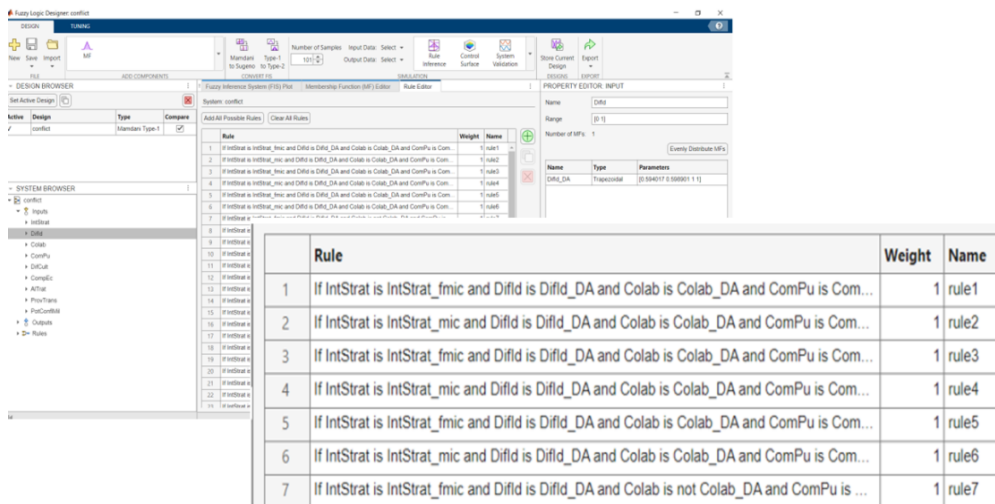
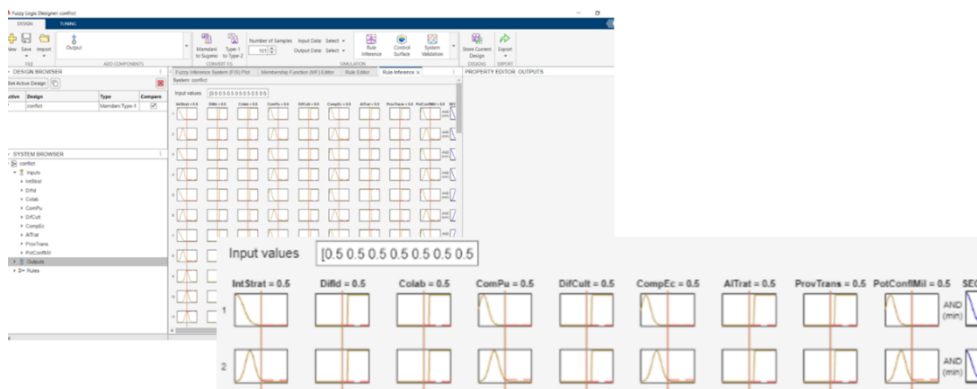


Figure 3 The way in which modifications can be made to the analysis rules after running the program

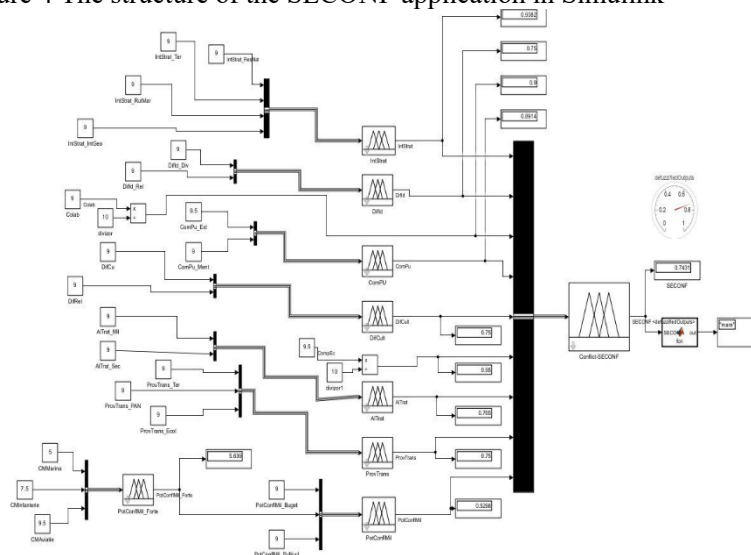


- System Implementation

The next stage in the construction of this system is the development of the program in which the fuzzy inference systems (FIS) are connected in order to obtain both the main variables and the final output. In this respect, Figure 4 illustrates graphically the way in

which the program was designed; thus, on the left-hand side the input data can be observed, while on the right-hand side the final result is displayed.

Figure 4 The structure of the SECONF application in Simulink



A graphical display module has also been added for the final value generated by the system, so that users who are not familiar with such models can view on screen both the fuzzy linguistic output and the numerical value corresponding to the respective degree of truth.

It should be noted that the final value resulting from the analysis of the main variables is a numerical value, representing a degree of truth ranging between 0 and 1. In this way, the interval between 0 and 1 has been divided into five distinct response categories.

Thus, a value between:

- [0, 0.2] represents a very low probability;
- [0.2, 0.4] a low probability;
- [0.4, 0.6] a medium probability;
- [0.6, 0.8] a high probability;
- [0.8, 1] represents a very high probability.

At the end, the system will analyse each value and rule entered by the user and will display in the graphical output module both the resulting value and the corresponding degree of truth.

This system output is assigned to a variable called SECONF, which represents for the user the degree to which the Thucydides Trap between the USA and China is likely, or not, to occur. The system architecture is illustrated in Figure 1.

The left side of the system contains the input variables, while the right side displays the final output.

The final SECONF value is expressed numerically on a 0–1 scale, which allows the probability of conflict occurrence to be interpreted:

SECONF Conflict Occurrence

- 0 – 0.2 very low probability
- 0.2 – 0.4 low probability
- 0.4 – 0.6 medium probability
- 0.6 – 0.8 high probability
- 0.8 – 1 very high probability

- Experimental Results

The system was tested using several sets of values. For eight testing versions (Vt1–Vt8), using the values specified in Table 1, the results shown in Table 2 were obtained. It should be noted that the test values were considered within the context of the model under study, namely the USA–China competition.

Table 1. Table of Variables SECONF (Test versions: Vt1 – Vt8)

No	Vt1	Vt2	Vt3	Vt4	Vt5	Vt6	Vt7	Vt8	Primary Variables		Composite Variables	Fuzzy Result							
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	IntStrat	ResNat	IntStrat (1)	SECONF							
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	IntStrat	Ter									
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	IntStrat	RutMar									
4	High	High	High	Very High	High	Very High	Very High	High	IntStrat	InfGeo									
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	DifIld	Diver	DifIld (2)		SECONF						
6	No	Yes	Yes	Yes	Yes	No	No	No	DifIld	Incomp									
7	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Colab		Colab (3)			SECONF					
8	Very High	High	High	Very High	Very High	High	Very High	Very High	ComPu	Ext	ComPu (4)								
9	Very High	Very High	Very High	Very High	Very High	Very High	Very High	Very High	ComPu	Ment	SECONF								
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	DifCult	Cult					DifCult (5)				
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	DifCult	Rel					SECONF				
12	Very High	Very High	High	Very High	Very High	Very High	Very High	Very High	CompEc							CompEc (6)			
13	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	AlTrat	Mil						AlTrat (7)			
14	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	AlTrat	Sec						SECONF			
15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	ProvTrans	Ter							ProvTrans (8)		
16	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	ProvTrans	PAN							SECONF		
17	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	ProvEcol									SECONF	
19	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	PuNucl										PotConfl
20	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	CMMarina	PotConflMil (9)									SECONF
21	High	High	High	High	High	High	High	High	CMInfantry										
22	Very High	Very High	Very High	Very High	Very High	Very High	Very High	Very High	CMAviation										
23	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	PotConflMil										

Table 2. Results obtained from running the program using the test values in Table 1

Nr.crt.	Valori de test	SECONF
1	Vt1	Very High
2	Vt2	High
3	Vt3	High
4	Vt4	High
5	Vt5	High
6	Vt6	Very High

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7	Vt7	High
8	Vt8	High

- Analysis of the USA–China Scenario

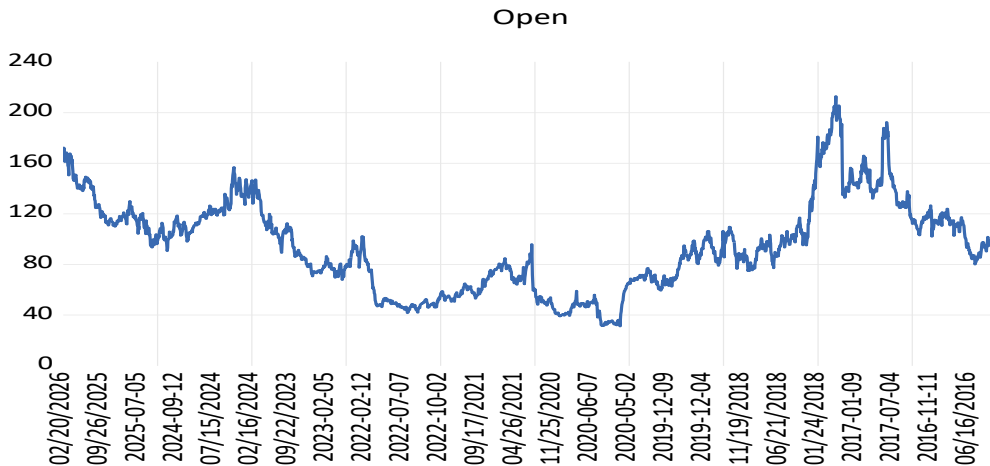
For the scenario considered the most realistic, the variable values are presented in Table 3.

Table 3. Main values established to test the occurrence of the Thucydides Trap in the case of USA–China relations

No.Item	Variable Values	Primary Variables (II)	Fuzzy Composite Variables (IV)
1	Yes	<i>IntStrat_ResNat</i>	IntStrat (1)
2	Yes	<i>IntStrat_Ter</i>	
3	Yes	<i>IntStrat_RutMar</i>	
4	Very High	<i>IntStrat_InfGeo</i>	
5	Yes	<i>DifId_Diver</i>	DifId (2)
6	Yes	<i>DifId_Incomp</i>	
7	Yes	<i>Colab</i>	Colab (3)
8	High	<i>ComPu_Ext</i>	ComPu (4)
9	Very High	<i>ComPu_Ment</i>	
10	Yes	<i>DifCult_Cult</i>	DifCult (5)
11	Yes	<i>DifCult_Rel</i>	
12	Very High	<i>CompEc</i>	CompEc (6)
13	Yes	<i>AlTrat_Mil</i>	AlTrat (7)
14	Yes	<i>AlTrat_Sec</i>	
15	Yes	<i>ProvTrans_Ter</i>	ProvTrans (8)
16	Yes	<i>ProvTrans_PAN</i>	
17	Yes	<i>ProvEcol</i>	
18	Yes	<i>PotConflMil_PuNucl</i>	PotConflMil (9)
19	Medium	CMMarina	
20	Very High	CMInfanterie	
21	High	CMAviatie	
22	Very High	<i>PotConflMil_Buget</i>	

The final result indicates a high probability of a Thucydides Trap-type situation occurring. The result is illustrated in Figure 5.

Figure 5. Result of the analysis performed for the values using the SECONF program



Conclusions

The paper presented the development of a fuzzy expert system for the analysis of interstate conflicts. The SECONF system demonstrates that fuzzy logic can be used to model complex geopolitical phenomena.

The results suggest that:

- The strategic competition between the United States and China is significant.
- The risk of a Thucydides Trap-type situation occurring is high.

However, the final outcome regarding the emergence of a conflict remains dependent on the **human factor**, which can alter the course of events through political and diplomatic decisions.

Authors' Contributions:

The authors contributed equally to this work.

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