Yugoslav Journal of Operations Research
32 (2022), Number 3, 325–356
DOI: https://doi.org/10.2298/YJOR210515002S

ESTIMATING THE POTENTIAL WILLINGNESS OF THE STATE TO USE MILITARY FORCE BASED ON THE SUGENO FUZZY INTEGRAL

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Received: May 2021 / Accepted: January 2022

Abstract: Estimation of the potential willingness of the state to use military force is an integral part of the analysis of international relations and the preparation of key decisions in in security sphere. Our problem was to develop a method for numerically estimating the potential willingness of any state to use military force. This method should take into account a large number of quantitative and qualitative criteria, the uncertainty of their relationships, as well as the uncertainty of the initial data, some of which can only be obtained with the help of experts. Our analysis has shown that the known methods have a number of serious shortcomings. We proposed to solve this problem based on the representation of partial estimations of states in the form of fuzzy sets, and the importance of criteria in the form of a fuzzy measure. We also proposed to aggregate the partial estimations using the Sugeno fuzzy integral. We developed a hierarchical structure of estimation criteria, determined the importance of the criteria, built an observation channel based on the Harrington curve to obtain input estimations, and also developed an aggregation algorithm. As a result, we calculated estimations for 137 states and examined their potential willingness to use military force. The results disclose new aspects of using fuzzy-integral calculus to construct hierarchical models of multi-criteria estimating, and also demonstrate the possibility of using artificial intelligence methods to obtain numerical estimations in the sphere of international relations.

Keywords: Willingness to use Military Force, Estimation, Fuzzy Set, Fuzzy Measure, Fuzzy Integral.

MSC: 28E10, 90B50, 91B06.

1. INTRODUCTION

As is known from the theory of war [1] (adhering to a realistic view), there are three necessary and sufficient conditions that a state to go to war against another state. Firstly, the first state must have contradictions in relations with the second state and consider them as existential, antagonistic and irreconcilable. Secondly, the first state must have the military tools and resources to go to a war. Modern research [2] calls these tools and resources as military force or national power. Third, the political leadership of the first state should positively estimations the expediency of using military force, that is, it should count on winning a future war.

Estimating each of these conditions is a challenging scientific problem. The first problem can be solved by comparing the positions of states on various international problems, as is done, for example, in the study [3]. The second problem can be solved using multicriteria decision-making methods, for example [4]. Here we want to find a solution to the third problem, which is a challenging too, since its solution requires an analysis of the subjective process of making important government decisions. It can be assumed that the solution to the third problem should be based on two elements: an estimating of the state's attitude to international contradictions and an estimating of the ratio of expected gains and losses. To obtain these estimations, it is necessary to analyze many data and estimations: the composition of international relations; establishment views on their priority; the psychological characteristics of the political elite; the results of comparing the national power of the state and the potential adversary and others. Because of this, the problem becomes a large dimension, and its solving in this formulation requires significant analytical efforts.

We propose to characterize the expediency of using military force with the help of potential willingness of the state to use military force (PWSUMF) by analogy with indices, which used in political analysis, for example, the level of science development [5], the level of education [6], national power [7] and others. These indices are indirect in nature; however they help to identify states which require increased attention when preparing political decisions. Our proposition allows significantly reduce the dimension of the problem. We define PWSUMF as desire, inclination, and preparedness to use military force for resolving contradictions in international relations.

The widespread term "armed aggression" is some approximation to PWSUMF. In 1974, the 29th session of the UN General Assembly formally defined armed aggression. However, armed aggression is an occurred act. Therefore, the term "armed aggression" cannot be used to solve problems in conditions when armed aggression has not yet occurred, for example, to solve problems that are related to the prevention of military conflicts. As will be shown below, the term "aggressiveness" is also used in the scientific literature. However, this term a priori has a negative connotation, so below we will use the proposed term PWSUMF.

Thus, our problem was to develop a method for numerically estimating the PWSUMF for any state. The three conditions listed above describe the place and significance of our problem in making key decisions in the sphere of international relations.

The indices for political analysis are usually calculated using hierarchical structures consisting of quantitative and qualitative criteria. Statistical data or expert estimations are used as initial data. Estimation algorithms aggregate initial data in accordance with criteria structures and taking into account their importance. The main shortcomings of the known methods are as follows:

semantic imbalance in the system of criteria, when at one level of the hierarchy researchers place criteria with incomparable levels of generalization;

the mathematical constructs that are used to describe the importance of criteria and initial estimations do not always or do not fully account an uncertainty;

the mathematical constructs used to aggregate the initial estimations do not provide the required selectivity;

methods of processing expert estimations do not take into account the competence of experts, what turns the expertise into a poll of experts.

Therefore, for measuring PWSUMF, we propose a method based on the following positions:

a new, balanced system of evaluation criteria;

we presented the importance of the criteria as fuzzy measures;

we presented initial and intermediate estimations as fuzzy sets;

we used the Sugeno fuzzy integral as an aggregation tool;

to generalize the estimations of several experts, we have developed an algorithm that takes into account the competence of experts and also uses the Sugeno fuzzy integral.

To disclose and substantiate the proposed method, we will further consider the following research questions:

1. Analysis of known approaches, which involves the analysis of approaches to understanding PWSUMF and approaches to measuring PWSUMF. This will make it possible to clarify the conceptual meaning of the estimation and to define the base method, which will then be used as a prototype for comparison with the proposed method.

2. Substantiating of the requirements for the PWSUMF measurement method based on the analysis of the shortcomings of the prototype, as well as on the basis of

the analysis of approaches that could be used for measurement. This will allow to formulate a general understanding about the most suitable method for measuring PWSUMF and, based on this, determine the sub-tasks listed below that need to be solved.

3. Determination of the hierarchy of criteria for estimating PWSUMF.
4. Determination of the importance of the PWSUMF estimation criteria.
5. Construction of an observation channel to obtain initial estimations.
6. Development of an algorithm for calculating PWSUMF based on group estimations.
7. Calculation of PWSUMF estimations using the developed method and their discussion.

2. KNOWN APPROACHES

Approaches to understanding PWSUMF. As we mentioned above, some approximation to PWSUMF is the term "aggressiveness", which is used in many scientific studies to describe the specific, extraordinary (possibly dangerous) behavior of a subject. For example, the study of the behavior of exchange players [8] considers aggressiveness as decisiveness, persistence, deviation from generally accepted behavior. The study [9] considers verbal aggressiveness as a personality trait that pushes people to attack the self-esteem of other people while communicating with them. The paper [10] studies the psychological aspects of aggressiveness, including the reasons for the desire of people and communities to engage in armed struggle.

In general, these studies confirm the admissibility of our proposed understanding of PWSUMF as the willingness of the state to use military force in its activities.

Approaches to measuring PWSUMF. An analysis of the literature shows that when studying foreign policy, researchers use similar categories, but do not seek to obtain numerical estimations, for example [11]. From other hand, there are few studies that describe methods for measuring PWSUMF, aggressiveness, or other similar categories. Therefore, we will consider those of them that are most suitable as analogs.

To measure verbal aggressiveness, researchers typically analyze phrases which a person utters during communication. For example, the authors of the study [12] count the number of words of a person-aggressor, which are aimed at causing harm to the person-target. At first glance, it may seem that we can use a similar approach, counting the number of aggressive messages that are published in the information space of the state-target. However, here we see serious difficulties. Firstly, the number of mass media is very large, as well as the number of information messages. Therefore, the measurement becomes complex and requires significant efforts to solve. Secondly, the world information space is very global (multi-connected). Often the mass media of some states work in the information space of other states. Therefore, sometimes it is difficult to associate a certain mass media with the state-host. Without this, it is impossible to determine which state is the aggressor. Thirdly, as practice shows, the number of aggressive information messages can change dramatically. Influential mass media can very quickly shift their focus from one event to another, changing the nature of their rhetoric. The use of unstable estimations is unacceptable from the view-point of making long-term state policy. Therefore, the measurement of verbal aggressiveness is not suitable for solving our problem.

Researchers also use a category with the opposite meaning. In particular, the study [13] reveals the foundations of the cultures' peacefulness on the basis of the correlation of the criteria values for 74 states. These criteria characterize mainly "internal" peacefulness, that is, the nonviolence of the state in relation to society and citizens. As a result, the study identified four groups of criteria that characterize the culture's peacefulness: "liberal development", "violent inequality", "use of the means of violence" and "concern for people." There is no doubt that the criteria of "internal" peacefulness should be taken into account, but they only indirectly characterize PWSUMF. The example of Myanmar convincingly shows that a state with a significant level of "internal" violence does not show aggression towards other states.

In the sphere of political analysis, researchers publish few results of problem solving. Therefore, we will further expand the analysis sphere and briefly consider those approaches which addresses similar security problems and which can be used to estimation of the PWSUMF.

The authors of the paper [14] propose to use rough sets to select the best variant among the many available actions in the operations of the security forces. The approach assumes: determination of variant attributes based on previously performed operations and simulated operations; identifying the most important attributes to reduce the dimension of the problem; defining guidelines for decision-making based on the analysis of the relationship of attributes with the success of operations.

The study [15] aims to solve the problem of choosing the best radar position for air traffic control based on several criteria. To solve the problem, the authors use interval type 2 fuzzy sets and the representation of the membership function in the form of trapezoids. These sets are processed using arithmetic operations.

The study [16] solves the problem of determining the structural elements of close-quarters combat weapons, with the goal of meeting the needs of the troops. The authors of this study use a multicriteria model in which the criteria are described in the form of interval rough numbers and processing is carried out with the help of arithmetic operations.

The paper [17] also describes a solution to the problem of evaluating weapons systems based on arithmetic operations with fuzzy numbers.

In the study, the authors solve the problem of multi-criteria selection of a group of construction machines to ensure the mobility of troops when performing combat missions. The study is based on the use of a modification of the provisions of the Dempster – Schafer theory of evidence and the new method RAFSI [18] (Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval).

Let us note some shortcomings of the presented approaches. Rough-set methods aim at classifying objects according to an unordered set of criteria. These methods are poorly suited for solving estimation problems in which the system of criteria is described in the form of a hierarchy. The use of fuzzy numbers in multicriteria estimation problems also has problematic questions. Firstly, the representation of fuzzy numbers in the form of a trapezoid simplifies the executing of arithmetic operations, but increases the errors in the formalization of the input data [19]. Secondly, the shortcoming of most of the known approaches to the implementation of an arithmetic operation with fuzzy numbers is an increase in the support of the resulting number in the case of a sequence of arithmetic operations [20]. Thirdly, arithmetic operations with fuzzy numbers must have properties that are similar to those of operations with crisp numbers [21]: commutativity, associativity, distributivity, properties of zero, unit and multiplication. In practice, it can be difficult to meet all these requirements.

The index of states peacefulness, calculated by the Institute for Economics and Peace [22], is most correlated with the purpose of our study and can be used as a prototype. The Institute annually publishes a report on measuring the peacefulness of 163 states and territories similar to states [23]. This report is not a scientific publication, but it is widely used in practice for political estimating. According to the methodology of the peacefulness index, the calculation of the peacefulness estimations is a hierarchical process of aggregating 23 quantitative and qualitative criteria, which are grouped into two groups: "internal peacefulness" and "external peacefulness". Aggregation of estimations in these groups allows you to calculate a generalized estimation of peacefulness.

In this study, the list of criteria was determined by a group of experts. A five-point scale was used to describe the set of criteria values. The set of values for qualitative criteria is composed of five gradations with a corresponding description. The set of values for quantitative criteria is composed of five intervals of the same size. The size of the intervals is calculated based on the minimum and maximum possible estimations. The importance of the criteria was also determined by a group of experts using the five-point scale. The experts' estimations were agreed upon through discussion.

Estimating of a qualitative criterion consists in choosing of the gradation, the description of which best matches the value of the criterion. Estimating of a quantitative criterion consists in choosing an interval where the current value of the criterion falls. The hierarchical aggregating process is divided into two stages. At the first stage, the algorithm calculates the estimations of the criteria groups as a weighted average of the current estimations of the criteria. At the second stage, the algorithm calculates a generalized estimate of the state peacefulness as a weighted average of the estimations of criteria groups. The importance of criteria group for "internal" peacefulness is 0.6, for "external" peacefulness is 0.4.

Next, we will consider the shortcomings of the prototype and other models in order to identify the problems that need to be solved.

3. SUBSTANTIATING OF THE REQUIREMENTS FOR THE PWSUMF

The methodology of the peacefulness index has a number of problems that can call into question the calculated estimations. In order to select a suitable PWSUMF measurement method, let us analyze these problems.

Semantic imbalance in the criteria system of the peacefulness index. Above, we paid attention to the fact that each level of the hierarchy of the estimating system should contain criteria comparable in meaning and level of systemic generalization. This requirement is due to the need to ensure the comparability of criteria when the expert determines their importance. For example, in our opinion, an expert will have difficulty comparing the importance of the following criteria: "Relations with Neighboring Countries" and "Number of Armed Services Personnel". Relations with neighboring countries depend on the intentions and actions of this countries, their views on domestic and international problems. Moreover, relations with one country can be positive, and relations with another country can be negative. In addition, relations may differ in various international questions. Therefore, this criterion must be located at the top level of the hierarchy. On the other hand, the number of military personnel is a partial criterion of national power and should be located at a lower level of the peacefulness hierarchy. Thus, these criteria do not have a comparable semantic context, what can be a source of errors in determining their importance. We observe the semantic imbalance in other criteria as well.

A method for describing input estimations. The methodology of the peacefulness index does not allow taking into account the uncertainty of qualitative criteria. In particular, according to the methodology in order to estimate the criterion, it is necessary to select only one of the five gradations of the scale. However, in practice, there are often cases when the criterion value lies in the interval between adjacent gradations. In such cases, the choice of only one gradation leads to an error in the criterion measurement. To improve the measurement accuracy, one can increase the number of gradations or use fuzzy sets, as suggested by Zadeh [24]. The use of more flexible mathematical foundations will be effective, especially in the case of a significant level of semantic generalization of the criteria. For example, the criterion "Level of Perceived Criminality in Society" is intended to describe many different in nature phenomena in the criminal sphere. Urban crime is different from rural crime, juvenile crime is different from adult crime, cybercrime is different from street crime, and so on. It is very difficult to describe a multifaceted phenomenon by one criterion. Therefore, the mathematical constructions used for the measurement should be more flexible. In our case, such flexibility is provided by the extension of an ordinary set to a fuzzy set.

A method for aggregating partial estimations. The peacefulness index methodology calculates aggregated estimations as a weighted average of partial estimations. A decreasing in selectivity when increasing in the number of criteria is the first problem of using this method. A decreasing in selectivity leads to an insensitivity of the generalized estimate in the case of a large number of partial criteria. To demonstrate this, in Table 1 we presented an example of estimating the "internal" peacefulness for a different number of used criteria $x_i, i = \overline{1, 7}$. We used the importance of the first criteria from the above report and assigned only the first criterion a "bad" estimate (five points). We estimated the remaining criteria as "good" (one point).

Table 1: Estimating the "internal" peacefulness of a hypothetical state using the methodology of the peacefulness index

Estimating element	Number of criteria	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Criteria importance, points		3	3					
Criteria estimations, points	2	5	1					
Generalized estimation, points		3						
Criteria importance, points		3	3	4				
Criteria estimations, points	3	5	1	1				
Generalized estimation, points		2.2						
Criteria importance, points		3	3	4	3			
Criteria estimations, points	4	5	1	1	1			
Generalized estimation, points		1.923						
Criteria importance, points		3	3	4	3	3		
Criteria estimations, points	5	5	1	1	1	1		
Generalized estimation, points		1.75						
Criteria importance, points		3	3	4	3	3	5	
Criteria estimations, points	6	5	1	1	1	1	1	
Generalized estimation, points		1.57						
Criteria importance, points		3	3	4	3	3	5	3
Criteria estimations, points	7	5	1	1	1	1	1	1
Generalized estimation, points		1.5						

An analysis of the calculation results shows that the generalized estimate has halved when the criteria number has reached seven. In other words, many "good" estimations canceled out one "bad" estimate. This property of the aggregating method may be acceptable if the "bad" criterion is not critical. However, there are some criteria that play a key role, for example, "the intensity of internal conflict". In this case, the aggregating method should provide the following logic: if at least one key criterion is estimated as "bad", then the generalized estimation cannot be "good". In our example, we can increase the importance of the "bad" criterion to five points. However, a halving of the generalized estimate will still occur with the criteria number equal to eleven. That is, increasing the importance of the key criterion only diminishes the negative effect, but does not cancel it.

Another problem of the weighted average is the significant complication of the aggregating procedure if the criteria depend on each other. As an example, consider two criteria from the peacefulness index: "Number, duration and role in external conflicts" and "Neighboring countries relations". Here dependence is due to the fact that in the case of a conflict with a neighboring state, relations with it inevitably become negative. In such cases, it is necessary to take into account the correlation interactions between the criteria. For each interaction it is necessary to determine at least the strength and direction of the correlation. If the interactions are complex and multiple, the problem becomes nontrivial. The description of the hierarchy analysis method [25] confirms this conclusion.

Thus, the analysis of the estimations aggregating method, which was used when calculating the peacefulness index, shows the following:

in the case of a large number of criteria, the use of the weighted average leads to the insensitivity of the generalized estimate;

the aggregating method must provide support of non-linear logic;

if there are interactions between criteria, the use of weighted averages will become more difficult.

In our opinion, in such problems it is better to use special decision-making methods that aggregate estimations presented in the form of fuzzy sets. An overview of these methods is presented in our paper [26], which describes an algorithm for measuring the result of hostilities. This algorithm is based on describing the criteria importance using a fuzzy measure proposed by Sugeno [27].

Sugeno called the non-additive function $g(\cdot) : 2^X \to [0, 1]$, where 2^X is the set of all subsets of the universal set X, as a fuzzy measure $g(\cdot)$. Sugeno also proposed defining the fuzzy measure based on the following rule. Let $B \subseteq X, A \cap B = \varnothing$. Then

$$g(A \cup B) = g(A) + g(B) + \lambda \cdot g(A) \cdot g(B),$$

where the parameter $\lambda \in [-1, +\infty[$ is the normalization parameter of the fuzzy measure $g(\cdot)$.

In the case of a discrete set $X = \{x_1, x_2, \ldots, x_N\}$ (where N is the cardinality of the set X), on which the density of the fuzzy measure $g(\{x_i\}) = g_i \in [0, 1], i = \overline{1, N}$ was determined, the fuzzy measure of an arbitrary subset $A \subseteq X$ can be calculated as follows:

$$g(A) = \tfrac{1}{\lambda} \cdot \left[\prod_{x_i \in A} (1 + \lambda \cdot g(\{x_i\})) - 1 \right],$$

where the parameter λ must be determined from the normalization condition $g(X) = 1$.

Depending on the value of the λ-parameter, the fuzzy measure acquires different properties. In particular, the λ-parameter determines the modality of a fuzzy measure, that is, the attitude of the statement content to reality [28]. For example, if $\lambda > 0$, the fuzzy measure is a superadditive measure or belief measure. If $\lambda \gg 0$, the fuzzy measure is a necessity measure. If $-1 < \lambda < 0$, the fuzzy measure is a subadditive measure or plausibility measure. If $\lambda = -1$, the fuzzy measure is a possibility measure. If $\lambda = 0$, the fuzzy measure is a probability measure [29].

To clearly explain the modality of a fuzzy measure, consider an example of a coin toss without taking into account the possibility of falling on an edge. From the view-point of the probability, the subjective estimation of any outcome is 0.5. However, from the view-point of possibility, this estimation is equal to one, since there are no fundamental obstacles to any outcome. From the view-point of necessity, the subjective estimation of any outcome is zero, since nothing guarantees any outcome.

Representation of the criteria importance using a fuzzy measure involves the use of a fuzzy integral to aggregate partial estimations, presented as a fuzzy set. Today, two variants of calculating this fuzzy integral are known: Sugeno [27] and Choquet [30].

The Sugeno fuzzy integral $(s)\int$ from the membership function $h : X \to [0, 1]$, determined on the discrete set $A \in X, X = \{x_i, i = \overline{1, N}\}$, over the fuzzy measure $g(\cdot)$ can be defined as follows:

$$(s)\int\limits_A h(x) \circ g(\cdot) = \max_{i=\overline{1,N}} (\min(h(x_i), g(H_i))), \tag{1}$$

where $H_i = \{x_j | h(x_j) \geq h(x_i), j = \overline{1, N}\}$.

The Choquet fuzzy integral $(c)\int$ from the membership function $h : X \to [0, 1]$, determined on the discrete set $A \in X, X = \{x_i, i = \overline{1, N}\}$, over the fuzzy measure $g(\cdot)$ can be defined as follows:

$$(c)\int\limits_A h(x) \circ g(\cdot) = \sum_{i=1}^{N} \Big[h(x_i) - h(x_{i-1})\Big] \cdot g(H_i), h(x_0) = 0. \tag{2}$$

What is the difference between these fuzzy integrals? Figure 1 demonstrates techniques for calculating them. Let us assume that the membership function is ordered in decreasing. The Sugeno fuzzy integral uses the basis of logical operations (maximum and minimum) and calculates the result as the intersection of a decreasing membership function and an increasing fuzzy measure. The Choquet fuzzy integral uses the basis of arithmetic operations (addition and multiplication) and calculates the result as area. The Sugeno fuzzy integral has some advantage over the Choquet fuzzy integral. In the case of the Sugeno fuzzy integral, the integration result takes into account only the elements of the subset H, and in the case of the Choquet fuzzy integral, the result takes into account all elements of the set X. Thus, the technique of calculating the Sugeno fuzzy integral allows us to determine the elements of the set X that were taken into account and influenced the result. These elements are additional data for analysis and can be used to explain generalized estimations. We will discuss this below.

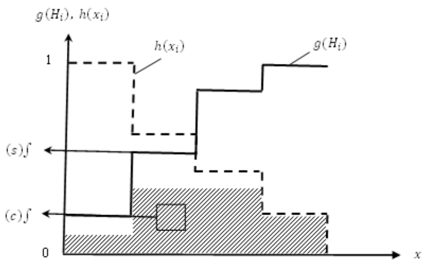

Figure 1: Comparison of calculating techniques the Sugeno and Choquet fuzzy integrals

The absence of the decreasing selectivity effect when an increase in the criteria number is the advantage of the Sugeno fuzzy integral over the weighted average. To demonstrate this, in Table 2 we considered an example similar to the example in Table 1. Using the fuzzy integral requires that the criterion estimations be normalized and the criterion importance converted to the fuzzy measure. Therefore, we normalized the criteria estimations by dividing them by five. To form fuzzy measures, we used the sequential approximation method described in [18]. Here we have established that the normalization parameter of the fuzzy measure will be equal approximately 4.5 (belief measure).

Table 2: Estimating the "internal" peacefulness of a hypothetical state using the Sugeno fuzzy integral (numbers are rounded)

Estimating element	Number of criteria	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Criteria importance (CI), points		3	3	4	3	3	5	3
Criteria estimations (CE), points		5	1	1	1	1	1	1
Normalized CI		0.2996	0.2996					
Normalized CE	2	1	0.2					
Generalized estimation		0.2996						
Normalized CI		0.154	0.154	0.21				
Normalized CE	3	1	0.2	0.2				
Generalized estimation		0.2						
Normalized CI		0.11	0.11	0.15	0.11			
Normalized CE	4	1	0.2	0.2	0.2			
Generalized estimation		0.2						
Normalized CI		0.09	0.09	0.11	0.09	0.09		
Normalized CE	5	1	0.2	0.2	0.2	0.2		
Generalized estimation		0.2						
Normalized CI		0.06	0.06	0.08	0.06	0.06	0.11	
Normalized CE	6	1	0.2	0.2	0.2	0.2	0.2	
Generalized estimation		0.2						
Normalized CI		0.05	0.05	0.07	0.05	0.05	0.09	0.05
Normalized CE	7	1	0.2	0.2	0.2	0.2	0.2	0.2
Generalized estimation		0.2						

Analysis of Table 2 shows that the generalized estimate changes only with an increase in the criteria number from two to three, and the Sugeno fuzzy integral shows good selectivity.

Note also that the result of the Sugeno fuzzy integral depends on the normalization parameter of the fuzzy measure. In the case $\lambda = 0$ the fuzzy integral is similar to the weighted average, in the case $\lambda = -1$ the fuzzy integral is equivalent to the fuzzy logical OR operation, in the case $\lambda \gg 0$ the properties of the fuzzy integral is approaching the properties of the fuzzy logical AND operation. In other cases, the fuzzy integral will have intermediate properties. In addition, in [31] Grabisch showed that fuzzy integrals can flexibly model interactions between criteria, what is important in our problem.

We can consider the set of T-norms and T-conorms [29] as an alternative to the fuzzy integral. These binary operations are used in fuzzy logic. They also implement fuzzy logical conjunction and disjunction operations. However, the fuzzy integral makes it possible to implement different aggregation logic using the same mathematical construction.

A method for calculating group estimations. We will call the estimation of a partial criterion a group estimation if it is calculated by aggregating the estimations of several experts. The methodology of the peacefulness index provides for calculating group estimations through joint discussion and agreement of estimations by experts. This means that the opinions of experts have the same weight, that is, the competence level of experts is not taken into account. This approach is applicable, as a rule, in sociological research, where it is difficult to find grounds to put forward a hypothesis about the respondents' competence. Sociologists compensate the errors related with this assumption by interviewing a large number of respondents. However, in our case, it is difficult to find a large number of competent experts, since each of them must have a very broad knowledge of both the history and the current situation in the international and domestic affairs of many states. Therefore, the competence level of experts should be taken into account when group estimating.

We can also solve this problem using the Sugeno fuzzy integral. In this case, the set of expert estimations will be described by a fuzzy set, the competence of experts will be described by a fuzzy measure, and the group estimation will be calculated using the Sugeno fuzzy integral.

Thus, the elements of the most appropriate PWSUMF measurement method are:

using of a hierarchical estimating system in which the partial criteria are consistent with each other from the view-point of meaning and level of generalization;

describing of criteria estimations using fuzzy sets;

describing the importance of the criteria and the competence level of the experts using fuzzy measures;

using the Sugeno fuzzy integral to calculate group estimations;

using of the Sugeno fuzzy integral for aggregating partial criterion estimations.

To implement this method, you need to solve the following subproblems:

define the hierarchy of PWSUMF criteria, that is, identify the structure of the estimating system;

determine the importance of PWSUMF criteria, that is, identify the parameters of the estimating system;

define an observation channel, which is intended to obtain estimations of PWSUMF criteria;

develop an algorithm for calculating PWSUMF based on group estimations;

calculate and analyze PWSUMF estimations.

4. PWSUMF CRITERIA HIERARCHY

Below we have presented the conceptual reasonings that formed the basis for the PWSUMF estimating, as well as the criteria hierarchy and explanations.

PWSUMF concept. So, PWSUMF characterizes the will (taking into account the desire, inclination, readiness) of a certain state to use military force against another state. We assume that the military-political leadership will act rationally, that is, the following reasonings will take place.

1. To use military force, it is necessary to prepare in advance the military infrastructure and armed forces, since their developing is time-consuming and costly. If the state bears such costs, we can confidently establish the fact that the state is preparing for a military conflict, no matter whether it is attack or defense. In both the first and second cases, the state is preparing to use military force. The development of military infrastructure and armed forces is both necessary and sufficient condition to conclude about a high PWSUMF. The creation of new offensive weapons and weapons based on new physical principles may indicate an increase in PWSUMF. Such weapons significantly increase the offensive potential of the armed forces. In general, the development of military infrastructure and military forces have significant importance in estimating the PWSUMF, since it directly indicates an increase in the size of a state's military power.

2. The military-political leadership of the state must control the domestic order and mood in society, since the conditions of a military conflict will require the complete subordination of public life to the main goal – victory. The control of the domestic order involves the restriction of civil rights and freedoms. As history shows, in the event of military defeats, social processes create a threat to the military-political leadership and generate domestic socio-political instability.

3. Society must support the domestic and international politics of the military-political leadership, which must have authority among the population. Without this, the use of military force cannot be successful. The military-political leadership must also be decisive and not be afraid of radical actions and possible negative consequences.

4. The state must prepare institutional capacity. In particular, the state should develop doctrinal provisions on the possibility of attacking first or delivering preemptive strikes. The political system of the state should not complicate the procedure for making decisions regarding the use of military force. The national economy must pay due attention to the military sector. The state must have developed police institutions to ensure proper control of domestic order.

5. The most important indicator of PWSUMF is the tradition of using military force to resolve contradictions in relations with other states. If a state, today or in the past, initiated a military conflict, we have every reason to increase PWSUMF. Therefore, the nature of the actions of the state today and in the past should be one of the most important criteria of PWSUMF.

We draw your attention to the fact that this study does not consider the willingness of states to use nuclear weapons, since in this case other conceptual reasonings should be used as the basis in the estimating system.

Hierarchy of PWSUMF criteria. Figure 2 shows the hierarchical criteria structure that implements PWSUMF concept discussed above. This structure also describes the order of estimating. Arrows indicate the subordination of partial criteria to more generalized criteria.

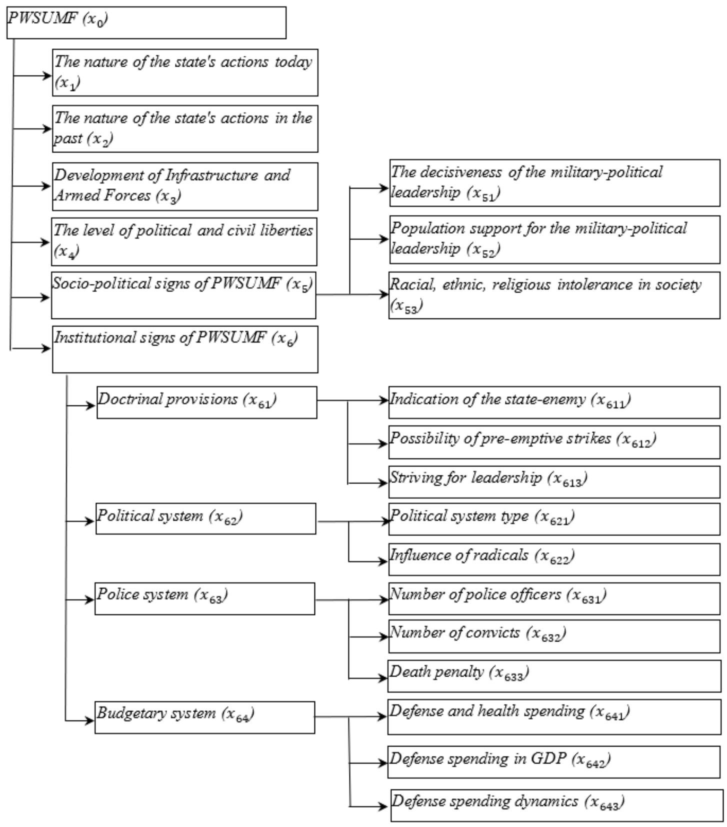

Figure 2: Hierarchy of PWSUMF estimation criteria

We will make several designations of some subsets of criteria that will be used below. Let us denote the set of partial criteria of the first level of the hierarchy as $A = \{x_1, x_2, \ldots, x_6\}$. These criteria are subordinated to the main criterion x_0. We have divided the set A into two subsets $A = A_1 \cup A_2$ depending on the method of obtaining the estimation of the partial criterion. The subset $A_1 = \{x_1, x_2, x_3, x_4\}$ form the criteria, the estimations of which will be determined directly by the experts. The subset $A_2 = \{x_5, x_6\}$ form the criteria, the estimations of which will be determined as a result of aggregating the subordinate criteria. The designations for the second and third levels of the hierarchy are similar:

the subset of criteria $B_1 = \{x_{51}, x_{52}, x_{53}\}$ is subordinated to the criterion x_5;

the subset of criteria $B_2 = \{x_{61}, x_{62}, x_{63}, x_{64}\}$ is subordinated to the criterion

x_6;

the subset of criteria $C_1 = \{x_{611}, x_{612}, x_{613}\}$ is subordinated to the criterion x_{61};

the subset of criteria $C_2 = \{x_{621}, x_{622}\}$ is subordinated to the criterion x_{62};

the subset of criteria $C_3 = \{x_{631}, x_{632}, x_{633}\}$ is subordinated to the criterion x_{63};

the subset of criteria $C_4 = \{x_{641}, x_{642}, x_{643}\}$ is subordinated to the criterion x_{64}.

Thus, the estimations of criteria from the set $E = A_1 \cup B_1 \cup \bigcup_{i=1}^{i=4} C_i$ will be determined directly by experts, and the estimations of criteria from the set $D = A_2 \cup B_2$ will be determined as a result of aggregating subordinate criteria according to the criteria hierarchy.

Explanations of the partial criteria. The criteria explanations given below can be considered as the rules for estimating these criteria.

The nature of the state's actions today (x_1) characterizes the current actions of the state related to the use of military force. If we observe several actions that differ in nature, then we take into account the action with the higher estimation. The sources of the data for the estimating are the news media.

The nature of the state's actions in the past (x_2) characterizes the actions related to the use of military force over the past five years. We have chosen this period, since in most states the five-year period determines the cadence of the military-political leadership. The sources of data for the estimating are news media, analytical materials describing conflicts and the history of the development of international relations.

The development of infrastructure and the armed forces (x_3) characterizes the intensity of modernization of the military infrastructure, the availability of the latest weapons and military equipment, and the preparation of the armed forces for a military conflict. The sources of data for the estimating are programs for the development of weapons and military equipment, equipping the armed forces, analytical materials describing the military potentials of states. Also, as the data sources we can use various estimations of national power, for example [7].

The level of political and civil liberties (x_4) characterizes the degree of control of domestic socio-political processes by the military-political leadership. This criterion is consistent with the index of political and civil liberties, which is calculated by the non-governmental organization "Freedom House".

The socio-political signs of PWSUMF (x_5) characterize several aspects that related to the will of the military-political leadership and the preparedness of society to support the use of military force. This criterion is defined on the set of the following partial criteria:

the decisiveness of the military-political leadership;

population support for the military-political leadership;

racial, ethnic, religious intolerance in society.

The decisiveness of the military-political leadership (x_{51}) characterizes the personal qualities of leaders which they show when making important for the state decisions. This is a complex criterion which depends on many elements: temperament, character, education, life experience, lifestyle, analytical skills, intelligence, emotionality, sociability, self-esteem, self-control and others. The study of all these elements is a matter of special research. For us it is important to estimate the leader's psychological propensity to use military force. Psychological portraits of state leaders are usually not available in open information sources. Therefore, here we can rely mainly on the knowledge and intuition of an expert. One of the sources of data for the estimating is the biography of a political leader.

The population support for the military-political leadership (x_{52}) characterizes the authority of the military-political leadership, as well as the degree of approval of its policy by the politically active part of the population. The high authority and population support will give leaders confidence that possible actions will be positively received and will not cause difficulties in domestic politics. It should be borne in mind that the military-political leadership can act according to the opposite logic. Sometimes politicians initiate a military conflict in order to divert the population attention from domestic problems and to raise their own authority. However, this logic is applicable only to powerful states, the level of national power of which guarantees victory. Most leaders cannot afford to take this risk. Sources of data for the estimating are sociological polls of the population regarding public support for the policy of the military-political leadership.

Racial, ethnic, religious intolerance in society (x_{53}) characterizes the potential inclination of society to violence. This manifests itself in the rejection of people who are of a different race, ethnicity or religious beliefs. A society tends to support the use of military force when members of this society reject people with a different background and mentality, they are hostile towards them. It should be borne in mind that radical members of society are politically active and to a greater extent influence public policy. The sources of data for the estimating are sociological surveys of the population regarding racial, ethnic and religious intolerance, as well as research data on radical sentiments in society.

The institutional signs of PWSUMF (x_6) characterize several aspects that related to the established political and economic foundations in organizing the work of state bodies and institutions of coercion. This criterion is defined on the set of the following partial criteria:

doctrinal provisions;
political system;
police system;
budget system.

Doctrinal provisions (x_{61}) characterize several aspects that determine the possible nature of state actions, as it's reflected in official security documents: doctrines, concepts, strategies, and others. Official papers are important sources of data for the estimating as they provide the legal basis for government action. These aspects are reflected in the following partial criteria:

indication of the state-enemy;
possibility of pre-emptive strikes;
striving for leadership.

The indication of the state-enemy (x_{611}) characterizes the level of concretization of the state-adversary in the official documents. If a state has directly named its adversary, it has an increased PWSUMF, since the adversary identification obliges the state to prepare for the use of military force. The sources of data for the estimating are official documents in the field of security (doctrines, concepts, strategies).

The possibility of pre-emptive strikes (x_{612}) characterizes the possibility of using military force by first. If the state directly or indirectly indicated such a possibility, it has an increased PWSUMF. The sources of data for the estimating are official documents in the field of security (doctrines, concepts, strategies).

The striving for leadership (x_{613}) characterizes the striving of the state to play a special role in the world or in its region, in particular, the striving to determine the rules of international relations. The role of the leader provides for the right to punish those states which challenge the established order. Therefore, striving for leadership is one of the hallmarks of an increased PWSUMF. The sources of data for the estimating are the statements of political leaders in the news media, as well as official documents (doctrines, strategies, and others) which reflect the position of the state in international relations.

The political system (x_{62}) characterizes several aspects which determine the order of decision-making by state bodies, as well as the norms and values that underlie the activities of domestic political subjects. These aspects are reflected in the following partial criteria:
the political system type;
the influence of radicals.

The political system type (x_{621}) characterizes the level of centralization of power, which is determined by the legislation of the state. Any state has a system of checks and balances that influence the decision to use military force. We assume that the higher the power centralization level in the state, the less influential this system is. The following types of political systems are listed according to the increase the power centralization level: democracy, authoritarianism, totalitarianism, theocracy. These types of political systems are correlated with the form of state power: monarchies of various types, presidential republic, parliamentary republic, mixed republic. From the view-point of PWSUMF, the political system type is more important for us. The sources of data for the estimating are legislation and studies of the political system of states.

The influence of radicals (x_{622}) characterizes the level of influence of radical leaders on the political decisions of state bodies. It doesn't matter if radical parties are represented in parliament or government. Radicalism is always related with violence. Therefore, the influence of radicals increases the PWSUMF. The sources of data for the estimating are news media and research data on radical sentiments in society and government agencies.

The police system (x_{63}) characterizes several aspects which determine the nature of the domestic coercive system. These aspects are reflected in the following partial criteria:

the number of police officers;
the number of convicts;
death penalty.

The number of police officers (x_{631}) characterizes the potential for forceful coercion in the state. A large number of police forces will give confidence in the success for ensuring domestic order in the case of the initiation of a military conflict. The sources of data for the estimating are statistical data.

The number of convicts (x_{632}) characterizes the current level of forceful coercion in the state and demonstrates the decisiveness with which state bodies establish domestic order. A large number of convicts shows a high level of forceful coercion and indirectly indicates an increased PWSUMF. The sources of data for the estimating are statistical data.

The death penalty (x_{633}) characterizes the possibility of using by state bodies the most severe punishment of citizens for crimes committed. Here we consider not only the possibility of the courts passing death sentences, but also the practice of their imposition and application. We believe that a state which permits death sentences for its citizens has an increased PWSUMF. The sources of data for the estimating are the studies of the legal system of states, news media.

The budgetary system (x_{64}) characterizes several aspects related with financing the costs of preparing for a military conflict. These aspects are reflected in the following partial criteria:

defense and health spending;
defense spending in GDP;
defense spending dynamics.

Defense and health expenditures (x_{641}) are the most important budget items. The ratio of spending on defense and health care indirectly characterizes the priorities of government bodies. If government bodies prioritize defense, we estimate PWSUMF as high. The sources of data for the estimating are statistical data.

Defense spending in GDP (x_{642}) also characterizes the priorities of government bodies. The high level of defense spending indicates the preparation of the state for a military conflict. However, it should be borne in mind that government bodies are interested in concealing the true costs. The sources of data for the estimating are statistical data.

Defense spending dynamics (x_{643}) focuses our attention on the trends in defense funding. Increased defense spending is a sign of increased PWSUMF. The sources of data for the estimating are statistical data.

5. THE IMPORTANCE OF PWSUMF ESTIMATION CRITERIA

As shown above, fuzzy measures are the most appropriate way to describe the criteria importance. To construct fuzzy measures, we used the sequential approximation method described in [26]. This method assumes a two-stage construction of fuzzy measures. The first stage forms the initial fuzzy measure using pairwise comparisons [25]. To do this, the experts compare the criteria in pairs using the dominance scale from 1 to 10 points. In this study, the authors took on the role of experts. When assigning dominance estimations to criteria, we followed the PWSUMF concept described above. This concept helps to define preferences of criteria. At the second stage, the iterative algorithm changes the initial fuzzy measure until the λ -parameter becomes equal to the set value.

Calculated fuzzy measures are shown in Table 3. In this table, the resulting criteria are those criteria which are defined on a set of subordinate criteria from the domain of definition. The initial criteria are those that make up the domain of definition of the resulting criterion.

Table 3: Fuzzy measures of importance of PWSUMF criteria

Resulting criteria	x_0					
Domain of definition (the set A)	x_1	x_2	x_3	x_4	x_5	x_6
Fuzzy measures of importance g_A	1	0.8	0.85	0.7	0.7	0.75
Resulting criteria	x_5					
Domain of definition (the set B_1)	x_{51}	x_{52}	x_{53}			
Fuzzy measures of importance g_{B_1}	0.2	0.2	1			
Resulting criteria	x_6					
Domain of definition (the set B_2)	x_{61}	x_{62}	x_{63}	x_{64}		
Fuzzy measures of importance g_{B_2}	0.6	0.35	0.4	0.5		
Resulting criteria	x_{61}					
Domain of definition (the set C_1)	x_{611}	x_{612}	x_{613}			
Fuzzy measures of importance g_{C_1}	0.7	0.65	0.4			
Resulting criteria	x_{62}					
Domain of definition (the set C_2)	x_{621}	x_{622}				
Fuzzy measures of importance g_{C_2}	0.3	0.5				
Resulting criteria	x_{63}					
Domain of definition (the set C_3)	x_{631}	x_{632}	x_{633}			
Fuzzy measures of importance g_{C_3}	0.4	0.5	0.2			
Resulting criteria	x_{64}					
Domain of definition (the set C_4)	x_{641}	x_{642}	x_{643}			
Fuzzy measures of importance g_{C_4}	0.3	0.5	0.25			

6. THE OBSERVATION CHANNEL

Recall that the set $E = A_1 \cup B_1 \cup \bigcup_{i=1}^{i=4} C_i$ is composed of criteria, the estimations of which must be determined by experts. For ease of use, we reindex the set E. Let us denote $e_\alpha \in E$ as an element of the set E, where the index $\alpha = \overline{1,18}$ reindexes the elements of the set E, as shown in Table 4.

Table 4: Fuzzy measures of importance of PWSUMF criteria

$x_1 \to e_1$	$x_2 \to e_2$	$x_3 \to e_3$	$x_4 \to e_4$	$x_{51} \to e_5$	$x_{52} \to e_6$
$x_{53} \to e_7$	$x_{611} \to e_8$	$x_{612} \to e_9$	$x_{613} \to e_{10}$	$x_{621} \to e_{11}$	$x_{622} \to e_{12}$
$x_{631} \to e_{13}$	$x_{632} \to e_{14}$	$x_{633} \to e_{15}$	$x_{641} \to e_{16}$	$x_{642} \to e_{17}$	$x_{643} \to e_{18}$

Let us denote the set of experts as $F = \{f_j, j = \overline{1,M}\}$, where M is the number of experts. In accordance with [32], the observation channel is intended to determine the values $\varepsilon(f_j, e_\alpha)$ of the partial criteria $e_\alpha \in E$, on the basis of which the algorithm described below will calculate PWSUMF. We constructed the observation channel based on the Harrington desirability curve [33], which is shown in Figure 3.

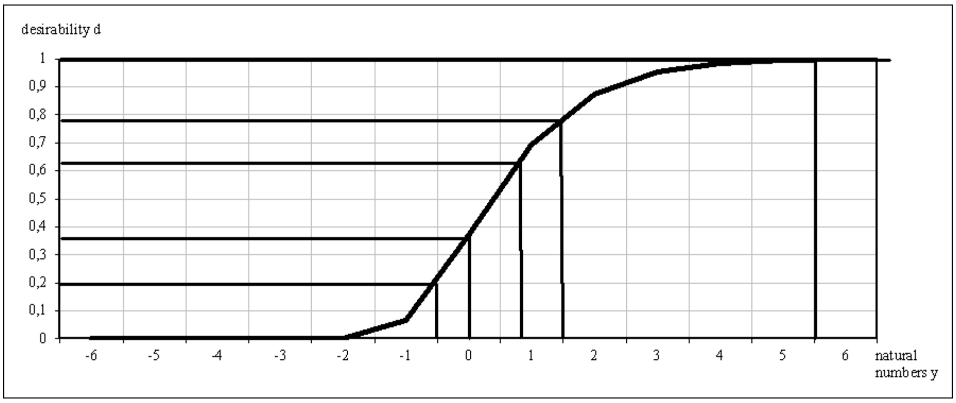

Figure 3: "desirability" curve of Harrington

The domain of values of this curve is divided into five intervals, which have linguistic meanings, as shown in Table 5.

Table 5: The characteristics of the situation

Linguistic estimation of the characteristic value	Intervals of Harrington's curve $C_k = \{c_k, k = \overline{1,5}\}$
Excellent	0.8 - 1
Good	0.63 - 0.79
Satisfactory	0.37 - 0.62
Bad	0.2 - 0.36
Very bad	0 - 0.19

To obtain an estimation of $\varepsilon(f_j, e_\alpha)$, expert f_j must explore the available data sources and select from Table 5 the linguistic value k that best matches his opinion. Then the expert must choose a numerical estimation $\varepsilon(f_j, e_\alpha) \in c_k$ from the corresponding interval. This two-step procedure allows you to increase the accuracy of reflecting the expert's opinion into numerical estimations and, due to this, also to increase the accuracy of measuring the input estimations.

7. ALGORITHM FOR CALCULATING PWSUMF BASED ON GROUP ESTIMATIONS

The algorithm consists of the following steps.

Step 1. Aggregating estimations of several experts, taking into account their competence.

For simplicity, we will assume that all experts estimate all criteria, although in practice there may be other cases. Experts have different skill levels, which can be a priori described as a fuzzy measure of an expert's competence in the form $g_F(\cdot) : 2^F \to [0,1]$. The Sugeno fuzzy integral of the membership function $\varepsilon(f_j, e_\alpha)$ over the fuzzy measure $g_F(\cdot)$ calculates the group estimate $w(e_\alpha)$ of each criterion from the set E:

$$w(e_\alpha) = (s) \int_F \varepsilon(f_j, e_\alpha) \circ g_F(\cdot). \tag{3}$$

These estimations will later be aggregated according to PWSUMF criteria hierarchy (see Steps 2-4).

Note that by changing the λ-parameter of the fuzzy measure $g_F(\cdot)$, we can change the logic of group estimating and the logic of PWSUMF estimating as a whole. For example, if we construct a fuzzy measure $g_F(\cdot)$ with $\lambda = -1$ (fuzzy measure of possibility), then the group estimation will be maximum in the case when the estimation of at least one expert will be maximum. This logic can be conventionally called "the minority logic". On the contrary, if $\lambda \to +\infty$ (a fuzzy measure of necessity), then the group estimate will be maximum only if the estimations of all experts are maximum. This logic can be conventionally called "the majority logic".

Step 2. Calculating estimations of partial criteria from the set $x_5 \cup B_2$.

Here we use fuzzy measures of importance determined on the sets B_1, C_1, C_2, C_3, C_4 of partial criteria (see Table 3). The estimations $\mu(x_5)$ and $\mu(x_6|C_k)$ are calculated as follows:

$$\mu(x_5) = (s) \int_{B_1} w(e_\alpha) \circ g_{B_1}(\cdot), \tag{4}$$

$$\mu(x_6|C_k) = (s) \int_{C_k} w(e_\alpha) \circ g_{C_k}(\cdot), k = \overline{1,4}. \tag{5}$$

Step 3. Calculating estimation of the partial criterion x_6.

Here we use a fuzzy measure of importance determined on the set B_2 of partial criteria (see Table 3). The estimate $\mu(x_6)$ is calculated as follows:

$$\mu(x_6) = (s) \int_{B_2} \mu(x_6|C_k) \circ g_{B_2}(\cdot). \tag{6}$$

Step 4. Calculating estimation of main criterion x_0 (PWSUMF estimation).

Here we use a fuzzy measure of importance determined on the set A of partial criteria (see Table 3). The estimate of main criterion $\mu(x_0)$ is calculated as follows:

$$\mu(x_0) = (s) \int_{x_i \in A} \mu(x_i) \circ g_A(\cdot), i = \overline{1,6}. \tag{7}$$

8. PWSUMF ESTIMATIONS

With the help of the described algorithm and on the basis calculated fuzzy measures (see Table 3), we estimated PWSUMF for 137 countries using 2018 baseline data. We did not include a state in this list if we could not find the necessary data about it. Table 6 contains ordered in increasing PWSUMF estimations.

Table 6: PWSUMF estimations

States with very low PWSUMF $\mu(x_0) = [0, 0.19]$, no states							
States with very low PWSUMF $\mu(x_0) = [0.2, 0.36]$, no states							
States with very low PWSUMF $\mu(x_0) = [0.37, 0.62]$, 26 states							
Benin	0.4	Lesotho	0.44	Uruguay	0.5	Guinea	0.59
Cabo Verde	0.4	Madagascar	0.44	Malta	0.524	Bolivia	0.6
Jamaica	0.4	Seychelles	0.441	Namibia	0.524	Brazil	0.6
Paraguay	0.4	Nepal	0.48	Moldova	0.528	Nicaragua	0.6
Belize	0.42	Niger	0.51	Fiji	0.55	Tanzania	0.6
Costa Rica	0.424	Cote d'Ivoire	0.48	Mozambique	0.567		
Panama	0.437	Guyana	0.5	Sri Lanka	0.567		
States with very low PWSUMF $\mu(x_0) = [0.63, 0.79]$, 32 states							
Austria	0.65	Angola	0.75	Kazakhstan	0.75	Oman	0.75
Bangladesh	0.65	Belarus	0.75	Kenya	0.75	Philippines	0.75
Czech rep.	0.65	Bhutan	0.75	Kyrgyz rep.	0.75	Serbia	0.75
Finland	0.65	Congo, rep.	0.75	Lao PDR	0.75	Singapore	0.75
Mexico	0.65	Dominican rep.	0.75	Lebanon	0.75	Swaziland	0.75
Switzerland	0.65	Gambia	0.75	Malaysia	0.75	Tajikistan	0.75
Tunisia	0.62	Honduras	0.75	Mali	0.75	Togo	0.75
Algeria	0.75	Iceland	0.75	Nigeria	0.75	Venezuela	0.75
States with very low PWSUMF $\mu(x_0) = [0.8, 1]$, 79 states							
Albania	0.8	Estonia	0.8	Montenegro	0.8	Ethiopia	0.85
Argentina	0.8	Georgia	0.8	Netherland	0.8	France	0.85
Australia	0.8	Germany	0.8	New Zealand	0.8	Ghana	0.85
Barbados	0.8	Greece	0.8	Norway	0.8	Senegal	0.85
Belgium	0.8	Guatemala	0.8	Pakistan	0.8	Ukraine	0.85
B and H	0.8	Hungary	0.8	Peru	0.8	Burkina Faso	0.9
Botswana	0.8	India	0.8	Poland	0.8	Morocco	0.9
Bulgaria	0.8	Indonesia	0.8	Portugal	0.8	United Kingdom	0.9
Cambodia	0.8	Ireland	0.8	Romania	0.8	Yemen	0.9
Cameroon	0.8	Italy	0.8	Rwanda	0.8	Armenia	0.95
Canada	0.8	Japan	0.8	Sierra Leone	0.8	Azerbaijan	0.95
CAR	0.8	Jordan	0.8	Slovak rep.	0.8	China	0.95
Chile	0.8	Korea, dem. Rep.	0.8	Slovenia	0.8	Iran	0.95
Colombia	0.8	Latvia	0.8	South Africa	0.8	Israel	0.95
Croatia	0.8	Lithuania	0.8	Spain	0.8	Russian Federation	0.95
Cyprus	0.8	Luxembourg	0.8	Sweden	0.8	Saudi Arabia	0.95
Denmark	0.8	Makedonia	0.8	Thailand	0.8	Syrian Arab rep.	0.95
Ecuador	0.8	Malawi	0.8	Uganda	0.8	Turkey	0.95
Egypt	0.8	Mauritania	0.8	Vietnam	0.8	USA	0.95
El Salvador	0.8	Mongolia	0.8	Zambia	0.8		

9. DISCUSSION OF THE RESULTS

Comparison with estimations of peacefulness. Above, we have chosen the peacefulness index as a prototype. Therefore, below we will compare the PWSUMF estimations from Table 6 and the estimations from the "Global peace index 2018" [34], as the PWSUMF estimations refer to 2018. For comparison to become possible, it is necessary to convert the estimations to a single basis. Let us recall that the estimations of peacefulness are presented on a five-point scale and have the opposite logic: the lower the estimation, the less the state's non-peacefulness. This logic is the same as the PWSUMF logic: the lower the estimation, the lower the PWSUMF. Therefore, we divided the estimations of peacefulness by five to convert them into the range from 0 to 1.

These estimations are presented in Table 7.

Table 7: Estimations of non-peacefulness

States with very low PWSUMF $\mu(x_0) = [0, 0.19]$, no states							
States with very low PWSUMF $\mu(x_0) = [0.2, 0.36]$, 48 states							
Iceland	0.219	Australia	0.287	Malaysia	0.324	Italy	0.353
New Zealand	0.238	Sweden	0.3	Bulgaria	0.327	Madagascar	0.353
Austria	0.255	Finland	0.301	Croatia	0.328	Costa Rica	0.353
Portugal	0.264	Norway	0.304	Chile	0.33	Ghana	0.354
Denmark	0.271	Germany	0.306	Botswana	0.332	Namibia	0.361
Canada	0.274	Hungary	0.306	Spain	0.336	Malawi	0.362
Czech Republic	0.276	Bhutan	0.309	Latvia	0.338	Laos	0.364
Singapore	0.276	Mauritius	0.31	Estonia	0.345	Mongolia	0.364
Japan	0.278	Belgium	0.312	Poland	0.345	Zambia	0.364
Ireland	0.279	Slovakia	0.314	Sierra leone	0.348	Korea, Republic of	0.365
Slovenia	0.279	Netherlands	0.315	Lithuania	0.35	Panama	0.365
Switzerland	0.281	Romania	0.319	Uruguay	0.352	Tanzania	0.367
States with very low PWSUMF $\mu(x_0) = [0.37, 0.62]$, 78 states							
Albania	0.37	Gambia	0.398	Georgia	0.426	Saudi Arabia	0.483
Senegal	0.37	Paraguay	0.399	Rwanda	0.428	Iran	0.488
Serbia	0.37	Tunisia	0.4	Brazil	0.429	Azerbaijan	0.491
Indonesia	0.371	Greece	0.404	Lesotho	0.429	Cameroon	0.497
United Kingdom	0.375	Burkina faso	0.406	Uganda	0.434	India	0.501
Montenegro	0.379	Guyana	0.409	Kyrgyzstan	0.436	Philippines	0.502
Vietnam	0.381	Angola	0.41	Algeria	0.436	Ethiopia	0.505
France	0.382	Nepal	0.411	Cote d'Ivoire	0.441	Mexico	0.517
Cyprus	0.383	Mozambique	0.411	Guatemala	0.443	Egypt	0.526
Moldova	0.388	Macedonia	0.412	China	0.449	Venezuela	0.528
Argentina	0.389	B and H	0.413	Thailand	0.452	Mali	0.537
Sri Lanka	0.391	Jamaica	0.414	Tajikistan	0.453	Colombia	0.546
Nicaragua	0.392	Dominican Republic	0.415	El Salvador	0.455	Israel	0.553
Benin	0.395	Bangladesh	0.417	Honduras	0.456	Lebanon	0.556
Kazakhstan	0.395	Bolivia	0.418	Armenia	0.457	Nigeria	0.575
Morocco	0.396	Cambodia	0.42	USA	0.46	Turkey	0.58
Swaziland	0.396	Guinea	0.42	South Africa	0.466	Pakistan	0.616
Oman	0.397	Jordan	0.421	Congo	0.469	Ukraine	0.623
Peru	0.397	Togo	0.421	Kenya	0.471		
Ecuador	0.397	Belarus	0.422	Niger	0.472		
States with very low PWSUMF $\mu(x_0) = [0.63, 0.79]$, 3 states							
Russian Federation	0.632	Yemen	0.661	Syrian Arab rep.	0.72		
States with very low PWSUMF $\mu(x_0) = [0.8, 1]$, no states							

Comparative analysis of estimations from tables 6 and 7 shows that the method of the index of peacefulness has a low selectivity. Almost all states are concentrated in two categories: “low” and “satisfactory”. Not a single state was included in the “high” category. Of the entire range from 0 to 1, only 60% is used: from 0.2 to 0.8. This can be explained by the properties of the weighted average discussed above: ”good” estimations balanced ”bad” estimations.

Influence of the normalization parameter of a fuzzy measure. Above, we mentioned that the result of aggregating partial estimations depends on the normalization parameter of a fuzzy measure which describes the importance of the criteria. Let’s consider this dependency.

Provided in Table 6 the PWSUMF estimations are calculated by integrating partial criteria estimations over a fuzzy measure which describes the importance of the criteria and which is a measure of possibility. As we indicated above, in this case the Sugeno fuzzy integral implements the so-called ”the minority logic”. Taking into account that we measure PWSUMF, this logic can also be figuratively called ”the logic of the presumption of guilt”, that is, PWSUMF will be maximum if at least one of the partial estimations is maximum. In addition, we propose to consider a different logic of aggregating partial estimations, in particular ”the majority logic” or ”logic of the presumption of innocence”. The Sugeno fuzzy integral implements this logic if the criterion importance measure is a belief measure which has a normalization parameter, for example, $\lambda = 4.5$. Above, we used a fuzzy measure with a similar parameter value when we wanted to demonstrate the superiority of the Sugeno fuzzy integral over the weighted average.

Table 8 shows a fuzzy measure of importance determined on the set A of partial criteria. This measure is a belief measure and has $\lambda = 4.5$. We calculated this measure using the method described in the study [26]. Table 9 contains PWSUMF estimations calculated using "the majority logic".

Table 8: Fuzzy measure of importance determined on the set of partial criteria A

Resulting criterion	x_0					
Domain of definition	x_1	x_2	x_3	x_4	x_5	x_6
Domain of definition	0.266	0.061	0.13	0.011	0.011	0.028

Table 9: PWSUMF estimations calculated using "the majority logic"

States with very low PWSUMF $\mu(x_0) = [0, 0.19]$, 18 states							
Angola	0.1	Jamaica	0.1	Guyana	0.129	Rwanda	0.129
Benin	0.1	Malta	0.1	Honduras	0.129	Uganda	0.129
Cabo Verde	0.1	Panama	0.1	Lao PDR	0.129	Uruguay	0.194
Congo, rep.	0.1	Argentina	0.129	Lesotho	0.129		
Guinea	0.1	Gambia	0.129	Madagascar	0.129		
States with very low PWSUMF $\mu(x_0) = [0.2, 0.36]$, 32 states							
Barbados	0.2	Mozambique	0.2	Singapore	0.215	Paraguay	0.3
B and H	0.2	Nepal	0.2	Swaziland	0.215	El Salvador	0.308
Botswana	0.2	Sierra Leone	0.2	Tanzania	0.215	New Zealand	0.308
Cameroon	0.2	Sri Lanka	0.2	Togo	0.215	South Africa	0.308
Cote d'Ivoire	0.2	Zambia	0.2	Tunisia	0.215	Bolivia	0.355
Fiji	0.2	Algeria	0.215	Ghana	0.3	Costa Rica	0.355
Iceland	0.2	Niger	0.215	Ireland	0.3	Dominican rep.	0.355
Mali	0.2	Oman	0.215	Moldova	0.3	Seychelles	0.355
States with very low PWSUMF $\mu(x_0) = [0.37, 0.62]$, 61 states							
Bhutan	0.383	Ethiopia	0.431	Germany	0.5	Slovenia	0.512
Austria	0.4	Cambodia	0.438	Greece	0.5	Sweden	0.512
Belarus	0.4	Senegal	0.461	Indonesia	0.5	Canada	0.513
Belize	0.4	Belgium	0.478	Italy	0.5	Ecuador	0.513
Brazil	0.4	Bulgaria	0.478	Kenya	0.5	France	0.513
Colombia	0.4	Denmark	0.478	Kyrgyz rep.	0.5	Guatemala	0.513
Korea, dem. Rep.	0.4	Latvia	0.478	Mexico	0.5	Hungary	0.513
Makedonia	0.4	Lithuania	0.478	Mongolia	0.5	Lebanon	0.513
Malawi	0.4	Luxembourg	0.478	Nigeria	0.5	Netherland	0.513
Malaysia	0.4	Portugal	0.478	Philippines	0.5	Mauritania	0.524
Namibia	0.4	Albania	0.5	Spain	0.5	Montenegro	0.524
Nicaragua	0.4	Bangladesh	0.5	Switzerland	0.5	Turkey	0.549
Serbia	0.4	Croatia	0.5	Thailand	0.5	Yemen	0.549
Tajikistan	0.4	Czech rep.	0.5	Venezuela	0.5		
Burkina Faso	0.431	Finland	0.5	Vietnam	0.5		
CAR	0.431	Georgia	0.5	Romania	0.512		
States with very low PWSUMF $\mu(x_0) = [0.63, 0.79]$, 22 states							
Estonia	0.65	Australia	0.75	Japan	0.75	Syria	0.75
Kazakhstan	0.65	Azerbaijan	0.75	Jordan	0.75	Peru	0.763
Norway	0.65	Chile	0.75	Morocco	0.75	USA	0.763
United Kingdom	0.65	Cyprus	0.75	Pakistan	0.75	Israel	0.778
Ukraine	0.73	Egypt	0.75	Poland	0.75		
Armenia	0.75	India	0.75	Slovak rep.	0.75		
States with very low PWSUMF $\mu(x_0) = [0.8, 1]$, 4 states							
Russian Federation	0.8	Saudi Arabia	0.8	China	0.812	Iran	0.812

Stratification of states by PWSUMF categories. Depending on the level of PWSUMF, we distributed all considered states over categories, which are also indicated in Table 6 and Table 9, together with the number of states in these categories. Category boundaries are determined based on the intervals of the Harrington desirability curve (see Table 5). The use of the same scale for determining the input estimations and for interpreting the results simplifies the analysis, since it provides a single universum of all estimations and frees the expert from studying many scales.

Figure 4 shows the share of states in each of the mentioned categories. In the case of "the minority logic", no state is a state with a low or very low PWSUMF. About one fifth of all states are states with a satisfactory PWSUMF, and about one fourth of all states are states with an increased PWSUMF. The largest number of states are states with a high PWSUMF. In general, we can estimate the potential of PWSUMF in the world as high. In the case of using "the majority logic", about a third of states move to categories with a low or very low PWSUMF. About half of states can be estimated as states with a satisfactory PWSUMF and about a fifth of states are states with an increased and high PWSUMF.

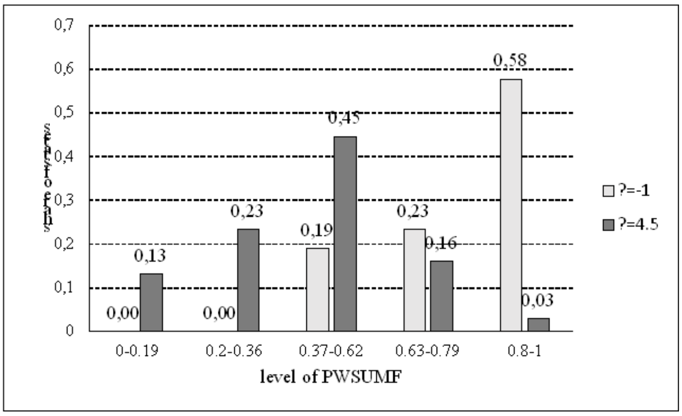

Figure 4: Distribution of the number of states by PWSUMF categories

As we can see, the distribution of states by categories can change radically depending on the properties of the fuzzy measure of the importance. As a whole, we consider using "the majority logic" a more appropriate approach, since this logic increases the sensitivity of the PWSUMF measurement.

Stratification of states by PWSUMF categories and continents. We can also study the distribution of states by PWSUMF category and continent. The total number of states located on different continents is different. Therefore, in order to provide a common basis for comparison, we normalized the number of states by dividing on the total number of states located on the corresponding continent. The stratification results are shown in Table 10.

Table 10: Stratification of states by PWSUMF categories and continents

Continent	Number of states	Distribution of the normalized number of states				
		0-0.19	0.2-0.36	0.37-0.62	0.63-0.79	0.8-1
Africa	37	27	43	24	5	0
Australia	2	0	67	0	33	0
North America	3	0	0	67	33	0
South America	21	29	29	33	10	0
Eurasia	70	3	12	62	23	6

As the analysis shows, African states have mostly low and very low PWSUMF. This is also true for Australia and Oceania. The states of North America are classified as states with a satisfactory and increased PWSUMF. The states of South American are roughly equally distributed on categories with a very low, low and satisfactory PWSUMF. The states of Eurasia are most often the states with a satisfactory and increased PWSUMF. Moreover, all states with high PWSUMF are located in Eurasia.

Possible dynamics of the volume of PWSUMF categories. We can make the following assumption about states located near category boundaries. Suppose that we increased the estimation of one of the partial criteria of a certain state, for example, Israel or the United States (see Table 9). Since the fuzzy measure is a non-decreasing function of the set, the PWSUMF estimation of this state will either not change or increase. In the case of an increase, the state can move to another PWSUMF category. If a state is located near the lower bound of a category, a decrease in the partial criterion estimation may also cause that this state to move to another PWSUMF category. Thus, we can talk about the possible dynamics of the volume of PWSUMF categories. Table 11 for each category shows several states that can move to categories with a higher and lower PWSUMF.

Table 11: States that can move to categories with a higher and lower PWSUMF

PWSUMF categories	0-0.19	0.2-0.36	0.37-0.62	0.63-0.79	0.8-1
States that can move to a category with a higher PWSUMF	Uganda, Uruguay,	Bolivia, Costa Rica, Dominican rep. Seychelles	Montenegro, Turkey, Yemen	Israel, USA, Peru	
States that can move to a category with a lower PWSUMF		Barbados, B and H Botswana	Bhutan, Austria, Belarus	Estonia, Kazakh-stan, Norway	Russia, Saudi Arabia

Explaining the calculated estimations. Above, we said that the technique of calculating the Sugeno fuzzy integral allows one to determine the set H of the elements of the universal set that influenced the resulting estimation, and use them to explain this estimation. Table 8 shows these elements from the criteria set A (see Table 3). Since the limited size of the article does not allow considering all estimations, in Table 12 we have shown estimations for only some states. When choosing states, we tried to comply with two conditions:

states should be located approximately in the center between the boundaries of PWSUMF categories;

states must be influential in the world arena.

Table 12: Explanations of state estimations

State	PWSUMF category	Criteria that influenced the result
Argentina	0-0.19	$\{x_2, x_4, x_5, x_6\}$
Tanzania	0.2-0.36	$\{x_3, x_4, x_5, x_6\}$
Germany	0.37-0.62	$\{x_1, x_2, x_3, x_6\}$
India	0.63-0.79	$\{x_1, x_2, x_3, x_5, x_6\}$
China	0.8-1	$\{x_1 x_2, x_3, x_4, x_5, x_6\}$

Here we can draw two conclusions. First, the set of partial criteria that influenced the resulting estimations are not the same for different states. By studying these sets, the researcher is able to understand why the state received this estimation. Having passed through the chains of partial criteria in the direction opposite to the direction of calculations, the researcher will find those initial criteria that determined the resulting estimation. Second, we see that the power of the set of partial criteria that influenced the resulting estimation increases with the growth of PWSUMF. We explain this by the property of a fuzzy measure of importance that implements "the majority logic". In other words, in the case the state with a high PWSUMF all partial criteria will be influenced the resulting estimation.

10. CONCLUSIONS

In this study, we proposed using the Sugeno fuzzy integral in a multi-criteria hierarchical model to estimation the willingness of any state to use military force in international relations. We have developed a new hierarchical system of criteria, the main advantage of which is the semantic consistency of criteria, which ensures the balance of the system as a whole. We used a fuzzy measure to describe the importance of the criteria. Since the domain of definition of a fuzzy measure is the set of all subsets of the universal set, a fuzzy measure takes into account the interaction between criteria. This makes it possible to simplify the aggregation procedure in the case of correlations between the criteria.

To aggregate the partial estimations, we used the Sugeno fuzzy integral. Its main advantage is the preservation of selectivity while increasing the number of criteria. Another advantage is the ability to explain the resulting estimation through defining a set of criteria that were taken into account and influenced the result. In addition, the proposed aggregation algorithm makes it possible to use initial estimations defined by several experts. The algorithm takes into account their level of competence, which is described as a fuzzy measure. To obtain initial estimations, we built an observation channel based on the Harrington function. The advantage of this channel is a two-stage procedure, which improves the accuracy of defining the initial estimates.

In practice, the use of PWSUMF estimations makes it possible to identify states that require special attention in the formation of a long-term foreign policy and military strategy.

The main problematic questions when using the proposed approach are the significant laboriousness of the pairwise comparison procedure when constructing fuzzy measures, as well as the unclear grounds for determining the required normalization parameter. The main directions of development of the proposed approach are: improving the system of criteria; development of more efficient procedures for constructing fuzzy measures; creation of a procedure for continuous monitoring of PWSUMF changes to ensure continuity of support for making important government decisions.

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