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A Mathematical Approach to Conflict Resolution in the Arctic Region

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***Abstract*—The Arctic region is one of the most sensitive and vulnerable to climate change. The dramatic melting of Arctic ice has several negative consequences for the whole ecosystem as well as for a way of life of native people but it also creates new opportunities for the region. First, it opens up potential for exploitation of large deposits of natural resources such oil and gas. Second, it shrinks Arctic shipping routes which offer significant economic savings for many countries. These benefits has already attracted many countries, both Arctic and non-Arctic, thus resulting in potential conflict of interests. In our paper we present a mathematical approach to the problem of conflict resolution in the Arctic. First, we propose an approach how the level of interest in each part of the region should be evaluated with respect to main resources – oil, gas, fish and maritime routes. Second, we present several models of areas allocation to resolve the problem of conflict resolution. As a result, we applied several scenarios of areas allocation, evaluated their efficiency based on the total satisfaction level and identified conflict zones in the Arctic.**

Keywords—conflict resolution; Arctic region; areas allocation; international relations; natural resources

I. Introduction

Arctic region has been a matter of intense disputes for the last several decades. Although it encompasses approximately 6 percent of the globe, the Arctic contains an estimated 20 percent of the world's undiscovered oil and gas deposits [1] and around 450 species of fish [2]. Due to extreme climatic conditions and, consequently, high costs, exploration and development of natural resources in the Arctic looked unattractive several decades ago. The recent changes in climate, resulting in ice melting, opened up new opportunities for the region. First, Arctic waters became more accessible for oil and gas exploration and exploitation. The interest in north natural resources has also arisen due to increased global demand for energy. Second, Arctic shipping routes, which potentially may offer significant economic savings for many countries, became more accessible. Next, fishing seasons were also considerably extended by increased periods of open water [3]. These potential benefits has already attracted many countries.

The Arctic region is shared by eight Arctic states - the United States, Canada, Finland, Denmark (Greenland), Iceland, Norway, Russia, and Sweden. However, the territory of these countries is limited to an exclusive economic zone (EEZ) of 200 nautical miles (approximately 370.4 km) adjacent to their coasts. The waters beyond the EEZs are considered the "high seas" or international waters which are not owned by any country. This fact resulted in territorial claims and many disputes on how to determine who has the right to Arctic resources. The interest in the Arctic was also observed by many non-Arctic countries such as China, Japan, Republic of Korea, India etc. Thus, we can see a potential conflict of interest coming concerning the Arctic region.

In [4] there was an attempt to estimate the utility of each area in the Arctic region. As a result, there was proposed a model which analyzes preferences of the countries interested in the Arctic region and reveals potential conflict zones among them. Our work is a continuation of this study and it is focused on the conflict resolution in Arctic. We present several models of potential conflict resolution based on different preferential allocation of resources among interested countries.

The paper is organized as follows. First, we describe the methodology of our research and describe the data. Second, we propose several models of conflict resolution which allocate each zone of the Arctic to a particular country with respect to the utility of main resources – oil, gas, fish and maritime routes. Finally, we provide the results of the model and evaluate the efficiency of each scenario as well as the dissatisfaction level of each interested country.

II. Methodology and Data

A. Problem Statement

Consider a set of Arctic areas X characterized by a set of parameters K and a set of countries Y which are interested in these areas. The problem lies in the evaluation of the utility of each area for each agent as well as the intensity of a potential conflict in order to find some allocation that satisfies all interested parties. A list of countries we are focused on and their position in the world map are presented in Fig 1.

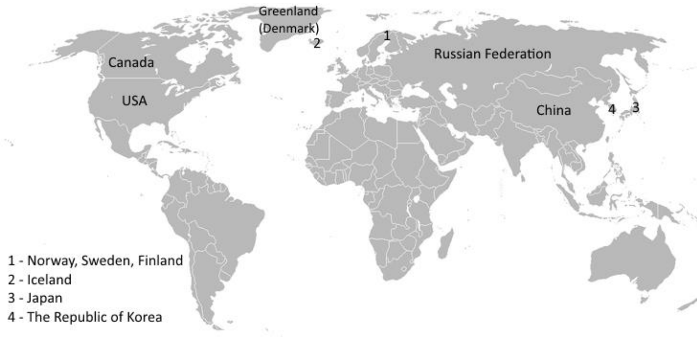

Fig. 1. Arctic and non-Arctic countries

In this paper we focus on the United States, Russian Federation (Russia), Canada, Denmark, Norway, Iceland and their EEZs capture in Arctic waters. We also consider several non-Arctic countries such as China, Japan and the Republic of Korea (South Korea). The total number of interested parties is nine, i.e., $|Y| = 9$.

Areas of the Arctic region under consideration are located to the north of 63° North latitude. The whole region was divided into 640 000 areas (see Fig. 2). Among them, 192 000 areas have natural resources and only 107 000 areas both have natural resources and do not belong to EEZ of any country.

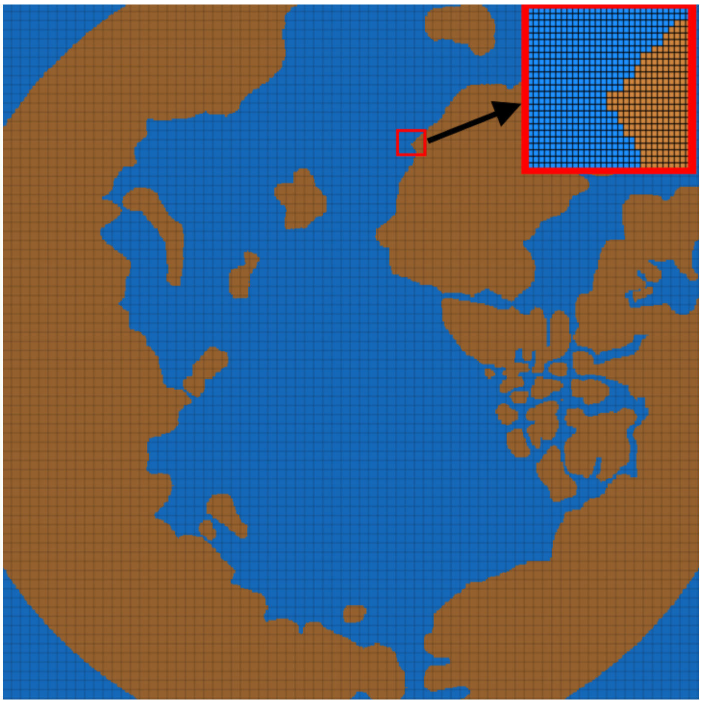

Fig. 2. Arctic region partition

Each area is located at some distance from each country and possesses some natural resources. We consider four main natural resources: oil (O), gas (G), fish (F) and maritime (M) resources. Based on recent research and studies on natural resources availability in the Arctic we can demonstrate that information in Fig 3 [4-5].

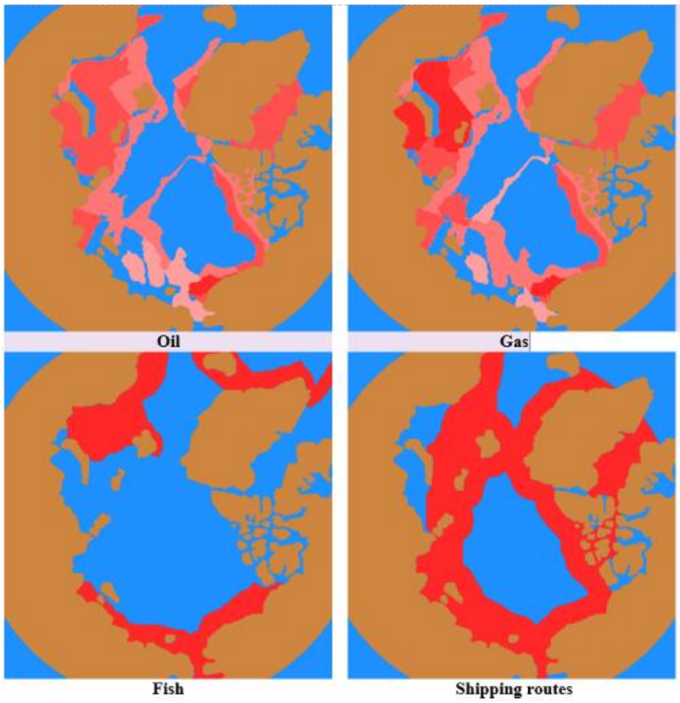

Fig. 3. Natural resources availability in Arctic region

B. Level of Interest in the Arctic Region

Denote by $f(O,x), f(G,x), f(F,x), f(M,x)$ the volume of oil, gas, fish and shipping routes in region $x \in X$ (the volume is estimated by 0-4 scale based on Fig. 3) and by $u_k^O(x), u_k^G(x), u_k^F(x), u_k^M(x)$ the utility of each resource for country $k \in Y$. Intuitively, the level of interest of all zones in the Arctic should be evaluated differently for the same country. Moreover, among two areas with the same number of natural resources the priority should be given to the closest one. Thus, we assume that the interest of a country in each resource is constant in its EEZ, proportional to the distance to the area outside its EEZ ($d^{EEZ} \approx 370.4\ km$), and equal to zero after some distance d^* (assume $d^* = 4000\ km$). Then the interest of each country in natural resources located in some area is characterized by the following formulae.

- Interest in oil

$$u_k^O(x) = \begin{cases} f(O,x)\ if\ d_k(x) \le d^{EEZ}, \\ \max\left(0,\ f(O,x) \cdot \left(\dfrac{d^* - d_k(x)}{d^* - d^{EEZ}}\right)\right) otherwise. \end{cases} \quad (1)$$

- Interest in gas

$$u_k^G(x) = \begin{cases} f(G,x)\ if\ d_k(x) \le d^{EEZ}, \\ \max\left(0,\ f(G,x) \cdot \left(\dfrac{d^* - d_k(x)}{d^* - d^{EEZ}}\right)\right) otherwise. \end{cases} \quad (2)$$

- Interest in fish

$$u_k^F(x) = \begin{cases} f(F,x) \text{ if } d_k(x) \le d^{EEZ}, \\ \max\left(0,\ f(F,x) \cdot \left(\frac{d^* - d_k(x)}{d^* - d^{EEZ}}\right)\right) \text{ otherwise.} \end{cases} \quad (3)$$

where $d_k(x)$ is the distance from the closest point of the country k to the area x.

The interest in Arctic shipping routes should be evaluated differently since it more depends on its usage than on the distance. Thus, based on transit statistic for the last two years provided by the Northern Sea Route Information Office [6] we evaluated the importance of the shipping routes imp_k for each country k and calculated the total interest by the following formula

$$u_k^M(x) = f(M,x) \cdot \max\left(imp_x, \left(\frac{d^* - d_k(x)}{d^* - d^{EEZ}}\right)\right) \quad (4)$$

The total utility of each area $u_k^T(x)$ is calculated as

$$u_k^T(x) = u_k^O(x) + u_k^G(x) + u_k^F(x) + u_k^M(x) \quad (5)$$

Thus, we can evaluate an interest of each country in a specific area of Arctic region and find regions of the most interest.

C. Areas Allocation

Since we have some areas which do not belong to any country but are in interest of many countries, there is a potential conflict of interests. To resolve it, we propose several models of areas allocation in the next Section. The models of areas allocation should be fair in some sense for each interested country. The fairness of the allocation can be evaluated differently; in our paper it is based on the satisfaction level of each country $S_k(P)$ which is calculated as

$$S_k(P) = \sum_{x \in X:(x,k) \in P} u_k^T(x) - \sum_{x \in X:(x,k) \notin P} u_k^T(x), \quad (6)$$

where P is a binary relation $P \subset X \times Y$ that characterizes the final allocation of areas. In other words, the satisfaction level of a country is calculated as the difference between the total utility of areas that were allocated to this country, and the potential total utility of areas that were not allocated to the country. The efficiency of the allocation can be evaluated based on the satisfaction level of each country.

Next we propose several models of areas allocation, which are fair in some sense for each country.

III. Conflict Resolution Models

A. Conflict resolution model based on the lowest satisfaction level

The model of conflict resolution works as follows. Suppose there is some initial allocation of all areas in the Arctic region. Then we can evaluate the satisfaction level of each country. If some criteria is satisfied, the procedure of areas allocation stops. Otherwise, the exchange procedure is performed. Since the satisfaction level of countries is different, we can choose the most satisfied and unsatisfied countries and transfer area $x \in X$ from the most satisfied country k_2 to the most unsatisfied country k_1 which satisfies the following conditions

- $(x, k_2) \in P$;
- $u_{k_1}^T(x) \neq 0$;
- $\frac{u_{k_1}^T(x)}{u_{k_2}^T(x)} \to max.$

The criterion for the choice of exchanging area $x \in X$ between countries is similar to the criterion used for adjusted winner procedure [7]. First, the area $x \in X$ should belong to the most satisfied country. Second, the area $x \in X$ should be valuable for unsatisfied country. Finally, the exchange should be performed for the area which is valuable as much as possible for unsatisfied country and as less as possible valuable for satisfied country.

Thus, some new allocation is obtained and the whole procedure repeats again. There are different criteria that can be used to terminate the exchange procedure. In our paper the procedure stops if the total dissatisfaction level of the most unsatisfied country is maximized or there are no areas available for the exchange procedure.

Obviously, the results of this procedure depend on the initial allocation of areas in Arctic region. The initial allocation can be different, in this paper we define the initial allocation as allocation according to which each area of Arctic region is allocated to the closest country (see Fig. 4).

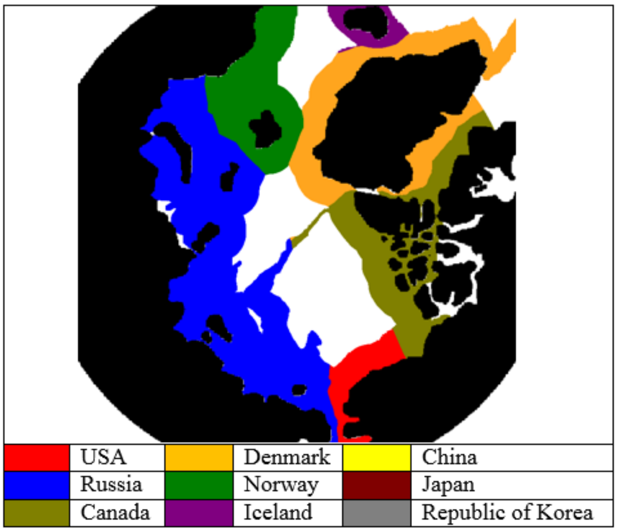

Fig. 4. Initial allocation for scenario 1.

B. *Conflict resolution model based on the idea of superposition*

Consider another model of areas allocation. Suppose there is only one party which is interested in some region. Therefore, the whole region will be entirely allocated to this party. Next, let us add another interested in the region party. To reduce the dissatisfaction of the second party, the first party can transfer some zones which are more valuable (according to the total utility, the majority rule or some other procedures [7-10]) to the second party. Again, let us add one more party which is interested in the region. Similarly, we can allocate to a new party some zones which it values more than its current owners. Thus, we can add all interested parties and allocate zones among them.

The proposed model is a model based on the idea of superposition. In general, superposition (or composition) consists in sequential application of different functions such that the output of the previous step is the input for the next step [7]. In our case as a function we add a new party and change the allocation of zones at each step. However, the superposition operation is not commutative, i.e., the change of the order may lead to completely different results (the properties of some superposition procedures and some counterexamples were provided in [11]). Thus, we should consider various sequences of interested parties. To test the model we randomly selected some sequences of countries which are presented in Table I.

TABLE I. SEQUENCE OF COUNTRIES FOR SCENARIOS

№	Sequence of countries
Scenario 1	Republic of Korea → China → Iceland → USA → Russia → Canada → Japan → Denmark → Norway
Scenario 2	Denmark → Iceland → China → Canada → Russia → USA → Japan → Norway → Republic of Korea
Scenario 3	Canada → Russia → Denmark → Japan → Republic of Korea → Iceland → USA → China → Norway
Scenario 4	Japan → Republic of Korea → Denmark → USA → Iceland → China → Canada → Norway → Russia

The exchange of zones between countries is performed by a simple majority rule [9]. In other words, a conflict zone is allocated to country *B* if the total number of resources in which country *B* is interested more than country *A* is more than or equal to 50%+1 of the total number of resources available in this zone.

It is necessary to note that the results of the procedure is similar to the allocation where all zones belong to the most interested country. However, in our model the satisfaction level of the less satisfied country can be higher since the utility of each zone in the Arctic is not always compared with the utilities of all countries under consideration.

IV. The Results

Denote by scenarios 1-4 the results for scenarios of the conflict resolution model based on the idea of superposition and by scenario 5 the results of the conflict resolution model based on the lowest satisfaction level.

The final allocation for scenarios 1-5 is provided in Fig. 5 and Fig. 6. It is necessary to note that almost 320 000 exchanges of areas were performed to obtain the final allocation for scenario 5. All computational analyses were performed in MATLAB.

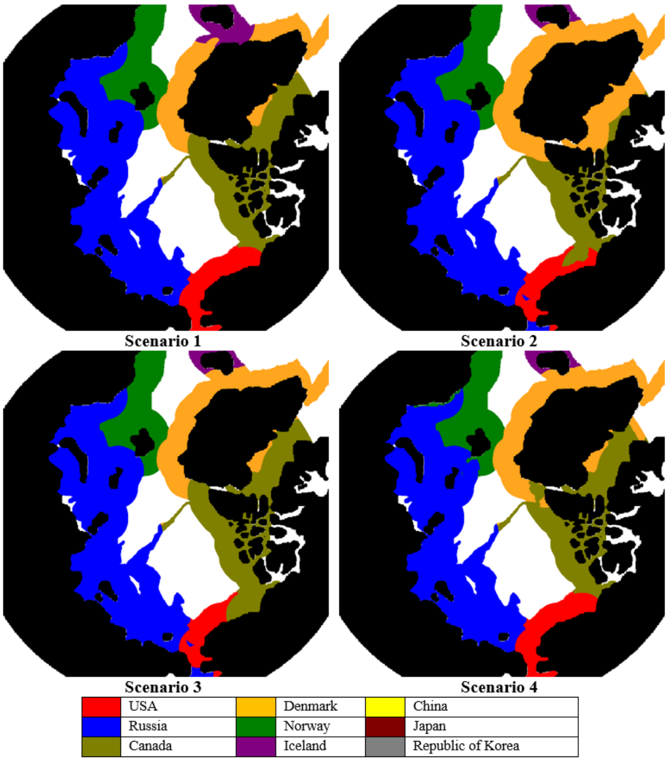

Fig. 5. Visualization of final allocations for scenarios 1-4

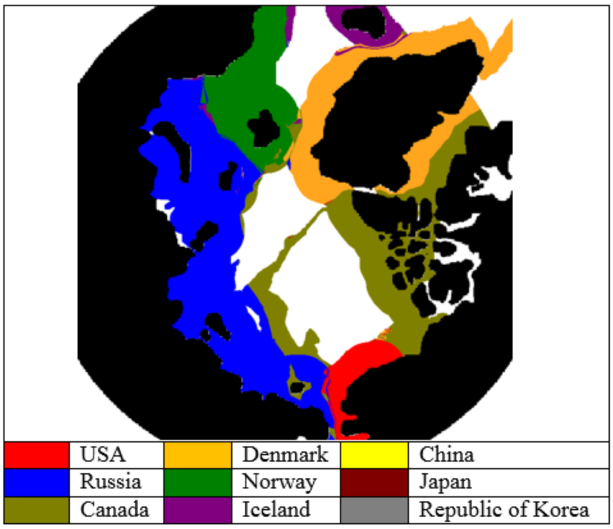

Fig. 6. Visualization of the final allocation for scenario 5

In Fig. 5 and Fig. 6 we may observe some regions which are allocated differently depending on the initial scenario. These regions are the regions of the highest level of conflict.

Now let us evaluate the efficiency of each model in terms of the total satisfaction level. The satisfaction level of each country according to different scenarios is provided in Table II.

TABLE II. TOTAL SATISFACTION LEVEL

Country	Scenario №				
	1	2	3	4	5
USA	-29993	-74409	-128673	-29993	-123841
Russia	46776	59672	59672	37016	-123823
Canada	-135604	-327244	-49820	-155156	-123860
Denmark	-252348	39524	-183636	-164084	-123824
Norway	-241861	-241861	-241861	-232101	-123861
Iceland	-98555	-167267	-167267	-167267	-123665
China	-34269	-34269	-34269	-34269	-34269
Japan	-53452	-53452	-53452	-53452	-53452
South Korea	-59423	-59423	-59423	-59423	-59423
Total	-858729	-858729	-858729	-858729	-890019

As it is shown in Table 2, the total satisfaction level is positive for Russia and negative for other countries according to scenarios 1-4. The positive total satisfaction level for Russia can be explained by its long maritime borders and low number of close neighbors which are interested in its adjacent marine areas (contrary to, for instance, Canada). According to scenario 2 the total satisfaction level is also positive for Denmark which can be explained by the large number of zones that were transferred from Canada and Iceland. We can also observe that the total satisfaction level for the second model (scenarios 1-4) is higher than the total satisfaction level for the first model (scenario 5). However, the difference in satisfaction level among Arctic and non-Arctic countries is almost equal in scenario 5 while in scenarios 1-4 there is a big difference in satisfaction levels. In other words, countries are equally satisfied with allocation obtained by the first model resulting in lower level of conflict.

The number of allocated areas is provided in Table III.

TABLE III. NUMBER OF ALLOCATED AREAS

Country	Scenario №				
	1	2	3	4	5
USA	10624	7666	5639	10624	6782
Russia	40215	41184	41184	39282	28247
Canada	21207	9795	25223	18763	23950
Denmark	18759	37373	23972	26416	27803
Norway	9419	9419	9419	10353	15738
Iceland	7576	2363	2363	2363	5286
China	0	0	0	0	0
Japan	0	0	0	0	0
South Korea	0	0	0	0	0

As for the number of allocated zones, it is shown in Table III, no areas were allocated to non-Arctic countries. It can be explained by the fact that according to our approach the interest of these countries in the Arctic is very low, since it is evaluated with respect to the distance and these countries are located very far from the region. As for Arctic states, we can observe that Russia, Denmark and Canada are the countries with the most allocated zones of Arctic region.

V. CONCLUSION

Using introduced model of utility values with respect to main resources – oil, gas, fish, as well as maritime routes – and different scenarios for an allocation of territories beyond EEZs among interested countries we evaluated dissatisfaction of countries using different models of evaluation of such satisfaction.

We also proposed several models of conflict resolution in the Arctic region. The first model is based on numerous exchanges of areas among countries and is focused on the maximization of the minimal satisfaction level. The second model is based on the idea that areas should be allocated to the most interested party. As a result, the first model demonstrated a lower efficiency in terms of the total satisfaction level compared to the second model and higher efficiency in terms of the difference of satisfaction levels among Arctic and non-Arctic states. The results also indicates conflict zones which are allocated differently with respect to a particular scenario.

The constructed model is a prototype which demonstrates the main idea. The model needs further development in terms of the initial data and evaluation of parameters.

We strongly believe that early forecast of such potential conflict zones and discussions on different scenarios of resource allocation might ease the decision making process in international relations.

ACKNOWLEDGMENT

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