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Modeling of Russian–Ukrainian war based on fuzzy cognitive map with genetic tuning

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Abstract

The Russian–Ukrainian conflict is considered as a dynamic system, whose variables are factors affecting the losses of the Russian army and the threat of the use of nuclear weapons. A fuzzy cognitive map (FCM) is used for modeling, that is, a directed graph whose vertices are model variables, and the weights of arcs are the degrees of positive and negative influences of variables on each other. The following factors influencing the losses of the Russian army and the threat of a nuclear strike were selected: resistance of the Ukrainian army, support of Ukraine with weapons, economic sanctions against Russia, opposition to the Russian government and its self-preservation instinct. The degrees of the influence of factors on each other and on the possibility of using nuclear weapons are evaluated by experts using fuzzy terms, which correspond to numeric values. To adjust the FCM, a genetic algorithm is used to select the degrees of influence of factors that minimize the discrepancy between the simulation results and expert estimations. The obtained FCM is used for scenario modeling of the conflict according to the "what if" scheme and ranking of factors according to their degree of influence on the level of nuclear threat.

Keywords

Russian–Ukrainian conflict, modeling, fuzzy cognitive map, genetic algorithm, scenario modeling, nuclear threat, ranking of influencing factors, pair effects

1. Introduction

On the night of 24 February 2022, the Kremlin announced a "special military operation in Donbass," unleashing a full-fledged and aggressive war with Ukraine. Much of the world rallied in opposition to the Kremlin's aggressive plans, showing unprecedented solidarity with Ukrainians. An attempt to quickly capture the neighboring country failed. In response to Russian aggression, the West began supplying weapons to Ukraine and announced economic sanctions against Russia. This lead to an increase in losses of the Russian army and the emergence of anti-war sentiments in the Russian society. Russia possesses nuclear weapons, the use of which, according to leading political experts, is possible if Russia fails to achieve the goals of aggression with conventional weapons. The factors constraining the nuclear threat are the opposition to the Russian government caused by economic sanctions and its self-preservation instinct, that is, the fear of a retaliatory nuclear strike from the West.

Military and combat operations are historically the first object of modeling in science, which is engaged in operations research[1,2] and game theory.[3] Mathematical methods of quantitative substantiation of solutions in this area can be found in the reviews.[4,5] Judging by the applied developments,[6] at the strategic level of decision-making, the

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differential equations of Lanchester[7] are most widely used, they simulate the dynamics of changes in losses of each of the belligerents, depending on the parameters of the combat effectiveness of weapons and the rate of entry of reserves. Lanchester models have the following disadvantages:

- The parameters of combat effectiveness included in the equations are based on statistical data that are difficult to obtain, and the reliability of which may be questionable. Similar problems arise in the statistical theory of system reliability,[8] where the absence of failure rates for new elements causes distrust of reliability calculations.[9]
- Factors (technical, political, economic, etc.) affecting the dynamics of losses are not included in F. Lanchester's equations. This does not allow us to vary such factors as controlled variables when modeling various scenarios of the development of military operations.
- The equations are not adapted to work with expert opinions, which are almost the only source of information for modeling under uncertainty.

An alternative to differential equations modeling the dynamics of the system is fuzzy cognitive maps (FCMs) which became widespread after the publication of few works based on it.[10,11] A primer on the use of FCM may be found in literature.[12–15] An FCM is a directed graph with weighted arcs. The vertices of the graph are the variables which are taken into account in the model, and the weights of the arcs are the degrees of the variables' influence on each other. The step-by-step dynamics of variable values is calculated using a recurrence relation resembling an ordinary Markov chain.[1] Unlike the Markov chain, which uses the probabilities of states and transitions between them, an FCM uses the levels of values of variables and the degrees of their influences, which are described by membership functions of fuzzy sets.[16] The use of fuzzy mathematics in the FCM provides the convenience of modeling the dynamics of systems with qualitative variables measured by experts. In addition, the *principle of incompatibility of high complexity with high accuracy* is respected.[16] It is interesting to note that models similar to the FCMs were considered in the book[17] long before the publications;[10,11] however, the book[17] is not mentioned in numerous works on FCMs.

The expediency of using FCMs for modeling military conflicts follows from the following analogies:

- Connection of F. Lanchester's equations[7] with the method of dynamics of averages,[1] which directly follows from Markov processes, is shown by Wentzel[1];
- According to Wentzel,[1] the method of dynamics of averages used to simulate combat operations is directly related to "predator–prey" models in population dynamics[18];
- The possibility of modeling population dynamics using the FCM is shown by Dickerson and Kosko.[19]

Thus, the use of the FCM is a natural alignment of the development of the theory of modeling military operations based on the equations of F. Lanchester.[7]

It should be noted that FCM is a relatively new tool for mathematical modeling. Therefore, there are still far fewer applications of FCM in the field of military modeling than the number of applications of classical methods of operations research.[4–6] The main ideas of using FCM for modeling military-political systems are contained in the fundamental work of V. Kosko.[10] These ideas were used for scenario modeling the crisis of the former Yugoslavian Republic of Macedonia[20] and the political-economic problem of Cyprus.[21] Perusich and McNeese[22] propose the use of FCM as a technique for supporting the decision-making process in effect-based military planning with an illustrative example of an operation using NATO to stabilize a country. The FCM-based technique for mediating the information made available to decision makers in Airborne Warning and Control System crew managing air assets in conflict situation are proposed in Perusich and McNeese.[23] Jones et al.[24] describe a fuzzy cognitive model to emulate the decision support system for army infantry platoon leaders. The application of FCM for the modeling of complex structure of public support for insurgency and terrorism is described by Osoba and Kosko.[25]

In most applications of FCM in military modeling, expert assessments of the forces of influence of model variables (concepts) on each other are used. This does not guarantee that the predictions obtained using FCM will be close to the results of observations. Rotshtein and Katelnikov[26] proposed a two-stage approach for obtaining the weights of the arcs of the FCM graph: in the first stage, the admissible intervals of the weights of the arcs are determined; in the second stage, the weights of the arcs are tuned according to the results of observations using the least squares method.

The purpose of this article is to show the use of FCM for modeling military–political systems on the example with the Russian–Ukrainian conflict. Taking into account the potential capabilities of one of the belligerents, the main emphasis in modeling is on predicting the level of nuclear threat and ranking the factors influencing it. The usefulness and necessity of ranking factors (causes) affecting some objective function (consequence) is noted by Nechiporenko[27]—one of the first monographs on the structural analysis of systems under uncertainty.