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Intelligent support for multi-agent decision making

Soporte inteligente para la toma de decisiones multiagente

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Contents

ABSTRACT:

The article describes a new management decision-making method for resolving international conflicts based on a multi-agent approach. The purpose of the paper is to summarize scientific achievements and develop methods for intelligent decision support in the management of international conflicts based on multi-agent technologies. The main research methods include systemic analysis and mathematical modeling, multi-agent approach, using scientific findings obtained in political science and conflict management. Intelligent models are based on different approaches: neural networks, genetic algorithms, fuzzy sets.

Keywords: modeling, forecasting, management, system, international conflict, dynamics

RESUMEN:

El artículo describe un nuevo método de toma de decisiones de gestión para resolver conflictos internacionales basados en un enfoque de múltiples agentes. El propósito del documento es resumir los logros científicos y desarrollar métodos para el apoyo a la toma de decisiones inteligentes en la gestión de conflictos internacionales basados en tecnologías multiagente. Los principales métodos de investigación incluyen análisis sistémico y modelos matemáticos, enfoque multiagente, utilizando hallazgos científicos obtenidos en ciencias políticas y manejo de conflictos. Los modelos inteligentes se basan en diferentes enfoques: redes neuronales, algoritmos genéticos, conjuntos difusos.

Palabras clave: Modelado, pronóstico, gestión, sistema, conflicto internacional, dinámica

1. Introduction

The purpose of the research is to form a new concept and model for the operational management of international conflicts by means of multi-agent systems that would enable to reduce the labor intensity of management processes and the duration of management cycles as a result of the use of intelligent decision-support tools and organizational procedures.

The developed multi-agent system for managing an international conflict is distinguished by the specifics of rapidly developing international conflicts and the presentation of each control element in the form of dynamic profiles. The subjects of the mechanism have inertial properties, and therefore, it is necessary to build the profile of dynamic actions of functional components, as self-managed agents, with certain assumptions, and also to identify dynamic models of each subject of functional components separately.

The elements of the Operational Management (OM) mechanism in a multi-agent system are agents who make and execute decisions, as well as report on the work performed to the center.

The application of a multi-agent approach in modeling management processes for complex dynamic objects under uncertainty contributes to increased management efficiency, by virtue of providing the ability to analyze changes in the properties of the object being studied when selecting control actions, which is caused by the reduction in time required for managerial decision making (Muda et al., 2019). Thereby, the quantitative indicators of the activities of the international conflict management system are improved: the labor intensity of management processes and the duration of management cycles are reduced as a result of the use of intelligent decision-support tools and organizational procedures (Feng et al., 2016).

The advantage of the multi-agent approach lies in high performance and efficiency due to asynchronous and parallel execution of processes, in fault tolerance and reliability, since the entire system continues to operate if one of its components fails, in scalability and flexibility, owing to the possibility of adding new agents to the system. Our method for process modeling to manage complex dynamic objects in the conditions of uncertainty promotes an increase in management efficiency, by virtue of providing the ability to analyze changes in the properties of the object under study when choosing control actions by reducing the time required for decision making. As an example, we will illustrate the proposed method by solving the managerial problem of determining the type of international conflict, the number of functional units involved in conflict management, the speed of conflict management activities, and the allocation of necessary resources.

The development of an organizational and functional system of operational management in the conditions of international conflicts based on a multi-agent approach is the conceptual framework of the study. The multi-agent information technologies are dealt with by Menga et al. (2019), Rizvanov and Yusupova (2015), Nagoev (2012), Shvetsov and Dianov (2015), Avdeenko and Vasilyev (2010), Aksenov et al. (2011), Alibekov and Mamaev (2017), Antonova and Aksenov (2012), Bogdanova et al. (2014), Shunkevich (2013). The use of multi-agent systems in decision making in various areas was considered by Nagoev et al. (2017), Avdeenko and Vasilyev (2010), Samorodov (2012), Zraenko et al. (2009), Skobelev (2013), Vittikh et al. (2002). The application of neural networks for the collective solution of intellectual problems is described by Bova and Dukkardt (2012). Current problems of practical use of multi-agent systems are reflected by Kulba and co-authors (2013), Inozemtsev and Dmitriev (2012), Rizvanov (2016), Yatsenko (2014).

The prospects for the application of intelligent technologies to solve security problems are discussed by Garbuk (2016). It is proved by Nagoev et al. (2017) that the multi-agent neurocognitive architecture is an effective formalism for describing the semantics of the spatial localization of events. A generalized algorithm based on a multi-agent approach was proposed by Rizvanov and Yusupova (2015) for solving the problem of resource management, taking into account the semantic constraints of the domain.

Multi-agent management systems are created using the methods of game theory, cooperative problem solving based on distributed artificial intelligence, collective behavior of machines, scheduling theory, optimal planning and adaptive control. The above methods are presented by Menga et al. (2019), Zheng et al. (2019), Gelaim et al., (2019), Bychkov et al. (2014), Kovalenko et al. (2019), Nagoev (2012). Note that the use of multi-agent systems can reduce the labor intensity of management processes, the duration of management cycles, organizational procedures, and the time for making managerial decisions.

2. Methodology

Systemic analysis, mathematical modeling, and multi-agent approach, using scientific findings obtained in political science and conflict management are the primary research methods. Let us schematically represent the agent system for international conflict (IC) management and resolution in Figure 1.

At the first stage, we define the set X = {Xi} of parameters determining the state of the critical agent, where:

x_0 – an introductory destructive factor that caused the emergence of a conflict situation;

x_1 – the rate of the IC development;

x_2 – IC potential;

x_3 – IC affecting factors.

Next, we define a set of S parameters characteristic of a protective agent, where:

S_1 – the population;

S_2 – property objects.

The IC emergence inevitably leads to a set of losses T $=\{t_i\}$, depending on the change of variables of the protective agent, where

t_1 – human losses;

t_2 – damage to property;

t_3 – environmental impact.

Let us describe a support and decision making agent as a set of variables R $=\{r_i\}$ representing managerial influences and decisions on critical and protective agents, where:

r_1 – the use of technical facilities;

r_2 – the use of labor force;

r_3 – the use of information tools;

r_4 – the use of economic means;

r_5 – intellectual labor.

The information agent describes a variety of methods for searching, processing, accumulating and analyzing data about the protective agent S, the critical agent I_1, the socio-economic agent I_2, and the implementation agent I_3.

While analyzing the entire system, the information agent transmits the processed data agent for the decision-making process to the Support and Decision Making (SDM) Agent. It is worth noting the special importance of reliability and timeliness of information.

The implementation agent will be described by the set Z $=\{Z_i\}$ of the available IC management resources, where variables Z_i represent the number of works W_i for the implementation of managerial effects and decisions R_i. The set Z $=\{Z_i\}$ is a resource pool for IC managing and resolving.

The socio-economic agent affects critical and protective agents, exerting a set of D influences, where:

d_1 are circumstances contributing to the escalation of a critical agent (involvement of indirect participants in the IC, non-participation in the negotiations, the use of armed force, threats, sanctions, etc. by the IC actor);

d_2 are circumstances facilitating the de-escalation of a critical agent (refusal to use armed force, desire to participate in the negotiation process, search for compromise solutions to overcome a conflict situation, etc.)

By implementing the set R of IC resolution methods, the protective agent takes the form of the set S_0 of the expected states of the protective agent, where T_0 is the set of allowable losses.

Let us describe the equations of uncontrolled IC, i.e. situations in which there are no control elements over the critical agent:

$\overline{X} = \alpha_0(X, D, X_0)$;

$\overline{T} = \beta_0(X, D, X_0)$;

$\overline{S} = j_0 (X, D, X_0)$.

In the case of managerial measures, the equations will appear in the following form:

$\overline{X} = \alpha_0(X, D, Z, X_0)$;

$\overline{T} = \beta_0(X, D, Z, X_0)$;

$\overline{S} = j_0 (X, D, Z, X_0)$. (1)

The OM mechanism consists of the information agent, the implementation agent, the SDM agent.
The information agent equation will take the following form:

$\overline{I}_0 = \varphi_0(I_0, I_1, I_2, I_3 T, S)$. (2)

The general form of the SDM agent equation will present the management algorithm with the availability of operational data on IC and will appear in the following form:

$\overline{Z} = \eta (R, T^0, T, D, X, X_0, S)$. (3)

where $\eta (\cdot)$ reflects the direction mechanism in the presence of operational information about the safeguarding and protective agents, factors influencing them, as well as existing and probable damage.
The implementation agent will take the following form:

$\overline{Z} = f (Z, R, D)$. (4)

where $f(\cdot)$ is an executive managerial decision-making mechanism, and the set D represents the factors influencing the execution of the set R of managerial decisions.

Figure 1
Agent system for IC management and resolution

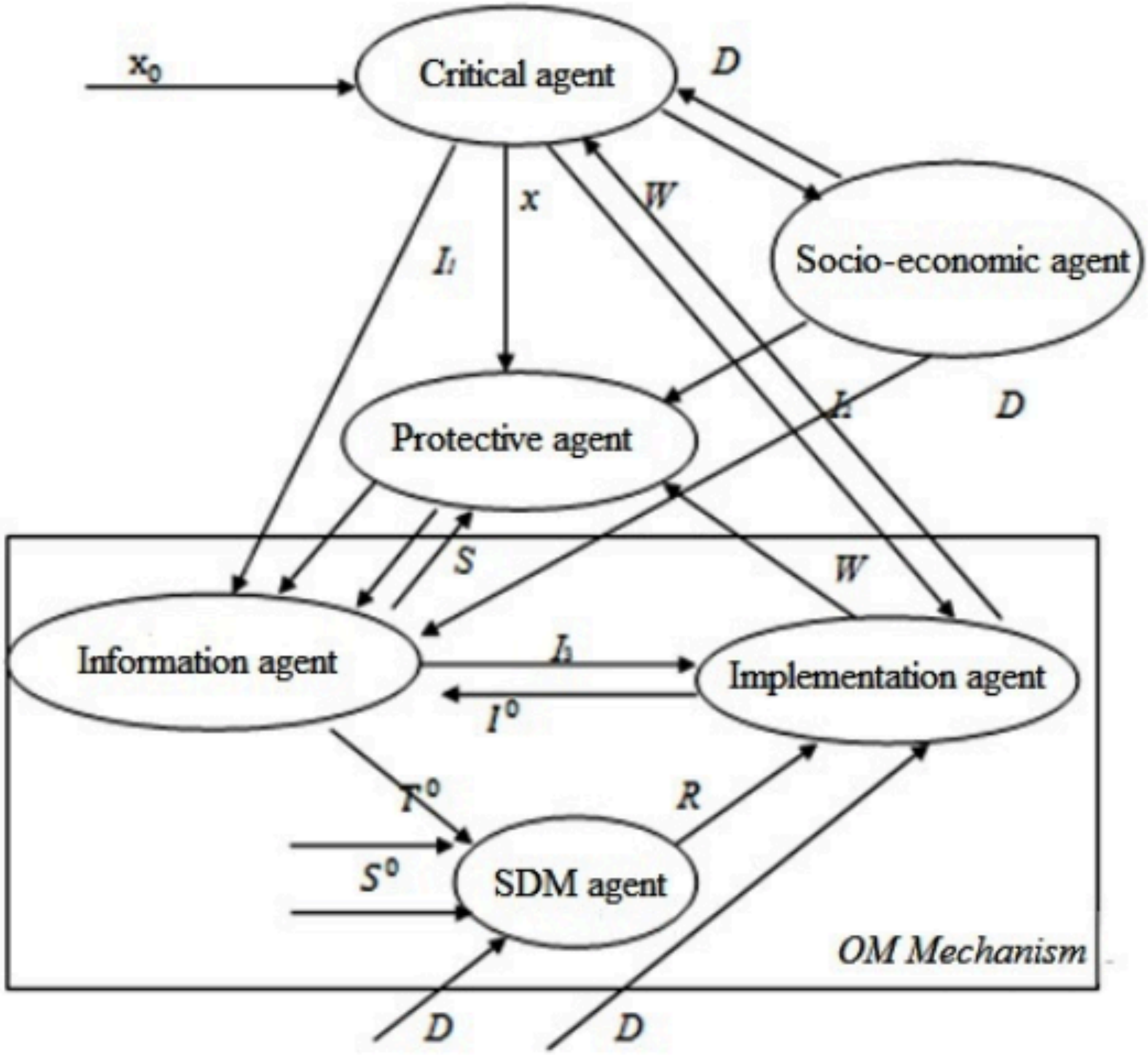
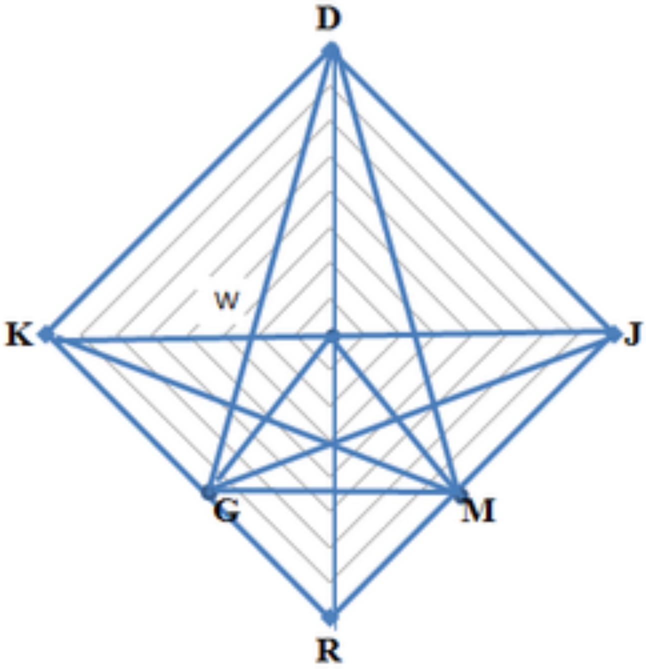


Figure 2 shows a combination of a multi-agent approach and an integrated management organization principle in the IC as a profile of ternary graphs, where each graph is a basic part of the whole mechanism.

Figure 2
Profile of integrated
management and regulation of IC


D
W
K
J
G
M
R

The profile of ternary graphs includes the following basic elements:

R – a set of goals for IC management and regulation;
W – measures for IC management and regulation;
D – agents' functions;
J – agent organizational structure (interaction of agents);
K – IC liquidator agents (analysts, experts, etc.);
M – the resources necessary to regulate the IC;
G – technologies for implementation of IC regulation measures.

The plurality of the integrated IC management and regulation profile elements can be used to compose thirty-five distinct subsystems, each of which describes a specific group and the relationship of the profile elements.

E = $\{R, W, D, J, K, M, G\}$.

The subjects of the mechanism have inertial properties and the system is influenced by external factors $d_{1i}(x)$; therefore, the amount of planned work will not correspond to those performed, i.e. $W_i \neq W_i^0$. There is a deviation $e_{vi}(x)$ arising, which means that a feedback channel is distinguished in the management mechanism, and the management subject adjusts the planned consumption of resources M_i^0(x) to maintain balance $W_i = W_i^0(x)$. The planning subject forms the planned volume $W_i^0(x)$ of works and deadlines, the executing subject forms the pace of work performed W $\overline{W}_i$(x) and the amount of resources spent. The input variable is the resource consumption rate $\overline{M}$(x), the output variable is the rate of work implemented $\overline{W}_i$(x) and the volume of work implemented $W_i(x)$.

These variables can be connected by a differential equation:

$$F_{oi}\frac{d^2W_i(x)}{dx^2}+\frac{dW_i(x)}{dx}=y_{oi}\left[F_i\frac{\overline{M}(x-z_i)}{dx}+\overline{M}_i(x-z_i)\right]+d_{oi}(x) \qquad (5)$$

F_{oi} is the time constant, reflecting the inertia of the transition from one pace of work implementation to another;

F_i – the time constant reflecting the characteristics of the implementation subject performance (professionalism of human resources, modern technologies, level of work organization);

z_i – the pure time delay associated with the analysis of the situation;

y_{oi} – the impact of the resource consumption rate on the execution of works;

d_{oi} – the influence of external factors that reduce the pace of work.

Let us apply the Laplace transform to equation (5), taking into account the zero initial conditions and select the transformation operator in the form of the transfer function:

$$S_{oi}(E)=\frac{y_{oi}(F_iE+1)}{E(F_{oi}E+1)}e^{-z_iE}.$$

Imagine a dynamic profile in two parts, one of which represents the model of the relative pace of work $\overline{W}_i$(x).

After applying the above assumptions, the transmission coefficient of the analyzing subject is equal to 1. The dynamic profile of the management subject (MS) in the form of a transfer function takes the following form:

$$S_{ci}(E)=\frac{y_{ci}(F_{ci}E+1)}{E(z_{2i}E+1)}e^{-z_{ci}E}; \qquad (6)$$

$$S_{ci}(E)=\frac{y_{ci}(F_{ci}E+1)}{z_{2i}E+1}e^{-z_{ci}E}. \qquad (7)$$

where z_{2i} is the time constant describing the inertia of decision making;

z_{ci} – the pure time delay for decision making;

F_{ci} – the time constant, reflecting the level of professionalism of the managerial work organization;

y_{ci} – the coefficient of MS sensitivity to deviations e_{vi} or $\bar{e}_{vi}$

Equations (6) and (7) represent the astatic and static management algorithms, respectively.

The management subject can be influenced by $d_{1i}(x)$ – external factors negatively affecting the decision-making process.

The planning element reflects the relationship between the planned scope of work $\bar{W}_i^0$ and the planned volume of resource consumption M_i^0 and the rate of resource consumption $\bar{M}_i^0$ and can be represented as follows:

$$W_i^0 = y_{hi} M_i^0;$$

$$M_i^0 = \omega \bar{M}_i^0 x;$$

$$\bar{W}_i^0 = y_{0i} \bar{M}_{io}$$

where y_{hi} is a planning coefficient.

The dynamic process is reflected via the following transfer function:

$$S_{hi}(E) = \frac{W_i^0}{M_i^0} = \frac{y_{hi}(F_{hi}E+1)}{z_{1i}E+1} e^{-z_{hi}E}, \qquad (8)$$

where z_{1i} is the time constant reflecting the inertia of the planning process,

F_{hi} reflects the level of professionalism of the planning process.

The management subject shows the relationship between the planned scope of work W_i^0 and the planned rate of resource consumption M_i^0 when implementing these works, which we represent as a transfer function:

$$S_{hyi}(E) = y_{ri}E,$$

where y_{ri} is the coefficient of formation of the planned resource consumption rate, with regard to the plan and characteristics of the implementing subject and management objects, therefore:

$$y_{ri} = \frac{1}{y_{oi}}.$$

It should be noted that a support subsystem for the preset pace $\bar{W}_i^0$ can function within the dynamic profile of actions of a functional unit. At the same time $\bar{M}_i^0$, reflecting the rate of resource consumption, will be proportional to $\bar{W}_i^0$:

$$\bar{W}_i^0 = y_{hi}\bar{M}_i^0.$$

All operational management systems have a combined control principle, which means that feedback control is combined with open-loop control.

The interrelation of the head management element (hereinafter referred to as the IC HME) with the functional units contains the following main provisions. Firstly, the IC HME manages the functional component (FC) through planning and allocating funds upon FC requests. Also, the IC HME is the center for the supply of resource sources to provide the FC operation. FC, in turn, carrying out the planned scope of work using the resources provided, submit the data on the funds used and form the subsequent requirements.

At their discretion FCs allocate the HME requirements for the planned rate of resource expenditure, taking into account the conflict potential, the available funds, and the required rate of the IC regulation.

It follows from the above that it is possible to model the probable directions of IC and to construct the IC OM mechanism, which reveals the value of each agent in the management algorithm, as well as the effect of management deficiencies on the final result.

3. Results

The following basic results were obtained in the study:

1. The principles, requirements and stages of IC modeling have been formulated that are necessary for the qualitative and timely management of the conflict process and decision-making on its regulation, enabling to investigate the conflict as a dynamic, multilateral and complex process, taking into account the risk of IC occurrence.

2. An agent-based IC management and resolution system has been developed based on a multi-agent approach.

3. Formulas (5-8) were used to obtain transient curves for the resolution of a bilateral IC on the basis of computational simulation in the MATLAB 9.3 environment.

4. A software complex “IC plus” has been developed.

Figure 3
Transition processes to resolve a bilateral international conflict during the autonomous operation of two FCs:
a) Changes in the indicators IC/1 and IC/2 during liquidation and change in the damage O1 and O2;
b) Total damage from the international conflict

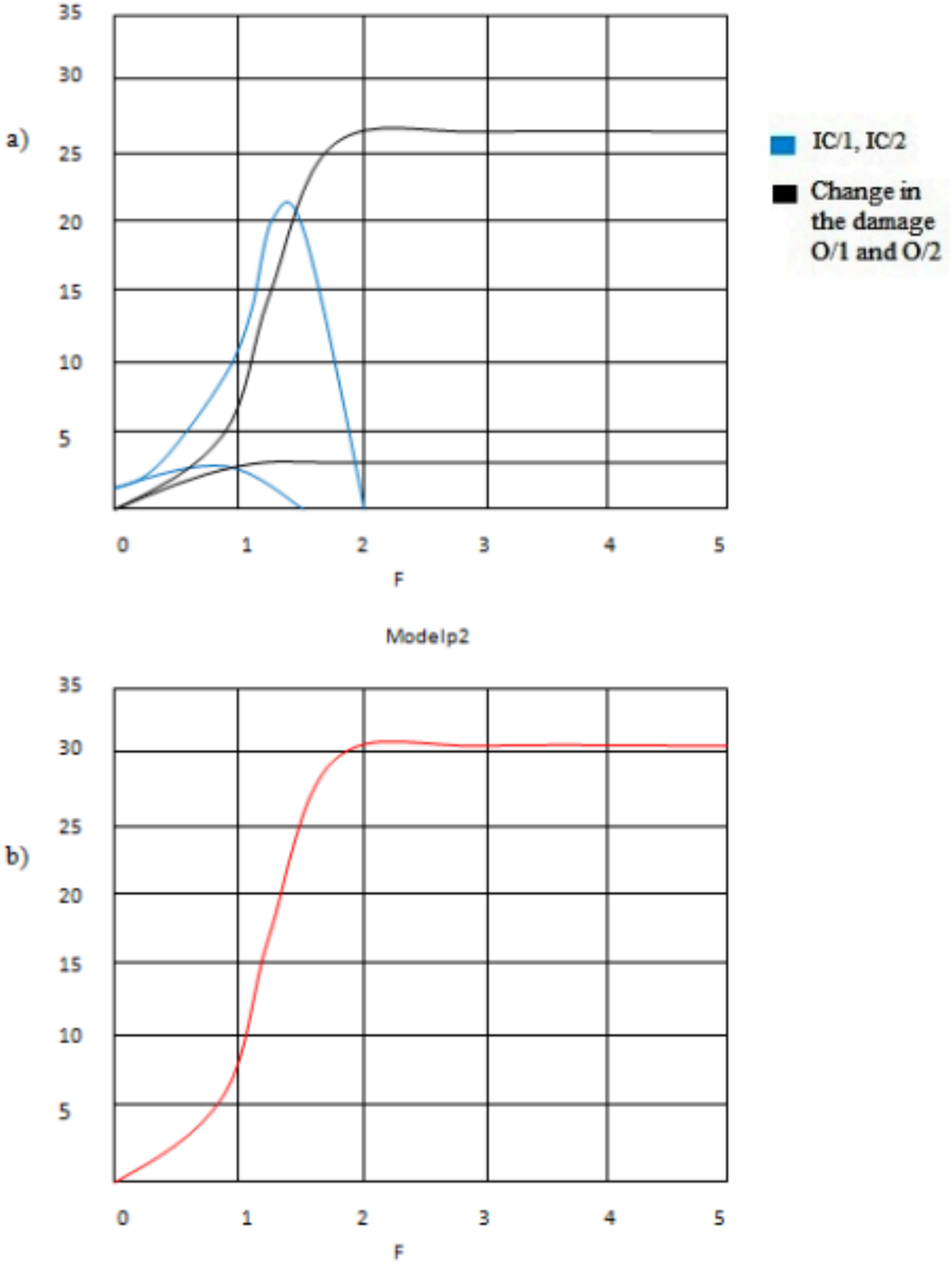
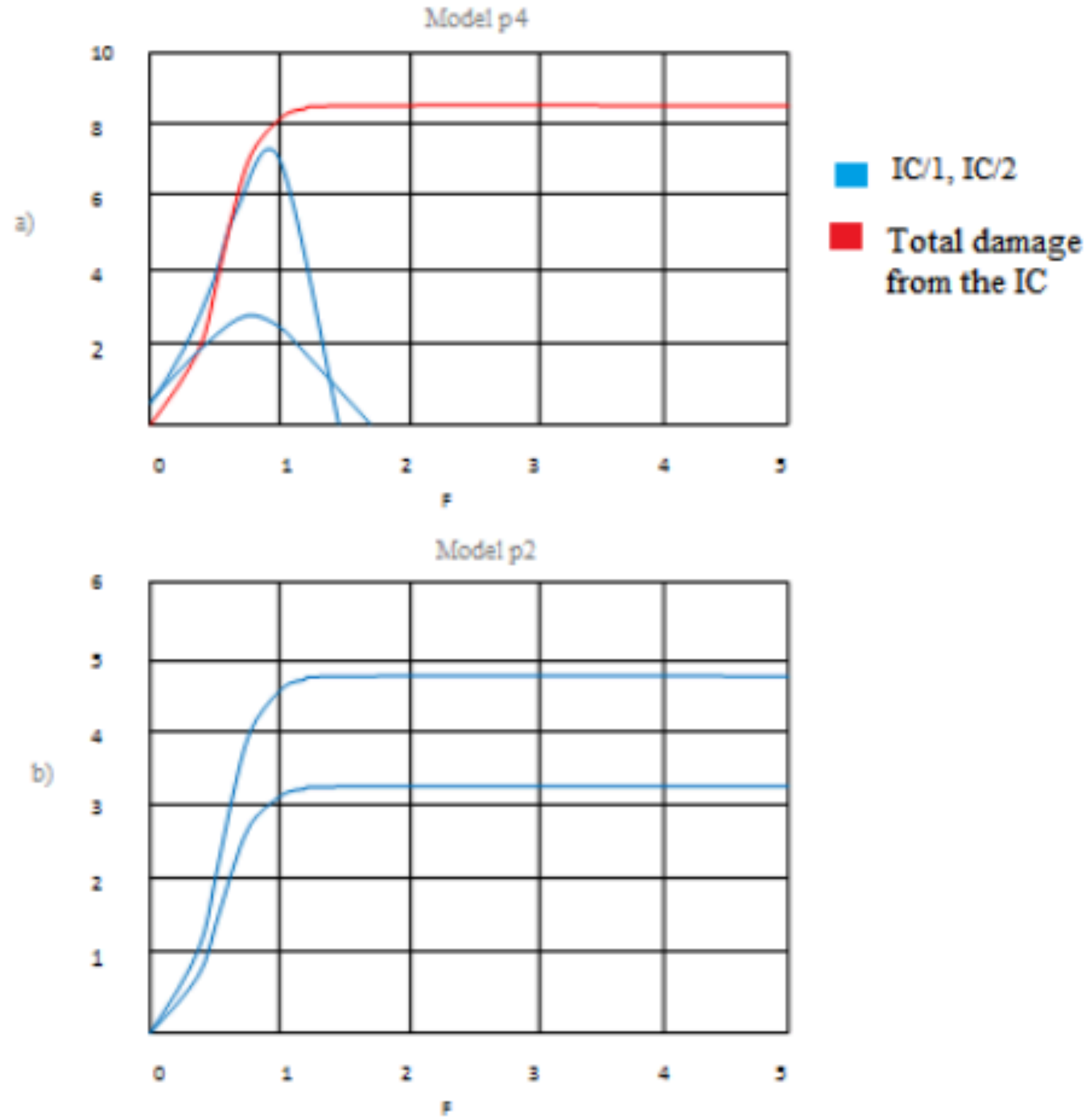


Figure 4
Transition processes to resolve a bilateral international conflict by three FCs:
a) Changes in the indicators IC/1 and IC/2 during liquidation and total damage from the international conflict;
b) Change in the damage O1 and O2;



Based on computational simulation in the MATLAB 9.3 environment, transient curves for the IC resolution were obtained according to the resolution of the MC. The obtained simulation results were analyzed for each curve.

Figure 3 shows the transient processes when resolving a bilateral IC, taking into account the autonomous operation of several functional components. The curves reflect the effectiveness of the activities of the functional components at certain points in time (F). At F = 2, the rate of rise in IC/2 is equal to zero, and at F = 1.5, IC/1 is equal to zero, which means that the IC is effectively resolved with the autonomous functioning of both FCs. And here the damage from IC/1 makes 4 units, the damage from IC/2 amounts to 26 units, with the total damage being 30 units.

Figure 4 shows the transition processes when resolving a bilateral IC, in which the first FC and the second FC act independently of each other, and the third FC regulates the part of the international conflict that is rapidly developing or carries a greater degree of threat.

It is clear from the presented figures that in case of the autonomous functioning of two FCs and the participation of the third FC the damage from the first IC amounts to 3.3 units, the damage from the second IC makes 4.8 units, with the total damage from the conflict being 8.1 units, i.e., it is reduced by more than half.

This means that the use of three FCs causes the greatest efficiency in resolving a bilateral IC. With the use of three FCs for IC resolution, the maximum positive effect is observed.

Therefore, it can be concluded that the models presented describe the dynamics of development and resolution of a bilateral conflict by several FCs, enable to assess damages inflicted and make the right managerial decision on the conflict situation.

4. Conclusions

The practical significance of the study lies in the new scientific results in the field of studying complex dynamic systems, which are international conflicts operating under uncertainty, identifying links and regularities that enable to formalize and organize decision support by government bodies on international conflicts. And also its significance is determined by the solution of the important problem of improving information support of the decision-making process in the field of forecasting international conflicts.

The presented computational simulation of the process of managing international conflicts is based on the implementation of a new approach consisting in the purposeful selection of the parameter values of the state of the resource support system used in the regulation of IC with a comprehensive account of factors determining the magnitude of possible damage from the IC.

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