Game and System Models of Conflict Resolution Methods and Infrastructure Cybersecurity Under Active Attacks

Lubomyr Sikora[1], Natalya Lysa[1], Roman Martsyshyn[1] and Yulia Miyushkovych[1]

[1]Lviv Polytechnic National University, 12 Bandery St., Lviv, 79013, Ukraine

Abstract

The article deals with the development of methods for solving conflict situations in technological structures. Modern model approach in the construction of algorithms and strategies allows you to solve the problems of analysis and synthesis of systems of different nature, focused on achieving certain goals. This occurs using a unified methodological framework. The theory and methods of creating systemic and group conflicts have a history of thousands of years. This problem has become especially important in our time, as conflicts have become global in nature. The main component of crises and conflicts of active type is infrastructure with hierarchical integrated systems, the struggle for resources (information, intellectual, energy and material), which in our time of military events has escalated to a high level. The solution of the problem of conflict and crisis in the internal structure of systems and in interaction with external objects as participants in the game is an urgent task. The solution of such a problem by means of game theory, operations research, linear programming is not possible in full, since in such a case there is an incompleteness of the conceptual apparatus and instrumental means.

Keywords

Conflict, system, targets, systemology, cybersecurity, attacks, infrastructure.

1. Introduction

Solving the problem of conflict and crisis in the internal structure of systems (in interaction with external objects as participants in the game) is an urgent problem. It is not possible to solve this problem by standard means (methods and tools of game theory, operations research, linear programming). This is due to the incompleteness of the conceptual apparatus and tools of the mentioned means.

The systemology of purposeful structures allows to combine a wide range of applied constructive theories: computer science, systems theory, computer technology, CAD to analyze the dynamics of game systems under a certain structure of their organization. This unification becomes possible thanks to the information-resource concept.

The analysis of the problem situation relies on the knowledge base built from classes of conceptual models (systems, signals, processing and evaluation algorithms, decision-making

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EMAIL: liubomyr.s.sikora@lpnu.ua (L.Sikora); nataliia.k.lysa@lpnu.ua (N.Lysa); roman.s.martsyshyn@lpnu.ua (R.Martsyshyn); yuliia.h.miiushkovych@lpnu.ua (Yu.Miyushkovych)
ORCID: 0000-0002-7446-1980 (L.Sikora); 0000-0001-5513-9614 (N.Lysa); 0000-0003-2464-8146 (R.Martsyshyn); 0000-0001-5890-2208 (Yu.Miyushkovych)

algorithms and target strategies). The functional unifying concept will be the allocation of the paradigm: "Target space – the shaper of the image of the dynamic situation in the target space – the current state of the system – the target state – the strategy for achieving the goals – the price of resources – the strategy for solving the crisis".

Problem statement. In the systemology of goal-oriented structures, a conceptual apparatus for solving conflict problems has been formed. Conflict is interpreted as an increase or shortage of resources (material, energy, information, financial) to achieve the goal under perturbation. Another interpretation of conflict is the collapse of the structure of the system with uncoordinated game strategies.

The methodology of conflict resolution is based on assessing the stage of the moment when the trajectory of the object state enters a crisis situation (mapped in the target space of the system). The indicator of entering the conflict will be the deviation of the state trajectory from the predicted trajectory. Two stages can be singled out in a crisis exit strategy. Change in strategy of behavior, structure of the system, parametric adaptation and optimization of the system is the first stage of getting out of the crisis. Change or correction of the goal and, accordingly, strategies of behavior and structure of the system – the second stage.

Purpose of research. The purpose of research is to analyze the causes and factors of systemic and cognitive conflicts in the action of internal and external threats to the structure and process of management.

Subject of research. The system-game concept of presenting the model of the emergence of a conflict situation in the hierarchical infrastructure of the technogenic type.

Research methods. The methods of research were: system analysis, antagonistic game theory, cognitive psychology to identify the causes of conflict.

Research methods. To solve the problem of the causes of conflict in the infrastructure hierarchy, it is necessary to justify the methods of research and the choice of strategies to solve the following problems:

1. Analyze existing methods for resolving internal and external influences on conflict dynamics.
2. To substantiate the balance of means and resources for countering attacks.
3. To substantiate the concept of a complex antagonistic game as a scenario for countering threats.

2. Literature Review

The theory and methods of creating and solving small and large systemic and group conflicts have a history of thousands of years. In our time, this problem has become particularly relevant because conflicts have become global in nature, and the main component of crises and conflicts of an active type is infrastructure.

Problems of the conflicts emergence and their system analysis have been considered many times in the works of Ukrainian and foreign scientists.

Crisis situations can often arise at energy-active facilities [1], where the process of their functioning is largely influenced by the availability of material resources, the serviceability of technical resources and the personnel knowledge level. In particular, this is described in [2, 3]. In other literature the authors [4] raised the issue of visualization of information (about resources, parameters, etc.) in the process of crisis resolution.

Separately, a number of works devoted to the issues of modeling and simulation of complex systems [5] can be singled out. Preliminary modeling of processes allows to foresee the conditions of crisis occurrence and possible methods of its resolution.

Also, in order to solve crises and make decisions, it is always necessary to take into account the multi-criteria nature of the system [6]. Because the neglect of individual criteria can cause crises and accidents at facilities.

The problem of dynamical systems control has been repeatedly considered both by the authors themselves [7,8] and by a number of other authors. For example, the problem of adaptive control of dynamic systems was raised in [9, 10].

In [11] new methodologies for the design and analysis of adaptive control systems with feedback are considered.

One of the works of foreign scientists in the direction of adaptive resolution of crises and problems is the method of model-free adaptive control, presented in [12]. This approach makes it possible to control non-linear systems with uncertain (or variable) parameters and structure. In a broader sense, management issues have been studied in [13] and [14].

The authors of [15] considered the issues of security and cybersecurity, which are an integral part of the stable functioning of a complex system.

3. Materials and Methods

Methods for solving the conflict at a given problem situation in the technological system are based on the evaluation of the situation relative to the goal. The evaluation of the problem situation is carried out at the moment when the trajectory of the state of the dynamic system in the vicinity of the goal by the intelligent hierarchical observation system. This forms the criteria and indicators of the degree of proximity to the goal (resource, information).

3.1. Problem Solving Methods

The choice of a model strategy for solving the problem situation in the target space of the system is based on the assessment of internal and external resources and their sufficiency to achieve the goal. There is also a refinement of local decision-making strategies class and prediction of the future state trajectory. When internal material and informational resources are insufficient, the principle of relations with external structures and criteria for assessing the cost of necessary resources are formed. The solution to the crisis situation occurs through the mobilization of resources and a change in the local strategy of behavior. In a more global variant, the synthesis of the system new model and its structural adaptation can take place. The new structuring mode and cyclic repetition of positions in the system with optimized structure and strategy, reaching the level of dynamic equilibrium when internal and external influences change can also take place.

If the conditions of the method for solving the problem situation at the level of adaptation and optimization are not fulfilled, the transition to the next level takes place. At this level, the crisis situation is a criterion of completeness and consistency of the used information and logical-cognitive methodology, building a strategy for solving problematic problems. The main task for solving the crisis (or conflict) is to synthesize a goal-oriented system to generate new knowledge based on the data obtained in the previous game (and taking into account new concepts and paradigms). This eliminates the problem of methodological contradiction.

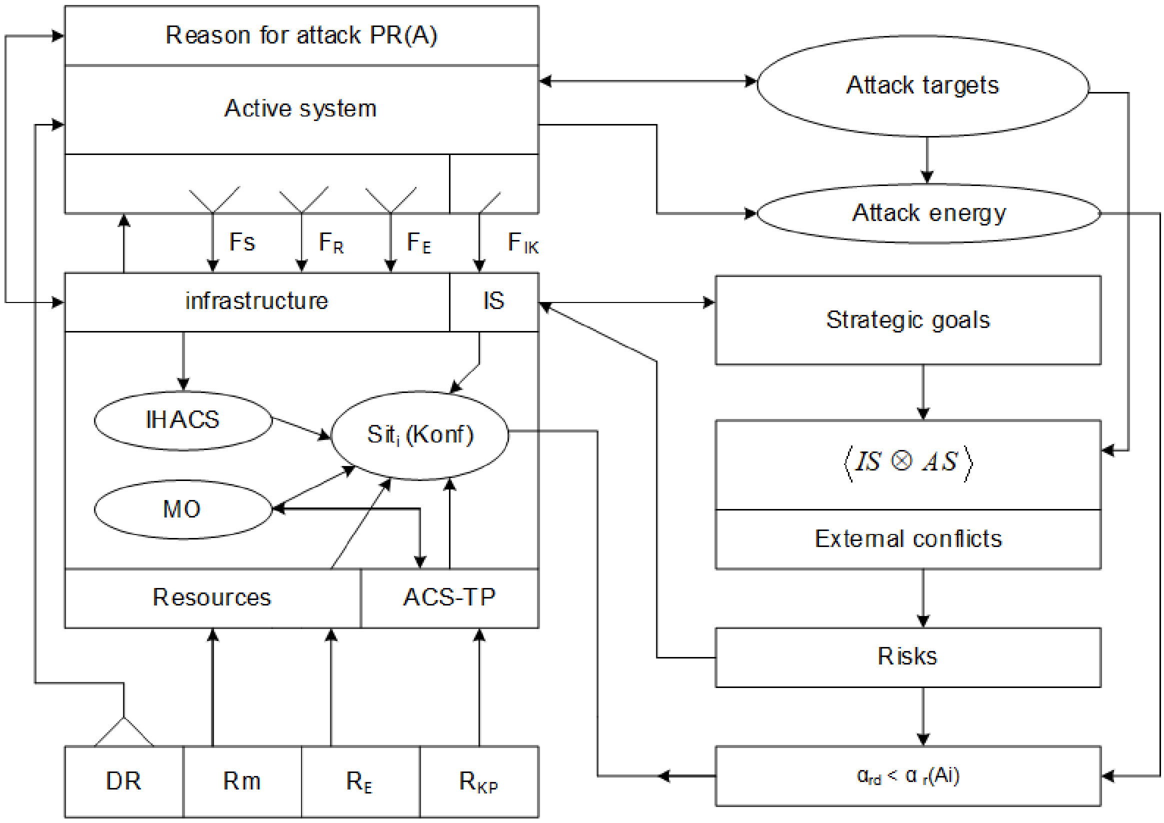

Figure 1: Game model of the conflict situation

Also on the basis of them there is a synthesis of targeted strategies to overcome the crisis and tactics for the use of resources in moments of crisis. There is a change of orientations and strategic goals, which again lead to a global analysis of the dynamics of resources in the renewed structures. The methods described above are reflected in the scheme (Figure 1).

The following notations are used in Figure 1: $\{F_{S,} F_{R,} F_E\}$ – factors of the resource-structural impact of the attack, F_{KI} – factor of cognitive and informational influence, $\{R_{m,} R_{F,} R_{KP}\}$ – resources (material, energy, cognitive resources of personnel), α_{rd} – acceptable risk, $\alpha_r(A)$ – risks from attacks, IHACS – integrated hierarchical automated control system, $\langle IS \otimes AS \rangle$ – an infrastructure game with an attacking system, $PR(A)$ – reasons for a complex attack on infrastructure, MO – management object, ACS-TP – automated control system for technological process.

3.2. Analysis of Knowledge Needed to Form Solutions to Identify Critical and Emergency Modes in the Hierarchical Structure

Under conditions of impact factors on both material and energy resources and information systems, technological failures and disorientation of information and control complexes occur. At the same time, it is difficult for the operator to verify the causes of failures and emergencies.

Therefore, at the time of identifying faults, it is necessary to mobilize the intellectual potential of the operator, heads of operational and management teams to identify the causes of failures and pre-emergency situations, using the following knowledge and methods:

- analysis of the system structure at the hierarchical level and modes of functioning in order to identify the breakdown of structural links;
- analysis of the processes dynamics to identify deviations of trajectories (based on the scenarios of events in the object state space);
- analysis of the actions logic according to management strategies (based on a clear sequence of plans and commands);
- identification of the conflict situation in the hierarchical structure.

Knowledge of the problem environment reflects the understanding of the (intelligent) purposeful system of the global properties of the solution search space and its logical structure (based on semantics, which is the basis for the knowledge base formation procedure).

Based on the fact that the logical structure of declarative representations is constructive, then we consider that declarative representations share structural and semantic knowledge.

Based on the nature and way of setting the control mechanism, we can say that:

- declarative representations are effective in metricized decision search spaces;
- semantic knowledge is expressed in numerical or logical form.

The basis for the description of objects and relations between them is a set of logical statements and general rules of inference, which form the structure of the knowledge base. Such a knowledge base is focused on solving the problems of a particular subject area of the hierarchical ACS.

Structural relationships in knowledge bases are based on classes of models of logical relationships, quantized logical operations and procedures and rules for drawing conclusions.

3.3. Heuristic Search for a Way to Solve Problem Goal-Oriented Tasks

The declarative representation of the heuristic search for a way to solve problem goal-oriented tasks is based on cognitive models of goal behavior. The tasks of the problem-solving model heuristic search are as follows:

- we use a state space model to describe situations in the subject area;
- ehe initial situation relative to the state of the research object is given in the form $s_o \in$ S;
- the target situation relative to the state of the object is given (designated) and the constructive possibility of its achievement is determined $T \subseteq$ S;

- the structural model of the hierarchical system is given;
- classes of possible strategies for the implementation of target tasks are specified;
- a system of resource and terminal restrictions is given when forming decisions;
- the decomposition model of the system structure and information and transport routes is given;
- given a set of operators that transform one situation into the second and change of states of the object $\{f_i\} \subset F: s_f \subset S_i F_i: s_i - s_{i+1}$.

It is necessary to find a sequence of transition operators from the initial state to the final state and evaluate the possibility of their implementation (efficiency) based on a system of constraints.

The process of solving the problem is based on the construction of a sequence of (finite) logical-mathematical operators in the form of (1)-(3):

$$\exists (f_1. f_2 \dots f_n) \in \mathrm{F}, f_1, f_2 \dots f_n) \in \mathrm{F} \quad (1)$$

$$\left[s \in S_f, s_0 \in S_0\right] f_1, f_2 \dots f_n(S_0) \in \mathrm{T} \quad (2)$$

for which is true

$$f_n\left(\dots\left(f_2\left(f_1(s_0)\right)\right)\dots\right) \in \mathrm{T} \equiv s \in Sf_1, \dots, f_2(s_0) \in Sf_2, (\dots, (f_n) \dots (f_2) f_1(s_0) \dots) \in S_{f_{n-1}} \quad (3)$$

Based on this provision, we can formulate two basic approaches to solving the problems of heuristic search for action scheme (plan):

- productive systems that use state-space representation of situations;
- reduction systems that reduce the problem-solving process to procedures for solving systems of subtasks based on their structural decomposition.

Resource balance. The overall balance of material resources in a terminal management decision-making strategy is described by a trajectory of a random process. This trajectory is formed on the basis of local components of incoming flows and used resources. It reflects the dynamic state of the system through the image of the situation in the target space of the system. The structure of the target space is determined by the models of the state space and phase space of the control object and their energy characteristics (based on the trajectory level when the resource balance conditions are met).

$$Z(t) \,/\, T_n = Z_0 + \int_t^{t+T_n} A_{ZF}(t,\theta)\left[\sum_{i-1}^{m} \Phi_{in}(t,U_i) - \sum_{j=1}^{k} \Phi_{out}(t,\xi_i)\right] dt \quad (4)$$

where $\mathrm{Z(t)} \in \mathrm{I_Z} \subset R$ – implementation of the state trajectory during the management process, $\mathrm{dimI_Z} = [maxZ - minZ]$ – permissible limits for the interval of variation of the state parameter, $\mathrm{GRAF}\big(\mathrm{Z(t)}\big) = \underset{Z,t}{E}\big\{\big(Z(t)\big), t \in I_Z \times T_n\big\}$ – graph of the spatial structure of the trajectory, U_i – management, $AS(S_i)$ – method of attack, $\Phi(\,)$ – state, $[I_z \times T_n]$ – state space, Z_0 – the initial state of the system, $\left[I_z \times I_{\frac{d}{dt}Z}\right]$ – phase space.

4. Experiment, Results and Discussion

4.1. Conflict Game in Infrastructure

For each participant of the game, as an intelligent system that makes decisions on the direction to achieve the goal, the method of forming management strategies taking into account the possible behavior of the competitor is characteristic. Based on the dynamics equations that describe the behavior of the players in the $G(IS \otimes AS)$ target space, we will obtain the balance of the game (5)-(6):

$$\exists\left(R_m^S, R_E^S\right): \frac{dZ_1(t)}{dt} = F_1(x_1, U_1) + F_{12}(U_2, \xi_2) \tag{5}$$

where $U_1 \in Strat(U|C_1)$ – system.

$$\exists\left(R_E^{\wedge}\right): \frac{dZ_2(t)}{dt} = F_2(x_2, U_2) + F_{21}(U_1, \xi_1) \tag{6}$$

where $U_2 \in Strat(U|C_2)$ – player.

Management strategies are based on the classification of situations. That is, it is based on the assessment of the tractor state belonging to the class of the target space and the choice of the control team (which translates the system and the target class). We have the following structure of the division of classes as n-dimensional sets:

- $\{K_i\}_{i=1}^m: K_i \cap K_{i+1} = \emptyset, m \dim K_i = I_Z$, with $\left(R_F^S > R_E^A\right), \alpha_i$ – goals;
- $\left\{K_j\right\}_{j=1}^n: K_j \cap K_{j+1} min\Delta_K, m \dim K_j \leq I_Z$ with $\left(R_F^S < R_E^A\right)$.

Taking into account the terminal time and the division into classes and state spaces, we will have an invariant or locally invariant structure of the game interaction space:

- $\{K_i\}_{i=1}^m \times T_n = KL_I$ – invariant system classification of the partitioning of the goal space
- $\left\{K_j\right\}_{j=1}^n \times \{T_K\}_{K=1}^m = KL_{II}$ – locally invariant classification of the situation in the space of loading states into the goal space (which is invariantly projected into the game space).

Local situations on the time interval partitioning of attack countermeasures are included in the game scenario.

The introduction of this class partitioning allows the principles of synthesis of dynamic behavioural strategies based on dynamic programming methods [16] and situational control to be formed.

The developed methodology and taxonomy of resource balance trajectory analysis during the game is based on methods of parametric and nonparametric statistics, decision-making theory under uncertainty, and statistical hypothesis testing theory. (To test statistical hypotheses that images of dynamic situations currently belong to alternative classes of reference models to which local strategies for making target decisions correspond and which are elements of global policy).

4.2. Infrastructure cyber security

The adaptation of goal achievement strategies under perturbations and disturbances is based on:

- on the problem and target situation models in a technological structure;

- on the synthesis of goal achievement strategies in a feedback control system;
- on the synthesis of the behavior of the system under a given structure under perturbations and disturbances;
- on the assessment of threshold disturbances that lead to a technological failure due to the distortion of information about the state of the system in the mode of assessing the situation and making decisions;
- on the synthesis of modes and parameters correction (during the evolution of the control object) and the system of observation, control and management within the framework of the target task;
- on the assessment of strong disturbances and correction of optimal signal processing algorithms and ensuring their robustness, effective filtering of the signal from disturbances (from the point of view of obtaining correct information as a basis for decision-making in conditions of uncertainty);
- on the correction of data processing algorithms for the formation of a dynamic situation images;
- on the correction of management object models and goal achievement strategies;
- on the verification of goal achievement conditions and evaluation of means and volumes of resources;
- on the assessment of the degree of availability and mobility of resources for the realization of goals in critical conditions;
- on the correction of the strategy of entering the target area and the degree of available resources at the time of the conflict (based on the cognitive resource of the ACS personnel).

4.3. Cognitive Characteristics of Risk

On the basis of the analysis, considered methods of solving problem-oriented tasks and taking into account the developed scheme of game model of conflict situation, the resulting table of cognitive characteristics of risk was built Table 1. The table presents the influence of various factors on the emergence of risks.

Table 1

Cognitive assessments of game risks $< \boldsymbol{System} \ldots \boldsymbol{ACS} \rightarrow \boldsymbol{ASatack} >$ on $\boldsymbol{\alpha_r(A)}$, $\boldsymbol{\alpha_r d}$, $(\boldsymbol{\alpha_r d} - \boldsymbol{\alpha_r(A)} = \pm\boldsymbol{\Delta\alpha_r})$

№	F_{ij}	ACS	AS(I,E)	$\alpha_r d$	$\alpha_r(A)$	$\Delta\alpha_r$
1	F_S	0.95	$0.8 \div 1.0$	< 0.15	≥ 0.2	$Prob \pm 0.5$
2	F_K	0.9	$0.2 \div 0.5$	< 0.1	≥ 0.15	$Prob \pm 0.85$
3	F_E	0.98	$0.1 \div 0.9$	< 0.2	≥ 0.3	$Prob \pm 0.15$
4	F_I	0.95	$0.1 \div 0.5$	< 0.1	≥ 0.5	$Prob \pm 0.04$
5	$F_{(C_i)}$	1.0	$0.1 \div 0.3$	0.05	≤ 1.0	$Prob \pm 0.5$
6	$F(U_2)$	0.95	$0.1 \div 0.6$	0.15	> 0.75	$Prob \pm 0.6$
7	$F(Rob)$	0.98	> 0.75	0.05	± 0.5	$Prob \pm 0.05$
8	$F(Cog)$	0.9	> 0.5	0.5	> 0.5	$Prob \pm 0.95$
9	$F(\mu d)$	0.1	> 0.2	0.15	< 0.5	$Prob \pm 0.2$
10	F_R	0.95	≥ 0.5	0.15	≥ 0.5	$Prob \pm 0.35$

Table 1 uses the following designations: $F_{(C_i)}$ – target factor of possible influence; $F(U_2)$ – factor of management actions; $F(Rob)$ – factor of possible management stability; $F(Cog)$ – agent's cognitive factor; $F(\mu d)$ – data blurring factor at the attack interval; F_R – a complex factor of the probable attack on the system.

5. Conclusions

An analysis of current events (with active infrastructure disruption factors) has shown that, despite existing indicators of possible threats (both low and high), projects of production structures have been targeted at minimum costs with maximum profits.

This concept has led to the instability of production systems in various industries. First of all, this is related to the energy sector, since it requires large material resources and high intellectual potential (which are necessary to ensure effective management and sustainable functioning). The projects completed in the past did not provide anti-crisis stability because the management systems were not modernized to eliminate the consequences of the possible occurrence of such threats.

Optimization of the system mode is based on the formation of the quality function. The components of this will be the indicator functions of saving resources, the terminal time of achieving the goal, the accuracy of maintaining the functional state. Optimization of signal processing algorithms and control strategies is based on the study of statistical characteristics of signal trajectories and interference, ensuring their robustness and information adequacy. To solve the problem of conflict situations in technological structures, it is necessary to create a complex of conceptual models of systems. Management and optimization strategies are also necessary. And on their basis - the synthesis of software and computer support, the selection of methods of countering attacks (at the resource level, the structural level, and the cognitive-intellectual level of personnel training).

This paper analyses the contemporary causes and factors of conflict and crisis exit strategies.

On the basis of the analysis, a game model of a conflict situation was constructed and methods of solving the problem were proposed. The presented table shows the resulting indicators of cognitive assessment of game risks.

The results (shown in the table) allow us to better account for the potential for risks in complex systems and to build methods for dealing with them.

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