Stochastic Modeling of the Spiral Dynamics of Social Conflicts in Public Governance

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***Abstract* – The article proposes a methodological approach to modeling the dynamics of social conflicts in public governance based on the combination of spiral dynamics and stochastic modeling methods. The developed conceptual model integrates the parameters of social distance, informational influence, and social tension, which jointly determine the trajectory of conflict development. A key feature of the proposed approach is the consideration of stochastic disturbances — random external and internal factors — that significantly affect the evolution of conflict processes and the transition from latent to open confrontation.**

The application of stochastic modeling allows not only to describe the non-linear dynamics of conflict escalation but also to identify critical bifurcation points, where the public governance system loses the ability to maintain control over the situation. The mathematical formalization of the model combines deterministic differential equations with stochastic perturbation components, which allows for simulating the influence of unpredictable information flows, spontaneous protest actions, and crisis situations.

The results of numerical experiments demonstrate that social conflicts develop as a sequence of spiral transitions, where each turn reflects the interaction between growing social distance, the intensity of information pressure, and the accumulation of social tension. The practical value of the proposed approach lies in its application for creating a system of early warning and prevention of social conflicts in public governance.

The developed model can serve as a scientific basis for the formation of analytical tools for monitoring conflict situations, identifying risk zones, and developing adaptive management decisions aimed at ensuring social stability in conditions of increased uncertainty and hybrid threats. The research results contribute to the development of modern scientific approaches to conflict management, the introduction of stochastic modeling tools into the practice of public administration, and the improvement of state policy in the field of social stability and security.

***Keywords* – Social conflicts, public governance, social distance, information flows, social tension.**

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1. Introduction

Social conflicts are an integral component of the functioning of social systems, especially under the conditions of growing social, economic, and political challenges. For the public governance system, the timely identification and modeling of conflict development are of particular importance, as they allow for the prediction of potential threats to social stability, the formation of adaptive management decisions, and the minimization of escalation risks. Modern social systems operate in an environment where information flows play a decisive role, triggering both consolidation and destabilization processes. Information wars, manipulative campaigns, fake news, and the distortion of public opinion create new challenges for public governance, intensifying social tensions and accelerating the transition of conflicts into an open phase.

Traditional approaches to the analysis of social conflicts are mostly based on static or linear models, which do not take into account the nonlinear nature of conflict development, their dependence on dynamic informational influences, and random external disturbances. Such an approach limits the ability to predict and respond in a timely manner on the part of public governance, especially under conditions of uncertainty and multifactorial influence. This creates the need to develop new methodological approaches to modeling social conflicts that would combine the spatio-temporal patterns of social system development, network interactions between actors, and stochastic fluctuations reflecting the impact of external factors.

The study of the dynamics of social conflicts at the intersection of sociology, political science, and mathematical modeling has attracted significant attention from scholars over the past decades. In particular, [1], [2] and [3] the fundamental principles of the statistical physics of social systems, examining collective behavior through interactions between individuals, which shape social norms and influence the evolution of social structures. A similar approach was applied in the works of [4], where mathematical models of sociodynamics were developed, taking into account stochastic fluctuations in the process of social self-organization.

Special attention in contemporary research is paid to the role of informational influence in the escalation of social conflicts. Researchers [5] emphasize that the spread of fake news and manipulative informational flows significantly distorts public perception of reality and contributes to growing social tension. In turn, [6] and [7] substantiate the concept of "connective action," highlighting that digital platforms create new opportunities for horizontal mobilization, which often leads to the spontaneous emergence of conflict situations without clear centralized control.

Among the studies focusing on the network nature of social interactions, the works of [8], as well as [9] and [10], hold particular significance, demonstrating that the structures of social networks have a critical impact on the speed of information dissemination and the formation of zones of social tension. The diffusion model in networks developed by [11] and [12] showed that collective behavior depends not only on individual attitudes but also on threshold values of neighbors' involvement in the social network, creating preconditions for sudden phase transitions from stability to conflict escalation.

The conflictogenic potential of social systems is also closely linked to cognitive limitations in information perception, as evidenced by the study of [13]. Their analysis indicates that the information overload inherent in modern societies increases the level of social polarization and creates conditions for manipulative influence.

Similar processes were explored by [14], who demonstrated that social media not only reflect public sentiments but also generate additional impulses for the self-reinforcement of conflicts through the "echo chamber" effect and algorithmic amplification of polarized content.

Of particular importance for public governance is the research of [15], who emphasize the need to implement adaptive approaches to managing social crises, taking into account the high uncertainty and rapid development of modern conflicts. Similar ideas are advanced by [16], who stress the importance of developing scenario-based models for forecasting crisis development and adapting management strategies in line with changing environments.

In the context of mathematical modeling, special attention is drawn to the works of [17] and [18], which demonstrate that even minor random disturbances can provoke radical changes in the state of a social system, especially in phases close to critical bifurcation points. These approaches form the methodological foundation for constructing spiral models of social conflicts that account for stochastic fluctuations and nonlinear development trajectories.

The formation of a comprehensive understanding of social conflicts also requires consideration of the dynamic characteristics of network structures. In this context, the works of [19] propose the concept of temporal networks, which allows for tracking how interaction structures change over time and how this influences the formation of conflict clusters. Notably, the research by [20] proposed algorithmic approaches for identifying communities within large social networks, which provides additional opportunities for detecting local tension zones and predicting the spread of conflict processes.

Thus, the modern scientific discourse on modeling social conflicts demonstrates a gradual shift from static models to dynamic stochastic approaches that take into account the network structure of society, information flows, and cognitive limitations of perception. The comprehensive combination of mathematical methods, network analysis, and social theories forms the foundation for the development of innovative tools for monitoring and forecasting social conflicts in public governance.

Aims: The aim of the study is to develop a conceptual and methodological framework for stochastic modeling of the spiral dynamics of social conflicts in the public governance system to identify patterns of their development, forecast critical escalation points, and create tools for early response by public authorities.

Objectives: Justify the theoretical approaches to the analysis of social conflicts in the public governance system, taking into account the impact of the information environment and social tension.

Develop a conceptual model of the spiral dynamics of social conflicts, which considers social distance, the level of informational influence, and social tension. Formalize a system of differential equations describing the dynamics of social conflicts, *incorporating stochastic components to account for* random external and internal disturbances. Perform a numerical implementation of the model and visualize the modeling results in the form of a spatio-temporal spiral trajectory of the conflict process. Identify the critical points of phase transitions, which indicate increasing risks of losing control over the social system by public authorities. Develop practical recommendations for using the results of stochastic modeling for the system of monitoring, prevention, and resolution of social conflicts in public governance.

2. Methodology

The methodological foundation of the study is based on the application of a comprehensive approach that combines stochastic modeling, network analysis, and the concept of spiral dynamics to represent the development of social conflicts within the public governance system. The formation and escalation of social conflicts are considered as the result of the interaction between the information environment, social distance, and social tension, unfolding in the form of a multidimensional spiral structure.

Social distance in the model varies depending on the level of informational influence and the nature of communication between social agents. The interaction between agents is represented as a weighted graph, where each node corresponds to an individual social subject, and the weight of the connections dynamically changes in response to information flows and feedback reactions within society.

To account for random factors, such as unexpected crises, informational manipulations, or spontaneous social disturbances, stochastic components are integrated into the model, simulating random fluctuations in social distance, informational influence, and social tension levels. This combination allows for the representation of both the deterministic escalation of conflict and its nonlinearity under the influence of external and internal random factors.

The visualization of the conceptual model is presented as a three-dimensional spiral, where the X-axis corresponds to social distance, the Y-axis — to the level of informational influence, and the Z-axis — to the level of social tension.

The spiral trajectory demonstrates how social conflicts unfold over time, gradually passing through phases of relative stability, increasing tension, and critical points beyond which the public governance system may lose control over the development of the situation.

Stochastic deviations are represented by individual points symbolizing random external disturbances that shift the trajectory of conflict development.

The modeling results were obtained through the numerical implementation of a system of differential equations in the Python environment, which made it possible to combine deterministic spiral dynamics with random fluctuations, simulate the evolution of the conflict situation in public governance, and assess the probability of phase transitions into open social conflicts.

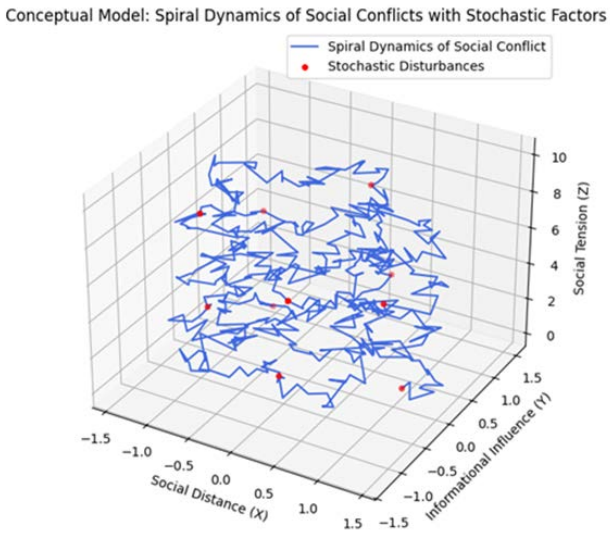

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*Figure 1. Spiral dynamics of social conflict with stochastic disturbances**

Figure 1 presents a conceptual model of social conflict development in the form of a three-dimensional spiral, where each coordinate reflects the key parameters of the system: social distance, informational influence, and social tension. The spiral structure accounts for both deterministic processes and stochastic fluctuations, which simulate random social shocks and informational provocations. This model not only describes the current state of the social system but also allows for forecasting the emergence of critical points at which the system may transition into the phase of open conflict.

3. Results

A social conflict is formed as a result of increasing social distance and changes in the informational space. The traditional diffusion model describes the movement of individuals in the social space but does not account for the dynamic state of the system under the influence of external factors.

3.1. Updated Model Structure

Description of social distance (δx) as an adaptive function:

$$\frac{d\delta x}{dt} = -y\delta x + F\left(h_i h_j\right) + \sqrt{2D\xi(t)} \qquad (1)$$

Where:

y – the convergence coefficient,

$F\left(h_i h_j\right)$– nonlinear influence through the communication field,

D – the coefficient of social mobility,

3.2. Implementation of Network Paradigmatic Analysis

The model goes beyond the spatial structure — a graph-based model is proposed, where individuals are represented as nodes, and interactions are determined through the calculation of the connection matrix.

$$\frac{\delta h_i}{\delta t} = D\sum_{j\in V} w_{ij}(h_i - h_j) - \alpha h_i + \eta_i(t) \qquad (2)$$

Where:

hi – the level of informational influence on the individual,

D – the coefficient of information diffusion,

wij – the weight of the connection between individuals i and j, which defines the intensity of their interaction,

α – the coefficient of informational influence loss.

$\eta_i(t)$– random noise reflecting external factors.

This allows for the calculation of both static and dynamic processes, addressing the shortcomings of earlier models.

3.3. Phase Transitions and Conflict Dynamics

One of the key aspects of the improved model is the identification of phase transitions between stable and unstable states of the social system. To achieve this, the concept of the potential energy of social interaction is applied:

$$V(y) = -Ay + Be^{-Cy^2} \qquad (3)$$

Where:

A – external influence (economic situation, political pressure),

B – social tension,

C – societal adaptability to changes.

The critical conflict point is determined by the equation:

$$\frac{dV}{dy} = 0 \Longrightarrow A - 2BCye^{-Cy^2} \qquad (4)$$

If there exists a y_c, at which d^2V/dy^2 changes sign, the system enters a phase of instability, which may lead to a social explosion.

Figure 2 presents a characteristic curve that illustrates the presence of zones of potential stability and critical points where the system may transition into an unstable state.

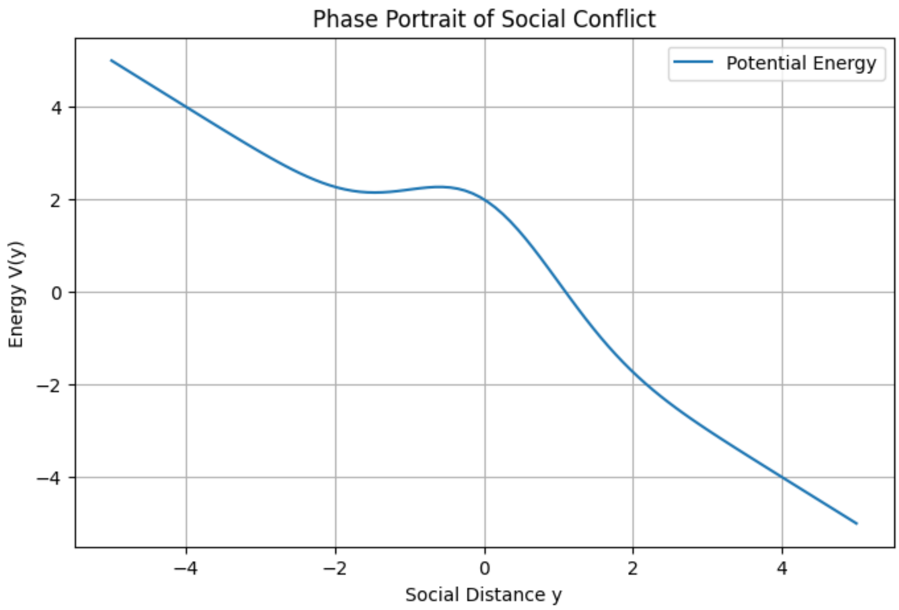

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Figure 2. Potential energy of social conflict as a function of social distance

This graph (Figure 2) demonstrates that at certain values of social distance, the system's energy reaches local minima, which correspond to points of relative stability. When exceeding these boundaries, the system enters a zone of increasing instability, which could potentially trigger conflict escalation.

3.4. Stochastic Conflict Modeling

A stochastic approach, particularly the Monte Carlo method, is used to test the model. Discretization of the equations allows for estimating the probability of social instability. The main algorithm:

1. Initialization of Initial Values $x_i, h_i, D(x,t)$.

2. Solving the Equations:

$$h_i^{t+1} = h_i^t + \Delta t[\sum_j w_{ij}\left(h_j^t - h_i^t\right) - \alpha h_i^t + \eta_i^t] \quad (5)$$

Where

h_i^{t+1}— the level of informational influence (informational field) on individual i at the next time step.

h_i^t — the level of informational influence on individual i at the current time step.

Δt — time step (discretization interval).

∑j — the sum of influences from all neighboring individuals j with whom individual i has a connection.

w_{ij}— the weight of the connection between individuals i and j, characterizing the intensity of their informational interaction (the greater the weight, the stronger the influence).

h_j^t— the level of informational influence of neighbor j at the current time step.

α — the coefficient of information decay (the loss of information relevance over time).

η_i^t— random fluctuation (noise) modeling unpredictable events, informational provocations, or other stochastic processes affecting individual i.

This formula describes how the informational influence on each individual in the network changes under the influence of information from neighbors, natural information decay, and external random impacts. It serves as a central component for modeling the informational environment in a social conflict.

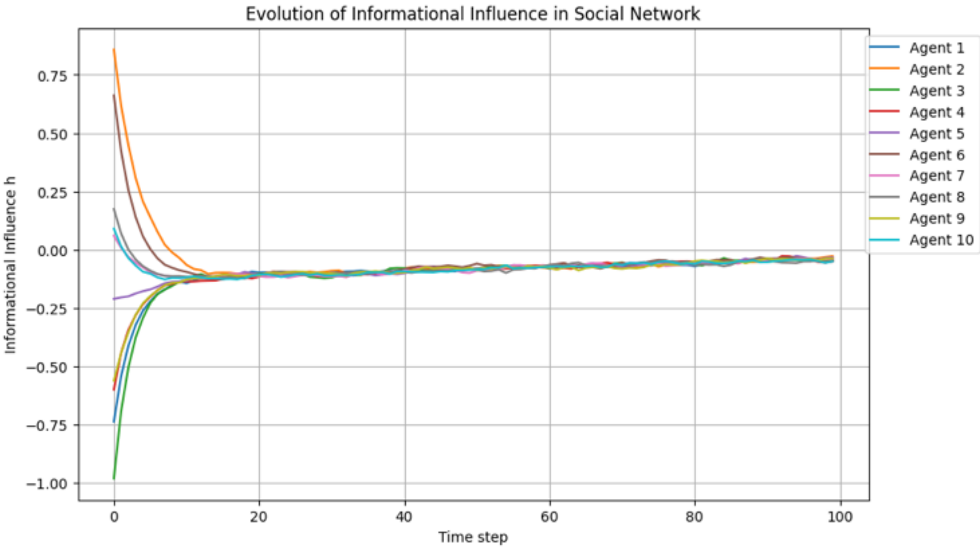

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*Figure 3. Evolution of informational influence of agents in the social network**

The graph in Figure 3 presents the dynamics of changes in the level of informational influence for each agent in the social system over time. Each curve corresponds to an individual agent interacting with others through the informational field, according to the equation.

The graph demonstrates how the harmonization of informational levels within the network gradually occurs. Initial fluctuations (influenced by individual starting conditions) are smoothed out under the influence of inter-agent connections and adaptation, and the system reaches a state of relative equilibrium with minor stochastic fluctuations.

$$x_i^{t+1} = x_i^t + \Delta t[k_i^s k_i^c \sum_j \frac{\partial h_j^t}{\partial x_j} + \sqrt{2D\left(x_i^t, t\right)\xi_i^t}\,] \quad (6)$$

Where:

x_i^{t+1}— the position of individual i in the social space at the next time step.

x_i^t — the position of individual i in the social space at the current time step.

Δt — the time discretization step (the time interval between calculations).

k_i^s – the coefficient of social activity of individual i, which reflects how actively the individual responds to the informational environment.

k_i^c— the coefficient of sensitivity to informational influence for individual i (informational susceptibility.

$\frac{\partial h_j^t}{\partial x_j}$— the gradient (spatial derivative) of the informational field formed by other individuals j.

$D(x_i^t, t)$ — the coefficient of social mobility, which can vary depending on the spatial position of the individual and time.

ξ_i^t — a random function (white noise) modeling stochastic (random) influences, including unpredictable external events or internal fluctuations.

The formula describes how the position of an individual changes under the influence of: Informational signals from other participants in the system (the gradient of the informational field), their own social activity and sensitivity, and stochastic random factors.

This is an extended version of the stochastic Langevin equation for social systems, which accounts not only for random influences but also for structured informational interactions between individuals in the social space.

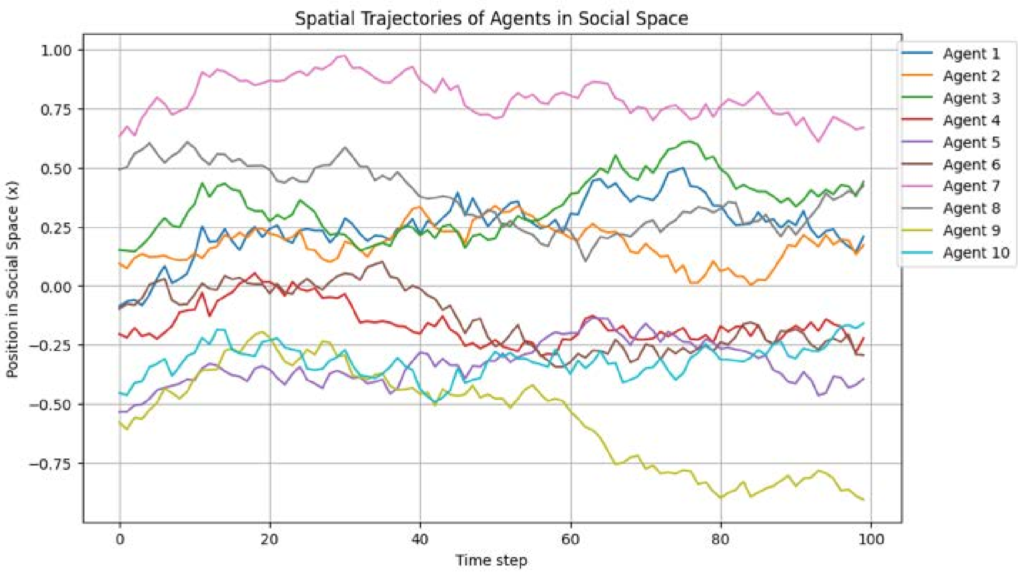

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*Figure 4. Spatial trajectories of agents in the social space **

The graph in Figure 4 illustrates the changes in the positions of agents in the social space over time. It is constructed based on a modified Langevin equation. Each line represents an individual agent's trajectory, which responds to informational influences from other network participants and to random disturbances. This combination of structured interaction and chaotic factors shapes the complex dynamics of movement within the social space. Different agents demonstrate varying sensitivity and adaptability to environmental changes, which is reflected in the differences in their trajectories.

3. Evaluation of Critical Parameter Values to Determine the Instability Threshold.4. Visualization of Phase Trajectories and Identification of Stability Zones.

The proposed mathematical model allows for the description of the dynamics of social conflicts, taking into account stochastic factors and the network structure of interactions.

Key features:

Introduction of adaptive social distance and a phase transition mechanism;

Use of network models to describe informational influence;

Stochastic nature of changes within social systems.

To dynamically represent the evolution of conflict in a three-dimensional space, a spiral model was developed, which captures changes in social distance, informational influence, and social tension over time.

This dependency was formalized through parametric equations:

$$x=r(t)\cos(t) \quad y=r(t)\sin(t) \quad z=f(t) \tag{7}$$

where r(t) is the radius, which depends on the level of tension, and f(t) is a function reflecting social instability over time.

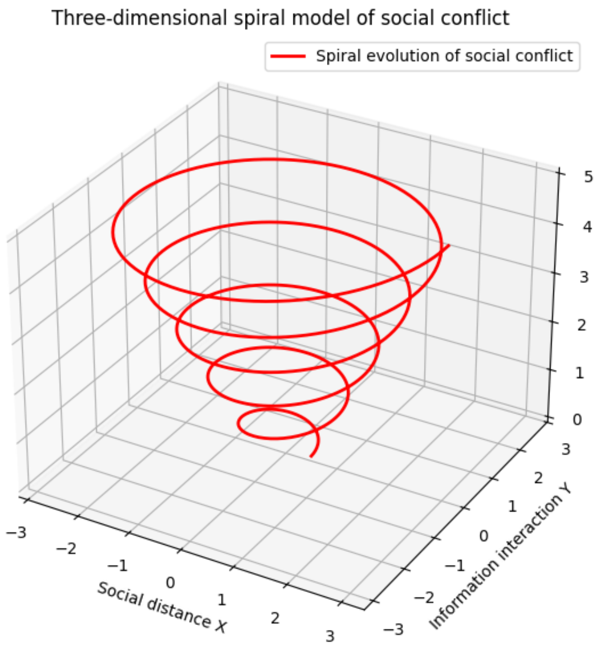

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*Figure 5. – Three-dimensional spiral model of social conflict **

The graph in Figure 5 shows that as the conflict process develops, social distance increases, informational interaction becomes uneven, and the level of social tension gradually rises, forming a spiral trajectory that characterizes the escalation of the conflict.

The use of stochastic modeling results to build an effective system for monitoring, preventing, and resolving social conflicts in public governance is based on the comprehensive combination of mathematical forecasting methods, indicative analysis of social tension, and adaptive mechanisms of managerial response. The application of stochastic models within the analytical monitoring system allows not only for tracking the current state of social tension but also for forecasting conflict development, taking into account random external disturbances and informational influences, which significantly expands the toolkit for strategic planning in public governance.

The data obtained through numerical modeling makes it possible to form a risk-oriented system for managing social processes, in which potential conflict escalation scenarios are forecasted based on the analysis of interactions between social distance, the level of informational influence, and social tension. Such scenarios incorporate both the deterministic trends of social system development and stochastic fluctuations caused by unpredictable informational attacks, crisis events, or shifts in the external political context. As a result, public governance gains the ability to adaptively respond to new challenges, adjusting management strategies based on changes in conflict potential.

A particularly important role in this process is played by the identification of critical phase transition points, at which the system of social relations loses stability and shifts into a stage of open confrontation. Identifying such points based on stochastic analysis of spiral dynamics makes it possible to ensure the timely implementation of a set of preventive measures aimed at reducing social tension and preventing conflict escalation. Special attention is given to the analysis of the informational field, as it is the unevenness of informational influence and the growth of informational manipulations that create additional risks for public governance.

The results of stochastic modeling should be integrated into the operational practice of the social process monitoring system through the creation of a unified information-analytical platform, which combines data from sociological research, media monitoring, and social network analysis with mathematical modeling of conflict dynamics. This approach provides a comprehensive assessment of the current state of social tension and allows for the forecasting of likely scenarios of its development, including the prediction of bifurcation points that are critically important for managerial decision-making.

In addition, the results of stochastic modeling should be used to develop targeted informational strategies aimed at reducing social tension and neutralizing destructive informational influences. Identifying high-risk groups that demonstrate maximum sensitivity to manipulative informational signals creates the foundation for developing targeted informational campaigns aimed at adjusting public sentiment and strengthening social cohesion.

The results of stochastic modeling of the spiral dynamics of social conflicts in public governance form the methodological basis for creating an effective early warning and conflict management system, ensuring systematic monitoring of social tension dynamics, forecasting escalation risks, and developing adaptive managerial decisions aimed at maintaining social stability under conditions of growing uncertainty.

4. Discussion

The development of modern approaches to the analysis and forecasting of social conflicts demonstrates a gradual complication of the methodological toolkit used to describe the evolution of social systems. In particular, the classical concepts of collective behavior proposed by [12], based on threshold models of participation in collective actions, form the foundation for understanding phase transitions in social systems. However, they do not account for the dynamic nature of information flows and the influence of stochastic factors.

At the same time, the works of [1], as well as [4], laid the groundwork for applying statistical physics and sociodynamics, which enable the study of collective behavior through the modeling of interactions between agents in a spatio-temporal continuum.

A significant step toward integrating the network approach into the analysis of social conflicts was made by [8] and [9], who revealed the mechanisms of information dissemination in complex networks and the influence of network topology on the formation of tension clusters. Meanwhile, [19] and [21] highlighted the importance of the temporal component in the development of social networks, which is particularly relevant for analyzing conflict escalation, when temporary coalitions and situational alliances form new centers of social tension.

Particular attention in contemporary research has been paid to the role of informational flows and their influence on social dynamics. Specifically, [5] demonstrated that the spread of fake news and manipulative information campaigns creates a distorted perception of reality, exacerbating social polarization and contributing to the radicalization of public sentiment. These conclusions align with the concept of "connective action" proposed by [6], [22], which emphasizes that digital platforms create a new architecture of social mobilization, capable of self-reinforcement through horizontal communication links, which are difficult to control using traditional public governance tools.

Studies of social conflict dynamics in the context of crisis management are presented in the works of [15], who emphasize the need to develop adaptive response systems capable of considering both deterministic trends and stochastic disturbances. In this context, the approach proposed by [16] is particularly relevant, as it involves the use of scenario modeling to assess variable trajectories of conflict situations, taking into account factors of uncertainty.

The models proposed by [17] and [18] are the closest to the objectives of the research, as they describe nonlinear scenarios of conflict escalation in social systems, taking into account noise effects. Specifically, [17] work demonstrates that even small random disturbances can serve as triggers for large-scale social shifts in systems approaching critical points. These results resonate with the concept of stochastic phase transitions, which forms the methodological basis of the study.

Thus, the conducted research demonstrates the relevance of further integrating stochastic approaches into the modeling of social conflicts in public governance. Unlike existing models, which mostly describe either static network structures or deterministic development trajectories, the spiral model with stochastic disturbances proposed in this article takes into account the complex influence of social distance, informational pressure, and random external factors.

This allows not only for tracking the current state of social tension but also for determining the probable scenarios of its development and identifying the critical phase transition points, which creates a scientific foundation for developing adaptive tools for managing social conflicts in the public governance system.

5. Conclusion

In the course of the study, a methodology for stochastic modeling of the spiral dynamics of social conflicts in the public governance system was proposed and substantiated. A conceptual model was developed, reflecting the interconnection between social distance, the level of informational influence, and social tension, while also accounting for stochastic disturbances arising from external and internal random factors. For the first time, it was substantiated that the stochastic approach to analyzing spiral dynamics not only allows for describing the patterns of conflict development but also identifies critical phase transition points at which the system shifts from a latent phase to open confrontation.

A mathematical model was developed, combining the deterministic components of social processes with random fluctuations that significantly influence the trajectory of the conflict process. Numerical modeling confirmed that social conflicts have a nonlinear development nature, and their dynamics are largely determined by interactions between social groups, the intensity of informational flows, and random external influences. The proposed model allows for tracking the dynamics of social conflicts over time and space, forecasting critical moments of rising social tension, and assessing the probability of transitioning to the stage of open confrontation.

The author developed an algorithm for identifying zones of heightened social tension, based on analyzing the conflict development trajectory in the three-dimensional space of "social distance – informational influence – social tension." This makes it possible to identify the most conflict-prone areas of the social system and determine the priorities for managerial response. Particular attention was given to the importance of monitoring the informational environment as one of the key factors in the formation and escalation of social conflicts in modern conditions. A mechanism for assessing informational risks was proposed, based on analyzing the intensity and direction of informational flows, as well as their impact on the dynamics of social tension.

The practical significance of the study lies in the development of scientifically grounded recommendations for building an early warning system for social conflicts in public governance.

A structure for an information-analytical platform for monitoring social processes was proposed, combining mathematical modeling, big data analysis, and expert assessments, ensuring comprehensive tracking of current threats and forecasting future risks to social stability.

The obtained results form a methodological basis for further improvement of the social conflict management system at the level of public authorities. The proposed model can be adapted to the specifics of different regions and types of social systems, ensuring its practical versatility. The prospects for further research lie in expanding the model by incorporating economic, cultural, and political factors, which will enable the creation of a comprehensive toolkit for forecasting and managing social conflicts under conditions of increasing societal instability.

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