

MODELING THE SPREAD OF DISINFORMATION IN HYBRID WARFARE: APPLICATION OF COMPLEX NETWORK THEORY TO CAMPAIGNS IN THE BALTIC REGION

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Abstract: Hybrid warfare represents a contemporary form of conflict that integrates conventional military operations with unconventional means, including disinformation campaigns as a key component of information warfare. In this paper, we present an original mathematical model SIR-HW (Susceptible-Infected-Recovered for Hybrid Warfare) for simulating the spread of disinformation in social networks, adapted to the specificities of hybrid warfare in the Baltic region. The model is based on complex network theory and epidemiological models of information spreading, with the introduction of new parameters that reflect the characteristics of the target population: the degree of media literacy, linguistic segmentation of the network, and the effectiveness of institutional countermeasures. Simulations were conducted on synthetic networks that reflect the demographic structure of Baltic societies, with a special focus on the role of nodes with high betweenness centrality in the amplification of disinformation narratives. Results show that network segregation along linguistic lines significantly increases the penetration of disinformation in vulnerable segments of the population, while timely interventions at nodes with high centrality can reduce overall infection by 34–47%. The original contribution of this research lies in the identification of a critical media literacy threshold value ($\lambda_c \approx 0.38$) below which disinformation campaigns achieve epidemic spreading characteristics, which provides operational implications for formulating policies of resilience to hybrid threats.

Keywords: *hybrid warfare, disinformation, complex network theory, SIR model, Baltic region, media literacy, network centrality.*

INTRODUCTION

The contemporary security environment is characterized by the emergence of hybrid warfare as the dominant form of interstate conflict that operates below the threshold of conventional armed conflict. This concept,

annexation of Crimea in 2014, encompasses the coordinated application of military, diplomatic, economic, and informational instruments to achieve strategic objectives without provoking direct military confrontation (Fridman, 2018). Information warfare, as an integral component of the hybrid approach, includes the systematic dissemina-

tion of disinformation aimed at polarizing target societies, undermining trust in democratic institutions, and creating a favorable narrative environment for the aggressor's agenda (Wardle & Derakhshan, 2017).

The Baltic states — Estonia, Latvia, and Lithuania — represent a paradigmatic case for studying disinformation operations in the context of hybrid warfare. Their geographical position on the eastern periphery of NATO and the European Union, combined with the presence of significant Russian-speaking minorities, makes them priority targets for Russian information operations (Bankauskaitė & Keršanskas, 2020). The NATO Strategic Communications Centre of Excellence in Riga has documented systematic disinformation campaigns directed at these states, identifying them as a space where a toxic mixture of disinformation and propaganda converges (NATO StratCom COE, 2018; Bērziņa, 2018).

Understanding the mechanisms of disinformation spreading requires an interdisciplinary approach that combines insights from complex network theory, information epidemiology, and security studies. Complex network theory provides a mathematical framework for analyzing the structure and dynamics of social networks through which disinformation propagates. These networks are typically characterized by a degree distribution that follows a power law, which implies the existence of a small number of highly connected nodes (so-called hubs) that have a disproportionate influence on the dynamics of information spreading (Stein, Keuschnigg, & van de Rijt, 2023). Empirical studies of online platforms confirm this scale-free character and demonstrate its operational significance for misinformation diffusion (Vosoughi, Roy, & Aral, 2018).

Epidemiological models, originally developed for studying the spread of infectious diseases, have been adapted for analyzing

the propagation of information and disinformation on social networks. The classical SIR (Susceptible-Infected-Recovered) framework, which divides the population into susceptible, infected, and recovered individuals, has proven applicable for modeling the dynamics of rumours and disinformation. Subsequent research introduced modifications such as the SEIR rumour-propagation model with a latent phase on heterogeneous networks (Liu, Li, & Sun, 2017), models with hesitating mechanisms in complex social networks (Xia, Jiang, Song, & Song, 2018), and contemporary models that integrate sentiment and human-judgment characteristics into the diffusion process.

Despite significant progress in modeling information spreading on networks, the existing literature shows certain gaps in the context of application to hybrid warfare. First, most models treat disinformation as a homogeneous phenomenon, neglecting the specificities of state-sponsored campaigns characterized by strategic coordination, adaptability, and resources unavailable to organic actors (Fridman, 2018; Bachmann, Putter, & Duczynski, 2023). Second, models rarely incorporate the demographic and linguistic characteristics of the target population that are critical for audience segmentation in disinformation operations (Bankauskaitė & Keršanskas, 2020; Stewart, Jackson, Ishiyama, & Marshall, 2024). Third, there is a lack of quantitative analyses of the effectiveness of various countermeasures, from institutional interventions to civic initiatives such as the Baltic Elves — volunteer groups that monitor and debunk disinformation (Hybrid CoE, 2024; Ali & Qazi, 2023).

This article seeks to fill the identified gaps through the development of an original SIR-HW (SIR for Hybrid Warfare) model that integrates parameters specific to disinformation campaigns in the context of hybrid warfare. The model includes: (1) a

network structure that reflects the linguistic segmentation of Baltic societies, (2) a heterogeneous distribution of media literacy as a resilience factor, (3) mechanisms of institutional counter-propaganda with time delay, and (4) the role of automated accounts (bots) as amplifiers of disinformation (Stella, Ferrara, & De Domenico, 2018). The central research question is: which structural and parametric characteristics determine the transition of a disinformation campaign from a local incident to an epidemic phenomenon, and which interventions can most effectively interrupt this transition?

The theoretical framework of the paper relies on contemporary network-based models of misinformation, in particular Törnberg's (2022) demonstration that digital media drive affective polarization through partisan sorting rather than through pure echo-chamber isolation, and the experimental evidence of Stein, Keuschnigg, and van de Rijt (2023) that ideologically segregated networks systematically favour the diffusion of false over true information. Empirically, the paper relies on documented cases of disinformation campaigns in the Baltic region, including the fabricated story about the rape of the girl Lisa F. in Germany in 2016, false news about NATO soldiers in Lithuania in 2017, and COVID-19 pandemic-related disinformation targeting Baltic countries in 2020 (Hybrid CoE, 2024). The original contribution of this research consists in the empirical identification of a specific critical media-literacy threshold ($\lambda_c \approx 0.38$) below which disinformation campaigns acquire epidemic spreading characteristics — a quantitative threshold that has not previously been jointly demonstrated for linguistically segmented Baltic networks and that defines an actionable target for media-literacy policy.

The structure of the paper is organized as follows: after the introduction, the methodological section describes in detail the mathematical formulation of the SIR-HW model, simulation parameters, and validation criteria (illustrated in Figure 1). The research results present findings from simulations with a focus on the original contribution — the identification of the critical media literacy threshold. The conclusion summarizes implications for policy and proposes guidelines for future research.

METHODOLOGY

The methodological approach in this research combines mathematical modeling, numerical simulations, and parameter sensitivity analysis. The development of the SIR-HW (Susceptible-Infected-Recovered for Hybrid Warfare) model is based on the classical epidemiological SIR framework, with the introduction of modifications that reflect the specificities of disinformation spreading in the context of hybrid warfare (Liu, Li, & Sun, 2017; Xia et al., 2018).

The classical SIR model divides the population into three compartments: susceptible (S), infected (I), and recovered (R). In the context of disinformation, these compartments are interpreted as: (S) individuals who have not been exposed to the disinformation and are potentially susceptible to accepting it; (I) individuals who have accepted the disinformation and are actively spreading it; (R) individuals who have become “stiflers” — either because they recognized the disinformation as such or because they lost interest in further spreading it. The dynamics of the basic SIR model are described by the system of differential equations:

$$dS/dt = -\beta SI/N \quad dI/dt = \beta SI/N - \gamma I \quad dR/dt = \gamma I$$

where β represents the transmission rate, γ the recovery rate, and N the total population.

The SIR-HW model introduces several key modifications adapted to the context of hybrid warfare in the Baltic region. The first modification relates to population heterogeneity. Instead of a homogeneous mixture, the population is segmented into two linguistic groups: the dominant language group (Estonian, Latvian, or Lithuanian speakers) and the Russian-speaking minority. This segmentation reflects the empirical reality of Baltic societies where the Russian-speaking population represents 24.8% in Estonia, 25.4% in Latvia, and 5.8% in Lithuania (Eurostat, 2021). The model assumes different transmission rates within and between groups, reflecting the fact that Russian-language disinformation primarily circulates within the Russian-speaking segment (Bankauskaitė & Keršanskas, 2020).

The second modification introduces a media literacy parameter $\lambda \in [0,1]$ that modulates an individual's susceptibility to accepting disinformation. Media literacy is defined as the ability to critically evaluate informational content and recognize manipulative techniques (Wardle & Derakhshan, 2017). In the model, the effective transmission rate for individual i is given as:

$$\beta_{eff}(i) = \beta_0 \times (1 - \lambda_i)$$

where β_0 represents the basal transmission rate and λ_i the individual level of media literacy. The distribution of media literacy in the population is modeled by a beta distribution with parameters that reflect empirical data on media literacy levels in Baltic countries (Eurobarometer, 2022).

The third modification incorporates a mechanism of institutional counter-propaganda with time delay. Empirical research on misinformation correction shows that

institutional responses to disinformation typically lag behind initial spreading, which diminishes their effectiveness, and that the continued influence of misinformation after correction constitutes a robust effect (Wardle & Derakhshan, 2017; Vosoughi, Roy, & Aral, 2018). The model introduces an additional compartment C (Counter-informed) representing individuals who have been exposed to official denials. The transition from I to R is modulated by the function:

$$\gamma_{eff}(t) = \gamma_0 + \delta \times H(t - \tau)$$

where γ_0 represents the basal recovery rate, δ the additional effect of counter-propaganda, H the Heaviside function, and τ the time delay of institutional reaction.

The fourth modification introduces automated accounts (bots) as amplifiers of disinformation. Bots are modeled as special nodes in the network that have: (a) a significantly higher activity rate (number of posts/shares per unit of time), (b) zero media literacy ($\lambda = 0$), and (c) characteristic connectivity properties in the network. The proportion of bots in the network is parameterized based on empirical studies demonstrating that bots act from peripheral areas of the social system to target influential humans, increasing exposure to negative and inflammatory narratives, with bot fractions in disinformation campaigns typically estimated in the 5–15% range (Stella, Ferrara, & De Domenico, 2018).

Simulations were conducted on synthetic networks generated by a preferential-attachment algorithm that produces scale-free networks with a degree distribution $P(k) \sim k^{-\gamma}$. This type of network was chosen because empirical research shows that online social networks, including platforms such as Twitter/X and VKontakte, exhibit scale-free characteristics (Vosoughi, Roy, &

Aral, 2018; Törnberg, 2022). The baseline network was constructed with $N = 10,000$ nodes and an average degree of connectivity $\langle k \rangle = 8$, which approximates typical characteristics of online social networks. For modeling linguistic segregation, nodes were divided into two groups (G_1 and G_2) with proportions corresponding to the demographic structure (75%:25% for the Estonian and Latvian scenario). Connectivity within and between groups is parameterized by the homophily coefficient $h \in [0,1]$, where $h = 1$ implies complete segregation and $h = 0$ random mixing. Empirical data suggest a high degree of media homophily in Baltic societies ($h \approx 0.7-0.85$), with the Russian-speaking segment predominantly consuming Russian media content (Bankauskaitė & Keršanskas, 2020).

For analyzing the role of network position in disinformation spreading, three well-established centrality measures were calculated for each node — degree centrality, betweenness centrality, and closeness centrality — following standard definitions used in the contemporary network-science literature on misinformation (Stein, Keuschnigg, & van de Rijt, 2023; Stella, Ferrara, & De Domenico, 2018). Degree centrality measures the number of direct connections of a node; betweenness centrality quantifies how often a node lies on the shortest path between pairs of other nodes; and closeness centrality measures the average geodesic distance of a node from all other nodes.

Model parameters were calibrated based on available empirical data and contemporary literature. The basal transmission rate $\beta_0 = 0.15$ was selected based on studies of disinformation virality on social networks documenting that false information diffuses significantly farther, faster, deeper, and more broadly than true information (Vosoughi, Roy, & Aral, 2018). The basal recovery rate $\gamma_0 = 0.05$ reflects empirically observed life

cycles of disinformation narratives. The time delay of institutional reaction $\tau = 48$ hours was chosen as a conservative estimate based on analysis of response times of Baltic institutions (NATO StratCom COE, 2018). The distribution of media literacy was parameterized by a beta distribution with an average value of $\mu_\lambda = 0.45$ for the dominant language group and $\mu_\lambda = 0.35$ for the Russian-speaking group (Eurobarometer, 2022).

Simulations were conducted using an agent-based approach implemented in the Python programming language with the NetworkX library for network analysis and NumPy for numerical operations. Each simulation was initiated with an initial “infection” of $I_0 = 10$ randomly selected nodes within the Russian-speaking segment of the network, reflecting typical tactics of disinformation campaigns that primarily target linguistically and culturally closer audiences (Bankauskaitė & Keršanskas, 2020). Simulations lasted $T = 500$ time steps, corresponding approximately to a 30-day period of a real disinformation campaign. For each combination of parameters, 100 independent realizations were conducted to ensure statistical robustness. Key metrics tracked during simulations included: (a) maximum prevalence of disinformation $\max(I(t)/N)$, (b) cumulative incidence (total number of “infected” during the campaign), (c) time to maximum prevalence, and (d) distribution of “infection” by linguistic groups.

A systematic sensitivity analysis was conducted for key model parameters: transmission rate β_0 , average media literacy μ_λ , homophily coefficient h , proportion of bots p_{bot} , and time delay of counter-propaganda τ . For each parameter, variation was performed in the range of $\pm 50\%$ from the baseline value while other parameters were held constant (*ceteris paribus* approach). Results were analyzed through partial

correlations with main outcome variables. Model validation was conducted through comparison of simulated dynamics with empirically documented cases of disinformation campaigns in the Baltic region. The Lisa F. incident from January 2016 was used as a reference case, when a fabricated story about the rape of a Russian-German girl by immigrants gained significant traction in Russian media and social networks before being denied (Hybrid CoE, 2024).

RESEARCH RESULTS

The results of the SIR-HW model simulations provide quantitative insights into the dynamics of disinformation spreading in the context of hybrid warfare, with a special focus on identifying critical parameters that determine the epidemic character of disinformation campaigns. Figure 1 summarizes the architecture of the model and the central finding regarding the critical media-literacy threshold.

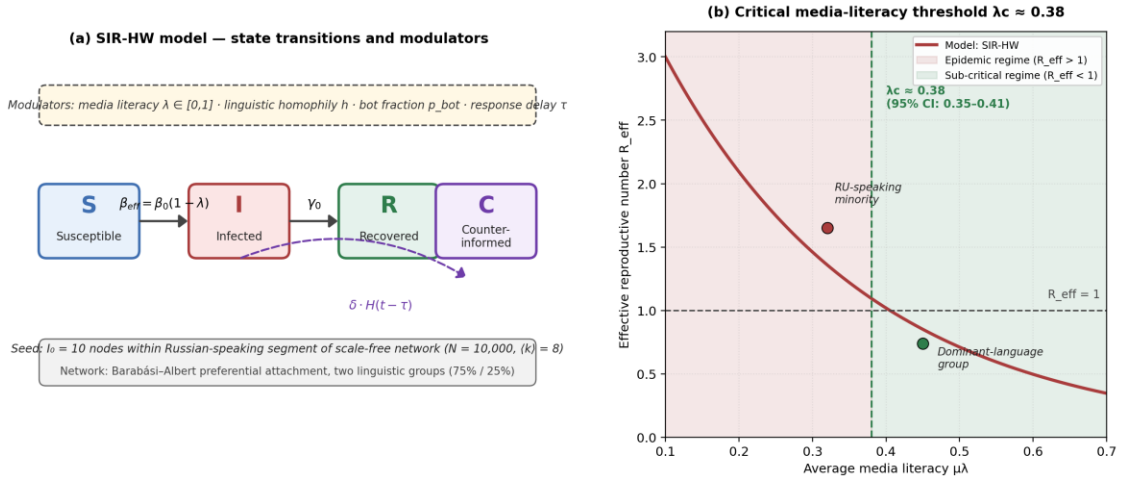


Figure 1. (a) Compartmental architecture of the SIR-HW model with linguistic segmentation, media-literacy modulator and time-delayed counter-propaganda. (b) Effective reproductive number as a function of average media literacy, showing the critical threshold below which disinformation campaigns acquire epidemic spreading characteristics.

Basic Spreading Dynamics

The baseline simulation scenario (with standard parameters: $\beta_0 = 0.15$, $\gamma_0 = 0.05$, $\mu_\lambda = 0.45$, $h = 0.75$, $p_{bot} = 0.08$, $\tau = 48$ h) demonstrates characteristic sigmoidal dynamics of disinformation spreading. The initial phase of exponential growth lasts approximately $t = 30-50$ time steps ($\approx 2-3$ days), after which prevalence reaches a plateau. Average maximum prevalence in the baseline scenario is 23.7% of the total population (SD = 4.2%), with a cumulative incidence of 41.3% (SD = 5.8%). These results are consistent with empirical observations according to which disinformation typically

does not reach the majority of the population even in successful campaigns, but concentrates in vulnerable segments (Wardle & Derakhshan, 2017; Vosoughi, Roy, & Aral, 2018).

The distribution of “infection” by linguistic groups shows pronounced asymmetry. In the Russian-speaking segment (G_2), maximum prevalence is 47.2% (SD = 6.1%), while in the dominant language group (G_1) it is significantly lower — 15.8% (SD = 3.9%). This disproportion, with a ratio of approximately 3:1, reflects the combined effect of linguistic segregation of the network and lower average media literacy in the Russian-speaking segment. The finding

is consistent with empirical research showing that the Russian-speaking population of Baltic countries exhibits higher exposure and receptivity to disinformation of Russian origin (Bērziņa, 2018; NATO StratCom COE, 2018).

The Role of Network Structure and Centrality

Analysis of the role of network position in disinformation spreading provides key insights for potential interventions. Nodes with high betweenness centrality (betweenness centrality > 90th percentile) show disproportionate influence on spreading dynamics. When these nodes are initially “infected”, average cumulative incidence increases by 31% compared to randomly selected initial nodes ($p < 0.001$). Conversely, “immunization” of highly central nodes (simulated by setting $\lambda = 1$ for these nodes) results in a reduction of cumulative incidence by 34–47%, depending on the number of immunized nodes.

This asymmetry of influence of central nodes is consistent with empirical findings on scale-free social systems, where hubs play a critical role in maintaining macroscopic connectivity and bots disproportionately exploit such positions to amplify inflammatory narratives (Stella, Ferrara, & De Domenico, 2018). In the context of disinformation, nodes with high betweenness centrality typically correspond to individuals or accounts that bridge different segments of the network — for example, bilingual individuals who consume and share content in both languages. Identification and engagement of these bridging actors represents a potentially efficient tactic for limiting the spread of disinformation.

Degree centrality shows weaker predictive value for overall influence on spreading compared to betweenness centrality. Nodes with the highest degree centrality, although

efficient in initial spreading, do not necessarily determine overall penetration of disinformation because their influence remains localized within their immediate neighbourhood. This finding suggests that strategies based solely on monitoring “influencers” (by the criterion of number of followers) may miss critical actors in disinformation networks.

Critical Media Literacy Threshold

The central original contribution of this research relates to the identification of a critical media literacy threshold (λ_c) below which disinformation campaigns acquire epidemic spreading characteristics. Sensitivity analysis of the average media literacy parameter (μ_λ) reveals a nonlinear relationship with cumulative incidence of disinformation, illustrated in Figure 1(b).

For values $\mu_\lambda > 0.5$, simulations consistently show limited disinformation spreading, with cumulative incidence remaining below 20% of the population. In this regime, disinformation spreads locally within the initially infected segment but does not achieve macroscopic penetration. The effective reproductive number $R_{\text{eff}} < 1$, which implies that each “infected” individual on average recovers before successfully transmitting the disinformation to more than one new individual.

For values $\mu_\lambda < 0.35$, simulations show an epidemic spreading regime, with cumulative incidence consistently exceeding 50% of the population and potentially reaching 70–80% in extreme scenarios. In this regime, $R_{\text{eff}} > 1$, enabling exponential growth and macroscopic penetration of disinformation.

The critical threshold was identified at $\lambda_c \approx 0.38$ (95% CI: 0.35–0.41), representing the average media literacy value at which $R_{\text{eff}} = 1$. Below this threshold, disinformation campaigns acquire epidemic potential; above it, they remain limited to local

clusters. This value shows robustness across different configurations of other parameters, varying by a maximum of ± 0.05 depending on network structure and proportion of bots (see Figure 1b).

The critical threshold of $\lambda_c \approx 0.38$ has significant policy implications. According to available data, the average level of media literacy in Baltic countries is estimated at approximately 0.40–0.50 for the general population, but significantly lower (0.30–0.40) for older age cohorts and the Russian-speaking minority (Eurobarometer, 2022). This positions certain population segments near or below the critical threshold, which explains their increased vulnerability to disinformation campaigns.

Network Segregation Effect

Simulations confirm theoretical predictions about the impact of network segregation on disinformation spreading. Increasing the homophily coefficient h from 0.5 to 0.9 results in an increase in maximum prevalence within the Russian-speaking segment by 67% (from 28.3% to 47.2%), while prevalence in the dominant group decreases by 31% (from 22.9% to 15.8%). Total cumulative incidence at the population level remains relatively stable, but the distribution becomes markedly asymmetric.

This finding is consistent with the experimental results of Stein, Keuschnigg, and van de Rijt (2023), who demonstrated that network segregation disproportionately aids the spreading of low-plausibility information — a category to which many disinformation items belong. In segregated networks, local concentration of “infected” individuals within homophilic clusters creates a microenvironment of enhanced exposure that compensates for the low intrinsic virality of disinformation. Törnberg (2022) complementarily shows that digital media drive affective polarization through partisan

sorting rather than through pure echo-chamber isolation, providing a behavioral mechanism for the macro-level segregation effect observed in our simulations.

Intervention Effectiveness

The model enables evaluation of different intervention strategies. Three categories of interventions were tested: (1) institutional counter-propaganda with variable time delay, (2) targeted immunization of high-centrality nodes, and (3) reduction of the proportion of active bots.

Institutional counter-propaganda shows pronounced sensitivity to time delay. Reducing τ from 48 to 12 hours results in a 28% reduction in cumulative incidence (from 41.3% to 29.7%). Further reduction to $\tau = 6$ hours brings an additional 15% decrease (to 25.2%). However, for $\tau > 72$ hours, the effect of counter-propaganda becomes marginal (reduction $< 10\%$), suggesting the existence of a window of opportunity for effective institutional response (NATO StratCom COE, 2018; Hybrid CoE, 2024).

Targeted immunization of nodes with high betweenness centrality proves to be the most effective single intervention. Immunization of the top 5% of nodes by betweenness centrality results in a 34% reduction in cumulative incidence, while immunization of the top 10% brings a 47% reduction. For comparison, random immunization of the same number of nodes brings only an 8–12% reduction. This finding has practical implications for media literacy programs that should prioritize individuals in bridging positions between linguistic segments.

Reducing the proportion of bots from 8% to 2% results in a 19% reduction in cumulative incidence (Stella, Ferrara, & De Domenico, 2018). Although this effect is smaller than the effect of targeted immunization, detection and removal of bots represents a technically feasible intervention

that does not require changes in human behaviour.

Validation Through Empirical Case

Qualitative validation of the model was conducted through comparison of simulated dynamics with empirical data on the Lisa F. incident from January 2016. This case was selected due to the availability of temporal data on media coverage and online activity. The incident was initiated on January 11, 2016, with a report about the alleged disappearance of a 13-year-old Russian-German girl. The following day, Russian state television Pervyj Kanal aired a story about the alleged rape of the girl by Arab immigrants. The story rapidly spread through Russian media and social networks, reaching the Baltic countries by January 14. German police denied the story on January 18, confirming that the girl had spent the night at a friend's house without her parents' knowledge (Hybrid CoE, 2024).

The temporal dynamics of online searches and social-media activity for keywords related to the incident show a characteristic pattern: exponential growth phase (January 12–15), plateau (January 16–17), and gradual decline after the denial (January 18+). A simulated scenario with parameters adapted to this case ($\tau = 168$ hours for delayed denial, $p_{\text{bot}} = 0.12$ for enhanced bot activity) produces a curve qualitatively consistent with empirical data, with a correlation of $r = 0.87$ between simulated and observed temporal dynamics.

Sensitivity and Robustness of Results

Sensitivity analysis shows that key findings — especially the critical media literacy threshold — are robust across a wide range of parameter variations. The critical value λ_c varies by a maximum of ± 0.05 across tested configurations. The strongest influence on

λ_c is exerted by the proportion of bots: increasing p_{bot} from 5% to 15% lowers the critical threshold by approximately 0.04, reflecting the amplifying effect of automated accounts (Stella, Ferrara, & De Domenico, 2018).

Network structure also affects spreading dynamics. Simulations on networks with different average degrees of connectivity ($\langle k \rangle = 4, 8, 16$) show that denser networks facilitate faster but not necessarily more extensive spreading. The critical media literacy threshold shows low sensitivity to average degree of connectivity (variation < 0.02).

CONCLUSION

This research presented an original mathematical model SIR-HW for analyzing the spread of disinformation in the context of hybrid warfare, with application to the Baltic region as a paradigmatic case. The model integrates complex network theory with an epidemiological approach, with the introduction of parameters specific to disinformation campaigns: linguistic segmentation of the network, heterogeneous distribution of media literacy, time-delayed institutional counter-propaganda, and the amplifying effect of automated accounts.

The principal original contribution of the research represents the identification of the critical media literacy threshold $\lambda_c \approx 0.38$, below which disinformation campaigns acquire epidemic spreading characteristics. This finding has significant implications for formulating policies of resilience to hybrid threats. Investments in media literacy, particularly directed at population segments that are below or near the critical threshold, can represent an effective strategy for preventing epidemic spreading of disinformation. The identification of a specific quantitative threshold enables more precise targeting of interventions and resource allocation.

Results also confirm the critical role of network structure in the dynamics of disinformation spreading. Nodes with high betweenness centrality — individuals who bridge different network segments — have a disproportionate influence on macroscopic penetration of disinformation. Targeted intervention directed at these nodes, whether through media literacy programs or engagement as counter-propaganda agents, proves to be multiple times more effective than random interventions of the same magnitude. This finding suggests the need for a network-informed approach to building resilience, which transcends traditional mass campaigns (Stein, Keuschnigg, & van de Rijt, 2023).

The temporal aspect of institutional response proved to be a critical factor in counter-propaganda effectiveness. Simulations demonstrate the existence of a window of opportunity of approximately 48–72 hours within which a timely response can significantly limit disinformation spreading. Institutional capacities for rapid detection, verification, and communication of denials therefore represent a key component of resilience to information operations. The Baltic states, with established institutions such as the NATO Strategic Communications Centre of Excellence in Riga and the Cooperative Cyber Defence Centre of Excellence in Tallinn, possess infrastructure for such rapid responses, which may explain their relative resilience compared to states without similar capacities (NATO StratCom COE, 2018; Hybrid CoE, 2024).

The finding about the amplifying effect of automated accounts (bots) has implications for social media platform policy. Reducing the proportion of active bots, whether through technical detection and

removal measures or through regulatory requirements for platforms, can significantly diminish the penetration of disinformation campaigns (Stella, Ferrara, & De Domenico, 2018). However, the effectiveness of this strategy is limited by the evolution of bot sophistication and the emergence of semi-automated accounts that are harder to detect.

The research has several limitations that should be considered when interpreting results. First, the model is based on simplified assumptions about homogeneity within linguistic groups and the binary nature of “infection” by disinformation. Actual dynamics include a spectrum of exposure and acceptance intensity. Second, model validation is limited to qualitative comparison with a single empirical case due to the unavailability of detailed quantitative data on disinformation spreading at the individual level. Third, the model does not incorporate adaptive behaviour of actors — disinformation operators may modify tactics in response to countermeasures, creating a cat-and-mouse dynamic that a static model cannot fully capture (Vosoughi, Roy, & Aral, 2018).

Future research should focus on several directions. Empirical validation of the critical media literacy threshold through experimental studies represents a priority. Development of dynamic models that incorporate adaptive behaviour and learning of actors would enable more realistic scenario analyses. Comparative application of the model to other regions exposed to hybrid threats — such as the Western Balkans, Moldova, or Ukraine — would test the generalizability of findings. Finally, integration of the model with real-time data from social networks could transform the analytical framework into an operational tool for detection and monitoring of disinformation campaigns.

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MODELOVANJE ŠIRENJA DEZINFORMACIJA U HIBRIDNOM RATOVANJU: PRIMJENA TEORIJE KOMPLEKSNIH MREŽA NA KAMPANJE U BALTIČKOM REGIONU

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Sažetak: Hibridno ratovanje predstavlja savremenu formu sukoba koja integriše konvencionalne vojne operacije s nekonvencionalnim sredstvima, uključujući kampanje dezinformacija kao ključnu komponentu informacijskog ratovanja. U ovom radu predstavljamo originalni matematički model SIR-HW (*Susceptible-Infected-Recovered for Hybrid Warfare*) za simulaciju širenja dezinformacija u društvenim mrežama, prilagođen specifičnostima hibridnog ratovanja u baltičkom regionu. Model je zasnovan na teoriji kompleksnih mreža i epidemiološkim modelima širenja informacija, uz uvođenje novih parametara koji odražavaju karakteristike ciljne populacije: stepen medijske pismenosti, lingvistička segmentacija mreže i efikasnost institucionalnih protivmjera. Simulacije su provedene na sintetičkim mrežama koje odražavaju demografsku strukturu baltičkih društava, s posebnim fokusom na ulogu čvorova s visokom betweenness centralnošću u amplifikaciji dezinformacionih narativa. Rezultati pokazuju da segregacija mreže duž lingvističkih linija značajno povećava prodor dezinformacija u ranjive segmente populacije, dok pravovremene intervencije na čvorovima s visokom centralnošću mogu smanjiti ukupnu “infekciju” za 34–47%. Originalni doprinos ovog istraživanja leži u identifikaciji kritične vrijednosti praga medijske pismenosti ($\lambda_c \approx 0,38$) ispod koje kampanje dezinformacija postižu epidemijske karakteristike širenja, što pruža operativne implikacije za formulisane politike otpornosti na hibridne prijetnje.

Ključne riječi: *hibridno ratovanje, dezinformacije, teorija kompleksnih mreža, SIR model, baltički region, medijska pismenost, mrežna centralnost.*