Artem SERDYUK
PhD Student
National University of Kyiv-Mohyla Academy
(Kyiv, Ukraine)

POLICY RESPONSES AND ORGANIZATIONAL ADAPTATION OF UKRAINIAN UNIVERSITIES DURING THE FULL-SCALE RUSSIAN INVASION: AN AGENT-BASED APPROACH

Keywords: Agent-based models (ABMs), wartime, effective adaptation strategies, Ukrainian higher education, institutional mobility, resilience.

Russia's full-scale invasion has severely disrupted Ukraine's higher education system, with 43 institutions damaged and 5 destroyed by early 2023 [12]. Approximately 20% of academic personnel at institutions like Zaporizhzhia Polytechnic were internally displaced or forced to emigrate, while 5% of students suspended their studies due to occupation and security concerns [5]. Despite these challenges, Ukrainian universities have demonstrated remarkable resilience through constant adaptation.

Agent-based models (ABMs) provide a powerful tool for understanding how complex social systems adapt to crisis by simulating how autonomous agents interact according to predefined rules [4]. These models are particularly valuable in crisis contexts where "the costs or risks associated with a policy change are high, and the context is complex," making it "not only common sense to use policy modelling to inform decision making, but it would be unethical not to" [4, p. 14].

Our research aims to:

– Build an agent-based model of Ukrainian higher education during wartime,
– Calibrate this model using available quantitative research,
– Test various policies and identify effective adaptation strategies.

Model Description

Our model is built in NetLogo 6.4.0 environment and simulates Ukraine's higher education system following the February 2022 invasion, incorporating real-world parameters: 336 universities, approximately 1,675 students per university, and a student-to-teacher ratio of 6.31 [10].

The model includes three agent types:

Students possess demographic attributes, academic characteristics, and psychological states. They apply to universities, potentially drop out when stress exceeds thresholds (with military-age males showing greater persistence), study abroad when conditions deteriorate, and eventually graduate.

Teachers have professional traits and psychological characteristics. They seek employment, may resign under excessive stress, face potential layoffs, and experience skill degradation under sustained stress.

Universities vary by location, quality, capacity, and operational mode. They assess local risk based on proximity to the frontline, adapt through relocation or mergers when necessary, transition to online teaching during high-risk periods, and may shut down when conditions become unsustainable.

The environment represents Ukrainian territory with a shifting frontline and a network of cities. The simulation begins in September 2022, with each tick representing one day. The model incorporates a realistic academic calendar with appropriate admission and graduation cycles.

Universities have limited capacity to adapt due to both internal inertia (established structures and resource allocation) and external inertia (legitimacy requirements). Our model examines five distinct adaptation strategies: Relocation — Moving away from war zones, Transition Online — Shifting to distance education, Merger — Consolidating with other institutions, Capacity Reduction — Reducing capacities and number of teachers according to the admission drop.

Model Calibration and Validation

Our model parameters were calibrated using empirical data from Ukrainian higher education during the invasion. University-level parameters were based on 2022 statistics with program distribution matching official statistics: 72.9% bachelor's, 24.6% master's, and 2.6% doctoral students [2]. We incorporated infrastructure recovery rates following attacks with universities returning from online mode [9]

when local risk drops below 40% and applied a 20% quality reduction to relocated universities, reflecting disruption to educational processes [12; 3]. Stress impacts were calibrated at 0.65 for teachers and 0.4 for students based on documented emotional exhaustion and academic performance decline [11; 8]. When stress exceeds 60%, teacher skills deteriorate by 5% per stress point, while student performance drops by 10% per stress unit [6]. Dropout thresholds were set at 52% for students and 60% for teachers based on PHQ-9 scores and emotional exhaustion data, with recovery mechanisms reflecting documented differences: students recovering at approximately 7.5% monthly [7] and teachers recovering more slowly at about 15% over six months [11].

We employed visualization and empirical validation methods [1], focusing on capturing fundamental adaptation mechanisms rather than perfect numerical replication. Following Gilbert et al.'s [4] perspective that a model's validity should be judged by its usefulness in generating scientific insights rather than strict empirical verification, our model demonstrated moderate success in reproducing general trends from 2022-2023. However, full empirical validation proved challenging due to exogenous shocks in the system. The model's predictive accuracy for university counts decreased to 75.8% in 2023 and 77.1% in 2024, consistently underestimating institutional resilience. For student enrollment, accuracy dropped to 65.5% in 2023 and 48.0% in 2024, missing the unexpected enrollment increase in 2023. These discrepancies likely stem from factors not incorporated in our model, including conscription policy changes, more effective institutional adaptation than anticipated, and international support bolstering the system.

Results

We tested seven specific scenarios to evaluate different adaptation strategies: (1) Baseline — Replicates actual wartime conditions with fluctuating war intensity, air raids, and standard university adaptation mechanisms, including relocations when local risk exceeds 80% and infrastructure damage exceeds 70%, and mergers under severe resource constraints. (2) Online — All universities operate in online mode from the beginning of the simulation. (3) No Relocation — Universities do not relocate from war zones even when local risk exceeds 40%. (4) Forced Relocation — Universities are mandatorily relocated as soon

as local risk reaches or exceeds 40% (the empirical value of a safety line at a certain distance from the frontline). (5) No Merger — Universities do not merge regardless of resource constraints or damage levels. (6) Forced Merger — Restructure the university network through aggressive consolidation. In small cities, all universities are merged into a single institution. In larger cities, universities with fewer than 5,000 students are mandatorily merged with larger counterparts. (7) No Deferment — Simulates removing military service exemptions for students.

Our analysis reveals critical insights for wartime higher education policy (see Fig. 1). Institutional strategies have more potent effects than individual-level factors, with forced mergers significantly reducing university numbers (-187.17) and student enrollment (-563,817) while paradoxically improving average quality (+9.17 points). Preventing relocations severely compromised the system (-55.18 universities; -104,600 students). Student stress remained relatively consistent across scenarios, while teacher stress varied significantly, decreasing under forced mergers (-44.7%) but increasing when relocations were prevented (+24.7%). The "No Deferment" scenario, removing student military exemptions, showed modest enrollment declines (-11,783) with slight academic performance improvements (+0.76 points).

Conclusion and Further Research

Our findings demonstrate complex trade-offs in adaptation strategies. While mergers reduce overall capacity and drive students abroad, they can improve quality metrics and reduce teacher stress. Institutional mobility appears crucial for system resilience.

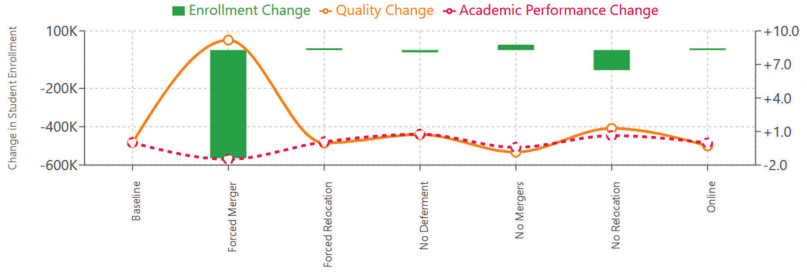

Figure 1. Impact of Policy Scenarios on Ukrainian Higher Education Metrics During Wartime (Simulation Results: Sept 2022 — Aug 2026)

Future research should focus on three directions: enhancing model calibration to reflect better external shocks like conscription policy changes and aid programs; exploring innovative structural adaptations such as distributed multi-node campus networks and cross-institutional resource-sharing arrangements; and facilitating stakeholder-engaged policy experimentation where university administrators and government officials collaboratively test adaptation strategies through model scenarios before implementation.

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