Simulation-Based Modelling of Migration Flows on the Balkan Route: A Contribution to the Development of European Migration Policies

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Abstract: Migration flows along the Balkan Route since 2015 have revealed structural weaknesses in the European Union's migration governance and highlighted the need for new, evidence-based approaches. This paper presents the MIG@B project, which develops an integrated simulation model of migration by combining agent-based modelling (ABM), system dynamics (SD), and discrete-event simulation (DES), supported by Bayesian methods for managing uncertainty. The model addresses both micro-level decision-making among migrants and macro-level feedback loops between policies and public opinion, as well as operational challenges related to border flows and asylum capacities. The approach contributes to the design of coordinated and sustainable EU and Slovenian migration policies, aligning with the New Pact on Migration and Asylum [1] and Slovenia's Migration Strategy 2023–2030 [2]. The expected contribution is threefold: scientific innovation through methodological integration, political usability by providing scenario-based testing of policy measures, and normative relevance through alignment with European solidarity and human rights values. The MIG@B framework exemplifies how simulation modelling can serve as a laboratory for migration policy, enabling transparent, robust, and data-driven decision-making.

Key-Words: migration, simulation models, Balkan Route, European Union, policy design

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1 Introduction

Migration remains one of the most pressing challenges for contemporary Europe. The 2015/2016 crisis exposed the limitations of the Dublin Regulation and placed disproportionate pressure on frontline states, including Greece, Italy, Croatia, Hungary, and Slovenia [3, 4]. Public opinion surveys confirm that migration is perceived as a key concern, particularly in EU border states [4]. Slovenia plays a dual role as a transit and destination country, facing specific policy and integration challenges.

This paper explores how simulation modelling can contribute to understanding migration processes along the Balkan Route and provide a tool for policy design. The guiding research questions are:

1. How can integrated simulation models (ABM, SD, DES) improve the understanding of migration processes on the Balkan Route?
2. In what ways can the results of integrated simulations support the development of coherent and sustainable migration policies in the EU and Slovenia?

The purpose of the paper is to present the MIG@B research, which uses integrated simulation approaches – agent modelling, system dynamics and discrete event simulation – to analyse migration processes on the Balkan Route and test how the results of the models can contribute to the creation of more coordinated, sustainable and data-supported European and Slovenian migration policies.

2 Literature Review

Classical migration theories [5, 6] emphasise push–pull factors and the economic logic of migration. Later approaches have highlighted world-systems perspectives [7] and network effects [7]. In the Slovenian context, Josipovič [8] and Bučar Ručman [9] underline the interplay of regional dynamics and individual decisions.

Simulation models complement these theoretical perspectives by providing experimental environments to test "what-if" scenarios [10]. ABM captures behavioural dynamics and emergent patterns [11], SD analyses macro-level feedback loops [10], while DES addresses operational bottlenecks such as asylum capacities and border throughput [12]. Bayesian approaches strengthen forecasting by incorporating uncertainty and incomplete data [13].

The European Union's migration policy has been evolving since 2015 towards greater coordination and accountability between Member States. The 2015/2016 crisis showed that the system based on the Dublin Regulation could not cope with the massive arrivals of refugees and migrants, as it unevenly

burdened the countries on the external border (Greece, Italy, Croatia, Hungary, and Slovenia). The role of the Balkan countries remains a particular challenge: Serbia, Bosnia and Herzegovina, North Macedonia, and Croatia remain key transit points where EU regulations and national policies, with varying levels of implementation, intertwine.

The European Commission implemented the proposed reforms in the New Pact on Migration and Asylum, adopted in 2024. The Pact introduces a mechanism of "mandatory solidarity", in which Member States can no longer unilaterally avoid responsibility. If they do not accept asylum seekers, they must contribute through financial support, staff or logistical assistance [1]. In addition, the Pact focuses on accelerating asylum procedures and more efficient returns of persons without the right to stay, while simultaneously emphasising the external dimension of migration, i.e. cooperation with countries of origin and transit. Special emphasis is placed on the Western Balkans, which the EU views as an area where, through appropriate collaboration and investment, it is possible to stabilise migration flows and reduce pressure on the EU's internal borders. In this context, numerous Frontex, IOM and UNHCR projects are financed to support border management and capacity development in Serbia, Bosnia and Herzegovina, and North Macedonia.

2.1 Balkan countries as a transit space

Serbia, Bosnia and Herzegovina, and North Macedonia remain key transit countries with limited capacities, whereas Croatia implements strict border controls as a member of the Schengen area. Both EU pressure and domestic political interests often condition the migration policy of these countries. Slovenia and Croatia, as EU members, assume the most significant responsibility for protecting external borders. At the same time, the migration policies of individual Balkan countries are responsive to EU pressure and often become an instrument of domestic policy. For example, Serbia uses migration as leverage in its EU enlargement negotiations, while Bosnia and Herzegovina faces internal political blockages that hinder the development of a common migration strategy.

2.2 Simulation models in predicting migration trends

Simulations offer predictions and reveal the mechanisms that create trends [10, 11]. This methodology allows testing risk-free "what-if" scenarios in a real environment and improves predictive power compared to classical statistical models. Simulations will be used for forecasting:

1. A bridge between micro and macro dynamics. Agent-based modelling (ABM) encodes the decision rules of individuals (e.g. utility functions, norms, networks) and shows how interactions lead to emergent macro patterns ("bottom-up"). In migration, this means that changes in motivations, information flows, or networks cause nonlinear jumps in flows (route rerouting, sudden waves) [11].
2. An experimental testing ground for policies and counterfactuals. System dynamics (SD) and discrete event simulation (DES) enable the testing of "what-if" scenarios without risk in the real world (e.g., changes to the border regime, additional procedural steps, or reallocation of capacities). In the literature, SD is established as a method for political/strategic analysis of complex systems with delayed and feedback effects [10], and DES as a tool for operational policies (health, transport) [12, 14].
3. Managing uncertainty and short/medium-term forecasts. In demography and migration studies, Bayesian approaches have enabled explicit work with incomplete data, structural uncertainty and expert information; forecasts are not a point, but a distribution [13]. This is crucial for non-stationary processes (conflicts, labour demand shocks).
4. Incorporating empirical evidence into behavioural models. Modern ABMs increasingly calibrate decision rules based on the theory of planned behaviour, discrete choice, and empirical networks [11], thereby improving predictive validity compared to "black boxes" without mechanisms.
5. Cross-domain transferability and warning signals. Simulations developed in healthcare (DES), evacuation and disaster management (ABM), or transport allow the derivation of general principles (e.g. thresholds, bottlenecks, feedback loops) that can be adapted to migration (e.g. saturation of reception capacities, knock-on effects due to border closures) [12, 14].
6. Joint modelling with stakeholders and transparency. SD emphasises stakeholder engagement (policy design as a process), which increases the legitimacy and practical utility of the forecast and facilitates the transition from analysis to implementation [10].

Specifically for migration, integrated simulation models enable:

- Behavioural mechanisms and networks: A review of ABM migration highlights that the correct

specification of decision-making (discrete choice, norms) and social networks significantly affects the predictive power—especially for route diversions and "cascades" [11].
- Bayesian forecasting: demographic migration forecasting with Bayes integrates data and expert knowledge, generates probability intervals, and is particularly useful in Europe, where flows are heterogeneous and politically conditioned [13].

Methodological guidelines for better predictive utility in migration:
- Combine ABM (micro) for decisions and networks with SD (macro) for policy-economy-public opinion feedback loops and DES (operational) for logistics fluidity; frame the results in Bayesian uncertainty distributions.
- Use multilevel validation (comparing samples, events, and distributions) and sensitivity analyses to identify parameters that decisively determine regime transitions.
- Scenario tracking: explicitly model policy shocks (e.g., changes in visas, border practices), as they are the primary drivers of sudden trend breaks in migration.

The most significant added value for migration forecasting is seen in combined mechanistic models (ABM+SD+DES), which are Bayesian-calibrated and regularly updated with new data (e.g., border registrations, surveys, media signals). Such a set is transparent (explaining "why"), robust to shocks (in various scenarios), and operational (in terms of capacity/bottlenecks), which goes beyond bare statistical forecasts without mechanisms.

The contribution to migration forecasting is demonstrated through the use of combined mechanistic models that integrate agent-based modelling (ABM), system dynamics (SD), and discrete event simulation (DES). Such integration enables the capture of both micro-decisions of individuals and macro-social processes, as well as operational constraints, in real-time. When models are additionally calibrated with Bayesian approaches and continuously updated with current data, such as border registrations, survey results and media signal analysis, they acquire high robustness and reliability.

The three sub-models interact through dynamic data exchange mechanisms. Specifically, outputs from the ABM – such as predicted migrant flow volumes or route choices – serve as inputs to the DES, determining queue lengths and border throughput under different operational conditions. Simultaneously, aggregated policy feedback and public opinion dynamics generated in the SD model modify parameters within the ABM, such as perceived risk or policy restrictiveness. This iterative linkage forms a closed feedback loop across micro (individual), meso (operational), and macro (policy) levels, ensuring systemic coherence within the simulation.

This makes a transparent tool, as it allows for the explanation of mechanisms and causal connections; resilient to shocks, as it is possible to test different crisis scenarios; and operationally sound, as it provides insight into available capacities and bottlenecks in the system. Such an approach extends beyond traditional statistical forecasting methods, which typically offer only projections without insight into the mechanisms that drive trends.

3 Methodological Framework: The MIG@B Project

The MIG@B project integrates ABM, SD, and DES into a unified, integrated simulation environment:
- Agent-Based Modelling (ABM): captures migrant decision-making and social network effects, including sudden shifts in migration flows due to changes in information channels or family ties [11]. The migrant decision-making process within the ABM is formalised through a composite utility function that balances perceived benefits and risks of movement. Factors include expected income differentials, perceived safety along routes, existing social networks, and policy restrictions. Behavioural rules are based on bounded rationality and heuristic adaptation: agents update their route and destination preferences based on local information and the experience of peers. Parameter weights for decision factors are derived from empirical studies and policy reports on Balkan migration behaviour.
- System Dynamics (SD): analyses delayed effects of policy decisions and feedback loops between migration policies, labour markets, and public opinion [10].
- Discrete-Event Simulation (DES): assesses operational aspects such as border control throughput, asylum centre capacities, and logistical bottlenecks [14]. The DES component will generate operational performance indicators essential for policy evaluation, including: (1) average and peak waiting times at border crossing points; (2) capacity utilisation rates of asylum centres; (3) overload percentage and queue dynamics under different inflow scenarios; and (4) surge capacity requirements for first reception facilities. These outputs will enhance the political usability of the model by translating

simulation results into tangible operational metrics that decision-makers can use.
- Bayesian Methods: provide probabilistic forecasts and manage structural uncertainty, presenting results as probability intervals rather than deterministic estimates [13].

The model will be validated using historical data, sensitivity analyses, and consultations with stakeholders, including the Slovenian Police, the Ministry of the Interior, and Frontex. After validation, we will simulate scenarios [15] with data obtained from individual Balkan regional centres.

Statistical comparison tests (t-tests, chi-square tests, and ANOVA) will be applied to evaluate differences between simulated and observed distributions of migrant arrivals, asylum applications, and processing times. These analyses will help verify whether the model reproduces empirical variance patterns and identifies potential structural biases in the simulation parameters.

Model validation will follow a structured multi-stage approach. First, simulated migration flows will be compared with historical observed data from 2015 to 2024 to assess temporal and spatial consistency. Second, sensitivity analyses will be conducted by varying key parameters such as policy restrictiveness, border permeability, and public opinion feedback strength. These tests will identify parameters with the most substantial influence on emergent migration patterns and system stability. The combination of historical benchmarking and sensitivity testing ensures both behavioural and structural validity of the integrated model.

Each method will have a clear research role and will be linked to specific predictions.

4 Expected Contributions

According to the methodological framework, we expect specific patterns that can be directly linked to the approaches used. ABM will reveal micro-dynamic changes and nonlinear jumps, SD will show lagged and rebound movements in response to policy changes, DES will identify operational bottlenecks, and Bayesian methods will enable more reliable interpretations of the results within probability intervals.

We expect the research to demonstrate that migration flows on the Balkan route are a result of economic disparities, political decisions, and regional coordination. Slovenia and Croatia, as EU members, bear the most significant burden, while the transit countries of the Balkans remain limited in capacity. We anticipate that the simulations will reveal that migration flows on the Balkan route are not only a consequence of economic differences but are strongly dependent on political decisions and regional coordination. Integrated simulation models, such as MIG@B, enable testing the effects of different policies without risk in a real environment and evaluating scenarios (e.g., closing the Croatian border, introducing new visa regimes), thereby reducing the risks associated with humanitarian crises. The interpretation of the comparative table shows that Slovenia and Croatia, as Schengen members, assume the most significant obligations. At the same time, Serbia, Bosnia and Herzegovina, and North Macedonia remain transit countries with limited capacities. This creates the need for greater cooperation and solidarity. The expected contribution of the research is the development of integrated simulation approaches that can serve as a tool for designing coordinated and transparent policies. The scientific innovations brought about by the model in the field of migration are:
- Integrating ABM, SD, and DES into a single framework, Bayesian-calibrated for migration studies.
- Development of multi-level validation methods that combine pattern, event, and distribution-based approaches.

The social utility of the model is:
- A simulation “laboratory” for testing EU and national migration policies without real-world risks.
- Scenario analyses of border closures, visa regime changes, or labour demand shocks.

Normative relevance:
- Contribution to EU solidarity mechanisms as envisaged in the New Pact on Migration and Asylum [1].
- Support for Slovenia’s Migration Strategy 2023–2030 [2], balancing security concerns with social cohesion and integration.
- Emphasis on human rights and protection of vulnerable groups in policy design.

The model will reduce uncertainty in migration forecasting and make more comprehensive, data-based decisions.

The Balkan countries have varying statuses regarding the EU and the Schengen area, which impact their migration policies. Serbia, Bosnia and Herzegovina act as transit areas, North Macedonia as a key point on the route, and Croatia as a Schengen border.

Simulation modelling provides a bridge between theory and practice. Unlike classical statistical models that generate point forecasts, simulation-based approaches explain the mechanisms that produce migration trends. For the Balkan Route, this

means identifying tipping points such as the saturation of asylum capacities, cascading effects of border closures, or nonlinear flow shifts due to network dynamics.

For policymakers, MIG@B represents a transparent tool for anticipating crises and designing coordinated responses.

5 Conclusion

The analysis of migration processes on the Balkan route clearly shows that migration flows are not only the result of economic differences, but are decisively shaped by political measures, regional coordination and countries' responses to crises.

The expected contribution of the research is the development of simulation approaches that can serve as a tool for designing coordinated and transparent policies. This manuscript presents an original synthesis of previous methodological insights within a newly developed integrated simulation framework. While the project background has been presented elsewhere, the present contribution extends those discussions by introducing a unified modelling environment that explicitly connects ABM, SD, and DES through shared data interfaces and Bayesian calibration routines.

Based on the research design and the literature review to date, we formulate framework recommendations that will be supplemented and validated in further phases of the research. They are expected to be divided into four content areas:

- Regional cooperation: strengthening cooperation between the EU and the Balkan countries to prevent unilateral border closures.
- Data-based decision-making: incorporating simulations and empirical data into policymaking.
- Migrant integration: balancing security measures with measures for social cohesion.
- Human rights: consistent respect for European values and protection of vulnerable groups.

The overall message of the MIG@B research is that the future of European migration policies is based on reconciling national interests with European solidarity and on a readiness for long-term regional cooperation.

Future research will extend the model by incorporating real-time data assimilation from Frontex and Eurostat, expanding the behavioural representation of migrant heterogeneity (e.g., gender, family status), and testing cross-border coordination scenarios under different EU policy regimes. The model can also be adapted for crisis management simulations, including those related to climate-induced migration flows.

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