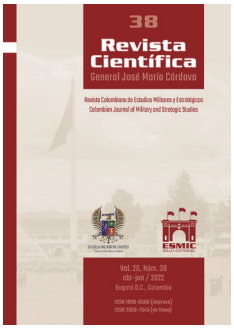

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Agent-based models: an effective tool in Ukrainian state formation and legal regulation

Modelos basados en agentes: una herramienta eficaz en la formación del Estado y la regulación legal ucraniana

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Abstract. This article explains the essence of the agent-based model method that simulates artificial societies to substantiate the thesis on its feasibility and scientific usefulness in lawmaking and law enforcement in Ukraine and research in the legal field. The primary research method used is synthesis, which allows combining components of a complex phenomenon and obtaining synthetic knowledge, which expands previous experience and constructs something new. Moreover, it allows going beyond the existing basis and drawing far-sighted conclusions, forecasting the directions of effective state formation and legal regulation in Ukraine.

Keywords: law enforcement; lawmaking; law enforcement; simulation; strategic planning

Resumen. Este artículo clarifica la esencia del método de modelos basados en agentes que simulan sociedades artificiales para fundamentar la tesis sobre su viabilidad y utilidad científica en la elaboración y aplicación de leyes en Ucrania y en la investigación en el ámbito jurídico. El principal método de investigación utilizado es la síntesis, que permite combinar los componentes de un fenómeno complejo y obtener un conocimiento sintético, que amplía la experiencia previa y construye algo nuevo. Además, permite ir más allá de la base existente y sacar conclusiones con visión de futuro, pronosticando las direcciones de la formación efectiva del Estado y la regulación legal en Ucrania.

Palabras clave: aplicación de la ley; legislación; modelos basados en agentes; planificación estratégica; simulación.

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Introduction

The rapid development of digital technologies in recent years has provided humanity the opportunity to use them to resolve the most complex and important problems. Globalization, population growth, the escalating struggle for resources, and economic, environmental, and political crises, among other modern challenges, exist in every society, driving the search for new approaches to their solution. As a result, forecasting and planning any state's economic, political, legal, social, and environmental development strategy has become more complex and substantive.

States with numerous crisis phenomena, including Ukraine, cannot afford to make mistakes when planning their strategic and tactical (regional) development. Therefore, implementing agent-based models (ABM) can be key to seeing the state apparatus of Ukraine in practice by creating *artificial societies* that mimic the formation and development of various social phenomena that require state influence. Furthermore, this method can help solve legal issues and scientific problems in the field of legal research.

Academician Makarov (2006) argues that cognition through construction –through development– is the primary method of studying society. According to Istratov (2006), agent-based economic models represent the economy as several agents independently deciding on their livelihoods, employment, exchange of resources, communication, and others. The rules of interaction between agents in most agent-based model construction and study efforts are straightforward; however, the results are quite meaningful. Agent-based modeling is a relatively young branch of knowledge whose development has been driven by the rapid development of computer technology. However, to date, models have not been built to cover all areas of human activity simultaneously or at least a large number of them.

Currently, in Ukraine, there is very little research on the use of ABM in state forecasting and legal regulation; however, it is a promising and highly effective area of research. This is evidenced in studies like Remarks on the foundations of agent-based generative social science (Epstein, 2006); Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model (Lamperti et al., 2017); and Socio-natural and socio-ecological-economic models created using the method of agent modeling and Agent modeling of socio-political systems and processes: the history of development and prospects for practical application (Ageeva, 2018; 2019). Other studies that have obtained important and useful conclusions in this area include the article: Agent-based modeling of mutual influence between horizontal-vertical greenery systems and air pollutants using the city of Yerevan, Armenia, as a case study (Akopov et al., 2020).

Regarding the essence and features of agent-based models and their possible application to predict socio-economic phenomena have been studied by experts in various fields of knowledge, namely: Ageeva (2019); Bakhtizin (2015); Makarov (2006); Istratov

(2006); Sushko (2012); Chekmareva (2016); Epstein (2006), Chyzhmar et al. (2019), Lamperti et al. (2017), Vakulyk et al. (2020), and others. For the most part, these studies have tried to predict social and economic processes through the use of ABM. However, their use in the field of state formation and legal regulation as a mandatory stage of lawmaking and law enforcement is a new and promising area. So far, apart from Ramazanov (2018), few scientists have studied this area. The purpose of this study is to clarify the essence of agent-based models (ABM) simulation methods to substantiate the thesis on the feasibility and scientific usefulness of this method in lawmaking and law enforcement in Ukraine and research in the legal field.

Methods

The research process involved theoretical methods, including analysis, synthesis, concretization, generalization, methods of analogies, and comparative methods. The empirical method included the review of scientific articles on studies using ABM concerning social and economic processes and the regulatory framework in lawmaking. The research on the problem was carried out in three stages:

- In the first stage, a theoretical analysis was made of the essence and features of the ABM agent as one of the prospective methods of simulation modeling. The advantages of this method, in comparison with other methods of simulation, were determined, and the problem, purpose, and research methods were identified.
- In the second stage, the theoretical and practical results of the application of ABM in scientific and practical works by other scientists in the economy, ecology, social problems, and strategic planning were investigated. Finally, the results obtained from the conclusions of the examined experimental and theoretical scientific and research work were analyzed, verified, and concretized.
- In the third stage, the theoretical and practical conclusions were codified; the obtained results were summarized and systematized. Then, concrete proposals were presented concerning the use of ABM as an effective method for forecasting sociological, political, economic, and ecological processes in society to provide effective and timely forecasting and adjustment of state formation and legal regulation in Ukraine.

Results and Discussion

ABM, as a special type of simulation

Today, the social sciences, including law, have approached the comprehensive and effective use of new means of acquiring knowledge. The state and society's most acute social,

economic, political, legal, and environmental issues can often be predicted at their inception using modern methods of analysis and prediction of complex systems. Analysis and forecasting, including social phenomena, can be carried out through modeling, which, according to Lychkina (2012), is one of the main methods of cognition. It is a form of reflection of a reality that clarifies or reproduces certain properties of real objects, reflecting objects and phenomena and other objects, processes, phenomena, or with an abstract description such as images, plans, maps, sets of equations, algorithms, and programs. Thus, in modeling, there is always an original (object) and a model that reproduces (models, describes, simulates) some features of the object. The model is an abstract description of a system (object, process, problem, concept) in some form different from its real existence.

One of these methods is simulation modeling, an experimental method of studying a real system based on its computer model. In this type of modeling, the logical-mathematical model of the studied system is an operating algorithm, software implemented on a computer. The methodological basis of simulation is system analysis. Today, there are three types of simulation: system dynamics, discrete-event modeling, and agent-oriented modeling. In a broad sense, simulation in science means the process of construction, analysis, and application of simulation models. In a narrow sense, simulation is interpreted only as a process of constructing a simulation model (Chekmareva, 2016). Agent-based models are the earliest type of simulation. A prototype of the first agent-oriented model was developed in the late 1940s; however, these models became widespread only in the early 1990s due to the advent of microcomputers and the ability to conduct computer simulations (Makarov & Bakhtizin, 2013).

According to Sushko (2012), an agent-oriented (multi-agent) model is an artificial society consisting of interacting independent agents, each of which has a given set of personal characteristics ('resources'), an objective function ('interests'), and obeys the rules of conduct that determine his reaction in various situations that affect the sphere of his interests. To Lychkina (2012), a simulation model is a computer program or software package using a sequence of calculations and graphical display of their results to simulate (reproduce) the social processes of an object or a set of objects under the influence of others, including random factors.

Thus, it is evident that the description of the concept of simulation models varies. Our study maintains that a simulation model is not a computer program. According to Article 2 on the distribution of copies of audio-visual works, phonograms, videograms, computer programs, databases (Law of Ukraine No. 1587-III, 2000), a computer program is a set of instructions in the form of words, numbers, codes, diagrams, symbols, or in any other form, expressed in a computer-readable form that actuates it to achieve a specific goal or result (this concept covers both the operating system and the application, expressed in source or object codes). Therefore, a computer program is not a simulation model itself but a technical tool to create this simulation model.

According to Makarov (2006), an artificial society consisting of interacting agents and computer models, where atoms are agents, is called an agent-oriented model. Thus, agent-oriented computer models, or agent-based models –abbreviated ABM– are artificial societies consisting of agents interacting with each other. The term "agents" is conditional. It has been widely used in the English-language literature, which gave impetus to this area of research, and has taken root and dominates. In different agent-oriented models, the term can represent a person, legal entity, government agency, or a combination of them, among others. Their relationship determines the agent-oriented model's properties noted in science. According to (Epstein, 2006), they include:

- Heterogeneity: agents differ from each other;
- Autonomy: agents act independently of each other;
- Given space parameters in which the agents are located and operate.
- Local interactions take place;
- Agents are characterized by limited rationality;
- Dynamics of events can have any vector of development and is not in equilibrium.

An artificial society is not just one agent; it is a model of society. Thus, there must be at least two agents; they must interact with each other as in society. Most importantly, agents must be similar in interactions to perceive them as similar. It is then that social behavior appears (Makarov, 2006). Compared with other means of simulation modeling, agent-based models allow modeling the system as close as possible to reality. They have the property of emergence (from the English, emergent: arises, suddenly appears), the emergence of special properties in the system that are not inherent in its elements, system effect. Moreover, they enable building models in the absence of knowledge about global dependencies in the relevant subject area, providing a flexible tool to easily add agents to the model and remove them and change the parameters and rules of their behavior (Makarov & Bakhtizin, 2013).

The essence of computer modeling is to obtain quantitative and qualitative results on the existing model. The qualitative analysis results reveal previously unknown properties of a complex system, its structure, development dynamics, stability, and integrity. Quantitative conclusions mainly involve the analysis of an existing complex system or forecasting future values of some variables. The ability to obtain both qualitative and quantitative results is the significant difference between simulation and structural-functional (Lychkina, 2012).

The well-known researcher in the field of ABM, Bakhtizin (2015), defined agents as follows: an autonomous entity, usually assigned a graphical representation, with a specific purpose and a certain level of possibility of learning in the process of existence, determined by the developers of the model. Examples of agents are:

1. People (and other living organisms), cars, and other moving objects;
2. Immovable objects; as well as;
3. A set of similar objects.

Generally speaking, agents in ABM can be any objects observed in real life; however, the main task of their accounting within the model is their correct specification. ABM are usually used in cases where:

- The relationship between the model's variables is difficult or impossible to build;
- The model contains stochastic components;
- To better understand the operation of objects within the system requires visualization of all processes occurring in it.

There are various software tools, including NetLogo, Repast, SWARM, and AnyLogic, that enable ABM development (Bakhtizin, 2015). The most voluminous projects solved with this technology must consider the mechanism of ABM and the application of its results. For instance, under the leadership of Joshua Epstein and John Parker at the Brookings Center on Social Dynamics and Policy, agent-based models were built to include the entire US population, about 300 million agents moving across a map of the country according to the matrix of correspondence of 4000 × 4000. A computational experiment was conducted, simulating the 300-day spread of a disease featuring a 96-hour incubation period and a 48-hour infection period. One of the study's results was a decline in the spread of the disease after 65% of people had recovered and acquired immunity. This model has been used repeatedly at Johns Hopkins University and the US Department of Homeland Security for rapid response to epidemics (Epstein, 2006).

It was used to simulate the effects of the spread of the Influenza A virus (H1N1/09). The model was extended to the Global-Scale Agent Model (GSAM), which included 6.5 billion agents interacting and moving according to the statistics available to developers. John Parker headed this project, which is currently the largest agent-oriented model, representing the planet's entire population. The results of the calculations were displayed on a global map using dynamic color markings according to the status of the agents living in a particular area (Khovpun et al., 2019). For example, black indicated disease-susceptible agents, red was used to isolate the infected, and blue indicated agents who had recovered or died. The figure showed the condition of agents living on the planet 4.5 months after the start of the H1N1 pandemic in Tokyo (Bakhtizin, 2015).

This example and many others included in the scientific literature (Ramazanov, 2018; Ramazanov, 2019; Ageeva, 2018; Ageeva, 2019; Akopov et al., 2020) allow us to conclude that the world economic leaders have access to advanced computer technology to address today's socio-economic, political, environmental, legal, and other challenges. Domestic scientists are beginning to immerse themselves in the topic of agent-oriented

modulation of socio-economic processes; however, such attention is insufficient and is not being used in many suitable areas of life.

Justification of the effectiveness of the use of ABM

With the help of computer simulation –namely ABM– in certain spheres of public life, it is possible to predict specific directions of their development and use this data for timely, effective, purposeful, adequate, and balanced legal decisions. Three basic conditions justify the objectivity of such decisions:

1. The objectivity of the data to be entered into a computer program to create an agent-oriented model (artificial society);
2. Mathematical - technical compliance of the computer program developed for this purpose;
3. Clear formulation of the goal to be achieved through simulation.
4. Clear formulation of the planned goal to be achieved through simulation.

We can conclude from this statement that there is a need for a collective team effort by legal scholars and specialists in mathematics and programming to create ABM. To increase these teams' (associations) efficiency and professionalism, they should not merely be enthusiastic scientists who, for the sake of diversity, have decided to "try their hand" and use ABM technology to predict a social phenomenon. These specialists must become experts and work with higher state body strategic legal decision-makers, such as the Verkhovna Rada of Ukraine, the Cabinet of Ministers of Ukraine, and the National Bank of Ukraine. In the future, forecast teams (centers) may exist in each ministry department. Strategic legal decisions should be made for a period of 5 to 20 years (in some more predictable sectors, up to 50 years), given the development of the economy and Ukraine's social sphere. In addition, they should consider international trends of globalization, cooperation, competition, and political stability of potential partners.

Currently, systemic challenges threaten Ukraine's status as an industrial state. The numerous months of voluntaristic decisions between cabinet ministers and ministers, the steady decline in the country's economic potential, living standards, devaluation of its currency, and increasing external loans undermine Ukraine's independence and threaten it to relegation as an agrarian state and a raw material appendage of the "Western partners." Thus, there is a need for fateful legal decisions on objective grounds. Strategic planning of ways out of the crisis and further state development must be a state priority and strictly abided. To normatively consolidate this development, adopting the law "On strategic planning in Ukraine" is vital to accomplish the following:

1. Regulate the need and procedure for long-term state planning, defining key economic and social indicators in various sectors of the economy;

2. Distribute the powers and responsibilities of state bodies and local governments at different stages of the plan's implementation;
3. Determine the procedure for adopting the "Strategic Program for State Development." One of its elements is to provide for the need to create and agree, within the Verkhovna Rada of Ukraine profile committees, on the ABM's specific areas.

Strategic planning and its organization with the help of ABM

According to Gorbulin and Kaczynski (2010), strategic planning is not the same as strategic thinking and action. Strategic thinking is of the utmost importance here, whereas strategic planning is useful only if it improves strategic thinking and action, but it does not replace them. The creation of strategic documents of different levels has different origins, including the state's top political leadership's vision, National Security and Defense Council's top managers' intuition, and subjects' collective experience. Strategic planning is one of them. All these sources must be considered to optimize strategic thinking and action. Thus, perhaps the most apparent benefit potentially provided by strategic planning is that it stimulates strategic thinking and action.

One can agree with the position of these authors on the primacy of strategic thinking, which is provided by strategic planning, and not vice versa. Therefore, strategic planning is not an end in itself and not a panacea for social unrest. It is a tool of interested leaders who have genuinely set the goal of achieving profound changes in all spheres of public relations and life, which will not give any benefits in the results of such planning (Radzivill et al., 2018). The use of ABM in legal decision-making is possible only if the government has clearly defined the goals of public administration and chosen a suitable vector for the development of society.

Science argues that specific and clear goals can help determine the direction of state national security policy, its individual components, and related programs. Goals in management are presented as an ideal image (logical model) of the vision of the state or object of management, formed based on the understanding and consideration of its objective laws and organizational norms, needs, and interests. Goals are a product of consciousness; thus, each goal can have quite a different relationship between real and ideal (Gorbulin & Kaczynski, 2010).

Most developed countries have laws on strategic planning that allow these countries to achieve economic and social development because they have specific strategic goals and defined ways to achieve them, well-established development vectors, and clear political preferences. For example, the UK's Planning and Compulsory Purchase Bill (RSV), adopted by Parliament in April 2004, provides the legal basis for the system's functioning and the implementation of the strategic planning process at the national level (Ivashchenko & Verbytsky, 2006).

The US legislative act defining strategic planning procedures at the national level is the 1993 Government Performance and Results Act (GPRA). In contrast to the United Kingdom, this document defines the hierarchy of strategic planning of the executive branch and the specific time frame for the preparation of planning documents. It consists of 11 sections: Summary, Data and Objectives Obtained, Implementation of Strategic Planning, Annual Performance Planning and Reporting Mechanism, Management Accountability and Flexibility, Pilot Projects, US Postal Service, Legislative support and supervision of the Congress, Preparation, Implementation of the law, and Technical and Harmonization Annexes (Ivashchenko & Verbytsky, 2006).

In 2014, the Federal Law on Strategic Planning in the Russian Federation (2014) was adopted. It establishes the legal framework for strategic planning in the Russian Federation, coordination of state and municipal strategic management and budget policy, the powers of federal authorities, public authorities of the Russian Federation, local governments, and the procedure for their interaction with the public and scientific and other organizations involved in strategic planning. The existence of normative support for strategic planning in Ukraine and the use of a mechanism for forecasting its consequences through their immediate objectification (in the form of ABM) should provide Ukraine with the necessary impetus for further development. However, the reluctance or inability of the government to provide a transparent, clear, and objective answer to the directions and ways of state development can hinder this stride.

Numerous works by Western scholars evidence a worldwide void in the development of this area of research in the legal field. State support to Ukrainian scientists concerning the development of this vector of scientific research depends on the interested authorities' ability to use the results of this research, which is not limited to providing a step forward but an instant look into decades in the future.

Using agent-oriented models will enable law enforcement agencies to determine the development directions of negative and positive phenomena in society in advance. For example, they can help determine trends in specific offenses and crimes, the best types and amounts of tax rates and tax sanctions, forecast demand for certain goods, and calculate the spread rate of serious diseases to effectively and opportunely take appropriate measures to overcome or support the studied phenomena.

The International Data Corporation (IDC) predicts that the total amount of data will reach 35,000 exabytes by 2020. Compared to 1,200 exabytes in 2010, this almost a 30-fold growth in ten years (blogs, social networks, analytical materials, photos, maps, etc.). The need to process such a large amount requires a new generation of analytical systems, including advanced calculation methods, pattern recognition, data warehouse organization, and statistics collection to extract meaning from the data and obtain information context. This wager includes agent models (Bakhtizin, 2015).

An ordinary personal computer with good performance can perform calculations with a satisfactory speed over the number of agents of about 20 thousand (the behavior of each is given by about 20 functions), and the average conversion time of one unit of model time (one year) is about a minute. With more agents (for example, 100 thousand), the computer simply "idles." However, using 1000 supercomputer processors and executing an optimized code allows the number of agents to reach 100 million agents and run a 50-year model. This enormous array of calculations is performed over a period of approximately 1 minute 30 seconds, depending on the type of processors used (Bakhtizin, 2015).

Conclusions

As shown in this study, the use of ABM to address a state's pressing social, environmental, and economic issues and strategic planning in favor of its development has been studied by many scientists worldwide. Stimulating, complex, and effective studies have been carried out. The real results obtained have had practical significance in forecasting social, ecological, and economic phenomena and, on these bases, state strategic planning. All these scientists unanimously recognize the effectiveness of ABM and agree on the need for its improvement and use in all spheres of society and the state. Similarly, some units of scientific work have been devoted to the possibility of using this type of simulation in forecasting and adjusting state formation and legal regulation.

Based on a well-defined explanation of the features and benefits of ABM, this study aimed to prove the need for their use in strategic state planning, law-making, and law enforcement. The article also formulated and substantiated specific proposals on the need to adopt a law on strategic planning in Ukraine and proposed its content. Furthermore, it justified the need to adopt a strategic state development program to create and coordinate ABM implementation programs within the relevant committees of the Council of Ukraine for specific areas.

We can conclude that the development of digital simulation technologies has provided new opportunities for humanity in recent years. ABM contribute to countries that have mastered their creation, allowing them to predict the emergence and development of socio-economic processes in society. There is no doubt about the effectiveness of ABM both in the field of legal research and law-making and law enforcement activities. The success of Western and some post-Soviet countries using these technologies indicates that, in the future, in conditions of total resource scarcity, civilizational competitiveness will be given to countries that prioritize strategic planning using simulation technologies, applying them to all spheres of life.

ABM technologies can provide answers in state strategic planning. However, they can also contribute significantly to scientific and legal research concerning quantitative and qualitative data on the economy, social reality, and political vectors of develop-

ment, aimed at obtaining objective indicators and their trends and activities using ABM. Unfortunately, as evidenced by the numerous works of Western scholars, there is a worldwide deficiency in the development of this area concerning the legal field. State support for Ukrainian scientists developing this vector of scientific research depends on the interested authorities' ability to use the results of such research.

Ukraine is moving towards Euro-Atlantic integration, so the experience of Great Britain and other European countries, the United States of America, and post-Soviet countries should inspire it to make more active use of ABM technologies. The success of these technologies and knowledge obtained through their use is evidenced in this article, which is clearly in favor of their use.

To ensure the possibility of using ABM to forecast socio-economic, environmental, and political problems in Ukraine, based on this knowledge of timely adjustment of legal decisions in the direction of national development, it is necessary to:

- Adopt the Law of Ukraine "On Strategic Planning," which provides for the sections formulated in the article;
- Based on this law, adopt a strategic state development program, which must be developed with the help of ABM;
- Organize the activities of state bodies that should be engaged in strategic planning (primarily the Verkhovna Rada of Ukraine, Cabinet of Ministers of Ukraine, and later, other state bodies and local governments), supported by a team of experts in economics, law, mathematics, programming, and other areas of knowledge required in specific cases to create ABM of relevant social phenomena and processes;
- Determine the issues concerning ABM development in specialized state educational institutions, and introduce new specialties related to these activities;
- Make strategic legal state decisions based on objective data and calculated for 10-50 years and grant priority and legal supremacy to other (regional, local) legal decisions and development programs.

Recommendations

The conclusions and justifications presented in this article were formulated primarily for use by government agencies and their officials, who analyze the state and forecast its development as a whole and individual areas or territories. Based on these findings, the state can take concrete steps to help strategic planning of its development and improve approaches to strategic legal decisions. The study results can also be useful for the legal community of Ukraine and other countries that seek to overcome global challenges with the help of new technologies and ensure sustainable development of society and the state. Finally, the proposals of this article can be used by large and medium-sized businesses trying to predict the development of the global or sectoral market in which it operates.

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