Modeling and Simulation of Urban Growth in the Use of Industry 4.0

Erdal Özbay^{1*}; Feyza Altunbey Özbay²

^{1*}Computer Engineering Department & Firat University, Turkey

^{2*}Software Engineering Department & Firat University, Turkey

^{1*}erdalozbay@firat.edu.tr; ²faltunbey@firat.edu.tr

DOI: 10.47760/ijcsmc.2020.v09i11.003

Abstract— *Industrial growth is the positive increase of various opportunities and factors in a region within the framework of certain planning over time. Along with the developing technologies, Remote Sensing (RS), Geographic Information Systems (GIS), and simulation models are used to see the results of industrial growth effects and to create predictions. The findings obtained are guiding in terms of planning, investment studies, and management. In this context, the data obtained by using RS and GIS are input data for different simulation models, while simulation models provide predictions for the future with information in the past and present time period. Various hybrid simulation techniques are used in the computer-aided industrial simulation, consisting of Monte-Carlo, Petri-Networks, reality and traffic simulation, and their combination. In this context, the basic components and properties of an industrially strong and healthy simulation will be emphasized. In this study, by considering the integration of RS and GIS with simulation models in modeling industrial systems, the Von Thünen Model, Concentric Zoning Theory, Central Field Theory, Sector Theory, Artificial Neural Networks, Markov Chains, Cellular Automaton, Logistic Regression, and SLEUTH model have been examined.*

Keywords— *Industrial Growth, Modeling, Simulation, Remote Sensing, Geographic Information Systems*

I. INTRODUCTION

Simulation is a modeling technique that provides the basis for monitoring the properties of the real system by moving the data of a physical system that exists in the real world to a virtual environment. It provides advantages in terms of time, cost, and risk management since it can make the development of processes traceable. The aim of the simulation is to miss the possibilities in advance in the virtual world and to plan the necessary preparations [1]. A successful simulation is possible by digitally modeling all the data of the physical system. It has become a method that can be used in every field from manufacturing to business administration, from health to education, in terms of giving necessary responses thanks to the plans prepared for new situations [2].

The development of simulation-based design technologies has accelerated with the increase of computer systems and tools. Modeling methods, computing tools, virtual reality environments, collaborative engineering environment infrastructure, and similar tools are increasing day by day [3]. Before the 70's, it was widely believed that industrial design was of a dimension based on tests in many areas and that it would not be possible

to observe the results without realizing and testing the model. In the 1980s, a change occurred with the help of computer systems, and today, with computer-aided simulation environments, industrial design optimization, analysis, reverse engineering has become economically beneficial before advanced rapid prototyping and even in determining the industrial dynamics of the company [4].

A more realistic and sustainable realization of urban planning with analytical approaches in developed societies is among the important goals. Today, technological developments provide important tools in the creation and evaluation of sustainable plans. In this context, RS, GIS, and simulation models appear as current and important techniques that increase the accuracy of the studies. With remote sensing, the current data requirement can be met by obtaining data at various resolution levels and at any time. GIS, on the other hand, offers important tools for both the examination of the current situation and planning studies with its powerful analysis capabilities. Simulation models, on the other hand, are a key step for effective planning studies where the necessary measures are taken by projecting future changes. The increasing population and the need for new residential areas have been very effective in the development of urban growth simulation models in order to make better transportation and city plans. Models such as the Von Thünen Model, Concentric Zoning Theory Model, Central Area Theory Model, and Sector Area Theory Model are accepted as the first urban growth models. Today, many simulation models such as Cellular Automata (CA), Artificial Neural Networks (ANN), Markov Chains, SLEUTH Model, etc. have been developed in modeling urban growth and land use/cover changes [5].

II. RELATED WORKS

The development of steady-state simulations and original-case simulations differed from each other [6]. While steady-state simulations are expressed in a clear mathematical structure like a chemical reaction process, original state simulations may not have simple mathematical representations [7]. Studies to develop simulation tools have increased especially after 1987. Today, Monte-Carlo simulation, Petri-net simulation, reality simulation, traffic simulation, and hybrid simulation techniques established with the combination of these methods are used in many areas from condensed matter physics to manufacturing, from logistics to management [8]. Monte-Carlo simulation, named by Nicholas Metropolis, was used by Stanislaw Ulam and John Von Neumann to calculate neutron chain reactions [9]. The main purpose of all studies is to find out what features a successful industrial simulation should have [10]. In 1992, Cornell University professor Lee W. Schruben developed the SIGMA program, which consists of the first letters of the words simulation, graphic modeling, and analysis, to increase the quality of simulation training. In many decision-based areas such as manufacturing, logistics support, distribution, health, communication, and computing networks, events are shown with connection nodes, and the relationships between events are shown with arrows in graphics for unique situation simulations. In this respect, an example of the time-delayed condition graph is shown in figure 1 [6]. Mackulak *et al*. Reported the intelligent simulation system research, which they called IntelliSIM [11].

Fig. 1 Example of a time-delayed condition status graph

The virtual reality infrastructure created with simulations provides temporal gains in today's conditions where competition is very high. In many areas, newly designed product features can be tested in a computer environment and production can be carried out after the most suitable features are obtained. In 1998, the general change in the design approach was defined as a spatial concept with continuous recycling in which the design, simulation, and evaluation processes work together with a dynamic spiral design rather than with two-dimensional planar models with feedback [3]. The simulation and evaluation processes of industrial design approaches are shown in figure 2. According to this definition, in simulation-based design, simulation should be used throughout the entire life cycle of the product, from concept development to detailed design, prototype manufacturing to manufacturing processes and maintenance. This concept is also important in the simulation of industrial dynamics [4].

Fig. 2 Industrial design approaches

2.1. Simulation and Sample Applications in Industry 4.0

Weyer *et al.*, in their study in 2016, emphasize the importance of the physical world and digital components for the creation of new generation smart factories. In order for simulation tools to support engineering and decision-making systems, it is aimed to evaluate external and internal changes and react to critical effects on manufacturing management in a timely manner. In this respect, the flowchart about simulation tools and the decision-making process is shown in figure 3. In the factory of the future, it is aimed to have a more intelligent structure and a wider network in order to transform field devices, tooling machines, production modules, and products into a Cyber-Physical System [12, 13].

Fig. 3 Simulation tools and decision-making process

While traditional simulation technologies are mostly used in the design and engineering phases, it is expected that multidisciplinary simulation will be used in every field in order to make the right decision in a short time, especially in the stages of increased production. This situation is called “simultaneous simulation”. In order for the simultaneous simulation to be applied successfully, it is expected that the correct digital representation will show the flexible change in accordance with the physical copy. In the relevant simulation models, dynamic wealth, internal supply preparation, data exchange between physical and digital factory, and all real-world changes should be able to be viewed in a virtual environment. Figure 4 shows the process steps in the use of simulation as a decision support system in CPS-based production [13].

Fig. 4 Simulation layout diagram before real change decision

Developing internet technologies strengthen communication between devices, machines, manufacturing modules, and products that can work autonomously with regional control intelligence [13, 14]. Thus, the traditionally used rigid manufacturing hierarchy turns into an organization that can make decentralized decisions and operates automatically [15]. With the adaptation of the plug and play principle to industrial technologies, it will be possible to add and remove manufacturing components to operations. At this stage, it will enable the smart factory management to plan and supervise production faster by establishing an autonomous management infrastructure by creating virtual processes that were previously seen with simulations [16].

It has been reported that simulation models should be internally connected and synchronized with each other, create a real synergy between simulation tools by providing the real-time exchange of relevant data, and be open to new opportunities in more complex scenarios. Direct user interface (via computer, tablet systems) provides end-user access to simulation tools [13]. The second stage includes the simulation development data of the functional process logic and the third stage represents the data acquisition through the CPS. At this stage, real descriptive data must be integrated into the CPS with existing standards. The asset should include static data, sub-models, internal standards. As a result, the dynamic data of the CPS should show the current state of the device with relevant behavioral patterns, appropriate logic signals, process functions [13].

Simulation tools have a wide range of industrial uses, from manufacturing to health, from business to marketing. Even Kamihigashi and Stachurski have reported a simulation algorithm to model industry dynamics, even the development of the industry can be decided in the simulation environment [17]. Today, rapid modeling tools and physically-based simulation tools have a wide range of uses in design. In this area, it is seen that a virtual product development environment is created with the integration of many commercial CAD / CAM / CAE systems and other auxiliary computer programs and analysis programs. Thanks to the technology that virtual reality environments constitute, the effects of change in industrial product design can be observed instantly and thus errors can be minimized. High-quality graphics systems have been developed for this purpose [18]. With computer-aided manufacturing systems, tool paths can be simulated in advance, and risks such as collision by unsuitable tool and tool holder components can be prevented. Denkena and Winter reported on a simulation-based road-mapping method to reduce time and cost during the rotor blade production planning stage for the wind turbine industry [19].

III.URBAN GROWTH SIMULATION MODELS

Many theories have emerged to determine urban growth. However, many models are inadequate today due to the complex nature of cities, and new approaches have been developed in the light of technological developments. In this study, urban growth simulation models; first simulation models, and simulation models for complex city systems are examined under two headings.

3.1. Simulation Models

3.1.1 Von Thünen Model

At the beginning of the 19th century, Von Thünen investigated how land-use changes depending on the location. In this context, he considered its market position as the center of the city and thought that the distance to the center might cause differences in agricultural products. These differences also created differences in land use. As shown in figure 5, in this theorem, where the transportation factor is assumed to be distributed homogeneously throughout the area, land uses are expressed with different circles [20].

Fig. 5 Land use types according to Von Thünen model

3.1.2 Concentric Zoning Theory

In the Concentric Zoning Theory proposed by Ernest Burgess in 1926, the urban space consists of five intertwined regions as shown in figure 6. This figure shows that the trends of any town or city can expand radially from the central business districts. In the area surrounding the city center, there is a transition zone used by business and light manufacturing. The third zone is the areas where industrial workers who escape from the transition area but want to have easy access to their work areas live. Around this area, neighborhoods are consisting of apartments or single-family residences. In the fifth zone, there are suburban areas or satellite city areas [21].

Fig. 6 Concentric Zoning Theory

3.1.3 Central Field Theory

The Central Field Theory was designed by geographer Christaller in 1933. In the model, the settlements are defined with geometric shapes such as triangle and hexagon. As shown in figure 7, the center is determined by the number of small districts that are equidistant from it [22].

According to the theory, from the very poor and socially deviant in the inner transition zone, concentric zones are introduced around the central area defined by settlement structures, moving towards a peripheral suburban ring.

Fig. 7 Central place theory [23]

3.1.4 Sector Theory

Sector Theory is a theory proposed by Hoyt in 1939 as a result of developing the Concentric Field Theory put forward by Burgess as seen in figure 8. In this model, it has been observed that the main transportation roads disrupt the concentric circles on the land, and the residences and business centers move along the main transportation routes. In addition, it is accepted that social pressures, topographic structure, and geographical factors are effective in the formation of slices [24].

This theory is based on the observation that land utilization along major transport routes disrupts the concentric circle's theory, and some business and residential areas tend to develop along the main transport channels on which they are located. In this theory, the assumption is accepted that social pressures, geographical, topographic, or other types of gravity constitute slices. However, in this theory, it is seen that the social class difference is very simplified. Planning decisions of public institutions are not taken into account. Finally, in this theory, like the concentric zoning theory, special places for industry and green areas are not given. It can be said that this theory is more valid for the cities of less developed countries.

Fig. 8 Homer Hoyt's Sector Theory [24]

3.2. Simulation Models for Complex Urban Systems

It is much more difficult to predict possible changes in complex systems than in simple structures [25]. For this reason, classical methods are insufficient due to the complex situations in cities under the effect of rapid growth. This is due to the fact that space and time-dependent situations do not progress in a normal structure, the errors that the variables have, and the actual changes are not linear, although the model used is linear. In this context, many urban growth models have been created in order to get realistic results. Measuring and visualizing the concept of complexity with these models provided reliable and accurate results [26].

3.2.1 Artificial Neural Networks

Artificial Neural Networks (ANN) can collect information about samples, make generalizations, and then make decisions about those examples by using the information they have learned when compared to examples that they have never seen. Due to these learning and generalization features, artificial neural networks have found wide application opportunities in many scientific fields today and have demonstrated the ability to successfully solve complex problems.

ANN is based on the principle of learning events and generating appropriate responses to new situations, using existing examples. This method is inspired by the human brain. Learning is carried out through artificial nerve cells (neurons). In the ANN model; A neuron/processing element is a processing element that sums up its inputs and produces output only when the sum of inputs exceeds the internal threshold value. The signals at the neuron inputs are taken and multiplied by the weight vectors and added. If the summed signal power exceeds the threshold function, an exit signal is generated. As shown in figure 9, ANN is created by connecting these simple neurons (nodes or units) to a network [27].

ANN is used effectively in analyzes such as transportation planning, land use classification, land-use changes and urban growth simulation.

Fig. 9 A schematic artificial neural network (ANN) with two hidden layers and a single neuron output

3.2.2 Markov Chains

Planning uncertainties are frequently encountered in urban planning processes. Uncertainties encountered are generally uncertainties arising from the variable as a result of an event-related uncertainty or change but cannot be calculated. In such problems encountered, planning phenomena can be transformed into mathematical systems and the uncertainty variable can be defined with probability calculations. This transformed mathematical model is called Markov Chains. In the Markov Chains model, analysis is made according to the probabilities of events that are thought to happen in the future. In this context, the possibilities of past and present events are used [28]. The working principle of the model is to predict an event at time $t + 1$ in the future

based on a time t . The Markov Chains model is a particularly useful model for problems related to the transition from one state or location to another state or position. The word “status” refers to the size of city classes, land uses, income classes, agricultural production types, and other variables. The changes caused by these variables are described with the Markov Chains model, and analysis is successfully achieved through this model. Markov Chains have been applied to develop dynamic models to identify changing land uses over time. This model is widely used in modeling the land-use changes in rural and urban areas within the framework of large scales, taking into account the time-dependent transition models [29]. In this context, planning studies can be directed by predicting possible future changes [30].

3.2.3 Cellular Automata

The main goal of computer science is to design models suitable for the computing abilities of computers. Cellular automata were first proposed by John Von Neumann, who determined the working principles of today's computers [31]. Neumann had the knowledge and experience to design models suitable for the computational capabilities of computer architecture. Neumann stated that computer systems should work using discrete and binary number systems and made his proposed principles accordingly [32].

Cellular automata attracted the attention of a few scientists until the 1970s. Understanding the working logic of cellular automata and attracting the attention of scientists was achieved with the “Game of Life” designed by Conway. The Game of Life had a 9-neighbor structure developed by Moore, different from the fact that each cell had 5 neighbors proposed by Neumann. According to Moore's neighborhood, each cell in the grid plane determines its next state concerning itself and the eight cells around it. The neighborhoods of Neumann and Moore are shown in figure 10 [33].

Fig. 10 Neumann and Moore neighborhood

The program simulates a simple hypothetical organism's struggle to survive in different environments such as solitude and overcrowding. Nowadays, this basic idea is used to better understand or predict occurrences such as pedestrian behavior, escape, and panic dynamics, the spread of forest fires, population growth, and migration [34]. In the Game of Life model, a cell determines its own situation by getting information from eight cells it is neighbor. As a result of this rule, the cell can be formed alive or dead. For any cell, the states of the cells can be as follows:

- If a living cell has two or three living neighboring cells, it passes to the next generation unchanged (Figure 11-a)).
- If a living cell has more than three live neighbors, it dies due to crowding and if it has fewer than two live neighboring cells it dies due to loneliness (Figure 11-b)).
- A dead cell comes alive if it has exactly three living neighbors (Figure 11-c)).
- If a dead cell has more than three or less than two live neighboring cells, it continues in a dead state (Figure 11-d)).

Fig. 11 The Game of Life

Many models that are integrated with The Game of Life or based on The Game of Life have been developed and are used effectively in simulating urban growth.

3.2.4 Logistic Regression

Logistic regression analysis is based on a nonlinear, multivariate regression relationship between a dependent variable and more than one independent variable. It is used to predict the results of a categorical data variable based on one or more predictive variables. Dependent variables create categorical data and take discrete values,

while independent variables are continuous or categorical, although they do not have such an obligation. The logistic regression method is defined by the following linear equation:

$$Y = b_0 + b_1x_1 + b_2x_2 + \dots + b_nx_n \quad (1)$$

In the equation (1), Y is the dependent variable between zero and one, b_0 is the value of the dependent variable when the independent variables take the zero value, $b_1 \dots b_n$ regression coefficients of independent variables, $x_1 \dots x_n$ denotes the independent variables.

The purpose of logistic regression analysis is to predict the state of the dependent variable in the simplest way. In land-use studies, the extent to which the land is affected numerically by more than one dependent variable can be explained qualitatively based on the mathematical formula with the Logistic regression method. Regression analysis, which has recently become widespread, especially in social sciences, is widely used, especially in studies based on cause-effect relationships. Based on this factor, which constitutes the principle of geography, the geographical explanation can be made according to dependent and independent factors. Logistic regression analysis can be done with statistical programs as well as with different remote sensing software. In particular, land use planning is made for the future with the model where the land cover change can be calculated with a remote sensing program such as IDRISI.

3.2.5 SLEUTH

Cellular automaton-based SLEUTH software was used within the scope of the Gigalopolis project, which was carried out jointly by USGS and the Department of Geography of the University of California, Santa Barbara, aiming to create simulation models of urban dynamics. SLEUTH is a cellular automaton-based model used to simulate urban growth and identify other land-use changes. The model was first created by Keith C. Clarke in 1992 [35]. The variables that the SLEUTH model takes from its initials are;

- 1- Slope,
- 2- Land Cover,
- 3- Exclusion,
- 4- Urbanization,
- 5- Transportation,
- 6- Hillshade.

SLEUTH, a study derived from the “Clarke Urban Growth Model” (UGM), uses the Cellular automaton, maps and Land Cover Deltatron (LCD) model to illustrate urban growth. If the Unix-based program is to be used in the Windows operating system, it is necessary to use an intermediary software called Cygwin. The program is run with the “grow” command, the necessary parameters are defined by the changes made in the script file. The LCD Model is contained in a code that is operated and called by the UGM. LCD is mapped to urban code; however, UGM can also work independently of them. All of the combined models are called SLEUTH. The SLEUTH model first started in the USA and then spread all over the world and became used in scientific studies. The model, which was created with a geographer's point of view and emphasizes geographical factors, is used extensively in urban development and land-use simulations. As shown in table 1, SLEUTH uses four growth rules and the five growth coefficients associated with these rules when constructing the simulation model.

Table. 1 SLEUTH growth rules and coefficients

Growth Rule	Growth Coefficient
Natural Growth	Distribution, Slope
New Spreading Center	Appearance, Slope
Perimeter Growth	Spread, Slope
Road Effect Growth	Emergence, Slope, Shooting Road, Scattering

The structure of SLEUTH consists of three stages:

- Growth Cycle
- Basic Simulation
- Process Flow Mode
- Test Process Flow
- Calibration Process Flow
- Prediction Process Flow

Growth rules in the SLEUTH model correspond to a range of coefficients ranging from 0 to 100. There are five different factors that control the model's behavior. These are scattered, emergence, spread, slope, and road gravity coefficient specified in table 1 [36].

With the SEUTH model, especially urban development is explained by growth rules under the effect of growth coefficients. With the SLEUTH model, which is a geographical model, urban land use is determined and development axes are predicted more accurately in the light of geographical factors.

SLEUTH model can be integrated with raster-based remote sensing data due to its cellular data structure [37]. As stated above in the model, two topographic data in the form of slope and relief are required. Although relief data is used in visualization in the model, it does not play a role in determining the model behavior. Land use data classified in two different periods are required for the implementation of the Deltatron sub-model. However, land use data are not required to simulate urban growth. An outer zone layer is used to put constraints on urban growth. This layer can also be a weighted layer, thus acting as "resistances" to growth to slow down urbanization. Urban areas are critical and necessary data for the model. Urban areas layer is needed for at least 4 different times. These layers show the extent of urban areas at different times. The last layer required for the use of SLEUTH is transportation. Transportation maps of different time periods show the development of the transportation network over time. Roads in the transport network are classified according to their types, as different types of roads affect urban growth in different ways. The advantages of the SLEUTH model in modeling physical dynamics are as follows [38]:

- Independent scale
- Dynamic and future-oriented
- Using under different conditions by changing some initial conditions and input data layers
- Can be applied to all regions with different data sets

IV. CONCLUSION

The goal of planning is to predict future problems and help solve these problems. In this context, urban growth simulation studies are of critical importance in terms of urban planning. In this study, the methods used to simulate urban growth for industry 4.0 were discussed and information was given about the first simulation models and new approaches. In addition, the importance of remote sensing in obtaining the data required for simulation, preparation of input layers, and GIS was emphasized.

Developments in computer technology made it possible to simulate especially urban complexity by simplifying it. Simulation models, which are used extensively as explanation methods in the world literature, are of vital importance especially in terms of future land use and sustainable development. Simulation models that offer predictions for the future by taking into account the past and current land use can be calculated more accurately, easily, and quickly, especially with remote sensing programs. Cellular automaton, Artificial neural networks, Markov chains, Logistic regression, Stochastic mathematical modeling, Agent-based models, and the SLEUTH model are among the most widely used simulation models. In our study, which we presented by geographically grouping land-use models, it would not be right to ignore the integrated use of models. Some of the models put forward express the spatial change and some of them express the temporal change very well. With the integrated use of these, both temporal and spatial changes can be revealed. The best example of this is the Cellular automaton - Markov (CA_Markov) model.

In conclusion, simulation is an indispensable component in the creation of future factories, systems, and services in the industrial field. For this reason, the following articles are of great importance.

- Development of simulation-based decision-support systems to increase automation in every field.
- Creating a profile of students with professional and technical knowledge who can establish the smart factories of the future in engineering departments.
- Opening multi-disciplinary departments based on simulation, establishing institutes, and developing simulation-supported education infrastructure in accordance with Industry 4.0.

REFERENCES

- [1] B. Hans-Joachim, et al. Modeling and simulation: an application-oriented introduction. *Springer Science & Business Media*, 2013.
- [2] F. Landriscina, Simulation and Learning A Model-Centered Approach, *Springer-Verlag New York*, 2013.
- [3] M. A. Bossak, Simulation based design, *Journal of Materials Processing Technology*, 76, pp. 8–11, 1998.
- [4] C. Garavaglia, Modelling industrial dynamics with "History-friendly" simulations, *Structural Change and Economic Dynamics*, 21, pp. 258-275, 2010.
- [5] S. Sangawongse, C. H. Sun, B. W. Tsai, Urban growth and land cover change in Chiang Mai and Taipei: results from the SLEUTH model. In *Proceedings of MODSIM* pp. 2622-2628, 2005.
- [6] L.W. Schruben, SIGMA-A Graphical Approach to Teaching Simulation, *Journal of Computing in Higher Education*, 4, 1, pp. 27-37, 1992.
- [7] J. Banks, J. Carson, Discrete event system simulation, *Printice Hall, NJ*, 1984.
- [8] M. Jahangirian, T. Eldabi, A. Naseer, L.K. Stergioulas, T. Young, Simulation in manufacturing and business: A review, *European Journal of Operational Research*, 203, pp. 1-13, 2010.
- [9] D. P. Kroese, R. Y. Rubinstein, Monte Carlo methods, *WIREs Computational Statics*, 4, pp. 48–58, 2012.
- [10] J. Banks, E. Aviles, J. R. McLaughlin, R. C. Yuan, The Simulator: New Member of the Simulation Family, *Interfaces*, 21, 2, pp. 76-86, 1991.
- [11] G. T. Mackulak, J. K. Cochran, P. A. Savory, Ascertaining Important Features For Industrial Simulation Environments, *Simulation*, pp. 211-221, 1994.

- [12] J. Lee, B. Bagheri, H. A. Kao, A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, *Manufacturing Letters*, 3, pp. 18-23, 2015.
- [13] S. Weyer, T. Meyer, M. Ohmer, D. Goreck, D. Zühlke, Future Modeling and Simulation of CPS-based Factories: an Example from the Automotive Industry, *IFAC-PapersOnLine*, 49, 31, pp. 97-102, 2016.
- [14] M. Broy, H. Kargermann, R. Achatz, Agenda Cyber Physical Systems: Outlines of a new Research Domain, *Acatech*, Berlin, 2010.
- [15] M. Tseng, F. Piller, The customer centric enterprise: advances in mass customization and personalization, *Springer Science & Business Media*, Berlin, 2011.
- [16] U. Rossgoderer, Industrie 4.0 - Digitalization Strategy, *Plant Simulation Worldwide User Conference Siemens AG*, Stuttgart, 2015.
- [17] T. Kamihigashi, J. Stachurski, Perfect simulation for models of industry dynamics, *Journal of Mathematical Economics*, 56, pp. 9–14, 2015.
- [18] NVIDIA, [Online]. Available: <https://www.nvidia.com/en-us/design-visualization/quadro-desktop-gpus/>
- [19] B. Denkena, F. Winter, Simulation-based planning of production capacity through integrative roadmapping in the wind turbine industry, *9th CIRP Conference on Intelligent Computation in Manufacturing Engineering-CIRP ICME '14*, Procedia CIRP, 33, pp. 105-110, 2015.
- [20] Land Use Models, [Online]. Available: <https://cografyabilim.files.wordpress.com/2012/03/06-arazi-kullanc4b1m-modelleri.pdf>
- [21] R. E. Park, E. W. Burgess, R. D. McKenzie, The City. *The University of Chicago Press*, 50, London, 1925.
- [22] İ. E. Ayazlı, Ulaşım Ağlarının Etkisiyle Kentsel Yayılmanın Simülasyon Modeli: 3. Boğaz Köprüsü Örneği, Doktora Tezi, *Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü*, 129 s, İstanbul, 2011.
- [23] P. Agarwal, Walter Christaller: Hierarchical patterns of urbanization. *Centre of Spatially Integrated Social Science*, 36, 2007.
- [24] E. J. Kaiser, D. R. Godschalk, F. S. Chapin, Urban land use planning (Vol. 4). *Urbana: University of Illinois press*, 1995.
- [25] R. J. Crawford, What Can Complexity Theory Tell Us About Urban Planning? *New Zealand Productivity Commission Te Komihana Whai Hua o Aotearoa*, 2016.
- [26] D. Bowyer, Measuring Urban Growth, Urban Form and Accessibility as Indicators of Urban Sprawl in Hamilton, New Zealand, *Master's Thesis, Physical Geography and Ecosystem Science Centre for Geographical Information Systems Lund University*, 133 p, Lund, Sweden, 2015.
- [27] G. Holmgren, P. Andersson, A. Jakobsson, A. Frigyesi, Artificial neural networks improve and simplify intensive care mortality prognostication: a national cohort study of 217,289 first-time intensive care unit admissions. *Journal of intensive care*, 7, 1, 44, 2019.
- [28] İ. Daşdemir, E. Güngör, Çok Boyutlu Karar Verme Metotları ve Ormanlıkta Uygulama Alanları. *Zonguldak Karaelmas Üniversitesi Bartın Orman Fakültesi Dergisi*, 4, 4, pp. 1-19, 2002.
- [29] L. Collins, An introduction to Markov chain analysis. *Norwich: Geo Abstracts*, 1975.
- [30] A. Çağlıyan, D. Dağlı, Arazi Kullanımında Simülasyon Modelleri ve Entegre Kullanımları. *TÜCAÜM VIII. Coğrafya Sempozyumu*, 2015.
- [31] J. V. Neumann, The theory of self-reproducing Automata, A. W. Burks, Dü., *Urbana and London: Univ. of Illinois Press*, 1966.
- [32] V. V. Nabyev, Algoritmalar Teoriden Uygulamalara, *Seçkin Yayıncılık, Ankara, Türkiye*, 2013.
- [33] E. F. Moore, Machine models of self-reproduction, *Proc. Symp. Appl. Math.*, 14, 17-33, 1962.
- [34] A. D. Yazıcı, D. Öztürk, İ. E. Ayazlı, Kentsel Büyümenin Modellenmesi ve Simülasyon Modelleri. *International Journal of Multidisciplinary Studies and Innovative Technologies*, 3, 1, 44-47, 2019.
- [35] K. C. Clarke, C. Dietzel, N. Goldstein, A Decade of SLEUTHing: Lessons Learned from Applications of a Cellular Automaton Land Use Change Model. *Classics in IJGIS: twenty years of the international journal of geographical information science and systems*, 413-427, 2007.
- [36] N. Bihamda, A. Soffianian, S. Fakheran, Using the SLEUTH Urban Growth Model to Simulate Future Urban Expansion of the Isfahan Metropolitan Area. *Journal of the Indian Society of Remote Sensing*, 43, 2, 407-414, 2013.
- [37] S. Sangawongse, C. H. Sun, B. W. Tsai, Urban Growth and Land Cover Change In Chiang Mai and Taipei: Results From The SLEUTH Model. *MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand*, 2622-2628, 2005.
- [38] Ö. Şevik, Application of SLEUTH Model In Antalya, Master's Thesis, *Middle East Technical University Geodetic and Geographic Information Technologies*, 112 p, Ankara, 2006.