Structural Analysis of the Pricing for the Power Grid Company Team Management Process Based on the System Dynamics Model

A. R. Kinzhalieva and Anna A. Khanova

Abstract The lack of the necessary investment in the electric grid complex over the past 20 years has led to a significant physical and technological obsolescence of electrical networks. In this regard, the task is automatic. The task of ensuring the reliability of the provision of services by electric network companies with a minimum level of costs largely depends on the reduction of the duration of the power interruption of consumers, which can be achieved by improving the process of managing on-duty personnel of operational and field teams. The task of improving the process of managing the field service teams of a power grid company in case of accidents and technological failures is considered. A conceptual description of a system dynamic model based on the Forrester flow diagram is given. A formal description of the process of own and borrowed resources operation pricing is presented. An applied basic system dynamics model for creating simulation models of electricity distribution companies is developed and proposed.

Keywords Simulation modeling · System dynamics · Costs · Power grid company · Field service teams · Accident

1 Introduction

Modern society increasingly depends on a reliable power supply to ensure a sufficient level of functionality and degree of basic need satisfaction. As a consequence, an uninterrupted electricity supply is critical to society, and power grid companies are becoming one of society's most important infrastructures [1] defined as the physical and logical systems necessary for social welfare [2]. Achievement of this task is assessed by the service reliability level [3]. This indicator is directly affected by the average duration of consumer power supply interruption [4]. Therefore, finding ways

A. R. Kinzhalieva (✉) · A. A. Khanova
Astrakhan State Technical University, Tatishcheva street 16, Astrakhan 414056, Russia

A. A. Khanova
e-mail: akhanova@mail.ru

A. G. Kravets et al. (eds.), *Society 5.0: Human-Centered Society Challenges and Solutions*, Studies in Systems, Decision and Control 416,
https://doi.org/10.1007/978-3-030-95112-2_16

to reduce the duration of power outages is required [5]. Particular attention should be paid to the issue of the organization of the team management process during accidents and technological failures, the quality of which depends on the timing of accident and technological failure corrective measures implementation, which ultimately affects the overall customer satisfaction [6]. On the other hand, the rational use of resources allows optimizing the costs associated with their use [7].

The process of managing field service teams during the occurrence of accidents and technological failures in electricity distribution companies is complex, with a large number of possible situations and states. The works of Russian and foreign authors concerning the management and optimization of repair work processes describe the application of artificial intelligence methods [8, 9], including neural networks [10, 11], fuzzy set theory [12, 13], and simulation modeling [14–16]. At the same time, the stochastic nature of emergencies, which is influenced by the specific features of the work of field service teams, the distribution of material and technical resources and the pricing implies the advisability of choosing the simulation modeling method as a research tool [17]. Among the known methods of building simulation models (discrete-event, agent-based, or system-dynamic) it is necessary to choose an approach to modeling, the end result of which should not be the prediction or anticipation of future economic situations, but understanding the essence of the dynamics of the system under study [18, 19]. It is the simulation models of system dynamics that will make it possible to bypass a number of limitations in the study of the management process for field service teams caused by the practical impossibility of obtaining information about this process in various situations during which the system and environment parameters change over time and a number of management processes can be described only approximately [20, 21].

The purpose of this work is to improve the efficiency of the pricing process in the field service team (FST) management for electricity distribution companies by creating and analyzing the behavior of the system dynamics model.

2 Materials and Methods for Solving The Problem of Process Cost Management

In case of receiving an accident alert, the network control center (NCC) determines the category of accident complexity, then determines the adequacy of its own resources (OR)—the number of on-duty personnel and equipment at the FST locations. To eliminate an accident, the NCC forms the FST and provides it with the equipment, depending on the complexity category and the estimated time of elimination. In the event of the lack of own resources, the entire available FST reserve, as well as involved resources (IR)—contractor personnel and equipment, are directed to the accident location. In this case, the FST is formed from ORs and IRs. In the case where all own resources are involved in the emergency and recovery work, the minimum required contractor team is involved. In the simulated system, accidents occur according to the Poisson flow with a given intensity for m days of model time. Suppose the field service teams composed of a total of A people are on duty 24 h a day. The total number of equipment that can be involved is B units. The model implements a mechanism for equipping the FST with personnel and rented equipment in case of lack of own resources, while at the same time a pricing process is implemented.

We begin the construction of the system dynamics model by creating a conceptual description of the system in the form of a Forrester flow diagram [22]. The diagram (Fig. 1) shows the two main cost flows generated by the operation of OR and IR. These flows are similar to each other and are broken down into cost flows related to labor compensation and equipment operation. According to the communicating vessels principle, the costs accumulated at previous levels affect the cost value at subsequent levels (in the diagram, the levels are represented as rectangular blocks 1–9). The cost value at the initial level of each flow depends on the rate of cost flow (in the diagram, the rates are represented as valves I–V). The rate of cost flows is directly affected by: the number of resources involved (personnel and equipment) (A, a_i, a_j, b_i, b_j), tariff rates $(S_1, S_2, S_3, S_4, S_5)$. In this case, the variable A is presented as a constant, because the constant part of the on-duty personnel labor compensation is made regardless of whether the personnel was involved in the accident elimination. This model reflects a simplified scheme for calculating the labor compensation costs of own and involved personnel and costs associated with the operation and rental of equipment.

The following equations determine the cost levels of resource operation.

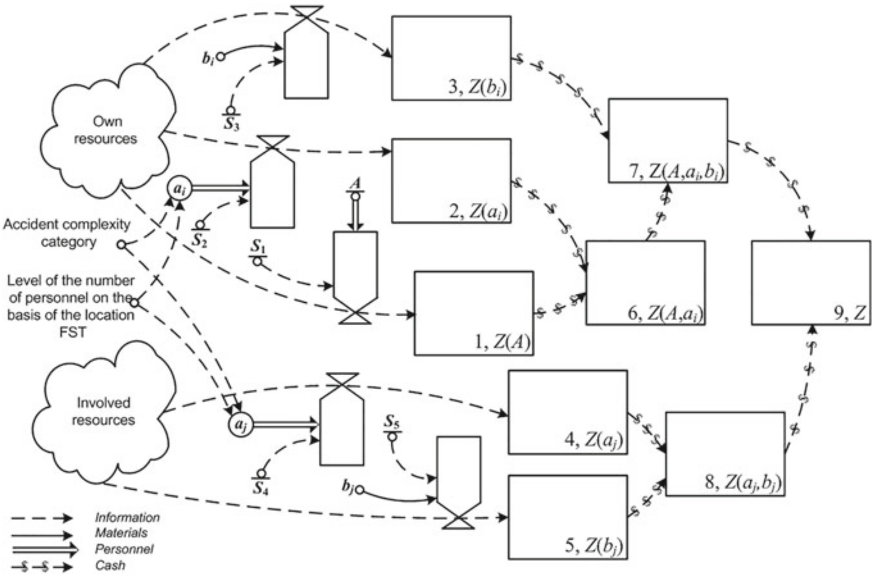

Fig. 1 Diagram of the cost flows associated with the elimination of accidents

The cost value of own personnel (constant part) *Z(A)* is calculated using the following formula (Fig. 1, level 1):

$$Z(A) = A \times S_1 \times m \tag{1}$$

where S_1 is the size of the constant part (tariff rate) of own personnel salary, Rub.

The amount of labor compensation costs for own personnel (variable part) $Z(a_i)$ is calculated using the following formula (Fig. 1, level 2):

$$Z(a_i) = \sum_{i=1}^{k} T_i \times a_i \times S_2 \tag{2}$$

where k is the number of accidents that occurred over m days of the model time eliminated using own resources; S_2 is the rate accrued by own personnel a_i, involved at the time T_i to eliminate the i accident, Rub., $i = \overline{1, k}$.

The cost value of operating own equipment $Z(b_i)$ is calculated using the following formula (Fig. 1, level 3):

$$Z(b_i) = \sum_{i=1}^{k} T_i \times b_i \times S_3 \tag{3}$$

where S_3 is the rate for 1 machine-hour (model time) of work of own equipment b_i involved at the time T_i to eliminate the i accident, Rub.

The labor compensation cost value for the contractor's personnel $Z(a_j)$ is calculated using the following formula (Fig. 1, level 4):

$$Z(a_j) = \sum_{j=1}^{l} T_j \times a_j \times S_4 \tag{4}$$

where l is the number of accidents occurring over m days of the model time, for the elimination of which the contractor is involved; S_4 is the rate accrued by the contractor's personnel a_j involved at the time T_j to eliminate the j accident, Rub., $j = \overline{1, l}$.

The value of the cost of operating rented equipment $Z(b_j)$ is calculated using the following formula (Fig. 1, level 5):

$$Z(b_j) = \sum_{j=1}^{l} T_j \times b_j \times S_5 \tag{5}$$

where S_5 is the rate per 1 machine-hour (model time) of the rented equipment b_j involved at the time T_j to eliminate the j accident, Rub.

The cumulative labor compensation cost amount for own personnel $Z(A,a_i,)$ is calculated using the following formula (Fig. 1, level 6):

$$Z(A, a_i) = Z(A) + Z(a_i) \tag{6}$$

The cumulative value of the labor costs of own personnel and operation of own equipment $Z(A,a_i,\mathrm{b}_i)$ is calculated by the following formula (Fig. 1, level 7):

$$Z(A, a_i, b_i) = Z(A, a_i) + Z(b_i) \tag{7}$$

The cumulative labor compensation cost value of the contractor and the operation of rented equipment $Z(a_j,b_j)$ is calculated using the following formula (Fig. 1, level 8):

$$Z\left(a_j, b_j\right) = Z\left(a_j\right) + Z\left(b_j\right) \tag{8}$$

The total cost value Z is calculated using the following formula (Fig. 1, level 9):

$$Z = Z(A, a_i, b_i) + Z\left(a_j, b_j\right) \tag{9}$$

The cost flow diagram (Fig. 1) is designed to structure the costs of own personnel and contractor personnel, as well as the amount of costs associated with the operation and rental of the equipment and is implemented in the AnyLogic simulation software (Fig. 2).

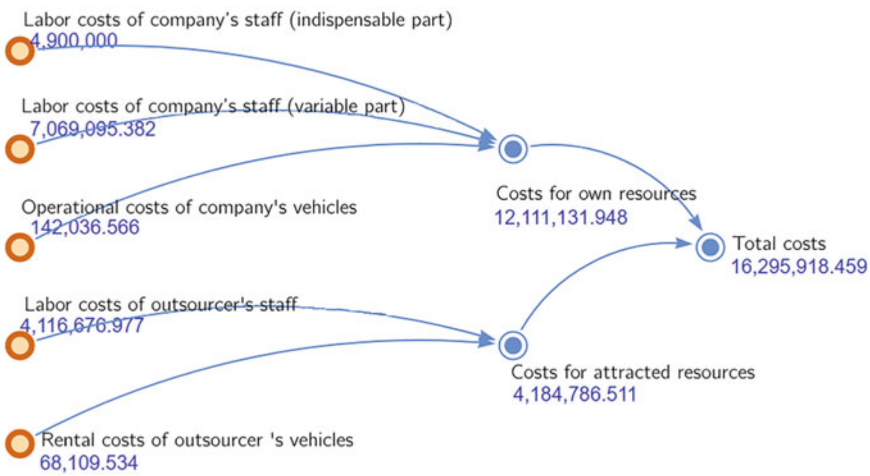

Fig. 2 System dynamics model diagram in Anylogic

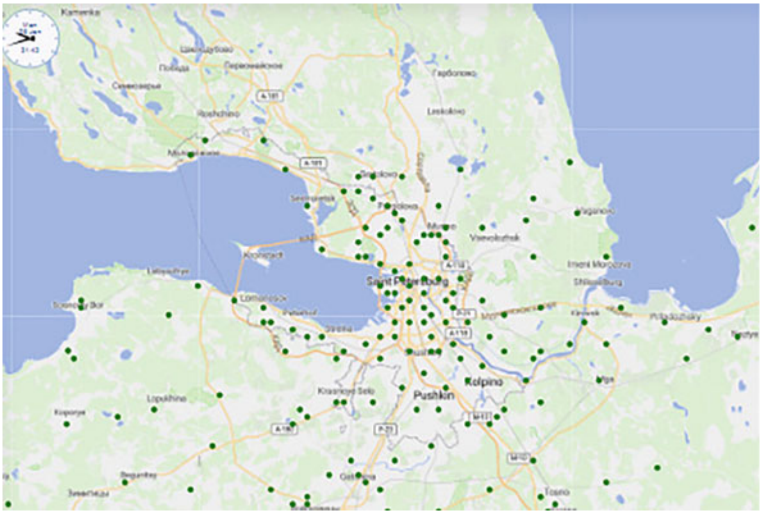

Fig. 3 GIS map of the system dynamics model in Anylogic

The animation diagram of the model should display a GIS map, on which power facilities are marked with green GIS points. Their color should change depending on the difficulty category of the accident: red if there is a category 1 accident; orange if there is a category 2 accident; yellow if there is a category 3 accident. During the entire time of accident elimination, the text information near the GIS point containing the number of involved own personnel and equipment and, separately, the number of involved personnel and rented equipment should be displayed [23]. At the end of the accident elimination time, the GIS point changes color to green, and the text information disappears (Fig. 3).

Depending on what system information is needed and what task is required to be solved using the simulation model, the planning of the experiment is performed taking into account resource constraints. Machine experiment planning is essentially a plan for obtaining the necessary amount of information, the cost of which can vary depending on the method of data collection and processing. Computer simulation experiments are expensive in terms of experimenter time and labor, as well as machine time. The more effort an experimenter puts into one study, the less time they can spend on another, so it is important that they plan the experimentation to get as much information out of each experiment as possible. Thus, the main goal of planning experiments is to determine the most important factors in order to conduct the least number of runs in the model experimenting process.

3 Experimental Results of the System Dynamics Simulation Model

The decomposition of the experiment planning process with the simulation model of cost analysis for the field service team management process of the power grid company is presented in the EPC notation (Fig. 4).

It is assumed that the work with the simulation model will be performed by the Analytical Competence Center (ACC) by a user group with the ACC Specialist role.

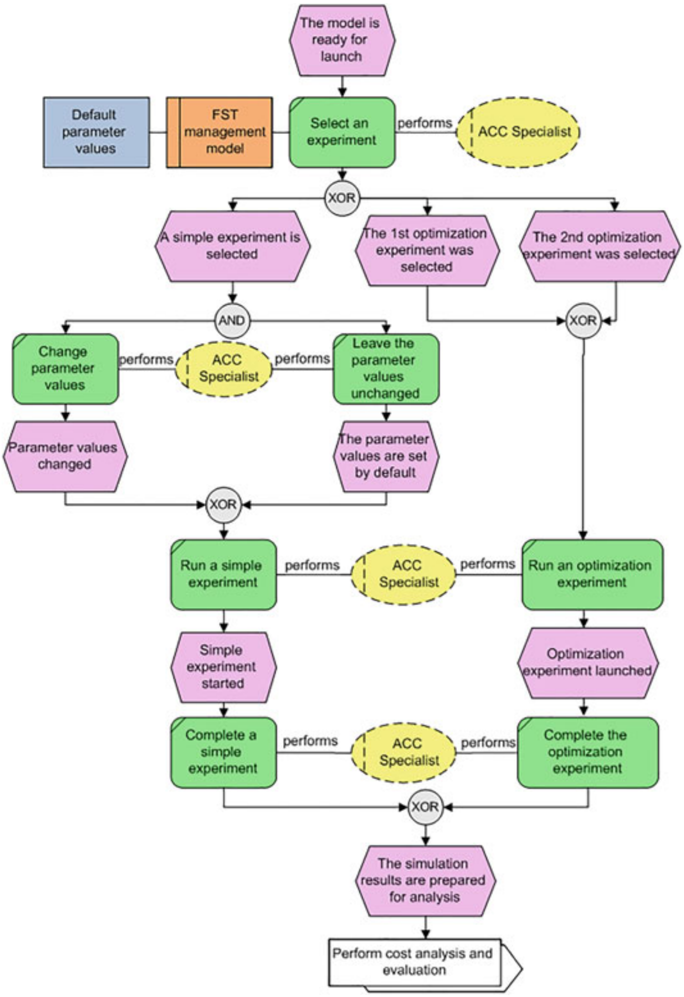

Fig. 4 Stages of the experiment with the model in EPC notation

The simulation model allows an ACC Specialist user to change the default parameter values before running the model. It is assumed that AnyLogic Private Cloud is installed inside the corporate network of a power grid company and PC users connected to the corporate network (with no limit on the number of users) will be able to view the model uploaded to AnyLogic Private Cloud by an ACC Specialist user.

The costs associated with the use of resources to eliminate accidents are visually accumulated in the running model window throughout the simple experiment. The diagrams (Fig. 5) are designed to display the time trend of the cost values for own personnel labor compensation $Z(A,a_i)$; operation of own equipment $Z(b_i)$; contractor labor compensation $Z(a_j)$; operation of rented equipment $Z(b_j)$.

The Consumer power outage duration chart (Fig. 6a) is designed to display the

Fig. 5 Time trends of cost values (animation fragment)

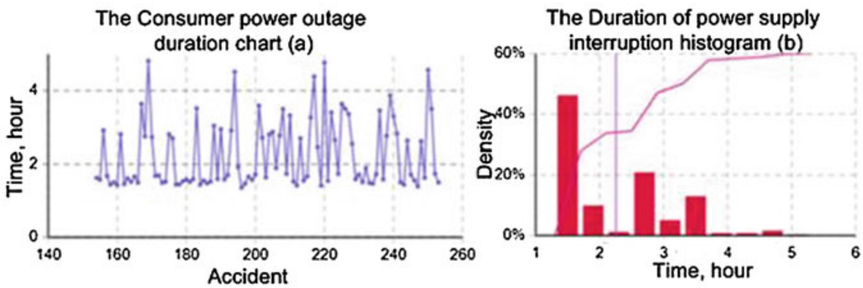

Fig. 6 Time trends of power outage duration (animation fragment)

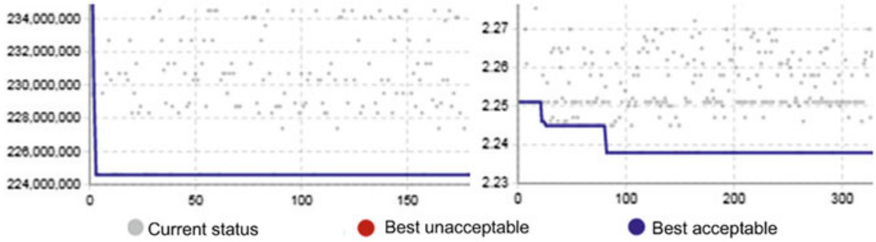

Fig. 7 Experiments with the model

time trend of the average consumer power outage duration. The Duration of power supply interruption histogram (Fig. 6b) is designed to display data on the duration of consumer power supply interruption: the histogram divides the time scale into 10 intervals; the interval in which a greater number of durations occur becomes higher, which means a greater density of entries in this interval.

In determining the optimal number of on-duty personnel and the optimal number of equipment to minimize costs (optimization experiment 1), the best result $Z =$ 224,609,199.40 Rub. was found, which is achieved when $A = 75$ and $B = 37$ (Fig. 7a). In determining the optimal number of on-duty personnel and the optimal number of equipment to reduce the duration of power supply interruption (optimization experiment 2), the best result (power outage duration equal to 2.238 h) was found, which is achieved with $A = 111$ and $B = 50$ (Fig. 7b).

The system dynamics simulation model was developed for Lenenergo PJSC and is a basic model for creating models of similar electricity distribution companies. To adapt the system to the conditions of other power grid companies, it is possible to add and/or change significant factors affecting the level of abstraction, customize the algorithm of field service team formation, set the locations of power facilities on the GIS map, etc.

4 Conclusion

In order to improve the efficiency of field service team management in case of accidents and technological failures, a simulation model with elements of system dynamics was developed to determine the optimal number of resources involved in eliminating accidents and technological failures, in which the average duration of consumer power supply interruption is minimal, as well as to optimize costs associated with personnel compensation and the operation and rental of equipment involved in the elimination of accidents and technological failures.

References

1. Zio, E.: Challenges in the vulnerability and risk analysis of critical infrastructures. Reliab. Eng. Syst. Saf. **152**, 137–150 (2016). https://doi.org/10.1016/j.ress.2016.02.009
2. Sperstad, I.B., Kjølle, G.H., Gjerde O.: A comprehensive framework for vulnerability analysis of extraordinary events in power systems. Reliab. Eng. Syst. Saf. **196**, 106788 (2020). https://doi.org/10.1016/j.ress.2019.106788
3. Ge, S., Sun, H., Hong, L., Li, J., Zhang, X., Cao, Y.: Reliability evaluation of multi-energy microgrids: energy storage devices effects analysis. Energy Proc. **158**, 4453–4458 (2019). https://doi.org/10.1016/j.egypro.2019.01.769
4. Kazakov, I.D., Shcherbakova, N.L., Rayushkin, E.S., Shcherbakov, M.V.: A method for change detection in operating of power generating equipment. In: Kravets A.G., Bolshakov A.A., Shcherbakov M. (eds.) Cyber-Physical Systems: Design and Application for Industry 4.0. Studies in Systems, Decision and Control, vol. 342. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-66081-9_23
5. Pourbeik, P., Kundur, P.S., Taylor, C.W.: The anatomy of a power grid blackout–root causes and dynamics of recent major blackouts. IEEE Power Energ. Mag. **4**(5), 22–29 (2006). https://doi.org/10.1109/MPAE.2006.1687814
6. Abedi, A., Gaudard, L., Romerio, F.: Review of major approaches to analyze vulnerability in power system. Reliab. Eng. Syst. Saf. **183**, 153–172 (2019). https://doi.org/10.1016/j.ress.2018.11.019
7. Kjølle, G.H., Samdal, K., Singh, B., Kvitastein, O.A.: Customer costs related to interruptions and voltage problems: methodology and results. IEEE Trans. Power Syst. **23**, 1030–1038 (2008). https://doi.org/10.1109/TPWRS.2008.922227
8. Protalinskiy, O., Savchenko, N., Khanova, A.: Data mining integration of power grid companies enterprise asset management. In: Kravets A., Bolshakov A., Shcherbakov M. (eds) Cyber-Physical Systems: Industry 4.0 Challenges. Studies in Systems, Decision and Control, vol. 260. Springer, Cham, (2020). https://doi.org/10.1007/978-3-030-32648-7_4
9. Zio, E., Aven, T.: Uncertainties in smart grids behavior and modeling: what are the risks and vulnerabilities? How to analyze them? Energy Policy **39**(10), 6308–6320 (2011). https://doi.org/10.1016/j.enpol.2011.07.030
10. Yang, B.S., Han, T., An, J.L.: Art-Kohonen neural network for fault diagnosis of rotating machinery. Mech. Syst. Signal Process. **18**(3), 645–657 (2004). https://doi.org/10.1016/S0888-3270(03)00073-6
11. Menke, J.-H., Bornhorst, N., Braun, M.: Distribution system monitoring for smart power grids with distributed generation using artificial neural networks. Int. J. Electr. Power Energy Syst. **113**, 472–480 (2019). https://doi.org/10.1016/j.ijepes.2019.05.057
12. Krim, Y., Abbes, D., Krim, S., Mimouni, M.F.: Intelligent droop control and power management of active generator for ancillary services under grid instability using fuzzy logic technology. Control. Eng. Pract. **81**, 215–230 (2018). https://doi.org/10.1016/j.conengprac.2018.09.013
13. Bobyr', M.V., Titov, V.S., Nasser, A.A.: Automation of the cutting-speed control process based on soft fuzzy logic computing. J. Mach. Manuf. Reliab. **44**, 633–641 (2015). https://doi.org/10.3103/S1052618815070067
14. Gerrits, B.: An agent-based simulation model for truck platoon matching. Proc. Comp. Sci. **151**, 751–756 (2019). https://doi.org/10.1016/j.procs.2019.04.101
15. Song, J., Zhang, M.-g., Zheng, F., Chen, F.-z.: Dynamic simulation of the group behavior under fire accidents based on system dynamics. Proc. Eng. **211**, 635–643 (2018). https://doi.org/10.1016/j.proeng.2017.12.058
16. Protalinskiy, O., Khanova, A., Shcherbatov, I.: Simulation of power assets management process. In: Dolinina O., Brovko A., Pechenkin V., Lvov A., Zhmud V., Kreinovich V. (eds) Recent Research in Control Engineering and Decision Making. ICIT 2019. Studies in Systems, Decision and Control, vol. 199. Springer, Cham, (2019). https://doi.org/10.1007/978-3-030-12072-6_40

17. Chen, X., Shen, L., Sha, Z., Liu, R., Chen, S., Ji, G., Tan, C.: A survey of multi-space techniques in spatio-temporal simulation data visualization. Vis. Inform. **3**(3), 129–139 (2019). https://doi.org/10.1016/j.visinf.2019.08.002
18. Ghaffarian, S., Roy, D., Filatova, T., Kerle, N.: Agent-based modelling of post-disaster recovery with remote sensing data. Int. J. Disaster Risk Reduct. **60**, 102285 (2021). https://doi.org/10.1016/j.ijdrr.2021.102285
19. Durán, J.M.: What is a simulation model? Mind Mach. **30**, 301–323 (2020). https://doi.org/10.1007/s11023-020-09520-z
20. Long, Q., Lin, J., Sun, Z.: Modeling and distributed simulation of supply chain with a multi-agent platform. Int. J. Adv. Manuf. Technol. **55**, 1241–1252 (2011). https://doi.org/10.1007/s00170-010-3148-7
21. Podvalny, S., Vasiljev, E.: Simulation of the multialternativity attribute in the processes of adaptive evolution. In: Kravets A., Bolshakov A., Shcherbakov M. (eds.) Cyber-Physical Systems: Advances in Design & Modelling. Studies in Systems, Decision and Control, vol. 259. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-32579-4_13
22. Forrester, J.: Urban Dynamics. Pegasus Communications, Waltham, MA (1969)
23. Anokhin, A., Burov, S., Parygin, D., Rent, V., Sadovnikova, N., Finogeev, A.: Development of scenarios for modeling the behavior of people in an urban environment. In: Kravets A.G., Bolshakov A.A., Shcherbakov M. (eds.) Society 5.0: Cyberspace for Advanced Human-Centered Society. Studies in Systems, Decision and Control, vol. 333, pp. 103–114. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-63563-3_9