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Yereshko J.O.
PhD, Associate Professor
ORCID ID: 0000-0002-9161-8820

Tytarenko A.M.
ORCID ID: 0000-0002-8265-642X

Olesiuk I.J.
ORCID ID: 0000-0002-8560-7850
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

MULTI-AGENT SIMULATIONS FOR THE RENEWABLE RESOURCE MANAGEMENT

МУЛЬТИАГЕНТНЕ МОДЕЛЮВАННЯ В УПРАВЛІННІ ВІДНОВЛЮВАЛЬНИМИ РЕСУРСАМИ

The article is devoted to the research of the renewable resource management and, in particular, the multi-agent approach. Multi–agent systems model the behaviour and interaction of microscopic entities by focusing on their relations to explore parameters and behaviour of the whole system on microscopic level. Multi-agent simulations of this kind allow us to study economic processes in a completely different way, focusing on examining the influence of microagents on the macroscopic parameters of the entire system. In recent related researches the emphasis has been placed on the relations between microscopic and macroscopic levels, using bottom – up and top – bottom approaches.

The authors used the multi–agent approach in order to build a simulation of a renewable resource life cycle. There also was built a model, which uses such tool as the quota for the amount of the collectable resource for harvesting agents to explore how agents will change their behaviour. The behaviour of agents in the simulation is based on a maximization of its own benefit and the MRS (Marginal Rate of Substitution) parameter for the price evaluation. Several experiments were conducted for different values of the Quota parameter, during which the relation between the price level in the markets and the quota for resource extraction was shown. The description of the experiment, its results and conclusions are provided below. The developed solution simplifies the implementation of such experiments in this area, by making the process of their adjustment more flexible and simple.

A framework for creating renewable resource management simulations is being developed. It simplifies the development of environments in order to explore them and to discover diverse patterns and laws within, using particular custom models of agent behaviour. The multi-agent simulator in this article was developed in order to illustrate and discuss the principles of the economic theory of the renewable resource management.

This framework could be used in order to create the environments with the aim of their further studying, using different models of agent behaviour.

Keywords: multi-agent simulations, renewable resource management, distributed simulations.

Стаття присвячена дослідженню управління відновлюваними ресурсами і, зокрема, мультиагентному підходові. Мультиагентні системи моделюють поведінку і взаємодію мікро-суб'єктів, фокусуючись на їх відносинах з метою дослідження параметрів і поведінки всієї системи на мікрорівні. Мультиагентні симуляції такого роду дозволяють нам досліджувати економічні процеси в абсолютно новий спосіб, фокусуючись на вивченні впливу мікроагентів на макропараметри системи в цілому. Останні дослідження, що стосуються даної проблематики, зосереджують основну увагу на відносинах між мікро- і макрорівнями з використанням підходів знизу-вгору і зверху-донизу.

Авторами використано мультиагентний підхід для моделювання життєвого циклу відновлюваних ресурсів. Також, була побудована модель, в якій використовується такий параметр, як "квота" на кількість акумульованого добуваючими агентами ресурсу з метою з'ясування зміни агентами своєї поведінки відповідно до зміни заданого параметру. Поведінка агентів в симуляції заснована на максимізації власної вигоди і параметрі MRS (гранична швидкість заміщення) для аналізу цінового параметру. Було проведено кілька експериментів для різних значень параметра "квота", в ході яких було проілюстровано зв'язок між рівнем цін на ринках і квотою для вилучення ресурсів. Нижче наводиться опис експерименту, його результати і висновки. Розроблене рішення спрощує реалізацію таких експериментів у цій галузі, роблячи процес їх налаштування більш гнучким і простим.

Була, також, розроблена основа для імітаційного моделювання управління поновлюваними ресурсами, що спрощує розробку середовищ з метою їх дослідження і виявлення різноманітних закономірностей, а також, законів всередині системи, з використанням конкретних користувальницьких моделей поведінки агента. Мультиагентний симулятор був розроблений у даному дослідженні з метою ілюстрації та обговорення принципів економічної теорії управління поновлюваними ресурсами.

Розроблена авторами основа може бути використана для створення середовищ з метою їх подальшого вивчення з використанням різних моделей поведінки агентів, використанням додаткових параметрів.

Ключові слова: Мультиагентне моделювання, управління відновлюваними ресурсами, розподілене моделювання.

Introduction. Today multi–agent systems are used for many purposes, such as complex problem solving, logistics, transport, graphics and, especially, simulation. Multi–agent systems model the behaviour and interaction of microscopic entities, by focusing on their relations to explore parameters and behaviour of the whole system on microscopic level.

Multi-agent simulations of this kind allow us to study economic processes in a completely different way, focusing on examining the influence of microagents on the macroscopic parameters of the entire system. The developed solution simplifies the implementation of such experiments in this area, by making the process of their adjustment more flexible and simple.

An important role in theoretical and empirical studies on the methodological problems of the renewable resource management multi-agent approach belongs to such scientists, as: M. Antona, F. Bousquet, J. Epstein, R. Axtell, S. Luke, C. Cioffi-Revilla, L. Panait, K. Sullivan, G. Balanand others. They developed a bunch of approaches that help to either simulate different economic environments and/or discover a variety of patterns and laws within them.

However, all of those mentioned above methods for the renewable resource management using multi-agent systems have to be modified in order to meet the needs of ones, who use them as a tool for the research. This includes the architecture modifications for increasing its scalability and making available a customisation of the simulation agent's logic.

Setting objectives. In the related literature, resource management models are often represented in form of activities description for gathering the resources and following calculations of a resource outflow, i.e. sales and profit gaining (money resource). In such models, rules that describe the process of sale aren't commonly defined. The trade is needed only for the price equilibrium establishing, which influences on the scheme of resource consumption. Therefore, the scale of observing is being the resource environment.

Also, there are models, which examine processes, lying out of primary harvesting. Such approaches include model from [1], the resource exploitation process of which is examined in form of economical part of renewable resource's lifecycle. In such models, besides of harvesting agents, there are also agents, which make up resource's industrial chain and consumers through which the industry flow of money is modelled and which are the final owners of the renewable resource. They have several markets with their characteristic parameters and a common mechanism of exchange within them.

There are also management tools in the form of some rules or restrictions affecting the markets or the process of gaining the resource. These tools include taxes, resource quotas, random events, transportation costs, and others.

The main points that are rigidly set by the model are the rules by which conflicts of various kinds are solved, as well as general rules of exchange and processing of resources at each level of production. In this article, we are building a model, which uses such a tool as the quota for the amount of collectable resource for harvesting agents. Comparative descriptions for different values of this parameter will be presented, which include relevant indicators of markets.

Methodology. Methods, used during this research include: multi-agent systems design, software design patterns, economic models of renewable resource markets and extraction. The developed framework is being built using Python programming language.

Research results. Simulation is represented as a system that updates its parameters by the mechanism of the cellular automaton. The system consists of agent-participants in the simulation, a discrete grid-toroid, in the nodes of which the resource is located, and also the core, which is a means of communication for the agents. Agents are divided into three categories: harvesters, industrial agents and consumers. Harvesters move around the grid and collect the resource, and then sell it to the industrial agents of the next stage of the life cycle of the resource. The number of the production stage characterizes industrial agents. This number determines the buyers of the primary resource, the costs of production, and to whom it will then sell it. Consumers, in turn, buy the resource from the manufacturer senior by the number, and simply spend it, receiving, at each step of the discrete time, the external income, serving to simulate the receipt of the external money into the industry. Resources on the discrete grid are renewed at each step, i.e. the amount of the resource is incremented by a fixed constant so, that it does not exceed the capacity of the grid node. In the experiment, the calculation of value uses the notion of the Marginal Rate of Substitution [2], which is the ratio of the two relative internal scarcities, linked to the need for the resource (called by Epstein and Axtell metabolic cost). Thus, the price is formed on the basis of the cost of the resource and the mark-up, i.e. margin, which the seller strives to obtain.

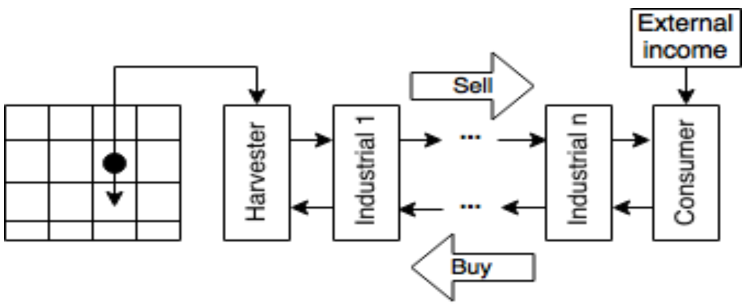

Figure 1 - The scheme of a production chain with n industrial agents

Agents. *Common properties*. Each agent is characterized by a position on the spatial grid. The amount of its funds is denoted by *Money* and represents the conventional units for the purchase of the resource and its processing. The amount of the resource, purchased or collected by it, which hasn't been transformed, is denoted by *InputQ*. *OutputQ* denotes the amount of the resource that was processed by the agent, but was not sold. Each agent is also characterized by the *Margin* parameter. This parameter determines the amount of money that the agent saves from the transaction, as well, as the amount of profit that he expects to receive. This parameter is especially important for the representativeness of the model, since without it the oscillations of the *Money* parameter for the agent are minimal. The parameter *ProdCost* reflects the cost of an internal manipulation with the resource, and for the different agents has a different meaning. Also, the agent has parameters *Wm* and *Wr*, reflecting the willingness to own funds and resources, respectively. They are used for the costs evaluation. In our experiment, the agent works like a finite state machine, alternating between states according to a certain principle.

Harvesters. Agents of this type do not transform the resource explicitly, but they undergo this procedure. This is justified by the fact that during collection, the agent spends money on the procedure of extraction itself, moving along the grid. The harvester, in our experiment, extracts the resource or moves to another cell, and then sells the resource to the industrial agents of the first stage.

Industrial agents. Such agents buy the product – the result of the previous production stage, then transform it and sell it to the agents of the next stage or consumers. In this production scheme, the resource for the transformation is not being fully utilized. A part of it remains untouched (1/4), another part needs to be transformed. The result of the transformation is the amount of commodities equal to 2/3 of the incoming for processing. These agents are also characterized by the position on the grid, which is taken into account when evaluating the price, in the form of the distance between the buyer and the seller multiplied by *TransportCost*. However, their position is immutable. They cannot navigate the grid. Such agents form the important research objects – markets, the price on which is an important indicator, characterizing the response of the system to the use of various management tools.

Consumers. These agents do not transform, nor sell anything. In cooperation with the industrial agents of the production stage, they form the market of the industry's final commodity. At each step, they receive an income from outside, which is partly spent on the purchase of a product, which is being consumed completely. An important parameter for them is the actual volume of this income, which regulates the inflow of money into the industry from outside and provokes corresponding changes in all markets and production stages.

Simulation's lifecycle. At the each step, the sequence of actions is a top-bottom movement, is starting with the harvesters and ending with them as well. I.e., first, the actions of the harvesters are performed, usually those being the collection of the resource or its movement. Next turn is that of consumers. Then the actions of the industrial agents of the last stage are performed, and after that, it is the turn of a penultimate stage and so on. And, finally, the harvesters again act, usually exposing the resource for sale. This order is kept due to the system of the sale/purchase, which will be discussed further.

Selling and buying. This simulation uses the local trade scheme proposed in [3]. At the stage of purchase, the agent sends the parameters, necessary to calculate the MRS (Marginal Rate of Substitution) of the buyer, which, in our experiment is calculated as:

$$MRS = \frac{Money / W_m}{InputQ / W_r}, \quad (1)$$

where W_m – willingness to have money, $Input\ Q$ – the amount of the resource purchased or collected by agent, which is not transformed, W_r – willingness to have resource.
to the core as the content of the purchase request. Then, the sellers of the previous stage of production choose the most profitable of these requests, comparing the gains that can be obtained. For this, the seller's MRS is calculated as:

$$MRS = \frac{Money / W_m}{OutputQ / W_r}, \quad (2)$$

where $OutputQ$ – the amount of resource that was processed by the agent and was not sold.

To calculate the profit, first needs to be performed the evaluation of the amount that the buyer can afford to himself:

$$WantedQ = \frac{Money_{buyer} - Margin_{buyer} - Margin_{seller}}{Price + ProdCost_{buyer} * 3/4}, \quad (3)$$

where $Money_{buyer}$ – the amount of money that the buyer owns, $Margin_{buyer}$ – margin value of the buyer, $Margin_{seller}$ – margin value of the seller, $ProdCost_{buyer}$ – the value that reflects the cost of an internal manipulation with the resource for the buyer.

Here *Price* is a preliminary calculation of the price and is the geometric mean between the MRS of the buyer and the seller. The numerator is the amount of funds that the buyer can spend on the purchase, and therefore the total amount of money is deducted from the *Margin* of the buyer, i.e. the amount of money that the agent will not spend, and *Margin* of seller, which is the mark-up on the sale. In the denominator, there is a preliminary price, without mark-up, and cost that are added to it, which the buyer will have to spend to transform the purchased goods.

Now, the actual quantity of the goods involved in the transaction is calculated as a minimum of *WantedQ* and *OutputQ* of the seller, i.e. cannot exceed the goods in the seller's possession.

Next, we need to recalculate *Price* with an extra charge:

$$Price^* = Price + \frac{ProdCost_{seller}}{RealQ}, \quad (4)$$

where $ProdCost_{seller}$ – the value that reflects the cost of internal manipulation with resource for buyer.

The final revenue from the transaction is now calculated with subtraction of the transportation costs:

$$Gain = \left(Price^* - TransportRate * Dist(Buyer, Seller)\right) * RealQ \quad (5)$$

where $TransportRate$ – quota of the transport (is a price at which a certain good is delivered from the seller to the buyer, $Dist$ – Euclidian distance between buyer and seller.

where $RealQ$ is the actual quantity of the goods participating in the transaction, *Dist (x, y)* is the distance (L2) between x and y. When the transaction is completed, the parameters are updated as follows:

$$Money_{seller} = Money_{seller} + Gain, \quad (6)$$

$$Money_{buyer} = Money_{buyer} - Price^* * RealQ, \quad (7)$$

$$OutputQ_{seller} = OutputQ_{seller} - RealQ, \quad (8)$$

$$InputQ_{buyer} = InputQ_{buyer} + RealQ, \quad (9)$$

where $Money_{seller}$ – the amount of money that seller owns, $OutputQ_{seller}$ – the amount of resource that was processed by the seller and was not sold, $InputQ_{buyer}$ – the amount of the resource purchased or collected by buyer, which is not transformed.

All remaining purchase requests are discarded from the queue, as are requests from the sellers, who did not find an acceptable option. This is possible, for instance, if the *WantedQ* value is negative, i.e. the buyer does not have enough funds to satisfy the seller's desire to obtain the requested profit (*Margin*). Naturally, for an arbitrary agent, the customer selection algorithm can be modified, but exactly this option was implemented in our experiment.

Resource transformation. The transformation of the resource in some form is present in the cycles of harvesters and industrial agents, and although the meaning of this procedure is different, the principle of its operation is approximately the same. Therefore, in spite of the fact that further formulas will be given to industrial agents, they should also be used for collectors too, with the correction that the *InputQ* parameter for them should be considered as *HarvestedQ*, that is, the resource removed from the environment. Also, the harvesters transform all the volume specified in the request and the final amount of the resource is exactly equal to this volume.

For industrial agents transformation goes in following way:

$$Money = Money - 0.75 * Amount * ProdCost, \quad (10)$$

$$InputQ = InputQ - 0.75 * Amount, \quad (11)$$

$$OutputQ = OutputQ + 0.5 * Amount, \quad (12)$$

where $Amount$ – the amount of resource that wasn't transformed.

Implementation. The framework is a Python module containing the necessary tools for implementation of the environments described above. It consists of several independent parts, responsible for the various functions of the simulation. Each part is independent of the others and can be modified without processing the entire framework.

World. The World class represents the space in which agents and resources are physically located, but the agent's object itself does not track. It also contains methods for finding the distance between points (L1 distance on a torus grid) and is characterized by the following parameters:

- size – the size of special grid;
- quota – amount of resource that cannot be harvested (0 to 1);

– capacity – maximum amount of resource in a cell;
– growth rate – amount of resource that is restoredinevery cell on every step.

Simulation. This class is a kind of interface for the framework, linking the visualization, the spatial grid, the agents and the core. Its constructor contains a number of important parameters that determine the nature of the simulation, such as simulation speed, duration, grid dimensions, grid parameters, and etc.

Visualization. In this part, the means for visualization of the simulation are gathered. At the moment, it contains the visualization of the grid and the work of the harvesters, enabling them to observe in real time their movements and changes in resource stocks on the map. Also, there are some tools for plotting important parameters for each market and stocks on the grid.

Data Collector. This part contains methods for tracking and recording the experimental state parameters and then saving them for further analysis.

Agents. This part includes agent classes. Among them there is an abstract class containing the necessary minimum for running simulations with custom behaviour algorithms defined by the user, as well as some ready-made implementations, some of which were used in the experiment.

Core. This part contains a handler for various requests from agents, helping them communicate and interact with each other. Simulation first calls the agent methods in which they send requests to the kernel. Then the kernel looks through all the requests and conducts transactions, changing the parameters of the agents (*Money*, *InputQ*, *OutputQ* etc.), making sure that there are no acts conflicting with rules or generating excessive amounts of resources and funds.

Experiment. We conducted an experiment based on the early version of the framework, in which the production chain of the following type was implemented:

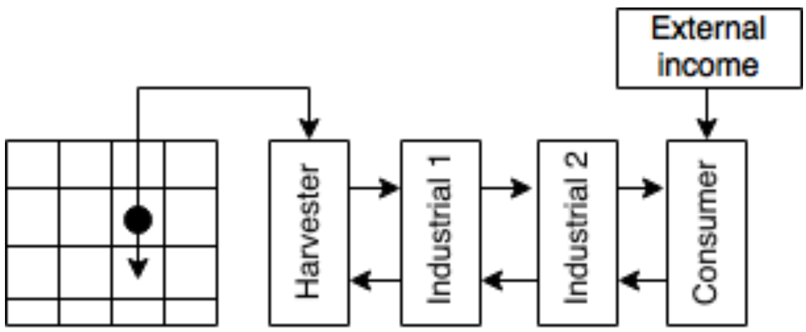

Figure 2 - The scheme of a production chain with two industrial agents

Spatial grid parameters. The simulated grid was 50x50, with the following parameters:

$$GrowthRate = 0.01$$
$$ResourceCapacity = 1$$
$$TransportCost = 0.3$$
$$Quota = 0.96$$

Agents. The parameters of the agents were taken with modifications from [1], and they are following (table 1).

Table 1 - Agent parameters

Agent	InputQ	OutputQ	Money	ProdCost	Margin	Wm	Wr
Customer	50	0	180	0	4	2	2
Industrial2	25	25	100	0.6	3	2	2
Industrial1	5	5	20	0.4	2	2	2
Harvester	0	1	2	0.5	1	2	2

Harvesters. The behaviour of harvesters in the model is defined as following:

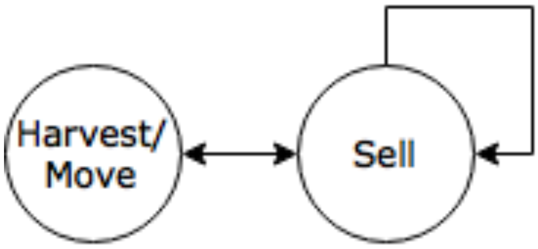

Figure 3 - The model of the harvester's behaviour

In the *Move / Harvest* state, the harvester interacts with the physical environment, collecting the resource. The amount of resource requested by the agent for collection is determined as following:

$$Amount = \frac{Money - Margin}{ProdCost} \quad (13)$$

ProdCost – the cost of converting an input resource into an outbound resource.

The query in response receives information about how much is harvested and how much is not harvested, which depends on the resource stock in the node in which the agent is located. If the agent has not managed to collect at least part of the resource, he understands that there is no more of it in the cell and leaves it. Moving is performed to that cell from the neighbourhood that has the largest amount of resource and is not occupied by anyone. After that, the state changes to *Sell*. Behaviour in this state is the same for all agents (excluding consumers), and is a kind of gradient search for the best offer on revenue out of available. If there is no such, the agent remains in the same state on the next step too.

Industrial agents. Their behaviour is defined as:

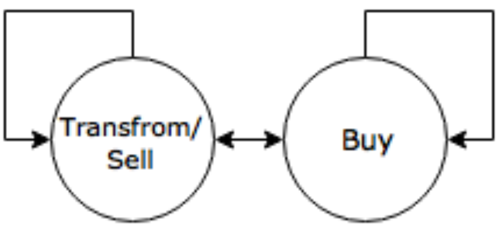

Figure 4 - The model of an industrial agent's behaviour

In the *Transform/Sell* state agent transforms resource using common rules, giving out the amount, that is defined as following:

$$Amount = \min\left(\frac{Money - Margin}{ProdCost} * \frac{4}{3}, InputQ\right) \quad (14)$$

and then sells the available resource by the common algorithm.

In the *Buy* state, the agent sends a purchase request. From both states, the transition is possible only when the request is satisfied, i.e. sales for a sale request and a purchase for a purchase request.

Several experiments were conducted for different values of the *Quota* parameter, during which the relation between the price level in the markets and the quota for resource extraction was shown. Initially, with *Quota = 0.96*, prices in all markets sharply increased at the beginning, but gradually converged to the values of order $10^0 - 10^1$, and this convergence was achieved for 350-400 transactions (1600 steps). The trend of convergence for the markets Harvester-Industrial1, Industrial1-Industrial2, Industrial2-Consumer can be seen on the charts (in the legend the market is marked by the second word of its name, ie, the agent-seller):

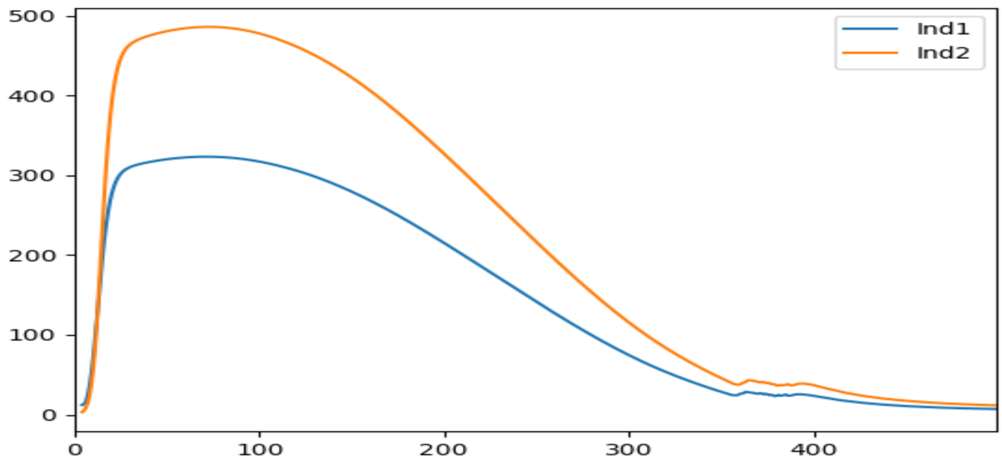

Figure 5 - The price level on the markets Harvester-Industrial1, Industrial1-Industrial2 ($Quota = 0.96$)

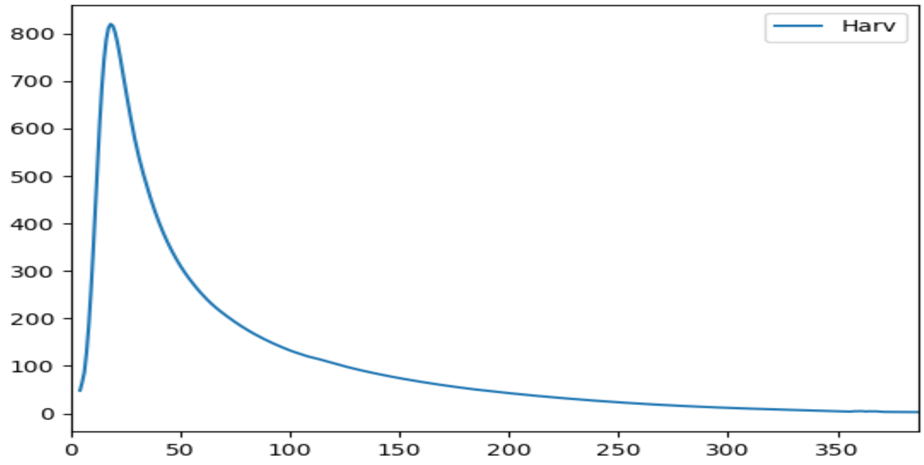

Figure 6 -The price level on the market Industrial2-Consumer ($Quota = 0.96$)

As the parameter grows, the convergence limit of the price curve becomes also grows because a resource flow in the industry decreases, and the convergence itself is achieved during the longer period of time. On the value of Quota = 0.99, prices converged to values of order $10^2 - 6 * 10^2$, while the convergence time increased significantly - to >2100 steps. This can be seen in the following graphs:

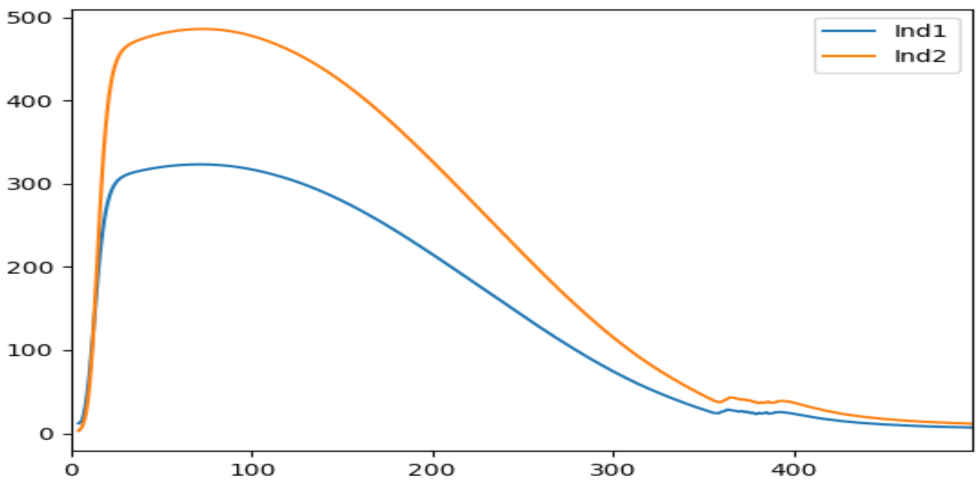

Figure 7 - The price on the markets Harvester-Industrial1, Industrial1-Industrial2 ($Quota = 0.99$)

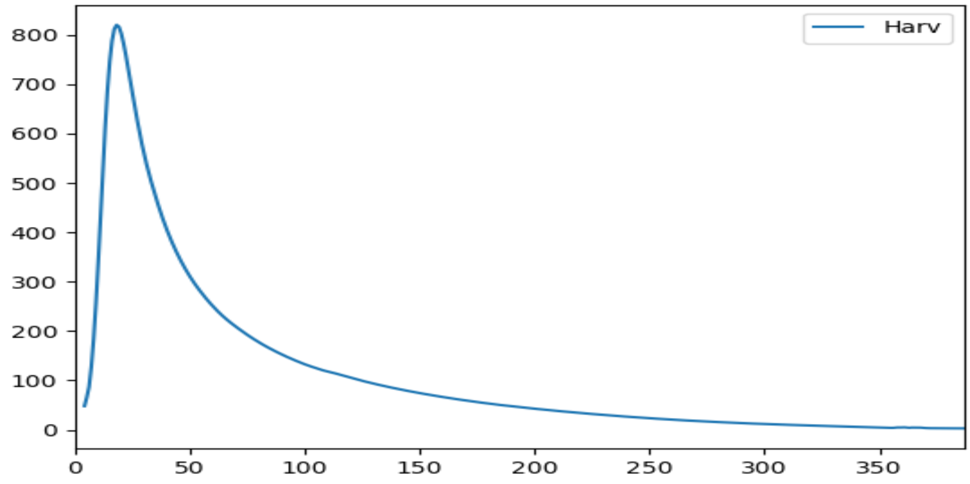

Figure 8 - The price level on the market Industrial2-Consumer ($Quota = 0.99$)

Conclusions. Multi-agent methodology is used for various purposes, such as distributed problem solving, network management, etc. In recent researches the emphasis has been placed on the relations between microscopic and macroscopic levels, using bottom – up and top – bottom approaches.

The multi-agent simulator in this article was developed in order to illustrate and discuss the principles of the economic theory of the renewable resource management. Using the multi-agent approach authors tried to find an efficient way to model the local interactions between environment and agents.

In this article, a model was built, which uses such tool as the quota for the amount of the collectable resource for harvesting agents to explore how agents will change their behaviour. Comparative descriptions for the different values of this parameter are presented, which include relevant indicators of markets.

The multi–agent approach described in [1] was used to build a simulation of the renewable resource life cycle. The behaviour of agent in the simulation is based on maximization of its own benefit. This kind of framework for creating the renewable resource management simulations that was developed by the authors gives us a possibility to explore the interactions between agents and the environment.

This framework might be used for creating the environments with the aim of their further studying, using different models of the agent behaviour. These behaviour models can be determined, based on predefined immutable set of rules and
an adaptive approach, that is, be able to modify the rules through learning, for example, learning amplification algorithms.

Furthermore, there are still many directions for the development, which give us a wide choice for further studies. Perhaps, the most likely is to consider and study models with the addition of agents with adaptive behavioural algorithms, such as reinforcement learning. This could be a promising continuation for the current research. In addition, similar experiments should be conducted with the addition of other management tools, such as taxes, random events etc.

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K. Zadko
ORCID ID: 0000-0003-2097-3582

O. Stets
PhD in Physico-mathematical sciences, Associate Professor
ORCID ID: 0000-0001-5514-3533

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

SIMULATION OF THE ACTIVITIES OF SUBJECTS OF E-BUSINESS ON THE BASIS OF A COMPATIBLE PROBABILISTIC MODEL

МОДЕЛЮВАННЯ ДІЯЛЬНОСТІ СУБ'ЄКТІВ ЕЛЕКТРОННОГО БІЗНЕСУ НА ОСНОВІ СКЛАДНОЇ ЙМОВІРНІСНОЇ МОДЕЛІ

The article deals with the situation of e-commerce and e-business in the conditions of modern economy of Ukraine. The relevance of this study is especially high today, because the success of electronic business depends primarily on the introduction of innovative projects based on the economic and mathematical modeling of the subjects of electronic business. The use of the probabilistic model for modeling the activity of the subject of electronic business is proposed to simulate the model of S. Patel and A. Schlizher, which is based on a simple probabilistic model and takes into account some psychological effects of consumer behavior when choosing goods in the market. In this model, the following effects are considered: the effect of minimizing damage, the effect of assessing the importance of qualities and properties, the effect of minimizing the distance to the average commodity. The research is based on the study of the work of scientists-economists, on the synthesis and complex analysis of domestic and foreign studies of consumer behavior in the context of e-commerce. Among the methods used in the study can be distinguished such as observation, analysis and synthesis, the method of modeling. In