Supply Chain Model of a Manufacturing Enterprise: Multi-Agent Approach

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Abstract— **The work aims to develop a supply chain model (SCM) for a production plant with limited supply chains, depending on the enterprise's orders stock. To identify an agents' cooperation model, dynamic interaction within the stochastic uncertainty in the raw materials supply and orders for finished products was modeled using a multi-agent approach. The cooperation model includes production processes, from the raw materials supply to the release of finished products. It consists of self-sustaining agent blocks describing the state and dynamics of the production system. The SCM considers the influence of suppliers, consumers, and structural components, allowing adequately and promptly respond to disturbing market factors and contribute to organizational and economic stability of the enterprise. The supply chain model is formalized mathematically. It examines agent-related changes based on the strategy for optimizing material flows. The strategy in point involves minimizing deviations from a given assortment structure under certain circumstances.**

Keywords— *supply chains, supply chain management, information system, logical system, multi-agent systems.*

1. Introduction

Enterprise effectiveness represents the cumulative efficiency of external and internal operations. In respect of the growing demands and needs of the customers, globalization, and strong competitive pressure, modern enterprises are faced with the necessity for supply chain integration. According to [1], nowadays, a company can no longer act as an isolated and independent entity but competes with other businesses. Moreover, the author mentions that the world markets are now entering the era of 'supply chain competition'. At the present stage of economic development, supply chain management provides for the business processes integration, involving an end-user and suppliers of goods, services, and information. In such a way SCM is increasing its importance to the consumer and other parties concerned. Due to the distribution of the tasks between supply chain members, the integration of business processes provides greater specialization and cooperation. Furthermore, such integration increases competitiveness, reduces operating costs, shares risks, benefits, and related information. The model change from competition between single companies to competition between entire supply chains causes the substitution of long-term partnerships by the traditional buyer-supplier relationships.

Since the late 1990s, the SCM concept is reviewed as a integrative philosophy [2], [3], to increase an organization's competitiveness by best satisfying the needs of the customer through effective and efficient management of the total flow of a distribution channel, from supplier to the ultimate user. The supply chain is a strategic concept, which comprises the delivery of the products, identification, and management of the value-added processes system. It is associated with the integral management of goods and information movement from the ultimate supplier to the end customer. The supply chain covers all logistics processes, operations, materials, and services conversion necessary for the service offer or production.

2. Literature review

Many attempts have be Modern production is characterized by the high complexity of technological processes and the need to ensure timely supplies of a significant number of various constituent parts. SCM is a factor in increasing the competitiveness of an enterprise. Thus, a steady increase is seen in the use of information systems in the logistics field to make managing a supply chain easier.

SCM mainly depends on the automation of production processes and the use of advanced technologies, such as software agents, the Internet of things (IoT), and service-oriented technologies. Moreover, various mathematical methods and models are applied to manage supply chains. The multi-agent approach as the basis for a decision support system is a modern one. It is claimed to be a computerized system composed of multiple interacting intelligent agents, with unique behavior, and the ability to accept management decisions, obtaining an effective result. Among main agents' properties are autonomy, ability to respond to system changes and interact with other agents, objectives achievement and flexibility to choose algorithms for it, modernizing after a negative result [4-8]. The core problem of the multi-agent approach is that each agent has its own goals, interests, and preferences. A common criterion across most studies are the main factors that negatively affect the efficiency of SCM [9]. They include the overall high level of supply chain complexity and the risks inherent in demand and supply, especially during the economic slowdown.

During the development of the multi-agent approach strategies, the question of the best mathematical method remains open [7].

In [5] propose using the multi-agent approach to develop the Construction Materials Planning System (CMPS) in the supply chain. They represent the CMPS architecture, designed to automatically search for agents' software services that coordinate the supply chain from the service repository. This coordination, in turn, uses the semantics-based service similarity analysis algorithm. To reduce information overload and increase agent consistency, [6] developed a neural network for ranking suppliers and their classification for data filtering. In [8] used the non-dominated sorting genetic algorithm (ERNSGA-III), adapted from NSGA-III. This algorithm applies a new control point measuring method based on the Bees algorithm in the selection operation.

Production supply chain participants often use the enterprise resource planning system (ERP). ERP is based on distributed artificial intelligence and is being a modern modeling technique for a distributed system in the production field [10].

Since the desired product delivery time is usually shorter than possible shipping time, conflicts may arise between agents. In this case, it becomes necessary to provide tools to support collaborative decision-making concerning supply chains via the Internet, for example. In [11] discussed the importance of joint compromise decision making in a multi-agent system. This process in SCM is additionally considered in [12-14]. The paper deals with the reasons for decision making using artificial intelligence for organizations applying a multi-agent system.

In [11] consider the implementation of a multi-agent system for dynamic behavior modeling and support of the supply chain management via the Internet. Geographically distributed retailers, logistics, warehouses, factories, and raw materials suppliers are modeled as open and reconfigurable agents' network, performing one or more supply chain functions. This approach offers a possibility to dynamically track and conduct a quantitative evaluation of compromise decisions between agents.

In [15] describe the method of applying a complex adaptive system theory (CAS) to the supply chain management. They present a self-adaptive and multi-agent model based on self-organized criticality theory and multi-agent technology. The CAS model covers the features of self-organization, self-adaptability, co-evolution, and innovation.

Kumar, Singh, and Gupta propose a technique based on genetic algorithm to optimize inventory in SCM [16]. The primary objective of the method is to determine the most probable level of excess stocks and the level of deficit, as well as minimizing the total cost of supplies.

In [17], through the example of multinational corporations, suggest using multi-agent simulation on big time-series data to optimize supply management and reduce the risk of longer lead time fluctuations in product demand.

A supply chain pricing issue has been examined by [13], who revealed that product prices should be flexible, dynamic, and adjusting to changing market conditions and competitors' strategies. The authors suggest estimating price distributions using fast neural networks.

Generally, the literature review on supplies management shows that the multi-agent approach is one of the newest. It provides for the use of agents' behavior patterns and rules to receive profit. The agents' actions are based on an understanding of the existing situation. They guarantee using knowledge accumulation algorithms along with the analysis of information saturation of the market under the conditions of environmental uncertainty. Thus, the multi-agent approach can be easily adapted to the information technologies application.

All supply management methods and tools are

dedicated to achieving several main effects. First of all, they intend to increase an income from the sale of products by improving service, supply accuracy, and demand forecasting. The second purpose is to cut down expenses by reducing the inventory levels, overhead and transactional costs in purchasing, warehousing, distribution, improve the production and logistics facilities.
The work focuses on developing a supply chain model for a manufacturing enterprise with production limited and supplies conducted in a stochastic uncertain environment.

3. Methods and materials

The work reviews foreign and Russian studies on inventory management, forecasting, multi-agent approach, economic and mathematical modeling.

4. Results

For the analysis of the main functions, the supply chain scheme can be divided into several modules (subsystems). Each module has a set of agents performing certain functions during the interaction. In general, the dynamic model of the system should include:
1) initial state of an economic agent;
2) technological methods of production (each method contains a mechanism for producing a number of products from the available set of resources);
3) optimality criterion.
Basing on the previous researches [17], [18] the following structure of supply chain agents of the production enterprise was developed:
- Administrator agent. This agent is responsible for supply chain administration, development of the raw materials and product flow formation within the analytical production plan and demand.
- Order acquisition agent is responsible for acquiring orders from customers, their processing and queuing. The order acquisition agent develops a strategy for servicing the queue and its procedure for its formation.
- Production coordination agent. It manages production within the limits of supply of resources, is responsible for adhering to the schedule of raw materials supplies and product output.
- Transportation agent. The agent performs the function of traffic management for product shipping. It forms a transportation schedule considering the methods of departure, shipment points, and transshipment of goods.
- Resource agent. The resource agent performs a function of inventory management. It formulates the concept of optimal stock level and estimates the demand for the resources.
- Warehouse agent. This agent manages the warehouse network. It forms the strategy of construction and the use of the distribution network, its location, and expenses for its maintenance.
- Controller agent. It manages deviations in key product value formation indicators at control points in the supply chain. It also performs the function of controlling and adjusting expenses in accordance with the received deviations.
- Risk management agent. It forms the strategy in case of risk events in a supply chain and mechanisms for their neutralization in the existing conditions and resource constraints.

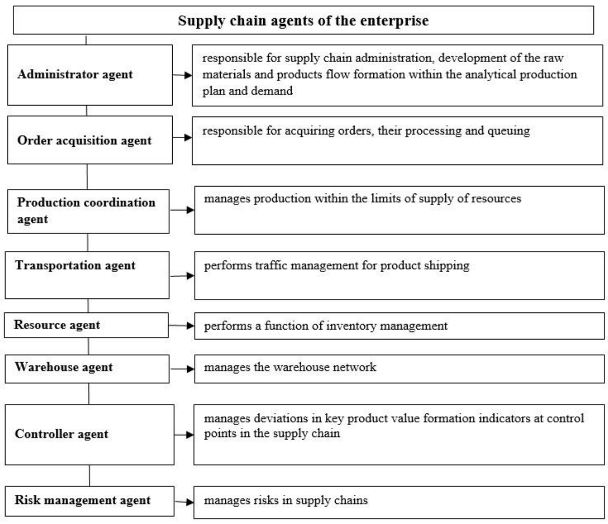

Figure 1. Supply chain agent structure

The interaction of these agents within one supply chain is shown in Figure 2.
The first step in modeling interaction within a single supply chain is to select agents. The general principle implies that one agent should be involved in one operation with narrow-profiled knowledge or technology. Each agent's activity consists of a set of operations. Supply management processes can be divided into two subsystems: Supply Chain Planning (SCP) and Supply Chain Execution (SCE). SCP focuses on planning different aspects of the supply chain or its business processes. SCE is the process of effectively

managing the supply chain through the warehouse and transportation execution systems.

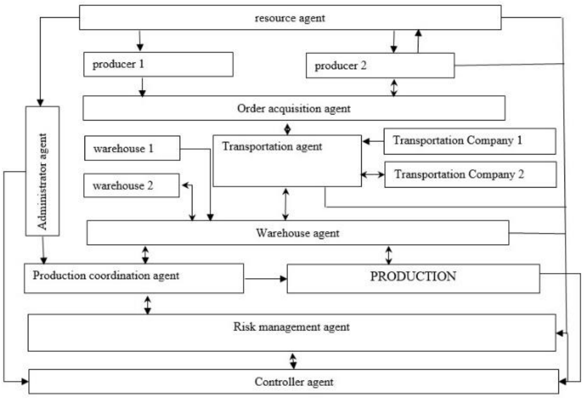

Figure 2. Iinteraction between agents in the supply chain

Besides, SCM includes the following steps that correspond those in the Supply Chain Operations Reference (SCOR) model:

1. Plan. Planning involves a wide range of activities. It clarifies the sources of supply, generalizes and prioritizes consumer demand, plans inventory, determines the requirements for the distribution system, the production volume, supplies of raw materials and finished products.
2. Source. This process involves the essential components of supply management. It describes how to manage inventory, the supplier network, supplier agreements, and supplier performance. It discusses when to purchase, receive, transport, control, store, and utilize the materials. Actions for managing the supply of goods and services are to meet planned or current demand.
3. Make. This process includes production, technological changes control, and planning, managing of production facilities (equipment, buildings), execution, and structural elements. Particular procedures as production cycles, quality controlling, packaging, storing, and releasing are also defined. All components of the incoming product processing into the end product must meet the planned or actual demand.
4. Deliver. This process typically involves order management, warehousing, and transportation. Order management includes the creation and registration of orders, value forming, and product configurations selecting. It is also responsible for creating and maintaining customers, goods and price databases. Warehouse management involves a set of actions for shipment and goods selection as well as creating special packaging or labeling for the client. The transportation management infrastructure is defined by the rules of channel and order managing, along with regulation of product flows and delivery quality managing.
5. Return. It deals with managing reverse flow of material from both the Production and the Delivery. This includes authorizing, scheduling, receiving, verifying, disposing and replacement. These processes also include certain elements of after-sales service.

The interaction of agents with related elements via the Internet at each level of detail makes an effective goal-setting possible. If the ability to communicate exists, the communication method will be chosen by the initiating agent. Quantitative or qualitative changes to the environment or the system itself should interact as the result of each agent's work.

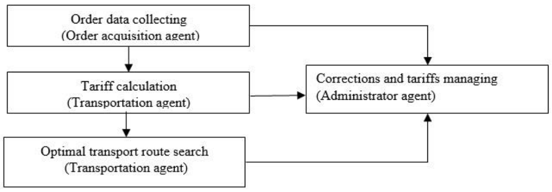

Figure 3. Connections between agents providing deliveries

Logistics decisions are made by the responsible agent at each stage. Such decisions are based on the probability of changes in market prices and optimal transportation tariffs, which should meet the unique demands of logistics service customers.

The order acquisition agent is responsible for orders classification. This process provides an understanding of whether the order belongs to a particular category, and enables the formation of an individual pricing policy. Thus, the order acquisition agent enables the development of personalized marketing strategies.

Another important step in making logistics decisions is choosing the best route and the number of optimal transport means. Such calculations allow forming total cost per order and implementing the policy aimed at achieving maximum customer satisfaction.

The administrator agent defines the probabilities of price fluctuations for energy carriers (mainly an increase), expendable materials, and changes in tax rates. However, the tariff policy of companies providing transportation services usually changes gradually rather than dynamically. The use of statistics gives an advantage in predicting changes, affecting the shipping cost, and an optimal tariff setting. To design a SCM system, the method of a multi-agent simulation modeling of dynamic interaction within the stochastic uncertainty in the raw materials supply and orders for finished products was used [19], [20]. For the proposed agent interaction scheme in a supply chain (Figure 2) consisting of interconnected autonomous agent blocks {At1, At2 ..., Atn} the following is achieved.

The "Delivery" block is modeled as accumulative arrays of j-type raw material supply from the i-supplier according to the appropriate process of rationing and time distribution (day of the week, time of day, seasonal) with various parameters of raw material conditions. The volume of j-type raw material supplies is determined by: Wj = $\sum_{i=1}^{n} Wij$

The "Warehousing" block represents the raw materials obtaining process (Wij) from the "Delivery" block to the warehouse under the distribution queue for production flows and intermediate storage during the time TAt2. Moreover, in this block a processing queue is formed by the production technology for each raw material type with the formation of new product variables.

$$\sum_{j=1}^{m}\sum_{i=1}^{n}\left[\frac{wij^{n}}{\sum_{j=1}^{m}\sum_{i=1}^{n} wij^{n}} - \frac{wij^{f}}{\sum_{j=1}^{m}\sum_{i=1}^{n} wij^{f}}\right]^{2} \rightarrow min$$

j=1; m; i=1; n

where Wij^{n}, Wij^{f} – planned and the actual volume of the i-type products from the j-type raw materials. The algorithm of the enterprise operations is reduced to the input material flow formation. It is based on the optimization analysis results of the i-type product release from the j-type of raw material in the TAt3 period. In this flow the aim of deviations minimization from the given assortment structure during the performance of the production plan is realized:

$$\sum_{sh=1}^{m}\left[\frac{x_i^{n}}{\sum_{i1=1}^{n} x_{i_1}^{n}} - \frac{x_i^{f}}{\sum_{i1=1}^{n} x_{i_1}^{f}}\right]^{2} \rightarrow min; \quad i = 1, n$$

where X_i^{n}, X_i^{f} – the planned and the actual release of the i-product.

The purpose of the algorithm of the agent actions is to form products in single material flow. This provides a guaranteed volume of the i-type product output in the regulatory regime.

The "Finished products storage and sale" block is a subunit of the enterprise where the delivery of finished products to the warehouse during the storage time (At5) is conducted in appropriate volumes and conditions. Parameters such as material flow and transport service statuses change in various combinations of service channels during the storage. The agent action algorithm in the "Finished products storage and sale" block is as follows:

1. Upon receipt of the next batch of primary products Wij^{f} from the Production Enterprise to storage warehouses, the accumulated stock order gij is determined as the sum of the current stock and the corresponding supply Wij^{f}:

$g_{ij} = g^{m}_{ij} + W_{ij}$; $i = 1, n$; $j = 1, m$

2. Upon receipt of a finished batch of goods, the accumulated stock X_i is determined as the sum of the current stock and the corresponding supply:

$X_i = X_i^{T} + W_i$ $i = 1, n$

3. Upon receipt of the trading organization order $W_{ij}^{trad,t}$ the volume of the order and one type of j-raw material is determined as:

$W_{ij}^{trad,t} = W_{ij}^{trad} + D_{ij}^{t}$; $i = 1, n$; $j = 1, m$

where D_{ij}^{t} is the debt to the t-customer according to the i-type product from the j- type of source raw material.

4. Upon receipt of the trading organization order $X_i^{trad,t}$, the volume of the order and one type of final product are calculated by the formula:

$X_i^{trad,t} = X_i^{trad} + D_i^{t}$; $i = 1, n$;

where D_i^{t} is the debt to the t-customer for the i-type of the finished product.

5. Trading organizations orders volume:

$$G^{i} = \sum_{t=1}^{k}\left(\sum_{i=1}^{n}\sum_{j=1}^{m} + W_{ij}^{trad,t}\sum_{i=1}^{n} X_i^{trad,t}\right)$$

6. After completing the order of the trading organization, the application is deleted with the correction of inventory volumes and backlogged orders. Thus, in the case of complete order fulfillment, the weight of the shipped products g^{t}_{ij}, X^{t}_{ij} is equal to the ordered product weight $W_{ij}^{trad,t}$, $X_i^{trad,t}$. Consequently, the current stock is reduced. In the situation of incorrect order fulfillment, the weight of shipped products g^{t}_{ij} , X^{t}_{i} and the debt owed to the t-supplier are calculated additionally.

The "Delivery to the customer" block reveals the process of orders receipt and processing for the i-type of finished products (i = 1, n), and the j-type products (j = 1, m) of primary processing of raw materials for trading organization order $W_{ij}^{trad,t}$. Furthermore, it imitates orders receipt for the i-type product of $X_i^{trad,t}$ order. Where *t* is the trade organization number (t = 1, k), depending on the day, time and seasons, based on the corresponding distribution plan of vehicles in different conditions.

The agent actions include the following:

1. Generation of $W_{ij}^{trad,t}$, $X_i^{trad,t}$ orders from consumers and their queuing according to priority.

2. The order comes for processing at the departure area, if the number of orders in the queue is more than zero, and the processed number in the expedition area does not exceed the maximum. There its registration, preparation of the delivery bill, and determination of the total order volume of all suppliers are conducted for further production program evaluation:

$$W_{ij}^{n} = \sum_{t=1}^{k} W_{ij}^{trad,t} \; ; \; X_{t}^{n} = \sum_{t=1}^{k} X_{i}^{trad,t}$$

The simulation cycle procedures repeat according to the next order with the highest priority.

5. Discussion

Benefits from the multi-agent approach in the SCM of a manufacturing enterprise are as follows:

- logistics is regarded as a management tool integrated by the material flow to achieve the goals of the micro- or macro-logistic system. The multi-agent approach reveals the modern paradigm of supply chain management, where individual firms, organizations, and systems are considered as logistics centers. The enterprises are directly or indirectly connected into a single integrated process of managing material and information flows to ensure maximum customer satisfaction.
- shared information space for all participants in the supply chain is necessary. It should be based on corporate or global telecommunication networks (for example, the Internet) and provide the possibility of information exchange in supply chain links, obtaining reliable information on the progress.
- real-time monitoring. Modern information technologies have given rise to an era of real-time competition, increasing the efficiency of logistics operations and functions. Timely and reliable information makes logistics forecasts more accurate and eliminates the need to maintain significant reserve stocks. The real-time supply chain monitoring system allows speeding up the logistics operations implementation, reducing the need for financial resources, or postponing their implementation until an order is received.
- accuracy, timeliness, and focus. The accuracy and reliability of the source data for demand forecasting and production requirement are important. Reliable information must arrive at the SCM system on time according to the technology. Timely information is essential for most logistics decisions since many tasks on transportation, handling, orders and inventory managing in the supply chain are controlled via on-line mode.
- appropriate data format. The data and message formats used in the computer and telecommunication networks should maximize the performance of telecommunications equipment and computer facilities (memory capacity, speed or operation, bandwidth).

The result of the agent's work should have an evaluation criterion in terms of rationality. Consequently, the agent can evaluate the results independently and, if possible, improve them or change the algorithm of actions.

Any agent must respond to changes in the external environment within its capabilities with the purpose of autonomy. Generally, external is the environment in which the system works as a whole. However, the system itself will also become the external environment, since the agent is to respond both to changes from outside the system and inside. Additionally, the agent must interact with other agents of the system. Therefore, it makes any sense in differentiating the environment into an external and internal one, because the agent must equally adequately respond to any changes that are significant for its work to maintain.

Hence, the agents act on the system using the communication tools or directly change the environment, where the entire system operates. Consequently, each agent can influence the system through the well-known communicative channel, within a physically separated group.

6. Conclusions

The establishment of the supply chain strengthens the interrelationship, interdependence, and interaction of various market sectors and economic agents. The system demonstrated in the paper is multi-agent. Therefore, many processes here are implemented simultaneously. Among them are data collection and preparation for analysis, real-time monitoring, models development and configuration, updating the precedents database. This allows having relevant data for decision making and preparing decisions in the form of precedents. Moreover, it enables using adequate economic and mathematical models to support management processes.

The dynamic model of the system includes:

1) initial state of the economic agent;

2) technological methods of production (each method provides a mechanism for obtaining a certain number of products from the available set of resources);

3) optimality criterion.

To identify an agents' cooperation model, dynamic interaction within the stochastic uncertainty in the raw materials supply and orders for finished products was modeled using a multi-agent approach. The model includes productive processes from the raw materials supply to the sale of finished products. It consists of self-sustaining agent blocks describing the state and dynamics of the production system. The SCM considers the influence of suppliers, consumers, and structural components. These components allow adequately and promptly respond to disturbing market factors and ensure the organizational and economic enterprises' stability.

The supply chain model is formalized mathematically. It examines agent-related changes based on the strategy for optimizing material flows. The strategy in point involves minimizing deviations from a given assortment structure under certain circumstances.

In comparison to the classical supply chain system, the multi-agent one is more active, has autonomy functions, and the ability to respond promptly. The features mentioned above give the multi-agent system the following advantages for production:

a) work speed increase by processing redistribution;

b) one agent failure does not affect the operation of the entire system, consequently, this system is more reliable;

c) higher response speed is provided by the system, due to the strong basic knowledge and the close interconnection between agents.

Real-time data management problems exist not only in the delay in their receipt (the period during which access to data for analysis is opened). According to the results achieved, the delays in the data analysis and in the decision-making time are also critical.

The interaction of agents with related elements via the Internet at each level of detail makes an effective goal-setting possible. If the ability to communicate exists, it is evident that the communication method will be chosen by the initiating agent. Quantitative or qualitative changes in the external environment should be the result of the agent's work. For this reason, each agent's work affects the external environment or the system itself.

References

[1] Christopher, M, *Logistics and Supply Chain Management, Financial Times.* Prentice Hall, 5th edition, 2016.

[2] Cox, A, *"Power, value and supply chain management"*, Supply Chain Management, Vol 4, No. 4, pp. 167-175, 1999.

[3] Min, S., Zacharia, Z. G., & Smith, C. D, *"Defining Supply Chain Management: In the Past, Present, and Future"*, Journal of Business Logistics, Vol 40, No. 1, pp. 44-55, 2019.

[4] Khayyat, M., & Awasthi, A, *"An Intelligent Multi-agent Based Model for Collaborative Logistics Systems"*, Transportation Research Procedia, Vol 12, 325–338, 2016.

[5] Pal, K., & Karakostas, B, *"A Multi Agent-based Service Framework for Supply Chain Management"*, Procedia Computer Science, Vol 32, 53–60, 2014.

[6] Alireza, J., Azrifah, M., Murad, A., Nasir, S., & Hasan, S, *"A Multi-Agent Supply Chain Recommendation and Negotiation Framework"*, Advanced Materials Research, Vol. 716, pp. 527-532, 2013.

[7] Kovalchuk, Y., & Fasli, M, *"A Demand-Driven Approach for a Multi-Agent System in Supply Chain Management"*, In: David E., Gerding E., Sarne D., Shehory O. (eds) Agent-Mediated Electronic Commerce. Designing Trading Strategies and Mechanisms for Electronic Markets. Springer, Berlin, Heidelberg. pp. 88-101, 2009.

[8] Gharaei, A., & Jolai, F, *"An ERNSGA-III algorithm for the production and distribution planning problem in the multiagent supply chain*", International Transactions in Operational Research, 2019.

[9] Giannakis, M., & Louis, M, *"A multi-agent based framework for supply chain risk management"*, Journal of Purchasing and Supply Management, Vol 17, No. 1, pp. 23-31, 2011.

[10] Chan, F. T. S., & Chan, H. K, *"A new model for manufacturing supply chain networks: A multiagent approach"*, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol 218, No. 4, pp. 443–454, 2004.

[11] García-Flores, R., & Wang, X. Z, *"A multi-agent system for chemical supply chain simulation and management support"*, OR Spectrum, Vol 24, No. 3, pp. 343–370, 2002.

[12] Yang, C., Yang, R., Xu, T., & Li, Y, *"Negotiation model and tactics of manufacturing enterprise supply chain based on multi-agent"*, Advances in Mechanical Engineering, Vol 10, No. 7, pp. 168781401878362, 2018.

[13] Hogenboom, A., Ketter, W., Dalen, van, J., Kaymak, U., Collins, J., & Gupta, A, *"Adaptive tactical pricing in multi-agent supply chain markets using economic regimes"*, Decision Sciences, Vol 46, No. 4, pp. 791-818, 2015.

[14] Balasubramaniam, C, *"A multi agent decision tree algorithm for supply chain management"*, International journal of computers & Technology, Vol 15, No. 6, pp. 6833-6837, 2016.

[15] Lu, Q., & Chen, J, *"A Self-Adaptive and Multi-Agent Model of Supply Chain Management System"*, In International Conference on Transportation Engineering, 2007.

[16] Kumar, T., Singh, S. R., & Gupta, C. B, "*Genetic Algorithm Based Multi Product and Multi Agent Inventory Optimization in Supply Chain Management"*, International Journal of Modeling and Optimization, Vol 2, No. 6, pp. 653-657 , 2012.

[17] Tanaka, K., Gu, S., & Zhang J, "*Designing Multi-Agent Simulation with Big Time Series Data for a Global Supply Chain System"*, International Journal of Automation Technology, Vol 10, No. 4, pp. 632-638, 2016.

[18] Fox, M. S., Barbucenau, M., & Teigen, R, *"Agent-Oriented Supply-Chain Management"*, The International Journal of Flexible Manufacturing Systems, Vol 12, No. 2-3, pp. 165-188, 2000.

[19] Cucker, F., & Smale, S, *"The Mathematics of Emergence"*, Japanese Journal of Mathematics, Vol 2, No. 1, pp. 197–227, 2007.

[20] Kintonova, A. Z., Andassova, B. Z., Ermaganbetova, M. A., & Maikibaeva, E. K, *"Development of distributed system for electronic business based on java-technologies"*, International Journal of Environmental and Science Education, Vol 11, No. 10, pp. 3861-3883, 2016.