Intelligent Agents and Multi-Agent Systems

TACTICAL MANAGEMENT OF SUPPLY CHAIN WITH AGENT BASED MODELING AND SIMULATION

Jacek Jakieła, Paweł Litwin, Marcin Olech

Abstract: *Excellence in Supply Chain Management depends on timely and effective translation of market demand into material and products control decisions across Supply Chain. As has been observed many times, this task may be complicated by several technical and business related constraints. Effective decision making processes are essential to execute Supply Chain in such a way that products will be made at lowest possible cost and delivered on time. In most cases, software support has to be used. Supply Chain related decisions are usually poorly structured and therefore only reasonable way to support them is to use simulation tools. The main aim of the paper is to show how Supply Chain Management process can be supported with Agent Oriented Simulation Platform. The case study presented describes in detail the decision situation that is analyzed from scratch, by simulating different scenarios for suggested problem solutions. Finally the paper shows how the analysis of simulation results may lead to final decision solving the problems encountered.*

Keywords: *Agent-based Models, Agent oriented Supply Chain Management, Agent-Based Simulation and Modeling, Agent-orientation as Modeling Paradigm*

ACM Classification Keywords: *I. Computing Methodologies; I.2 Artificial Intelligence; I.2.11 Distributed Artificial Intelligence; Multi-Agent Systems*

Introduction

Nowadays business is conducted in the networked world. Increasing global and competitive marketplace forces enterprises to work together to achieve individual as well as collective goals in more effective and efficient ways. Business partners are not isolated. They operate as nodes in a network of suppliers, products warehouses and specialized service functions. Such network, called Extended Enterprise, Virtual Enterprise or Supply Chain has to be agile enough to rebuild and adjust plans and make decisions in real time to take care of unexpected events. The agility is related to effective Supply Chain Management which crucial part is decision making process. The general areas where the decisions are made address demand planning, master planning, procurement, manufacturing and transportation management. For many companies it has become a matter of survival to improve their decision making processes. What is more firms are trying to apply software support to decision situations. This support may take form of full-blown ERP system but, what is done more often, especially for semi-structured and unstructured decisions, it is used in the form of simulation workbench. Simulation tools may aid human decision maker to make right decision by providing information in proper context and related to whole Supply Chain. Thanks to well-designed simulation experiment, decision makers are able to understand the overall Supply Chain business logic and characteristics, capture system dynamics related to unexpected events as well as their influence on Supply Chain, and conduct what-if analysis enabling to minimize risk associated with changes in the planning process.

As has been shown in [Nfaoui *et al.*, 2006] and [Kimbrough *et al.*, 2002] such business structures as Supply Chains require particular approach. In order to have all important characteristics of Supply Chain fully captured and included in the simulation model, agent-based approach is usually taken [Paolucci *et al.*, 2005], [North et al., 2007]. This way of problem domain conceptualization has also been adopted in this paper, which main aim is to show how Agent Based Modeling and Simulation approach can be used for supporting decision making processes related to Supply Chain Management. Presented case study is based on simulation experiment executed on Agent Oriented Platform designed and developed by authors of this paper and described in several articles. In [Jakieła, 2006] the basic assumptions related to using agent orientation as a modeling paradigm for contemporary organizations were shown. The rationale for the research currently conducted has been presented in [Jakieła *et al.*, 2009]. Papers [Jakieła, Litwin, Olech, 2010a], [Jakieła, Litwin, Olech, 2010b], [Jakieła, Litwin, Olech, 2011b] describe the partial results of the research in the form of reference model for the simulation platform and its applications to bullwhip effect analysis. Finally, the paper [Jakieła, Litwin, Olech, 2011a] shows how the simulation platform developed may be used as a Supply Chain analysis workbench.

The Concept of Supply Chain Management

According to Muckstadt *et al,* Supply Chain term is defined as the set of firms acting to design, engineer, market, manufacture and distribute products and services to end-consumers. This set of firms is structured as a network with every firm operating as a node [Muckstadt *et al.*, 2001]. Such business structure is quite complex and its behavior often unpredictable. Therefore the properly tuned management process should be applied. This process is called Supply Chain Management and as a popular term has started to be used in early 1990s.

According to Chang et al. it is a process of coordinating activities of suppliers, manufacturers, warehouses and retailers in order to minimize costs and satisfy customer requirements [Chang *et al.*, 2001]. Supply Chain Management may also be defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses and stores, so that merchandise is produced and distributed in the right quantities, to the right locations, in the right time, in order to minimize system wide costs, while satisfying service level requirements.

In Supply Chain Management decisions may be classified as strategic, tactical and operational. As their name suggests, strategic decisions are related to firm's strategy, are usually long-term and involve most partners in Supply Chain. Tactical decisions are mid-term and made in individual area of Supply Chain – by specific business partner. The main problems addressed by these types of decisions are related to demand, procurement, production warehousing and distribution. These decisions are usually semi-structured, what means that they do not have predefined procedures used for making them. Operational decisions are related to day-to-day operations [Chang *et al.*, 2001].

Although all these decisions categories are equally important, the paper focuses on tactical level decisions related to retailers' problem called "out of stock". This choice should be regarded as next "prove of concept" for simulation platform developed by authors of this paper. The running research is supposed to take into consideration most of the decisions made in Supply Chain Management process, show how to support them with simulation platform and collect all the solutions in the form of decisions patterns library.

Simulation as a tool for Supply Chain Management

As we mentioned above, Supply Chains are complex systems. Simulation offers an effective analytical tool for organizations that need to understand their behavior and measure the performance in the Supply Chain environment. There are several reasons why simulation should be used for analysis and understanding the behavior of Supply Chains. North and Macal put them forward in the following way [North *et al.*, 2007]:

- No one is able to understand how all parts of the Supply Chain interact and add up to the whole.
- No one is able to imagine all the possibilities that the real Supply Chain could exhibit.
- No one is able to foresee the full effects of events with limited mental models.
- No one is able to foresee novel events outside of their mental models.
- Decision makers want to get insights into key variables and their causes and effects.
- Decision makers want to make predictions of how Supply Chain will behave. Thanks to simulation they can get educated guesses and be provided with the range of possible futures.

Simulation addresses all these motivations and seems to be only reasonable analysis method for understanding existing Supply Chains as well as designing new ones.

According to Banks et al. simulation as a tool used in Supply Chain Management may be applied to different areas and problems in the Supply Chain lifecycle. In design phase simulation may help in evaluation of possible configurations of Supply Chain, concerning different business partners and locations of manufacturing as well as distribution facilities. What is more simulation may be used for analysis of different product configurations, and establishing the inventory levels that allow to achieve service level goals. Operational phase may be supported in the areas of Supply Chain planning and execution, in the processes of establishing production and logistics plans and schedules to meet long and short term demands. During the termination phase simulation can be applied in the area of analysis and selecting emptying the pipeline plans as well as shut down manufacturing and distribution facilities plans [Banks *et al.*, 2006].

Supply Chain Modeling, Model Implementation and Simulation

Modeling Supply Chain differs from modeling manufacturing systems, where models regard mainly material flow through machines and material handling systems, and are used for analysis of machine utilization, cycle times and bottlenecks. In case of Supply Chain, modeling the material flow is not enough and should be enriched by information flows related to business processes triggering and controlling flow of material, orders, products and money transactions. All these elements have been taken into consideration in the model used in simulation experiment presented in this paper.

The modeling process has been driven by agent orientation principles. As was shown many times, in case of such business models as Supply Chains using agents as a basic modeling constructs is reasonable solution because of the following characteristics of problem domain [North *et al.*, 2007]:

- Representation may be conceptualized as consisting of interacting agents.
- Decisions and behaviors can be defined discretely, that is, with well-defined boundaries.
- It is important that agents change their behavior and adapt.
- It is important that agents engage in dynamic strategic behavior.
- It is important that agents have dynamic relationships with other agents, and agent relationships form and dissolve.
- It is important that agents form organizations. What is more adaptation as well as learning are important at organizational level.
- The past may be a poor predictor of the future.
- Scaling up is important, and scaling up consists of adding more agents and agent interactions.
- Process structural change needs to be a result of the model, rather than an input to the model.

The agent oriented model of Supply Chain, used in the simulation experiment, has been based on the work of Veira *et al.* [Vieira *et al.*, 2005]. Agents that constitute the building blocks of the model belong to the following categories:

- Supplier Agent,
- Manufacturing Agent,
- Retailer Agent,
- Market Agent.

Every agent plays the role related to the position in Supply Chain. Agents' responsibilities have been formalized in the behavioral rules driving their behavior during the simulation process. Sample behavioral rule for retailer agent is presented in Figure 1.

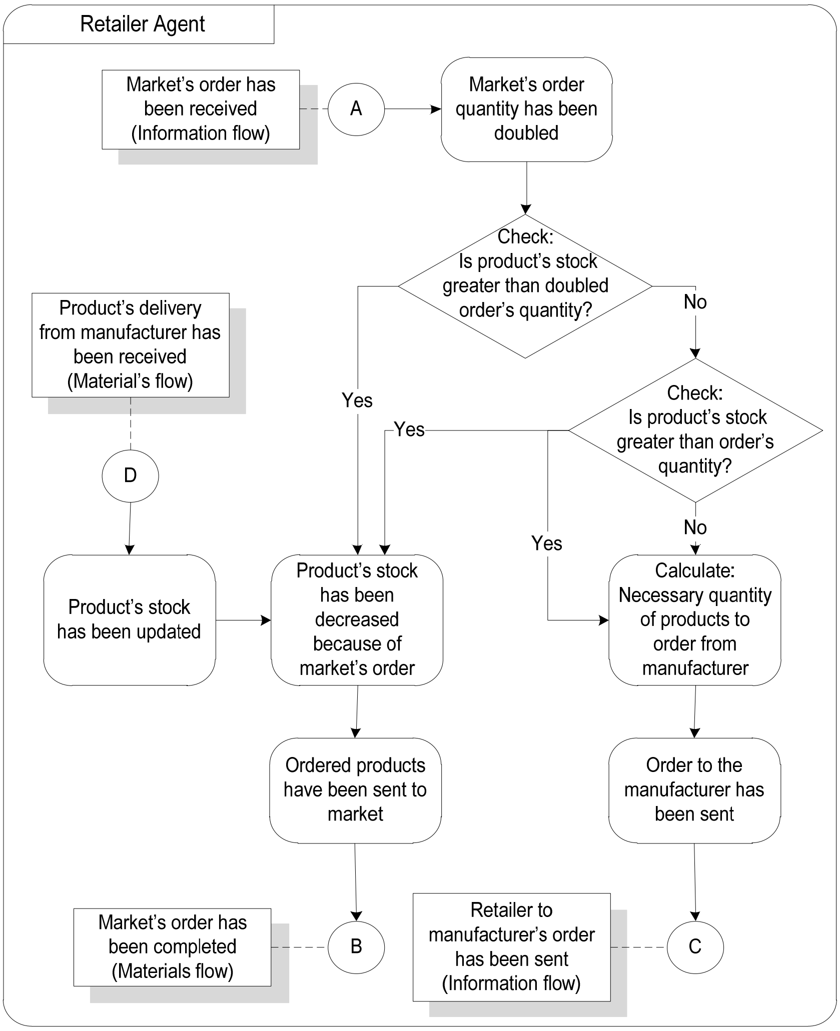

Fig. 1. Retailer Agent's Behavioral Rules

The starting point of Retailer Agent is the moment when an order is received, but in this case its source is the market. After the order is received and the number of order items is doubled, the retailer compares calculated value with its stock level. If the stock level is greater than the doubled number of order items, Market Agent is provided with products and process ends. In case the stock level is less than calculated value, but is enough to fulfill the order, the products are delivered and an order is placed to replenish the stock to the planned level. If the Retailer Agent does not have requested number of products it sends an order to Producer Agent and waits for delivery. When products are delivered, Retailer Agent fulfills the market demand and replenishes its stock level.

Detailed description of the reference model for simulation environment used in this paper may be found in [Jakieła, Litwin, Olech, 2010a].

Because the easiest and most effective way of conducting agent-based simulation is to use the package dedicated to this purpose, the model and the simulation experiment have been implemented in NetLogo environment, which is considered to be one of the most popular simulation environment. It includes several facilities such as tools for building user interface or system dynamics modeler. The environment is free of charges for educational and research purposes [Gilbert, 2007].

Case Study – Agent Based Supply Chain Management

As was mentioned above, Supply Chain Management is deeply entrenched in decision making processes taking place in different nodes of Supply Chain. Even if the decision is made individually by specific Supply Chain partner the characteristics related to whole Supply Chain have to be taken into consideration. Therefore there was assumed that it is possible to show that Agent Based Modeling and Simulation may be used as a powerful tool for Supply ChainManagement by showing how to support sample decision making processes.

The presented case study includes the decision situation analysis that has been characterized according to the pattern as follows. At first the problem to be solved is articulated. Then possible solutions to the problem are suggested. Next, metrics are carefully selected, formalized and the simulation is run. Finally simulation results are interpreted and applied to the decision making process. In the case study sample decision will be made with the support of agent based simulation and modeling platform.

Decision situation – out of stock problems

Problem to be solved and suggested solutions

This kind of problems is usually experienced by retailer. It is related to the situations when the customer's demand cannot be fulfilled, because there is not enough merchandise in stock. If the situation is frequent it may cause the decrease in customers' loyalty level and retailer's financial losses. Decisions made in case of such problems may be classified as a semi-structured and are regarded to be a tactical one.

The problem may be solved in the following ways:

1. Solution 1 – change the merchandise delivery parameters such as: different roads, routes and vehicles' loads. Every parameter setting may have specific influence on the problem solution – positive as well as negative. In order to find the optimal one, several simulations will be run with different parameters values. Simulations' results will be then analyzed and compared to the results used as a reference.
2. Solution 2 – find more appropriate safety level of the merchandise and improve current stock policy. This may increase the availability and eliminate out of stock situations but at the same time increase the costs of warehousing. Simulation experiment will take into consideration different values of safety stock levels. The experiment's results show how these values affect the problem solution.
3. Solution 3 – combine the solutions of types (1) and (2).

All the suggested solutions will be tested with the use of agent based simulation and finally the best solution will be selected and implemented.

Metrics Selection and Formalization

In order to test different possible problem's solutions, the following metrics have been selected:

1. OTIF (*On Time in Full*) – indicator that shows how often customers' demand is fulfilled directly from retailer's stock. This metric is calculated according to the formula below

$$OTIP = \frac{q_f}{q} \cdot 100\ [\%], \tag{1}$$

where: q_f – quantity of orders fulfilled directly from retailer’s stock, q – total number of orders taken by retailer.

2. Delivery time – time measured between the moment the order has been taken and the moment the order has been fulfilled. With regard to this metric such statistics as maximum, minimum, average and standard deviation have been calculated. It’s important to mention that only deliveries related to customers’ orders have been included.
3. Total retailer’s profit – profit generated by retailer during the simulation run.
4. Total delivery cost – total cost of delivery between retailer and manufacturer.
5. Average unit delivery cost – average unit delivery cost calculated for merchandise sold.

All these metrics have been used in the simulation experiment; however different configurations of them were selected for verification of problem solutions.

Simulation Runs

The first run is treated as a source of reference data used during the analysis of experiment results. The parameters of reference run, which will not be changed during all simulation runs are presented in table 1.

Table 1. Parameters of simulation runs

Parameters	Values
Time of the simulation experiment	650
Initial part’s price	3.8
Demand distribution	Normal
Mean of demand distribution	5
Standard deviation of demand distribution	0.8
Safety part’s stock at supplier	40
Safety part’s stock at manufacturer	30

For simulation runs and suggested solutions the following settings have been used:

1. Solution 1 – change the merchandise delivery parameters.
   a. Highway type road – the road selected for delivery is longer, faster and safer than the road type used in reference simulation run.
   b. Mountainous type road – the road selected for delivery is shorter but slower and more risky in comparison with reference run road type.
   c. Regular type road – alternative to reference run road.
2. Solution 2 – find proper safety level
   a. Merchandise safety stock level is equal 1 item
   b. Merchandise safety stock level is equal 2 items
   c. Merchandise safety stock level is equal 3 items
   d. Merchandise safety stock level is equal 5 items
3. Solution 3 – combination of best option from solution 1 and best option from solution 2.

Next section presents the results of simulation experiment executed. Every simulation run takes into consideration different settings as showed above. The results will provide us with the answer to the question: *Which solution is the optimal one?*

Simulation Results Analysis

The values of metrics calculated in reference run are presented in table 2. As the value of OTIF indicator (which is not very high) and standard deviation of delivery time (which should be smaller) show, the customers complaints related to "out of stock" situations are well-founded. Solving the problem will require to go through all the alternatives defined and find the best solution possible.

Table 2. Metrics values used for reference run

Metric	Value
OTIF [%]	65,28%
Delivery time [h]:	
- minimum	2,60
- maximum	16,30
- average	8,78
- standard deviation	2,15
Total profit	7913,33
Delivery cost:	
- total	4818,00
- average cost per unit	1,59

Solution 1 – use different delivery parameters

As was mentioned before, the first solution is to check how the situation will change if the type of road will be different. The results of the simulation with the road type set to highway are presented in table 3.

Table 3. Metrics values calculated for "higway" road type

Metric	Value
OTIF [%]	67,38%
Delivery time [h]:	
- minimum	2,30
- maximum	15,60
- average	8,39
- standard deviation	1,92
Total profit	7531,27
Delivery cost:	
- total	4193,00
- average cost per unit	1,41

The OTIF indicator value is almost the same as in reference run. The conclusion is obvious – the road type does not influence the merchandise availability. What is also well visible, and may be inferred from data in table 2 and table 3, road type selection will strongly affect the delivery time. All metrics related to delivery time have been improved. As can be seen selecting different road type reduced delivery costs (total as well as unit cost). Data related to other road types (mountainous and regular) are gathered and presented in table 4.

Table 4. Simulation results for mountainous and regular type roads

Metric	**Mountainous type road**	**Regular type road**
OTIF [%]	66,78%	67,56%
Delivery time [h]		
- minimum	2,20	2,00
- maximum	15,70	13,40
- average	9,76	8,35
- standard deviation	2,50	1,89
Total profit	7661,68	7449,62
Delivery cost		
- total	8409,00	5776,75
- average cost per unit	2,79	1,95

The comparison of simulation results for mountainous type road with regular and highway type roads reveals that the delivery time is the longest for the former one. Using shorter route not always provides improvements in delivery time (route is shorter but more risky and therefore slower). What is more, the stability of deliveries made along this route, determined by standard deviation, in this case is higher than in others.The final factor that settles getting rid this option of is delivery cost, which for this road type has the highest value.

In case of regular type road, such metrics values as delivery time and standard deviation are smaller than values for highway type road. Unfortunately the value of delivery cost is higher. Relative differences among all the metrics' values may be compared with the help of summary of all data presented in table 5.

Table 5. Metrics values summary for Solution 1

Metric	**Used road type**						
	Normal (reference)	**Highway**		**Mountainous**		**Regular**	
		Absolute	**Relative**	**Absolute**	**Relative**	**Absolute**	**Relative**
Average delivery time	8,78	8,39	-4,44%	9,76	11,16%	8,35	-4,90%
Standard deviation	2,15	1,92	-10,70%	2,5	16,28%	1,89	-12,09%
Delivery cost	4818	4193	-12,97%	8409	74,53%	7449,62	54,62%
Average delivery cost	1,59	1,41	-11,32%	2,79	75,47%	1,95	22,64%

According to simulation results, the best possible choice is to use the highway road type. The improvements can be achieved in all metrics values – delivery time, delivery cost and standard deviation. At first sight regular road type may seem the optimal solution; however after we take a closer look at delivery cost, it becomes clear that it is not an appropriate choice. Obviously, the worst option is to select mountainous road type.

<u>Solution 2 – find the right safety stock level</u>

What has already been observed, changing delivery parameters may reduce the delivery costs and time but unfortunately does not have an impact on the availability of merchandise described by OTIF indicator. The availability mainly depends on the stock level of merchandise. Therefore setting the proper safety stock level may sort the problem out. In the first step the maximum, minimum and average customer's order lot has been calculated. Then the OTIF indicator value has been determined in order to check how often the merchandise was available offhand. It important to remember that safety level will influence the profit company generates, because profit will be decreased by storage costs. Storage costs are related to the number of items we have in the warehouse. The above mentioned metrics' values calculated in reference run are presented in table 6.

Table 6. Metrics values related to merchandise safety level

Metric	Value
Minimum order lot	3
Maximum order lot	8
Average order lot	5,038
OTIF	65,28%
Profit	7913,33

Based on the metrics values presented in table 6, four following alternatives of merchandise safety stock level have been taken into consideration in simulation experiment:

1. Safety stock level is equal 1 item.
2. Safety stock level is equal 2 items.
3. Safety stock level is equal 3 items.
4. Safety stock level is equal 5 items.

The simulation has been run four times, once for every alternative presented above. The main metrics calculated during every run are OTIF indicator and total profit. The results are presented in table 7.

Table 7. Metrics calculated for different safety stock levels

Option 1		**Relative difference**
OTIF	89,28%	24,00%
Profit	6088,97	-23,05%
Option 2		**Relative difference**
OTIF	91,81%	26,53%
Profit	4675,71	-40,91%
Option 3		**Relative difference**
OTIF	89,60%	24,32%
Profit	3027,80	-61,74%
Option 4		**Relative difference**
OTIF	94,96%	29,68%
Profit	1970,33	-75,10%

As analysis reveals, the safety stock level which is equal or greater than 1 item provides better availability of merchandise about at least 24%. Unfortunately at the same time,the profit decreases rapidly because of storage costs related to number of items that constitute the merchandise safety level. Therefore, only one item which is set aside as a reserve is economically viable.

Solution 3 – combination of best alternatives from solution 1 and 2

The final step is to check if the combination of two best options of suggested solutions will provide better results than each option separately or putting this differently to check if synergy effect will take place. The table 8 shows simulation results. In this case the parameters have been set up in the following way: safety stock level = 1 item; type of road = highway.

Table 8. Metrics values for solution 3

Reference run		Solution 3		Difference	
Metric	**Value**	**Metric**	**Value**	**Absolute**	**Relative**
OTIF [%]	65,28%	OTIF [%]	87,58%	22,30%	N/A
Delivery time [h]:		Delivery time [h]:			
- minimum	2,60	- minimum	2,30	-0,30	-11,54%
- maximum	16,30	- maximum	13,90	-2,40	-14,72%
- average	8,78	- average	8,70	-0,08	-0,89%
- standard deviation	2,15	- standard deviation	2,32	0,17	7,79%
Total profit	7913,33	Total profit	6026,14	-1887,19	-23,85%
Delivery cost:		Delivery cost:			
- total	4818,00	- total	4053,00	-765,00	-15,88%
- average cost per unit	1,59	- average cost per unit	1,36	-0,23	-14,47%

In solution 3, OTIF indicator's value has been improved by 22,3%. There are also better values of delivery time and delivery costs. Unfortunately total profit has decreased by 24%. What we have already mentioned this is related to the storage costs which increase when the number of items grows.

Final decision

After careful analysis of the "out of the stock" situation, supported with Agent Based Modeling andSimulation, the final decision can be made. According to simulation results, the solution 1(a) has turned out to be the optimal one. The reason of such choice is that it gives the shortest delivery time what can boost our customers' satisfaction level, however in order to improve customer service with regard to "out of stock" problem, the warehousing system should also be improved. As the case study showed, in the current form of warehousing system, the process of increasing number of items significantly affects storage costs in the negative way.

Conclusions and Further Research

The paper shows that simulation done with the use of Agent Based Platform may be very powerful tool for supporting decision making processes related to Supply Chain Management. Although only one decision situation was analyzed it's clearly visible how sensitive this kind of modeling is and how well decision maker may be supported. The approach presented is especially well suited for semi-structured and unstructured decisions, where predefined solutions' procedures are not available and analysis has to include risk factor. The further research will be devoted to collecting decision situations patterns that take place in Supply Chain Management process and showing how these kinds of decisions may be supported by simulation experiments planned and executed on the developed platform. The vision of the research is to have library of simulation experiments patters dedicated to the most common decision situations taking place in the area of Supply Chain Management. This library is supposed to be some kind of "prove of concept" for the reference model for Agent Based Simulation of Extended Enterprises which is the final product of the research.

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SEMANTICALLY RICH EDUCATIONAL WORD GAMES ENHANCED BY SOFTWARE AGENTS

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Abstract*: With steadily evolving new paradigms for technology enhanced learning, educational word games such as quizzes, puzzles and quests raise new appeal and motivation for students in following game based educational processes. Traditional word games may be applied more successfully to game based learning in given scientific domain provided they are highly oriented to the content and problems of that domain. Such games may be more efficient if they include artificial agents simulating opponents, advisors or collaborators of the player. Authors present a semantic structuring model of learning content for logic and word games serving for educational purposes and, next, show the place of artificial agents within the game construction and possible ways of agent's realization. There are given results from practical experiments with playing a memory game using the semantic content model, without and with agents integrated into the game.*

Keywords*: Agents, quiz, word game, e-learning, game based learning.*