EVOLUTION OF UNPLANNED COORDINATION IN A MARKET SELECTION GAME - DELIVERY COMPANIES CASE STUDY

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Abstract: *This paper examines the possibility of using evolution of unplanned coordination among independent distribution companies (agents) in a market selection game. The proposed model is a non-cooperative repeated game with several agents on many markets. Every agent is supposed to simultaneously choose a set of markets (cities) for maximizing its own revenue obtained by providing delivery service at the selected markets. It is assumed that the total volume of logistic units (pallets) is determined by the total number of agents on that market, their prices and service levels. The point of the market selection is to choose a set of markets for each agent that is optimal taking into account the specificities of each agent. In addition, it is proposed to expand model by evolutionary computation and fuzzy logic.*

Keywords: *game theory, logistic units, coordination.*

1. INTRODUCTION

The market of good distribution is characterized by the existence of highly developed competition between all participants involved in it. The existence of competing companies has a big influence on all aspects of their operations (the price of shipments, quality of offered services, the volume of shipments, etc (Čupić, 2014)). In such conditions, companies are faced with the uncertainty of what will be the consequences of decisions taken in specific situations and circumstances. As is often the case, the consequences of business decisions does not depend only on one side which brings them but also by interacting with decisions brought by other side (Krčevinac et al., 2006). Since the interests of participants at the market of good distribution are almost always antagonistic, i.e. the companies operating on this market are in conflict, the business decisions that they bring are interdependent and monitored with uncertainty, this phenomenon is possible to describe such a game. Area of operations research which analyzes these problems and finds optimal solutions is called game theory (Krčevinac et al., 2006). Game theory is a very important area of possible applications of evolutionary computation. Special importance has the study of evolution of possible strategies applied by individual players.

1.1 Literature review

The large number of authors dealt with game theory to diverse problems from various branches of engineering. Ishibuchi et al. (2001) have studied the evolution of unplanned coordination of independent agents. They studied a market selection game by a large number of independent agents. This paper, among others, was the inspiration for this research so that it will hereinafter

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be described. Ishibuchi and others suggest that a game involving agents should be uncooperative, should consist of a large number of rounds and should be repeated. Within each round, all agents who seek to maximize profit at the same time choose one of a number of possible markets where they will sell their products. The product price is determined by the total supply on the market (in a particular market is high if at the market appears very few agents, and inversely). After consideration of the effects that have been achieved in a given round, agents in the next round again elect market for its operation. Agents can use different strategies for the market selection. Ishibuchi and others are through application of genetic algorithms determined the best schedule of agents by markets. The authors showed that achieves about the same average profit per agent in the event of "unplanned" and in the "planning coordination."

Witteloostuijn and Boone (1997) are used game theory to show how inert player can displace from the market more flexible player. Some authors have used game theory to clarify sociological and evolutionary phenomena pertaining to the greater effectiveness of cooperative individuals in relation to the non-cooperative individuals, during the game (Wang et al., 2015). In more recent papers Adami et al. (2016) have dealt with the evolutionary game theory where the agents, as opposed to the classical theory, were modeled individually simulating thus the heterogeneity of the population of participants in the game.

2. UNPLANNED COORDINATION IN A MARKET SELECTION GAME

The market of goods and services distribution is characterized by a large number of companies that participate in it. Their positions are different for several reasons: the size and technology development of company, the structure of the fleet, the geographical position in relation to customers and so on.

In practice, situations in which more companies have interaction whose outcome depends on the mutual strategy two or more parties that have a conflict of interest is not unusual. The solution of these problems is possible by applying the game theory, which according to (Krčevinac et al., 2006) define the following:

- players who are parties of the conflict;
- gain/loss that is the result of the game;
- a set of strategies (strokes, alternative) that represent the behavior of each player.

During the game, through a number of rounds will come to evolution of market selection strategy applied by individual agents (distributors). Consider the n agents who in each round completely independently make decisions regarding the selection y of m markets $(y \leq m)$. Agents randomly elect a new market selection strategy from a set of predefined possible strategies. It is also advisable when choosing a strategy to use the genetic mutation operator. Each agent has its own node from which it goes on the market and in which he returns. That node presents head of distribution centers or hub. Agent is completely independent in its decision making process. Profit derived by an agent depends on the number of other agents who have chosen the same market, as well as transport costs which have agent during collection and distribution of pallets. Any strategy selected by the agent is characterized by a particular value of the fitness function. The value of fitness function includes the profit generated by agent.

Respectively i and j are indexes of agents and markets $(i = 1,2, ..., n; j = 1,2, ..., m)$. The T is the total number of game rounds. The t $(t = 1,2, ..., T)$ denotes the index of the round.

We introduce into consideration binary variable m which describes the decision of the i agent in the t round. This variable is defined as follows:

$$x_{ij}^{t} = \begin{cases} 1 & \text{If agent } i \text{ choose market } j \text{ during rount } t \\ 0 & \text{in other cases} \end{cases} \qquad j = 1,2,\dots,m \qquad (1)$$

Since the agent i should choose y of m of potential markets, it must be fulfilled the following relations:

$$\sum_{j=1}^{m} x_{ij}^{t} \leq y \tag{2}$$

The total number of items/pallets collected by the agents in the market j during round t is equal to:

$$X_j^t = Q_j \frac{\dfrac{\sum_{i=1}^{n} p_i}{p_i}}{\sum_{i=1}^{n} \dfrac{\sum_{i=1}^{n} p_i}{p_i}} \tag{3}$$

The unit transfer price that during the round t agent charges in each market is denoted as p_i^t. The total number of items/pallets generated by the market in the node j is denoted by Q_j.

The agent i during round t has transport costs caused by transfer, processing and distribution of logistic units. That costs originating from performing at particular market j and they are calculated as in (Čupić, 2014), denoted as C_{ij}^t.

Profit derived by the agent i during the round t at the market j is equal to:

$$r_{ij}^t = X_j^t \cdot d_j - C_{ij}^t \tag{4}$$

where d_j is the average distance for transport of item/pallet at j node.

On the basis of relations (3) and (4) it can be concluded that the agent's profit does not depend only of the choices that he made but also of the choices that have made all the other agents.

Denote with s_i^t strategy of choice of agent i in the round t (in fact, it is a set of markets chosen by agent). In the initial round agents select markets randomly. Because there are m markets, the probability of selection of each market is equal $1/m$. In the present case, profit represents the value of the fitness function of the chosen strategy by the agent and can be marked as $r_{ij}^t\left(s_i^t\right)$ for market j.

We denote by $N(i)$ the neighborhood of the node i. Total number of nodes in the neighborhood is equal to N. Ishibuchi et al. (2001) have suggested that the neighborhood of the node i is a set of nodes to which belongs the node i and its nearest $N-1$ nodes. In addition to this definition, a neighborhood of nodes can be defined in some other way.

When playing the next round agent can keep the same strategy, i.e. the same set of nodes, or to choose a strategy from their neighborhoods for each individual selected market, i.e. for the city that covers by its transport network.

It is clear that, in the case of distribution companies, each agent has full information about the strategies that have been used in previous rounds of his neighbors.

Suppose that the agent has full information about the amount of logistic units that in some nodes took over his neighbors, although this is less likely. It should be noted that competition in some place generates profit (e.g. because of the proximity of the distribution center) while agent who observes his neighbors would make losses by including the same node in its transport network. The Pr indicates the probability with which the agent i when playing the next round changes the existing strategy s_{ij}^t for the observed node j by strategy s_{kj}^t of its neighbor k ($k \in N(i)$). Probability of strategy replacement is calculated as suggested by Ishibuchi et al. (2001):

$$P\left(s_{kj}^{t}\right)=\frac{r_{kj}^{t}\left(s_{k}^{t}\right)-r_{\min}^{t}\left(N(i)\right)}{\sum_{k\in N(i)}\left\{r_{kj}^{t}\left(s_{k}^{t}\right)-r_{\min}^{t}\left(N(i)\right)\right\}} \tag{5}$$

where $r_{\min}^{t}\left(N(i)\right)$ is the minimal profit made in the neighborhood of *N(i)*, i.e.:

$$r_{\min}^{t}\left(N(i)\right)=\left\{r_{k}^{t}\left(s_{k}^{t}\right):k\in N(i)\right\} \tag{6}$$

After the operation of strategy replacement performs the operation of mutations. Strategy obtained after replacement operation will be replaced with one of the other strategies of the neighborhood, with the probability of mutation P_m. Strategy obtained after replacement and mutation operations denotes with S_{ij}^{t+1}. In other words, the agent *i* will use a strategy S_{ij}^{t+1} *(i = 1,2,...,n)* during the round *(t+1)*, with respect to node *j*.

Algorithm of evolution of market selection strategy consists of the following steps (Ishibuchi et al., 2001):

- Step 1: Determine randomly initial strategy of each agent;
- Step 2: Play a round of games with selected strategies and calculate the profit of each agent;
- Step 3: With the probability of performing replacement, replace agent's strategy in each individual market with one of the strategies of agent neighbors;
- Step 4: With the probability of performing mutation, replace agent's strategy by new strategy different from the existing one;
- Step 5: If they are not fulfilled conditions for completion of the algorithm, should return to step 2.

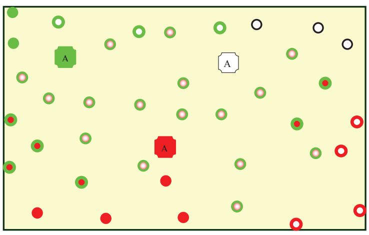

Figure 1. One stage in the evolution of market selection strategy

In the previous figure we can see an illustration of a stage in the evolution of market selection strategy. Nodes are colored. That represent each agent so in Figure 1 we have monochrome nodes which are covered only by one agent, nodes with two colors that covered by two agents and nodes that operate all agents. It is expected that the nodes which are extremely distant and have a small amount of logistic units are covered by a small number of agents, and vice versa.

3. EXTENSION OF THE MODEL BY EVOLUTIONARY COMPUTATION AND FUZZY LOGIC

The proposed model has several shortcomings that should to overcome through extensions given further more. In the first place, companies can have a completely different logic in forming strategies. Different logic is not the result of differences in the rationality of players but result of their different positions in the market, the location of processing and distribution centers, techno-economic performance of the companies themselves. The solution that is proposed is the introduction of fuzzy logic rules by which agents change their strategy. Rules are formed for each agent based on its indicators. The probabilities of changing the strategy of each agent are different because there are more or less inert companies.

It is therefore necessary to introduce multiple criteria decision making in the given model as described in Čupić (2014). With this expansion agents would be able, during the rounds, to change the price and offered quality of services. That would affect the number of clients they attract, transport and sorting costs and, finally, the change in profit. The probability of strategy replacement could be calculated for each indicator and it would made selections of each market, also as the quality of service that is offered by market. Unit price would be offered for each round but the same for all selected markets, which reflects the uniqueness of tariffs throughout the territory.

In the case of observing different company in some other game, the price can vary from market to market. Agents are interested for competitive prices, for percentage of the market that the competition attracted by those prices and the offered quality of services. Based on all available information, management makes a decision on changing the tariff policy. The only way for properly presentation of this process, in the opinion of authors of this paper, is writing fuzzy logic rules for each player that would be obtained by interviewing management on how to react to the given market situation. In the proposed model, all markets are the same in all, except the amount of logistic units that is collected on them. It is known, however, that markets react differently to the services offered.

In some markets the main parameter for agent selection is offered price of services, while on the other market the main parameter is quality of service. Modification could be applied to the expression (3) where each agent could receive a certain percentage of logistic units in market depending on the offered price and quality (assessment of service quality is marked with KV_i)). The quality which is offered by agent sometimes is not technologically possible to change (due to travel time, storage capacity, etc.) or the costs of such a project are extremely high. This fact must be taken into account when defining the probability of change of strategy related to quality of service.

If it turns out that the flexibility of agents with respect to changes in the quality of service they offer is low, then this parameter should be excluded from observation but only as part of a strategy that the agent can change. In any case, quality of service affects the probability of selection of a particular agent by the client. Also, percentage of conquered market depends of quality of service. The difference between markets would be obtained by defining the weight coefficients W_1 and W_2 expressing customers' preferences (price, quality) in this market (7):

$$X_j^t = Q_j \left[W_1 \frac{\frac{\sum_{i=1}^{n} p_i}{p_i}}{\sum_{i=1}^{n} \frac{\sum_{i=1}^{n} p_i}{p_i}} + W_2 \cdot \frac{KV_i}{\sum_{i=1}^{n} KV_i} \right] \tag{7}$$

Besides the rational parameters, clients often choose some distributor on the basis of subjectivity that is commonly recognized as a loyalty to distributor. In this sense, it is difficult to conquer new markets because the agent must 'hijacks' customers. This phenomenon could be included in the model through previous expression (7) by multiplication with an index of loyalty. Index of loyalty could minimize amount of logistic units to which the agent can count to the advent at the new market in the next round minimized. When agent stay at market, amount of logistic units could be magnified. In this way, agents were stimulated or not to win/retain markets. Since customer loyalty varies from market to market, this index should be determined specifically for each market [7].

From all the above it can be seen that it is very difficult to agent to determine the optimal strategy under conditions of competition. Therefore, the observed problem should be solved by evolutionary game.

4. CONCLUSION

The proposed model can be used in several ways depending on which the problem is solved. The first scenario is: all of the companies are already on the market of distribution of logistic units, have their own transport networks that are not fixed and have processing and distribution centers which are fixed (in special cases can be moved with additional costs). The game consists of changing the price, set of nodes and, consequently, the terms of collection/delivery. The second case is when an agent is new and has the freedom that, besides strategies with no additional costs, to the end of the game receives the topology of the transport network and timetable of lines that should be established. The last case is that all agents are new, new service is at the market and all players start from beginning and define all the parameters of its operations related to the service. It is necessary to compare the results of unplanned with planned coordination, where the central planner could deploy agents although access of planning coordination is not realistic in the case of distribution of goods.

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