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Agnieszka KOWALSKA-STYCZEŃ*

SIMULATION MODEL OF CONSUMER DECISION MAKING

In this paper a simulation model is presented, which by means of a cellular automaton allows us to analyze the process of decision making by consumers. The model takes into account the influence of the neighborhood, as well as of advertising. It works on the basis of a two-dimensional cellular automaton with a von Neumann neighborhood.

Keywords: *model, cellular automaton, consumer behavior*

1. Introduction

Consumer behavior is influenced by several factors. The choice made by a consumer is the result of the interaction of cultural, social, personal and psychological agents.

Since the study of consumer behavior in real conditions is quite expensive and often difficult, an interesting procedure consists of building a model and running a simulation of consumer behavior. Consumer behavior and models of such behavior are discussed, in particular, by SMYCZEK and SOWA in [11]. They conclude that a consumer's behavior should be considered together with the consumer's neighborhood, because the range and kind of decisions made on the market depends to a large extent on this neighborhood. A great influence on consumer decisions is exerted by other people's opinions and behavior (consumers very often buy what has been recommended by their friends and colleagues, as indicated by RUDNICKI [9]).

* The Silesian University of Technology, Department of Organization and Management, Chair of Computer Science and Econometrics, ul. Roosevelta 26-28, 41-800 Zabrze, Poland, e-mail: Agnieszka.Kowalska@polsl.pl

In this paper a model of consumer behavior is elaborated, taking into account the influence of the closest neighborhood and of advertising on consumers' purchasing decisions. In order to create such a model, articles related to consumer behavior were studied, such as [1], [2], [5], [9], [11].

From these articles one may notice that consumers making market decisions are influenced above all by the purchasing preferences of their closest neighborhood, that is to say of their family, friends and acquaintances. A very important part in decision making is also played by advertising.

In most countries, and also in Poland, the economy is dominated by an oligopoly [6], [8], i.e. by a few big companies selling the same products. What makes an oligopoly different from other market structures is, first of all, the fact that the participants in such a market are required to be conscious of the reactions of other companies [7]. There is fierce competition as to the price, quality and quantity of products sold. A considerable part is played by advertising. So, the following are important questions to ask: when is advertising efficient, and at what level should it be? In this paper I shall try to answer these questions on the basis of a model of consumer behavior founded on a two-dimensional cellular automaton [14] with a von Neumann neighborhood (Fig. 1).

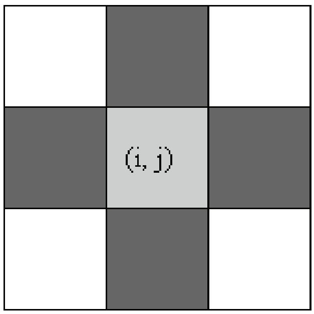

Fig. 1. Von Neumann neighborhood of a two-dimensional automaton cell (i, j) with $r = 1$ (the 4-element neighborhood)

A cellular automaton is a mathematical object consisting of, [4]:

- a network of cells $\{i\}$ in a D-dimensional space,
- a set of possible states for each cell $\{s_i\}$ consisting of k elements,
- a rule F defining the state of a cell at time $t + 1$ depending on the state of this cell and of its surrounding cells at time t, i.e. $s_i(t + 1) = F(\{s_j(t)\}), j \in O(i)$, where $O(i)$ is the neighborhood of the i-th cell.

It is thus a dynamic mathematical model of a process occurring in time. The D-dimensional space, in which the cellular automaton evolves, is divided into identical cells, each can assume one of the states (the number of possible states is finite). The neighborhood is defined in the same way for each cell. The state of a cell changes in time according to the rule F and depends on its previous state and on its neighbors' states. Thus, important parameters for a cellular automaton are: the dimensions of the lattice, D, and the number of possible states for a single cell, k. A frequently used parameter is the radius r, which defines the form of the neighborhood for a given cellular automaton. If the neighborhood $O(i)$ consists of the nearest neighbors of the i-th cell, then $r = 1$.

The consumers' environment in the following simulations is modeled as a discrete two-dimensional space, which consists of a finite square lattice of cells. One can then determine boundary conditions, which describe the behavior of cells at the border of the lattice. The cells are assumed to model a sphere. Hence, cells on the border of the square lattice are assumed to be neighbors of the cells situated on the opposite border of the lattice. This way of modeling aims at depicting our real surroundings: we live on and move across a globe.

The simple model suggested in this paper describes and shows the diffusion of preferences among consumers and, in a simplified way, how advertising affects the market. Consumers need information about the characteristics of products and their prices, in order to make rational decisions. Advertising can be a method supplying such information. The question arises: when is advertising efficient and when is it not?

2. Simulation model

The simulation models discussed in this paper are a development of the marketing models of C. SCHULZE [10] and K. and R. SZNAJD-WERON [13], based on the Sznajd model [12]. In the Sznajd model, the Ising model is applied to a description of the mechanisms governing decision making[1]. (The Ising model was originally used to describe a ferromagnetic material[2]). The Ising model deals with N fixed points, called lattice nodes, forming an n-dimensional lattice (n = 1, 2, 3, ...). The spin variable, s_i, assigned to each node of the lattice can assume one of two values: 1 for up-spins and – 1 for down-spins. K. Sznajd-Weron and J. Weron used the Ising model to describe the mechanisms governing decision making in closed societies, while papers [10] and [13] considered marketing models on the basis of it.

[1] This model was invented by W. Lenz in 1921, and was described by a one-dimensional atom chain by E. Ising in 1925. A two-dimensional model was created by L. Onsager in 1944 and it was then named the Ising model.

[2] Ferromagnetic material – a material having the property of magnetizing easily.

In [13] consumers of two products are placed on a square lattice. The initial proportion of consumers preferring product A is c_o, and the initial proportion of consumers preferring product B is $1 - c_o$. In this model, the middle cell consisting of four spins influences a neighborhood consisting of eight spins, see Fig. 2.

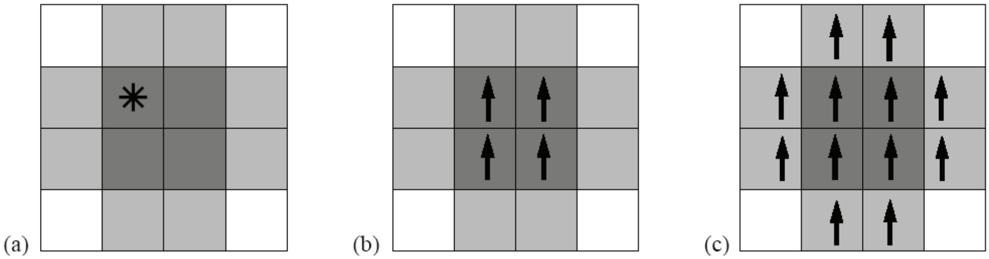

Fig. 2. (a) A customer (denoted by *) is selected randomly and then together with his/her three neighbors forms a panel (dark gray cells which can influence their eight nearest neighbors (light gray cells). (b) If a panel consists of four customers sharing the same opinion (spins in the same direction, here up-spins), then (c) all eight neighbors will turn in the same direction

Here, advertising is a kind of external field. The choice made by a customer between two products is influenced by neighbors' opinions and advertising. Consumer reaction to advertising (in the model only product A is advertised) is measured by means of the parameter h, a number from the interval [0, 1]. A consumer does not always decide to follow the majority opinion, i.e. she is responsive to advertising and chooses the advertised product regardless of the neighbors' opinions with probability h, see Fig. 3. There is a critical threshold of the influence of advertising h dependent on the initial concentration of consumers c_o, and if this is exceeded, product A will dominate the market. A low level of advertising, say $h = 0.25$, allows product A to conquer the market, in spite of the fact that initially approximately only 10% of consumers preferred this product.

However, in the Sznajd model, described above, there is one limitation important for the course of the simulation. The cellular automaton applied has only two possible states for each cell, which limits the simulation. In this paper we describe a model of consumer behavior, which uses two-dimensional cellular automata with an unlimited number of possible states for each cell, thus allowing the study of consumer behavior for more than two products, which makes it different from the model in [13]. Moreover, in the model we propose, contrary to the one presented in [13], the neighborhood influences the customer considered.

Such a two-dimensional cellular automaton is an $n \times n$ square lattice [3]. There is a defined consumer population density p (given as a %), while some of the cells are empty. These empty cells in the lattice allow us to introduce mobility into the model. In the real world, we go to work, school etc., thus shifting our nearest neighbors. Each consumer is described by two variables. The first one defines the direction in which a consumer is facing (north – 1, south – 2, east – 3, west – 4), and the second variable is a list of preferences consisting of *m* elements. The fact that each cell, representing a customer, has a randomly assigned orientation, allows us to introduce mobility. A consumer moves to the nearest empty cell according to its own orientation, so when assigned the northern orientation, s/he moves to the nearest empty cell situated to the north.

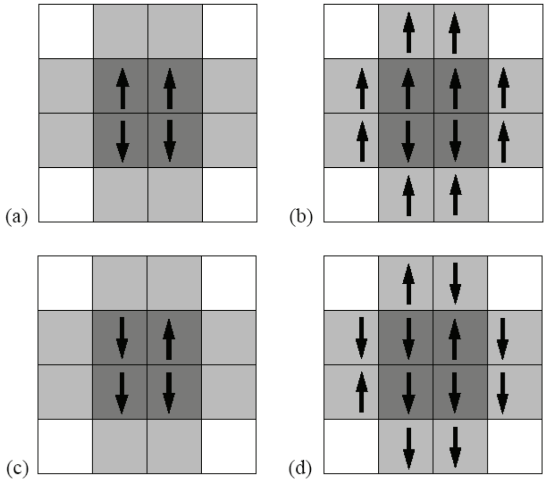

Fig. 3. (a) If a lattice consists of two customers of product A (up-spins) and two customers of product B (down-spins), then (b) all eight neighbors will be responsive to advertising. In the case of very strong advertising, $h = 1$, all of them will choose product A. (c) If a lattice consists of one customer of product A (up-spin) and three customers of product B (down-spins), then (d) with probability 3/4 neighbors will choose product B (which is preferred by the majority) and with probability 1/4 will be responsive to advertising

The system develops via time steps until no consumer changes preferences any more. A single cell can assume one of *k* states. The rule applied to this automaton consists of two intermediary time steps [3]. The first is to check the neighborhood preferences and to exchange experience with the neighborhood. The second time step is the shifting of individuals. The exchange of experience between a chosen customer and his/her neighborhood is one-way and can lead to a change in the chosen customer's preferences. The preference of the chosen customer changes to the one dominating in the neighborhood. This means that if more than 50% of consumers in a consumer's neighborhood have the same second characteristic describing preferences, then the chosen customer changes the status of this characteristic to the dominant one (different preferences of consumers are represented by different colors of cells). In the case where there is no such identical characteristic for over 50% of consumers in the neighborhood, the chosen consumer's preference remains unchanged. Then, in the second stage of the simulation, this consumer moves to the nearest empty cell that s/he is facing, which is defined by the relevant associated number, 1, 2, 3 or 4.

The lattice is filled by a combination of:

- empty cells,
- occupied cells defined by two elements: the direction an individual is facing and that consumer's preference.

The neighborhood applied in the models presented in this paper is the von Neumann neighborhood with $r = 1$. The neighborhood O_{ij} of the consumer k_{ij}, represented by cell (i, j) consists of the cells $(i, j+1)$, $(i+1, j)$, $(i, j-1)$ and $(i-1, j)$ – Fig. 4.

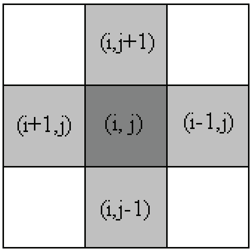

Fig. 4. Von Neumann neighborhood for cell (i, j) with $r = 1$

The behavior of consumer k_{ij} at time $t + 1$ depends on his/her behavior and the behavior of his/her neighborhood at time t, i.e.:

$$k_{ij}(t+1) = (k_{ij}(t); O_{ij}(t)) .$$

To carry out the simulation, the following values are given:

- n – size of the lattice,
- p – population density,
- m – number of products,
- t – number of time steps.

The simulation is run using a program written in the Delphi environment.

The following values were assumed for the runs illustrated here:

- $n = 20$,
- $p = 0.7$,
- $m = 2$,
- $t = 4$.

Similar results were obtained in simulations using other values of n and p.

The results of the simulations at various time steps are shown in Figs. 5 and 6. Fig. 5 shows the way in which the number of consumers with each preference changed. The two shades of grey (light and dark), corresponding to the original colors, stand for different customer preferences and white is used to denote empty cells.

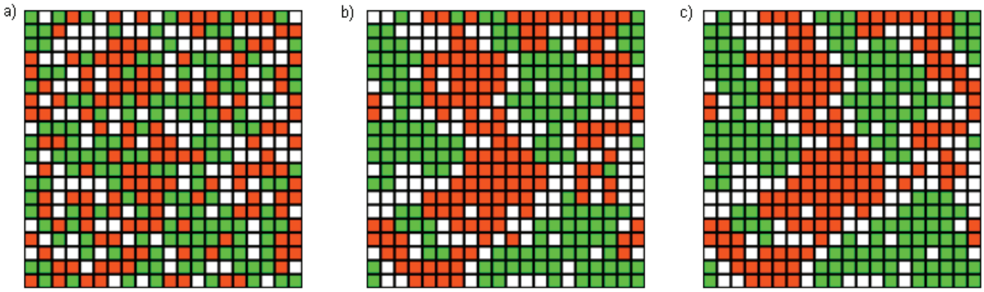

Fig. 5. Simulation results for a) the initial state, random distribution of consumers, b) $t = 2$ time steps, c) $t = 4$ time steps.
Source: Author's own work based on simulations in the Delphi environment

Conclusions for the simulation carried out for $1 \leq t \leq 4$ time steps are as follows:

- compact clusters of individuals sharing the same preferences and buying the same products form,
- the number of consumers with a given preference does not change radically (see Fig. 6).

In the simulations $t = 4$ was assumed, as for $t > 4$ the changes in the system are not significant (actually no consumer changed preference any more).

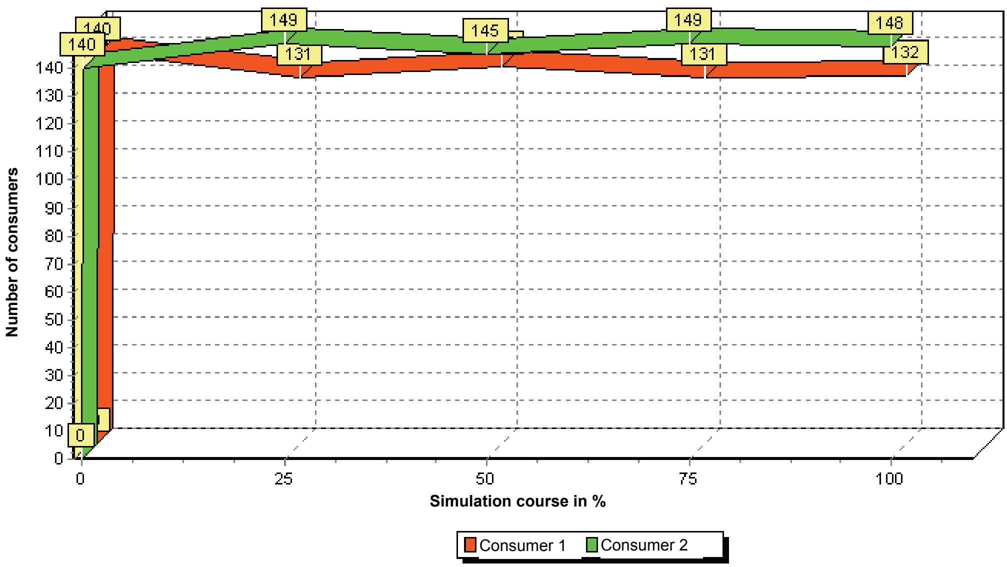

Fig. 6. Simulation results from the initial configuration to $t = 4$ time steps.
Source: Author's own work based on simulations in the Delphi environment

Simulations were also run for a larger number of products. The results were similar to those obtained in the simulation for $m = 2$. Below, the results of the simulation with four products are shown as an example. Each preference is shown as a different shade of grey, white stands for empty cells. In this simulation the following values were assumed:

- $n = 20$,
- $p = 0.7$,
- $m = 4$,
- $t = 4$.

The results of the simulation for $m = 4$ is shown in Figs. 7 and 8.

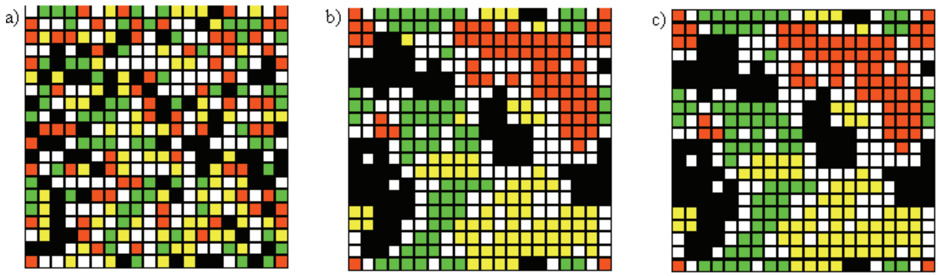

Fig. 7. Simulation result for $m = 4$: a) initial state with random distribution of consumers, b) $t = 2$ time steps, c) $t = 4$ time steps.
Source: Author's own work based on simulations in the Delphi environment

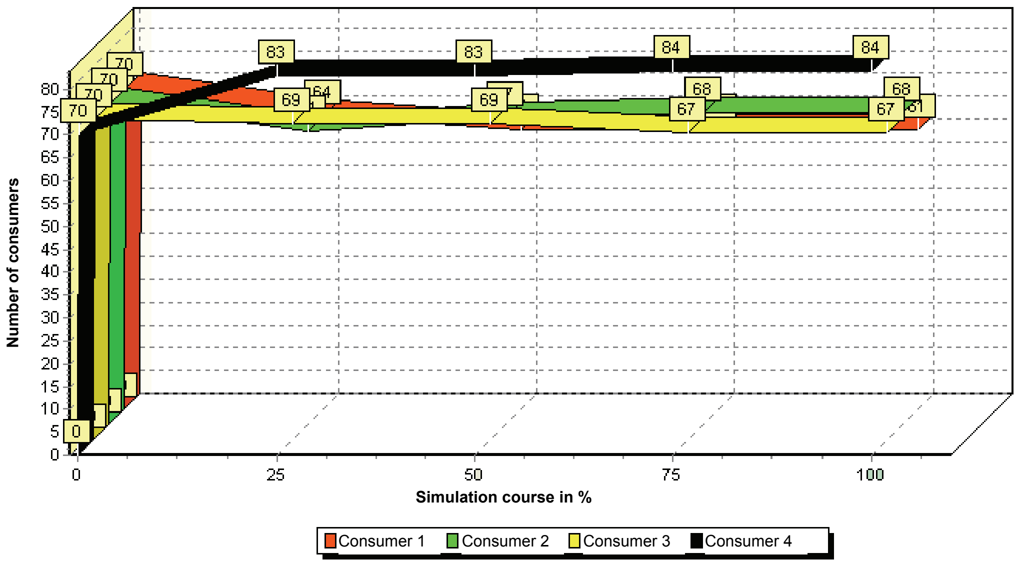

Fig. 8. Simulation result for $m = 4$ from the initial configuration to $t = 4$ time steps.
Source: Author's own work based on simulations in the Delphi environment

The conclusions for the simulations carried out for $1 \leq t \leq 4$ time steps are as follows:

- clusters of individuals sharing the same preferences form,
- the number of consumers with a given preference approximates the initial value (see Fig. 8).

The simulations carried out show that clusters form of consumers making the same choices. When running simulations for different numbers of products, one may notice a dependence of the number of groups of buyers on the number of available products. When there are more products, there are more groups making the same choices.

In the model one can also take into account the influence of advertising. Let us assume the level of advertising s is a number from the interval [0, 1], i.e., when the product is not advertised, $s = 0$. The rule defining consumer behavior takes, again, two time steps. The first consists of checking the preferences of the neighborhood of a chosen consumer and changing his/her preference to the dominant one. In the case where there is no dominant preference in the chosen consumer's neighborhood, s/he chooses the product with the highest level of advertising. When no change of preference takes place, in the second step of the algorithm the consumer shifts to the nearest empty cell s/he is facing.

The lattice is filled by a combination of:

- empty cells,
- occupied cells defined by two elements: the direction an individual is facing and that consumer's preference.

To carry out the simulation, the following values are given:

- n – size of the lattice,
- p – population density,
- m – number of the products,
- s – level of advertising,
- t – number of time steps.

The following values were assumed in the simulations illustrated:

- $n = 20$,
- $p = 0.7$,
- $m = 2$,
- $t = 8$.

It was also assumed that the number of consumers preferring product A equals the number of those preferring B and that only product A is advertised. (i.e. s equals 0 for product B, and for A it is optional, but greater than 0).

The results of the simulation at a sequence of time steps are shown in Figs. 9 and 10.

Figure 10 shows the changing number of consumers with each preference during the simulation. Dark grey stands for consumers of product A, light grey for consumers of product B.

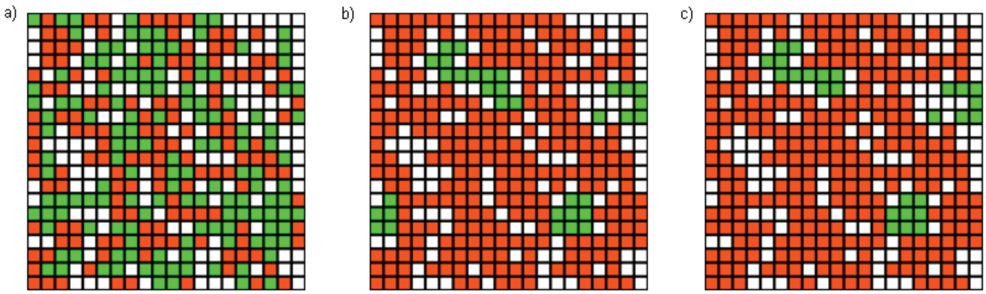

Fig. 9. Simulation results for a) the initial state being a random distribution of consumers; b) $t = 4$ time steps; c) $t = 8$ time steps.
Source: Author's own work based on simulations in the Delphi environment

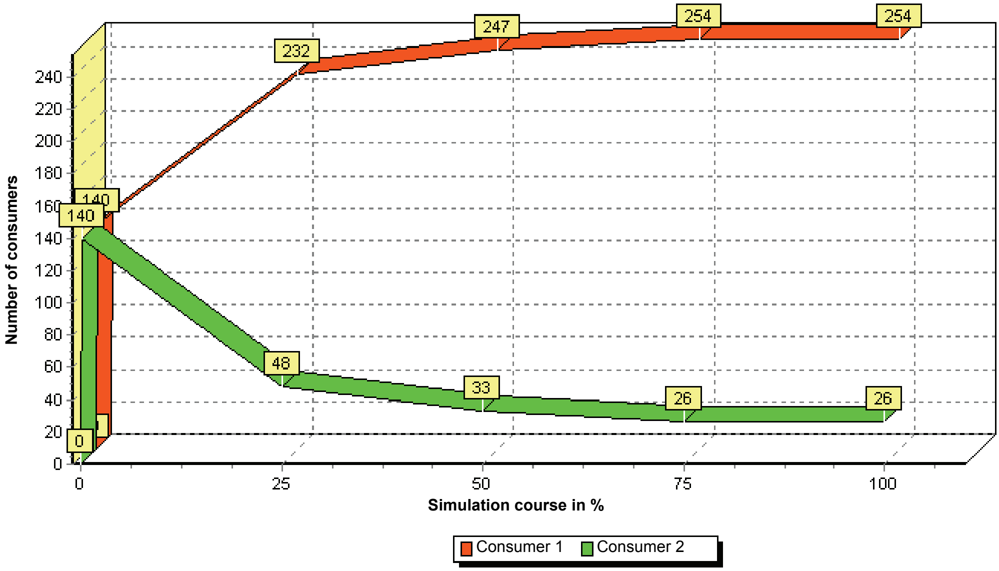

Fig. 10. Simulation results from the initial configuration to $t = 8$ time steps.
Source: Author's own work based on simulations in the Delphi environment

The results of the simulations for $1 \leq t \leq 8$ time steps are the following:

- in each population studied clusters of individuals sharing the same preferences (choosing the same product) form;
- the number of people choosing the product which is not advertised falls while the number of consumers choosing the advertised product rises;
- the number of consumers with each preference changes radically in comparison to the initial state (see Fig. 10).

The model taking into account advertising was then modified, in order to deal with the question as to what *s* should be to make advertising efficient. The cellular automaton rule in this case covers three steps. The first consists of checking the preferences of the neighborhood of a chosen consumer and changing the preference to the dominant one. In the case where there is no dominant preference in the chosen consumer's neighborhood, during the second step s/he succumbs to the influence of advertising, that is to say s/he chooses the advertised product with probability *s* (e.g. if for product A, $s = 0.2$, then 20% of the consumers of product B, who did not change their opinion in the first step of the algorithm change their preferences to product A). When no change of preference takes place, the consumer shifts to the nearest empty cell s/he is facing.

To carry out the simulation, the following values are given:

- *n* – size of the lattice,
- *p* – population density,
- *m* – number of products,
- *s* – level of advertising,
- *t* – number of time steps.

A series of simulations were carried out for different intensities of advertising and different numbers of consumers of products A and B. It was assumed that product A would be advertised. In this way the lowest value of the parameter *s* for a given initial percentage of product A consumers which allows product A to conquer the market was defined. It turned out that:

- a low level of advertising, $s = 0.2$, enables product A to conquer the market,
- this is possible when initially at least 10% of consumers prefer product A.

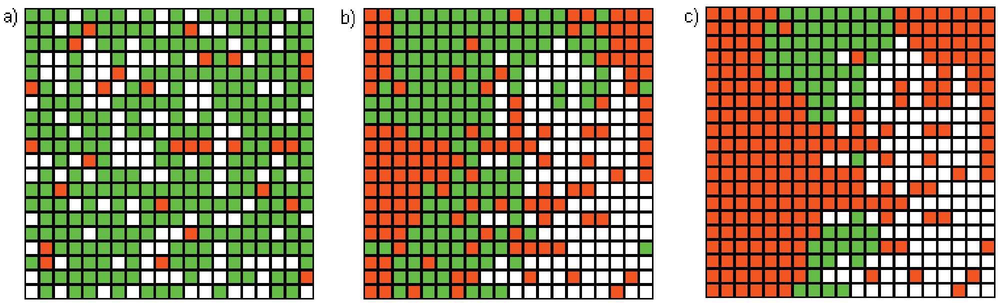

Fig. 11. Simulation results for the initial state a) random distribution of consumers; b) $t = 15$ time steps; c) $t = 60$ time steps.
Source: Author's own work based on simulations in the Delphi environment

Still, such a low intensity of advertising needs many more stages of simulation (about $t = 60$), in order to reach a fixed state in which no consumer changes opinion any more. The higher the intensity of advertising, the faster product A conquers the market. Below (Figs. 11 and 12) we show the results of the simulation for

- $n = 20$,
- $p = 0.7$,
- $m = 2$,
- $s = 0.2$,
- $t = 60$.

Dark grey represents consumers of product A, light grey consumers of product B.

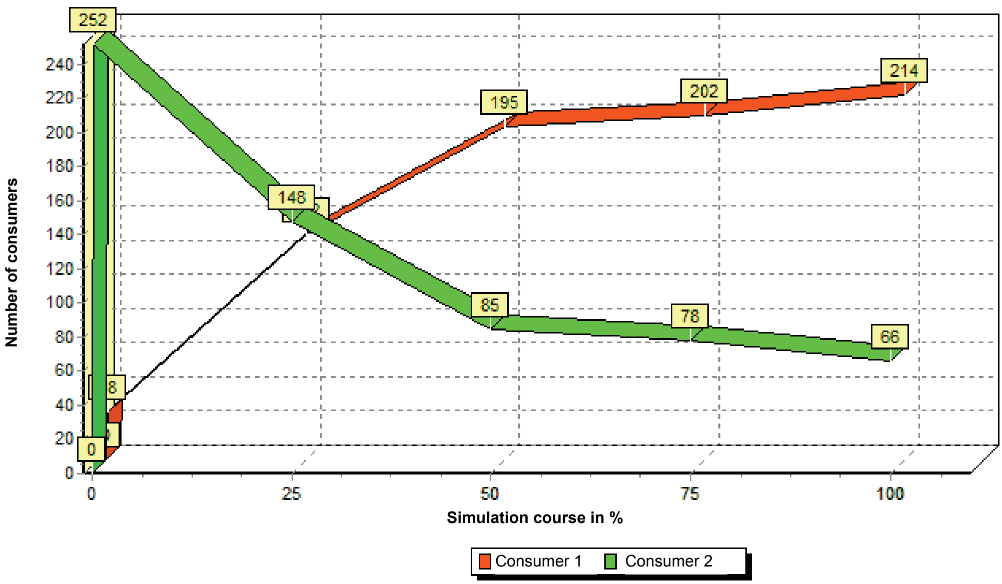

Fig. 12. Simulation results from the initial configuration to $t = 60$ time steps.
Source: Author's own work based on simulations in the Delphi environment

The results obtained are analogous to those using the Sznajd–Weron model [13], where an advertising intensity of 0.25 for product A allowed it to conquer the market in spite of the fact that approximately only 10% of consumers preferred this product at the beginning of the simulation. One can see that different ways of defining the association between a chosen consumer and his/her neighborhood (in model from [13] the chosen consumer influences the neighborhood, in the model presented here the neighborhood influences the chosen consumer) lead to the same results. It follows that to enable a given product to dominate the market it is necessary to conquer at least a small part of it at the beginning (the simulations show it has to be about 10%).

3. Conclusions

In order to create the model presented above, articles dealing with consumer behavior on the market were analyzed, as well as other marketing models such as [10], [13]. The articles imply that consumer behavior has to be studied in relation to the neighborhood as consumers' decisions are influenced by other people's opinions and behavior. Most consumers' decisions depend on their closest relatives' opinion and on advertising. This is also the case in the model suggested by the author: making a purchasing decision depends on the opinion of the closest neighborhood, as well as on the influence of advertising.

This paper provides an answer to the question as to what the advertising intensity should be in order to enable a product to dominate the market. It turns out that an intensity level of 0.20 allows a product to conquer the market, even if initially only 10% of consumers' preferred it.

This means that to enable a given product to conquer the market, it is necessary for this product to dominate at least a small part of it. Subsequent research into consumer behavior should aim at defining models, which would represent a real market in an ever more accurate way. The way a consumer makes decisions could be defined more precisely and more variables could be introduced into the model. One could introduce coefficients for the influence of a consumer's own preferences and of advertising intensity (that is to say a coefficient, which would describe the probability of an advertised product being chosen by a given consumer) and study the relation between them. It would also be interesting to deal with the question of too much advertising leading to an increase in consumer resistance to its influence. If consumers are constantly attacked with information about given products, would they not stop taking decisions based on advertising and after how much time would this happen?

In my future research work I shall try to answer these and other questions concerning models describing consumer behavior.

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Symulacyjny model podejmowania decyzji przez konsumenta

W pracy przedstawiono model zachowań konsumentów, w którym, po analizie literatury dotyczącej tych zagadnień, zachowania konsumentów zostały uzależnione od najbliższego otoczenia. Otoczenie to rozumiane jest jako rodzina, przyjaciele i znajomi. Do symulacji wykorzystano dwuwymiarowy automat komórkowy z otoczeniem von Neumanna. Konsumentów przedstawiono na kwadratowej kracie o wymiarach n na n. W przypadku gdy reklamowany jest tylko jeden z produktów, można zauważyć, że w krótkim czasie zdobywa on rynek i w przypadku braku reakcji na reklamę pozostałych sprzedawców w pewnym momencie nie jest opłacalne zwiększenie natężenia reklamy dla tego produktu.

W artykule przedstawiono również wiele symulacji dla różnego natężenia reklamy oraz różnej liczby konsumentów danego produktu. Okazuje się, że natężenie na poziomie około 0,20 pozwala produktowi zdominować rynek, jeśli na początku preferowało go jedynie około 10% konsumentów.

Słowa kluczowe: *model, automat komórkowy, zachowanie konsumentów*