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Research Article

Simulation of Land-Use Development, Using a Risk-Regarding Agent-Based Model

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The aim of this paper is to study the spatial consequences of applying different Attitude Utility Functions (AUFs), which reflect peoples' simplified psychological frames, to investment plans in land-use decision making. For this purpose, we considered and implemented an agent-based model with new methods for searching landscapes, for selecting parcels to develop, and for allowing competitions among agents. Besides this, GIS (Geographic Information Systems) as a versatile and powerful medium of analyzing and representing spatial data is used. Our model is implemented on an artificial landscape in which land is being developed by agents. The agents are assumed to be mobile developers that are equipped with several land-related objectives. In this paper, agents mimic various risk-bearing attitudes and sometimes compete for developing the same parcel. The results reveal that patterns of land-use development are different in the two cases of regarding and disregarding AUFs. Therefore, it is considered here that using the attitudes of people towards risk helps the model to better simulate the decision making of land-use developers. The different attitudes toward risk used in this study can be attributed to different categories of developers based on sets of characteristics such as income, age, or education.

1. Introduction

Land-Use/Cover Change (LUCC) is one of the most profound human-induced alterations of the earth's system [1–3]. LUCC is a complex process caused by the interaction between natural and social systems at different spatial scales [4, 5]. The heterogeneity and contiguity of space creates many difficulties in spatial models of residential land-use development. Therefore, there is no simple, uniform way to analyze and explain the dynamics of land-use changes [6]. A group of models have recently emerged and gained popularity in the LUCC scientific community. These models are commonly referred to as agent-based models (ABMs) [7]. These models use the real actors of land-use changes (individuals or institutions) as objects of analysis and simulation and pay explicit attention to the interactions of the "agents" of change [7]. Numerous attempts have been made to define the concept of agents [8, 9]. In this paper, we adopted the definition of Maes [10]: "An agent is a system that tries to fulfill a set of goals in a complex, dynamic environment. An agent is situated in the environment: it can sense the environment through its sensors and act upon the environment using its actuators." Agents can represent individuals, groups of individuals, and, if appropriate, inanimate objects such as houses or cars [11]. ABMs rely on interactions between many distributed agents to form emergent larger-scale patterns [12]. All agents structurally deal with an environment and with each other by a set of rules. Essentially, each agent behaves autonomously [13]. By simulating the individual actions of many diverse but interrelated actors and by measuring the resulting system outcomes over time (e.g., the changes in patterns of land-use in suburbs), ABMs can provide useful tools for assessing residential development [14]. In this paper, we developed and implemented an agent-based model equipped with new methods for searching landscapes, for selecting parcels to develop, and for allowing competitions among agents. Also, this paper links a Geographic Information System (GIS) with a simulation/modeling system purposely built.

Many ABMs have been proposed [15–20]. Therefore, several classifications of ABMs have been presented [15, 21]. Most models, however, are based on riskless axioms of rational choice. Risk is described as knowledge of the possibilities of undesirable results [22]. Comprehensive models that delineate the impact of attitudes towards risk on land-use development are rare. This paper aims to build a conceptual framework for including risk-explicit attitudes in the modelling of land-use development. Evaluating the patterns of land-use development in two cases of regarding and disregarding risk into account will elucidate the impact of attitudes of people toward risk on land-used development. Therefore, we defined and implemented two scenarios of regarding and disregarding risk. Also, since the attitudes of actual people towards risk in land-use development are difficult to detect, at least when the number of people gets large, this paper also attempts to suggest some criteria that categorize risky behaviors of people in land-use development.

In this study, an artificial raster landscape was prepared using GIS. The agents represent land-use developers that traverse the landscape seeking for land parcels to develop. The search is exercised in two scenarios, either regarding or disregarding risk. Ligmann-Zielinska (2009) studied the impact of risk-taking attitudes on a land-use pattern with ABM [23]. In her model the agents do not move in the landscape and they are randomly seeded. Moreover, there are only one to three agents who act in the landscape. In our model, the agents are not seeded randomly. They move explicitly in the landscape. Furthermore, number of agents is not limited and can be defined as appropriate to the conditions of study area. We also developed a new method for competition among agents.

In this study, the agents are categorized into five groups based on their desires and properties. Categorizing the developers helps the model to perform a better simulation of real situations. For instance, Loibl and Toetzer (2003) developed an ABM for urban sprawl in Vienna, Austria, with agents that were classified into six categories based on their characteristics [24]. However, here the classification is implemented by two methods: one method is through the different weights that they assign to the criteria maps and the other method is through considering different AUFs for them which reflects the attitudes of the developer agents toward risk. Tian et al. (2011) also reflected heterogeneity of agents by using different sets of weights according to the criteria maps [25]. On the other hand, Ligtenberg et al. (2008) developed a spatial planning model combining a multiagent simulation approach with cellular automata to simulate the urban development in the mideast of the Netherlands [8]. In that model, two types of actors were defined: the reconnaissance actors who had voting power during a planning process and the planning actors who had the authority to change the spatial organization. In that study, two scenarios have been defined and compared, although no validation method has been presented. Besides this, Bakker and van Doorn (2009) considered farmers as agents who change the land-use [26]. They defined four types for farmers and demonstrated that each farmer type shows a different relationship between landscape factors and land use changes.

In the rest of the paper, first Attitude Utility Functions are described. Then, the proposed methodology is explained using Overview, Design concepts, and Details (ODD) protocol. Next, implementation of pilot application is expressed. Afterward results and discussions will appear and the last section will be the conclusions and recommendations.

2. Utility Functions to Define Risk-Taking Agents

As highlighted in the introduction, two scenarios of regarding and disregarding risk are defined in this paper. Regarding risk is performed by considering an Attitude Utility Function (AUF) which reflected the attitudes of people toward risk. Therefore, AUF is briefly expressed here.

Considering the different attitudes of individuals, the consequences of particular decisions may be felt by some as gains and by others as losses [27]. In their most general form, attitudes are defined as relatively stable psychological tendencies that are expressed by evaluating specific entities with some degree of favor or disfavor [28]. Ligmann-Zielinska (2009) defined five-attitude templates, namely, Unbiased (risk-impartial), Reckless (risk seeking), Cautious (risk averse), Poor (risk avoiding), and Rich (risk bearing) that are mathematically presented in the following equations [23]:

$$
\begin{aligned}
y &= x, \\
y &= \frac{(e^{ax} - 1)}{a}, \\
y &= \frac{\ln(ax + 1)}{a}, \\
y &= ax^{a}, \\
y &= \left(\frac{x}{a}\right)^{(1/a)},
\end{aligned}
\tag{1}
$$

where a is a curving coefficient driving the shape of an AUF, equaling 3 in the above approximation, x is the original value of criterion c for option p, and y is the recalculated value of criterion c for option p based on the attitude. These AUFs are used in our paper.

3. Proposed Model and Its Main Features

In this study two methods of risk-regarding and risk-disregarding agents are considered. Heterogeneity of agents is articulated through diverse perceptions of decision criteria, which are embedded in AUFs. The model is explained in the following ODD protocol [29, 30].

```
Searching step
 Start
   For all agents
     For the number of allowed districts to search
       For the number of allowed regions to search
         Select a parcel
           Repeat
         Assess and save the state of . . .
         the neighborhood of the cell
         Go to the best neighbor around the cell
       Until allowed movement
     End For
   End For
End For
```

```
Developing Step
Start
While there is any unsatisfied agent
    Select an agent randomly
    Select the first choice settlement
    If there is any request for this cell
        Go to the competition
        Register the cell as developed
        Change the probability
Else
        Register the cell as developed
        Change the probability
  End If
End While
```

Figure 1: Pseudocode that shows the simplified algorithm of the model.

3.1. Overview

3.1.1. Purpose. The purpose of this paper is to establish an agent-based model of urban land-use development considering explicit risk attitudes in residential settlements using GIS environment.

3.1.2. Entities, State Variables, and Scales. The classification of agents follows the described categorization in Section 2. The landscape is a $500*600$ grid of cells and is divided into eight districts. Besides their type, each agent has a location in a cell of a landscape, a limited movement, a minimum required location change in a district, a number of districts to search, and a number of parcels to develop each session. Furthermore, the weights of criteria maps (Figure 3) may vary for different agent types, and every agent also has a Frustration (see Section 3.3.3(3)). Each run of the model is divided into four sessions and corresponds to one year. The model is run for five years.

3.1.3. Process Overview and Scheduling. There are two main steps in the model: the searching step and the development step.

Searching Step. In searching step the agents explore the landscape. At the beginning, the required number of agents is created and they are distributed in the districts. The selection of districts is based on the primary probability of selection, which is assigned to the districts. Neighborhoods of initially developed area are often exposed to further developments. Hence, when agents go to the districts, at first they move randomly to the neighborhoods of initially developed areas. Wherever the agent starts its activities, it assesses and records the state of its current parcel (standing parcel) and also its eight adjacent parcels. Next, the agent moves to its best neighbor parcel, or if more than one parcel achieves the same score, it chooses one of them randomly. If the agent movement is finished or it is not able to move to a neighbor parcel, the agent changes the search region in the district and jumps to another position in the same district. Moreover, the agents can search a specific number of districts in the same way. Thus, at the end of each searching step, each agent records the situation of several visited parcels and sorts them in descending order. This list may be known as investment list. The cells in the investment list of each agent are called searched cells for that agent.

Developing Step. When all agents finish the search, the Developing step starts, and agents choose the top scoring parcels in their sorted investment list to develop. In the conflict cases, the winner and the loser(s) are determined through the competition. The cells that are developed by the agents are assumed as developed cells hereafter. The pseudocode of the model algorithm is shown in Figure 1.

A searching step and a developing step are performed in each session. Properties of a session are like a year. Nevertheless, at the end of a year, the desired parcels of agents are developed so they are assumed to be initially developed in the next years. However this is not the case in the sessions. At the end of a session the agents have chosen their desired parcels but they have not developed them. Hence, those selected (reserved) cells are still undeveloped and the agents may traverse them in searching steps of next sessions. However, in developing step the reserved parcels cannot be chosen to develop. Therefore, the agents are forced to the less suitable parcels.

3.2. Design Concepts

3.2.1. Emergence. All of the resultant spatial land-use data from a completed simulation are emergent phenomena and include elements such as the pattern of development and the probability of districts to be selected.

3.2.2. Adaptation. After each session of runs, the probability of selecting districts for each type of agent is modified. This probability varies based on the settlements of the agents. Moreover, probable new clusters of developed cells in the previous year are now considered as initially developed area where attract the agents for further searches.

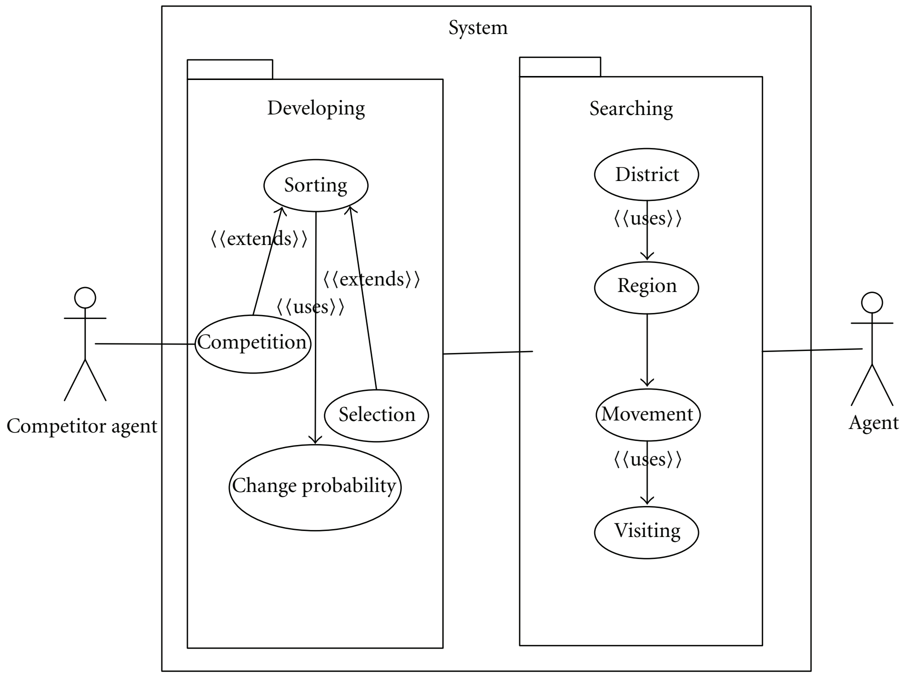

Figure 2: Use case diagram of the model.

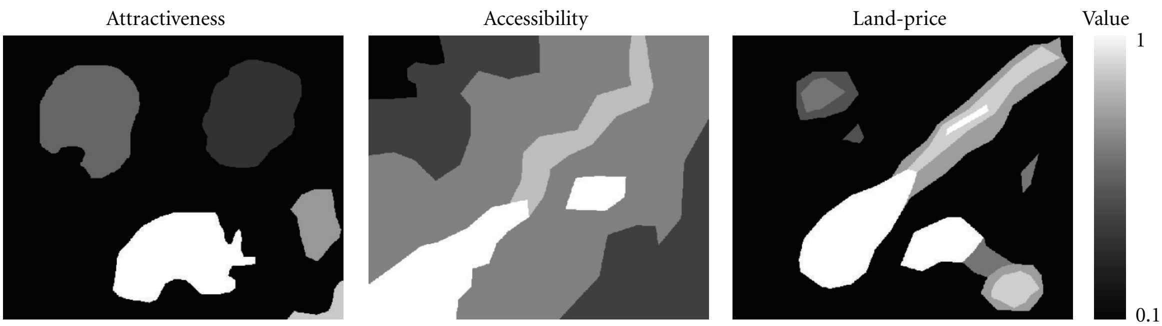

Figure 3: Three criteria maps, the lighter color means the higher suitability in the corresponding criteria map.

3.2.3. Objectives. The objectives of the agents are to find the most appropriate parcels (in the agent's judgment) for development and then to develop their predefined number of parcels, taking the most desired parcels from their search.

3.2.4. Sensing. The agents are free to surf the landscape. They know the districts, their borders, and their developed areas. The agents perceive the state of standing parcel and its neighbors. The state of adjacent parcels guides the agents to move to the best neighbor of its standing parcel. In developing steps, the agents may compete with some other agents to develop parcels.

3.2.5. Interaction. Each agent collects and saves the state of visited parcels. The high-score visited parcels are used to revise the probabilities of the districts. The changes in the probabilities of districts are indirect interactions among the agents. Competition is the direct interaction among agents who compete to develop a parcel.

3.2.6. Stochasticity. Choosing the districts is probabilistic. In the district, selecting the region of search is random, as well. Thus, there is a little variation in the several runs of the model. Hence, to ensure the stability of the results, the model is executed ten times.

3.2.7. Collectiveness. The agents are divided into five types with different aims and utilities.

3.2.8. Observation. For analyzing the results, the new developments simulated by the model can be assessed in some aspects. For each developed parcel, year of development, the type of the agent that has developed it, and number of requests for that parcel can be observed. Also, the total number of conflicts during the development which cause the competitions in each year is observable.

3.3. Details

3.3.1. Initialization. At the beginning, three criteria maps and the map of initially developed area are uploaded into the model. A predefined number of agents are created and moved onto the landscape. In this step, the probabilities of selecting districts are the same for all types of agents (Figure 2(a)).

3.3.2. Input Data. Using the GIS extension of NetLogo, input maps (Figure 3) are read from the files and then are converted to the initial software-specific format. The input maps are three criteria maps, the map of initially developed area, and the map of districts.

3.3.3. Submodels. There are some detailed aspects of models that can be briefly explained here.

(1) Ranking the Parcels. In the case of risk disregarding, the desirability of each parcel is obtained by a weighted summation of the value of that parcel in each layer. Otherwise, taking AUFs into account, an Ideal Point (IP) method is used.

(2) Changing the Probability of Selecting Districts. The districts have an arbitrary probability of being selected by each type of agents, which is assumed to be the same on initialization. However, the functionality of the agents changes this probability. When the selection of parcels for development is finished, the percentages of districts at the top half and top quarter of the sorted investment list of agents are calculated. Next, the calculated percentages from a top quarter with a weight of 2 are added with the calculated percentages from the top half with a weight of 1. After that, the result is compared with the previous probabilities and the difference for each district is calculated. The differences (which can be positive or negative for each district) are multiplied by a coefficient named the "coefficient of communication" and then are multiplied by a coefficient equal to (number of searched districts/number of whole districts). Finally, the results are added to the previous probabilities. Coefficient of communication is a parameter which regulates the impact of agents on changing the probabilities of districts.

(3) Competition. The competition among agents in cases of conflict is considered based on empirical observations. There are some heuristics in the competition of people for land. (1) All people do not compete for a parcel at the same time; they may find parcels at different times. (2) The power of people in competition is not equal. (3) People who lost some parcels in competition have more interest and pressure to win the next competition.

Based on these assumptions, the competition was implemented as follows: when the search in districts finished, the selection of parcels for development starts. The agents are selected one by one randomly until all of the agents develop their desired number of parcels. The top scoring parcel of each agent is considered for development. If that parcel is not the first choice of any other agent, the parcel is developed by the agent. Otherwise, the winner is determined via a competition. In a contest, the agent who achieves the highest score wins. The score is calculated with the following formula:

$$\text{Score} = W_{\text{Type}} \times \text{Score}_{\text{Type}} + W_{\text{Frustration}} \times \text{Frustration}, \quad (2)$$

where $\text{Score}_{\text{Type}}$ is the score assigned to each type of agent, Frustration is a digit that shows how many times an agent has lost a parcel, and W_{Type} and $W_{\text{Frustration}}$ are the weights considered for $\text{Score}_{\text{Type}}$ and Frustration, respectively. The score and the weight of score for each type of agents should be evaluated, but, for the sake of simplicity, it is assumed equal for all types of agents in this paper. The value of Frustration is equal to zero for all agents at the beginning. However, whenever an agent loses a parcel in a competition, its Frustration value increases by one. This increase means that the agent in the next competition will have higher propensity to develop a parcel. Figure 2 shows a use case diagram of the model.

(4) Bounded Rationality. The agents search limited parcels of landscape. Moreover, the parcels are traversed one by one and cannot be totally random. Furthermore, the perceptions of agents of the searched parcels are not the same because the AUF is taken into account. These are the bounded rationalities assumed for the agents in this study.

3.3.4. Verification. Verification of the model was performed at three different levels.

(1) *Unit Testing of Modules*. Program modules (code) were tested individually. For example, the method that moves an agent across the landscape was tested to make sure that an agent correctly moves towards districts, correctly moves in districts, and correctly jumps to different regions.

(2) *Testing of Basic Model Behaviors*. Interactions of agents can involve different program modules and thus are outside of the testing described above. Examples tested include competition for development. The model was executed with different numbers of agents and different types of agents, and conflicts were assessed. It was expected that conflicts would increase by increasing the number of agents of the same type.

(3) *Detailed Test*. The overall test could fail to detect some logical errors. Therefore, some aspects must be checked more precisely. For instance, the investment list of agents and their desirability, the suitability of parcels before and after using AUFs, the Frustration of agents when losing a parcel, and the nonexistent of repeated parcels in the investment lists of the agents were checked.

4. Implementation

Three artificial criteria maps (layers), namely, land price, attractiveness, and accessibility, were used (Figures 3 and 4) in this study. Because we wanted to emulate real-world conditions, we attempted to produce maps similar to a real land use.

The artificial landscape is composed of 300,000 raster cells with 600 rows and 500 columns. The parameters of the model are shown in Table 1.

The weights of three criteria maps are set to 0.1 but the weight of adjacency is tested in two cases equal to 0.5 and 1. Therefore, eight configurations of the model are constructed, and, for each configuration, five outputs that correspond to the five-year intervals are estimated. Because the maps are artificial, they may not match the real situation. For example, in the reality suburbs of the cities often have high accessibility and land price. Thus, the suburbs of the cities are exposed to development. However, this may not be the case in our artificial maps. In consequence, we assumed adjacency to the initially developed area. To implement the adjacency, number of adjacent initially developed cells is counted. Then, that number is multiplied by the weight of adjacency and is treated like a criteria map. This method directs the agents to the suburbs of initially developed area.

It should be mentioned that the artificial maps were created and prepared using AutoCAD Map 2009. NetLogo 4.1 and its GIS extension were used for agents-based modeling and ArcGIS 9.3 was used for preparing maps and statistical analysis.

4.1. Regarding and Disregarding Risk. Two major cases (scenarios) of regarding and disregarding risk are considered in this study. In the risk-regarding case, AUFs are used (1); thus the decisions of the agents are affected by their attitudes toward risk. On the other hand, in risk-disregarding case, decisions of the agents are based on weighted summation method and thus no attitude toward risk is considered.

In this situation where assessing and comparing the behavior of agents regarding and disregarding risk is desired, the parameters are set the same for both scenarios. After several executions of the model, the parameters tabulated in Table 1 were selected. The proportion of development was estimated after preliminary experimentations.

5. Results and Discussions

Figure 5 shows the developed area after a one- and five-year interval. A precise look at the development after one year reveals that, in the risk-regarding case, the development is scattered around the initially developed area where the three criteria maps (accessibility, attractiveness, and land price) are suitable. In the risk-disregarding case, however, almost all developments happened adjacent to the initially developed area. While, in the disregarding-risk case, all agents have randomly developed the landscape; in the risk-regarding case only two classes of agents, those of "poor" and "reckless," were seen in the surrounding area. When the weights of the three maps are the same and when the weight of adjacency to the initially developed area was considered higher than the others, the disregarding-risk agents are absorbed in the landscape adjacent to the initially developed area. However, this situation does not occur when dealing with a risky case. Based on the three criteria maps, the scattered developing regions have high attractiveness, low land prices and include good accessibility. However, they are not adjacent to the initially developed landscapes. If a high weight is assigned to adjacency to a developed area, the agents move toward the neighborhood of the initially developed area. Nevertheless, this movement is not the case for poor and reckless developers. For these classes of agents, the importance of wining perception is greater. Thus, their developed areas gain relative superiority, making them become scattered all over the region. Unbiased agents (not affected by risk) are proper for comparing agent behaviors. All unbiased agents were settled in the neighborhood of the initially developed area. This settlement confirmed that such an area is the best choice. Rich and cautious agents perceive the relative superiority of the area not adjacent to the initially developed area as less than their actual values. Therefore, these agents tend to settle into the neighborhood of the initially developed area. To clarify the results, Figure 6 shows the statistical conditions of development by diagrams. Here, the developing cells that are not adjacent to the initially developed area are counted by their class of developers.

According to Figure 6, after the first year, the cells developed by poor and reckless agents are now initially developed. Gradually, when the neighborhood of initially developed cells is occupied, some rich, cautious, or unbiased agents choose free cells (cells not directly in the neighborhood of initially developed cells) for development. However, the poor and reckless classes of developers still have the largest number of agents that select cells not adjacent to the initially developed area. Expressing the differences between the behavior of poor and reckless agents is still complex and requires further study. Exploring the details of developing cells in the map also reveals that a number of remote sites were chosen only by reckless agents and that developing areas chosen by poor agents are limited.

The difference between the two cases, those of regarding and disregarding risk, is clearly presented in Figure 6. When AUFs are neglected, all agents would be of the same type, and their behavior would be similar. This fact is revealed in Figure 6, Figures 6(a) and 6(b). However, in considering risk, each class of agent behaves differently. This trend is noticeable in Figures 6(c), 6(d), 6(e), and 6(f). Also, unbiased agents should have the same behavior in the two cases, which is also noticeable in Figure 6. Any changes in the behavior of unbiased agents are justifiable because the conditions of the agents in the two scenarios are different. In the risk-regarding case, unbiased agents must compete with other types of agents. Another parameter that can be set is the number of districts each agent visits. When this number is increased, the rationality of the agent increases and the agents are able to make better choices for development.

Some important observations are made during the execution of the model.

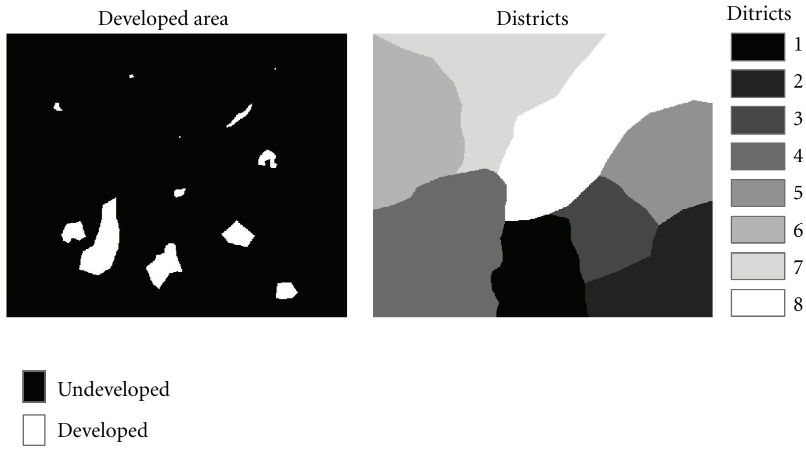

Figure 4: Maps of developed area and districts.

Table 1: The parameters of the model.

Number of agents	Number of executions (years)	Number of sessions per year	Agent movement (parcel)	Number of jumps in each region	Number of districts to search	Number of developments per session
50 (10 agents of each type)	5	4	21	2	5 and 6	3 and 5

(i) In the risk-disregarding case, agents may choose free cells to develop. If two or more agents search the same area adjacent to a initially developed area, then at least one of the agents may lose its desirable choices in competition; thus, it is possible to choose free cells for development. Moreover, the increase in session executions intensifies this behavior. At the end of each session, the parcels that have been chosen by agents are reserved. These parcels are not assumed to be developed. Therefore, in the next sessions, agents may search the reserved parcels but they are unable to select them for development. So, they may refer to the other searched parcels. Actually, the reserved parcels in sessions exclude some neighboring parcels of initially developed areas from selection by agents.

(ii) In the risk-disregarding case, when free cells are developed in a year, in the next year they are assumed to be initially developed and so will be the destination of search by agents. However, the area and perimeter of these newly developed parcels are less than the others. Consequently, the probability of losing their neighborhood in competition among agents increases. Therefore, some agents are pushed into another area.

(iii) In the risk-regarding case, the number of free cells is decreased. This reduction is mostly due to a decrease in the tendency of poor and reckless agents to free cells. The free cells are primarily chosen by poor and reckless agents. This choice means that those selected free cells are preferred in comparison to the neighborhood of initially developed areas. In the next years, the neighborhood of newly developed areas that have almost the same situation may also be chosen by agents, but they are not assumed to be free cells anymore because they are now in the neighborhood of the developed era.

(iv) In the risk-regarding case, the number of free cells selected by rich, cautious, and unbiased agents is decreased. The reason is similar to the reasons given for the first case.

One other item that is able to show the effect of AUFs is the trend of changes in the probability of districts to be selected. Figure 7 shows these probabilities besides the primary assigned probabilities for each district. The primary probability for each district to be selected for districts 1 through 8 are 20, 7, 13, 30, 5, 4, 6, and 15 percent, respectively, for all types of agents.

If AUFs are omitted, the behaviours of agents, such as the changes in the probability of districts, must be similar. Figure 7 substantiates this matter. The maximum difference in the probability of a district is less than 1.5 percent, whereas this maximum is about 4 percent when using AUFs. Figure 7 shows that the selection probabilities of districts 2 and 5 increase, although this issue was not observed for reckless agents. Moreover, unbiased agents show similar probabilities in both scenarios for regarding or disregarding AUFs. This fact verifies the unbiased operations. Nevertheless, it is important to notice that no superiority has been regarded for various types of agents in competition. Also, the coefficient of communication among agents has been set to 0.5. It is obvious that distinguishing different superiorities for different types of agents and increasing the coefficient of communication will increase differences in the probabilities of districts to be chosen by different types of agents.

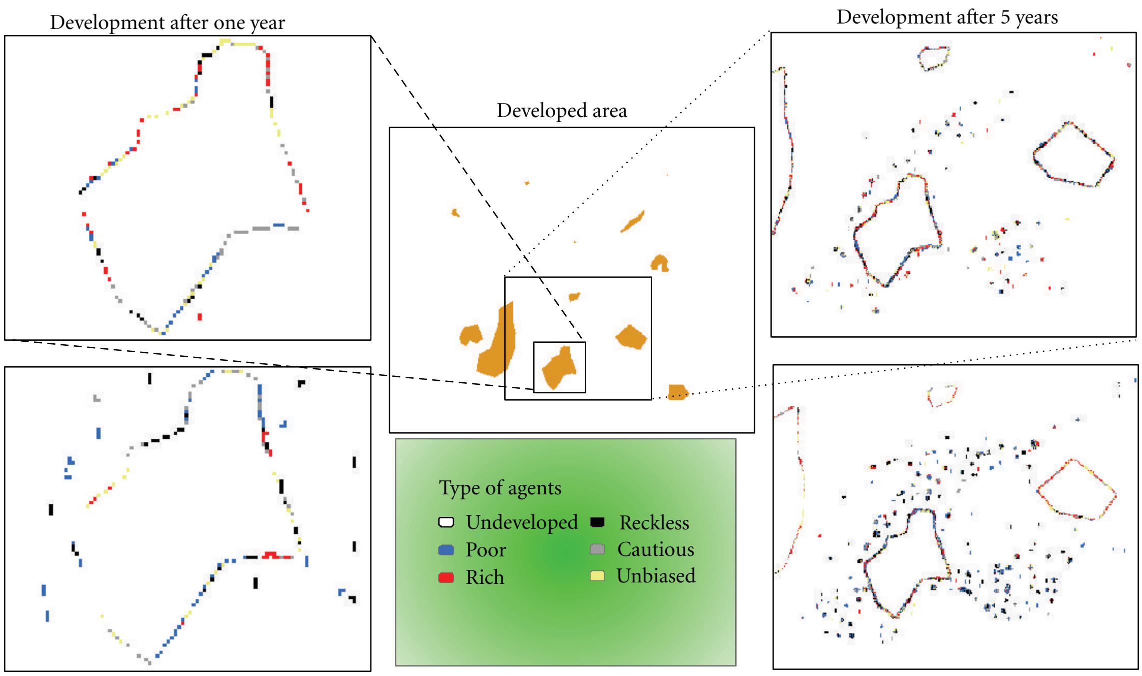

Figure 5: Developed area after one- and five- year intervals, top: without risk, and bottom: with risk. The parameters of the model are: weight of Adjacency to Developed area (WAD) = 1, Number of Districts to Search (NDS) =5, Development Per Session (DPS) = 3.

Proof of different behaviors of agents when taking risk into account will be helpful if the real land-use developers can be categorized according to their AUFs. The more precise the categories of land-use developers is, the more precise the simulation of their behaviors is in the landscape. Because a psychological categorization of land-use developers is almost impossible, an external reflection of their operations is helpful. Thus, this study attempts to propose a classification for land-use developers based on their AUFs. Referring to the paper of Loibl and Toetzer (2003) [24], five types of agents can be defined from economical and educational points of view. Such a classification is appropriate for describing the preferences of agents and for evaluating the importance of various development criteria. In this regard, cautious agents are suggested to be considered as lower income developers who seek low land prices. Poor agents are suggested to be treated as moderate income, highly educated younger developers, and unbiased agents are suggested to be defined as moderate to high income developers. Rich agents are also suggested to be defined as high income, highly educated developers, and last, reckless agents are suggested to be regarded as weekend-home seekers and enterprise founders. However, more studies are necessary to define such assignments.

6. Conclusions and Recommendations

This paper presented the concepts and specifications of an agent-based model for the simulation of urban land-use sprawl in a Geospatial Information Systems (GIS) environment. The multiagent system of residential development implemented in this paper demonstrated the critical impact of attitudes to risk on land-use patterns. Moreover, disregarding the attitude to risk in agents not only means assuming a more extended rationality for the agents but also puts all developers in the same category, which is not the case in real societies. This study demonstrated that the proposed method of risk-aware agents has a better compatibility with modeling patterns of land-use development compared to the model of neglecting risk. Also, it is imperative to note that competition among agents plays an important role in the pattern of settlement. Furthermore, the results affirmed that linking GIS with ABM can enhance the capabilities of a simulation/modeling system for spatial problem purposes.

Agent-based models allow accounting for agent-specific behaviour, that is, acknowledging that not all agents are optimizers and that they may have personal views on how to reach a particular goal. This information could contribute to land-use change understanding and eventually to better land-use change predictions. While the application of simulations to study human-landscape interactions is burgeoning, developing a comprehensive and empirically based framework for linking the social and geographic disciplines across space and time remains for further paper. A newly developed method for searching landscapes, selecting parcels, and having competitions among agents, in addition to taking into account AUFs, brings us better ways to simulate the behavior of land-use developers. This paper proposed that the different agents, corresponding to different attitudes to risk, may have external equivalents in a real society. However, a better model for heterogeneous agents requires defining and setting other parameters, such as heterogeneous weights for layers, considering dominance of agents during competition, different searching abilities,

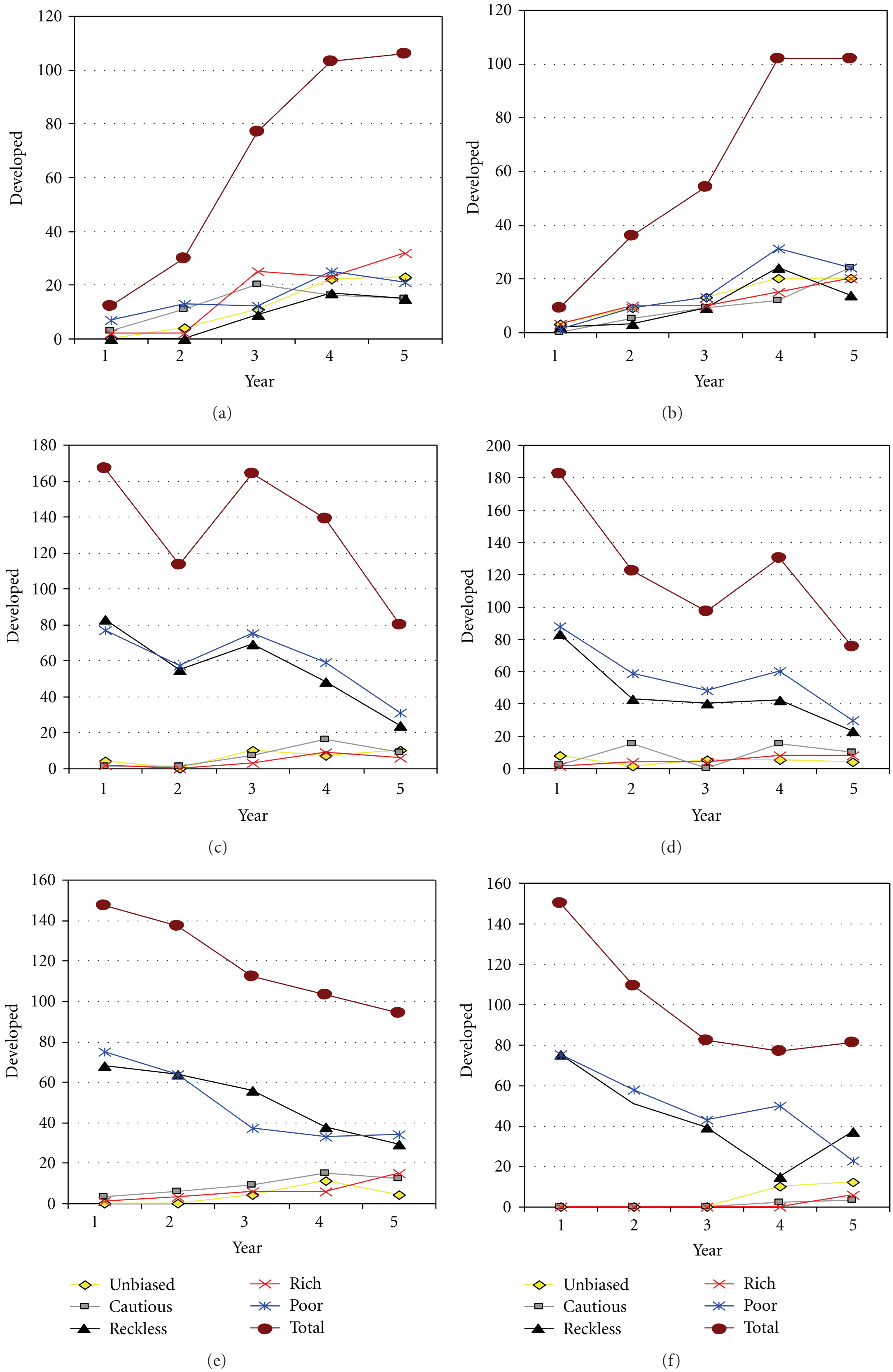

Figure 6: The cells—developed by agents—are not adjacent to a primarily developed area. (a) Disregarding risk, WAD = 1, NDS = 5, DPS = 3. (b) Disregarding risk, WAD = 1, NDS = 6, DPS = 3. (c) Regarding risk, WAD = 0.5, NDS = 5, DPS = 3. (d) Regarding risk, WAD = 0.5, NDS = 6, DPS = 3. (e) Regarding Risk, WAD = 1, NDS = 5, DPS = 3. (f) Regarding risk, WAD = 1, NDS = 6, DPS = 3.

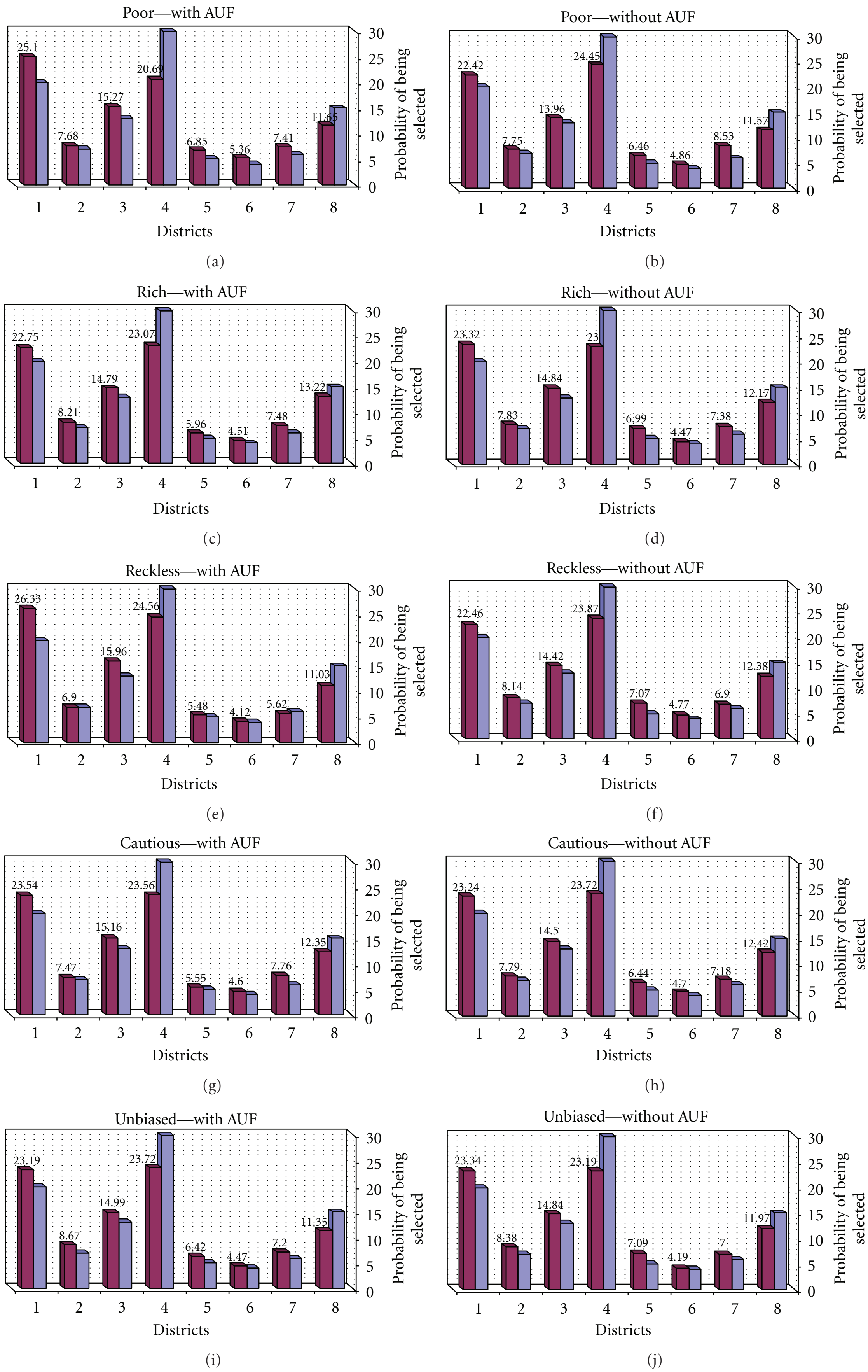

FIGURE 7: Probability of districts (in percentage) to be selected by each type of agent after five executions of the model. (Light purple) for primary probabilities which are the same for all of the agents when the model is initialized, (dark purple) for newly achieved probabilities.

varying probabilities of selecting districts, and various compatibilities for land-use development. Further paper will be needed to define and set these parameters and to implement the proposed model with real data.

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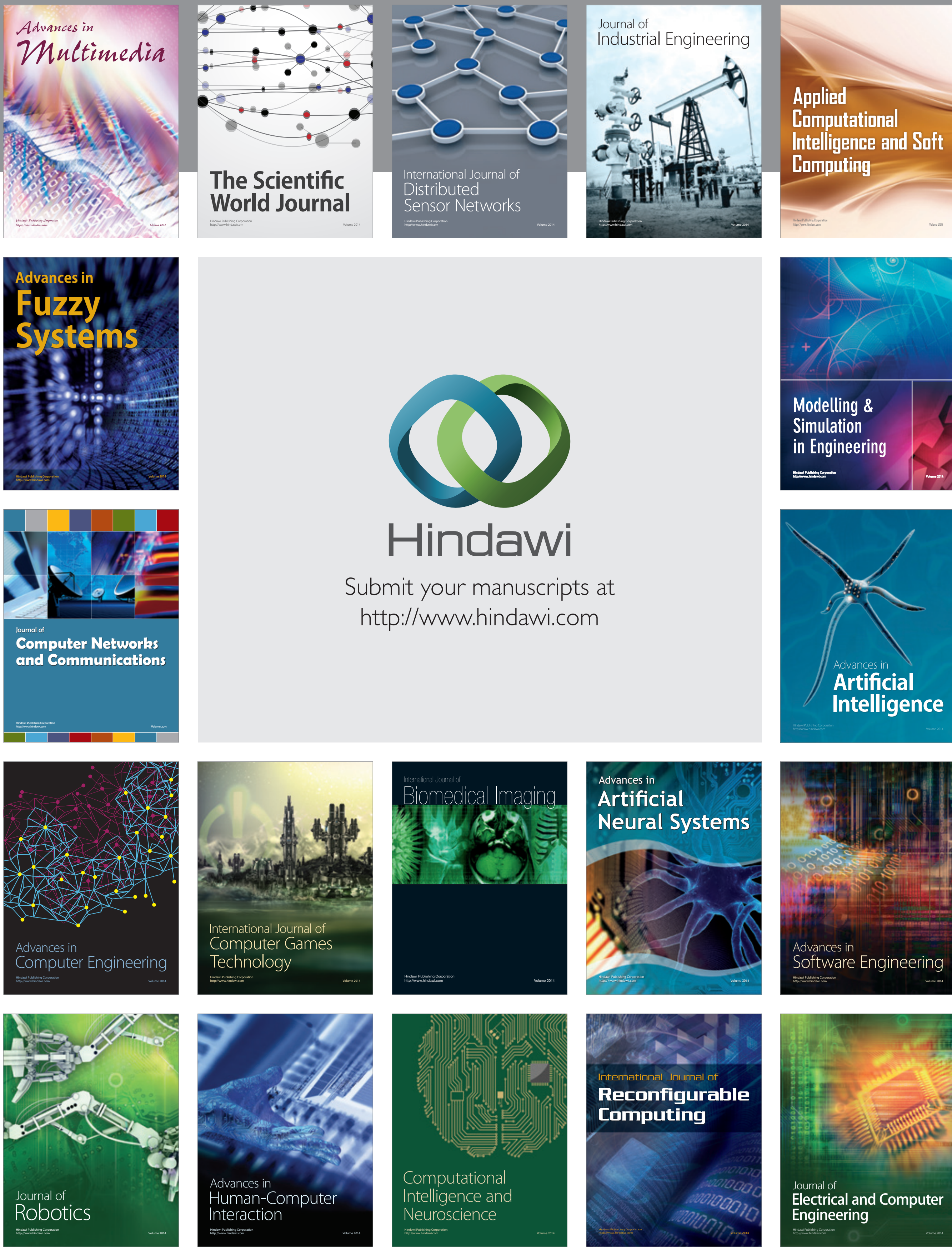
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