



HOSPITAL SITE SELECTION USING A BDI AGENT MODEL

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ABSTRACT

This paper presents a newly developed Belief-Desire-Intention (BDI) Agent-based model for estimating suitable hospital sites. Our model makes use of existing geospatial functions and a novel BDI architecture of agent techniques. More specifically, the fundamental concepts of practical reasoning architecture such as belief, desire, intention, along with commitment, and interaction have been combined with analyses and applications of Geographical Information System (GIS). The proposed model can be customized for a wide range of decision making problems in GIS, one of which is site selection. In this model, minimal travel time, air pollution and land cost are considered as the goals of agents, and then the agents observe, and believe in the environment. The agent then determines the intention to implement on the environment for achieving their desires. The desires are generated from agents' goals. The interactions among agents are considered as a part of process for achieving contemporarily goals. In this paper, the fundamental components of agent such as observation, belief, desire, intention, commitment, and interaction are introduced spatially, and a BDI-GIS model is defined based on these components. The Desktop GAgent software, introduced in this paper, has the advantage of using agents for spatial analysis. The interface helps guiding decision makers through the sequential steps for site selection, namely; importing data, defining goals, determining actions and identifying the agent's characteristics. For demonstrating the robustness of our new model, a case study was planned and executed in Tehran, Iran. The efficiency of the BDI-GIS model in the decision making process for selecting suitable hospital sites was also demonstrated based on the characteristics of the agents and the types of their interactions.

Keywords: Geographical information system (GIS), Agent, Belief, Desire, Intention, Interaction, Hospital site selection

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INTRODUCTION

Recently, site selection has been deemed necessary for the sustainable development of land use, to solve the issue of competitive demands of space, to avoid undesirable environmental loads, and to

ensure profitability of space (Radiarta *et al.*, 2008; Cho *et al.*, 2011). Site selection is an important planning process which affects different regions in the economic, the ecological, and the environmental health sectors (Barlaz *et al.*, 2003; Kouznetsova *et al.*, 2007; Goorah *et al.*, 2009; Gorsevski *et al.*, 2011). Site selection would minimize the risk of environmental load, maximize economic compensations, and minimize competition with the use of other resources (Cho *et al.*, 2011).

Choosing a health center setting is one of the major problems facing city planners worldwide. Many countries and institutions currently pay great attention to this problem (Wang *et al.*, 2009). The problem is especially severe in developing countries where urbanization and poor planning, contribute to the management practices (Gorsevski *et al.*, 2011). In particular, health management in developing countries has intensified dramatically due to increasing the population, as well as changes in life patterns brought by recent trends of modernization (Gorsevski *et al.*, 2011). Several factors are involved in choice of appropriate place for a hospital that each of them is important enough not to be omitted and determines limitations in site selection (Adeli and Khorshiddoust, 2011). Factors such as distance from residential areas, distance from main roads, economic constraints, pollution, availability of land, (Brabyn and Skelly, 2002; Jordan *et al.*, 2004; Vahidnia *et al.*, 2009) make site selection for health center difficult.

Site selection can be regulated by means of a carrying capacity model, Geographic Information Systems (GIS), Multi-Criteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP), or fuzzy models. GIS is useful for manipulating spatial aspects of selecting suitable sites due to the ability to bring together many diverse and complex factors to facilitate development and administrative decisions (Ross *et al.*, 2009; Silva *et al.*, 2011). Site selection with the aid of GIS technology is a widely used procedure in a variety of fields, including: regional and urban planning, water resource management, health care resource allocation, and natural hazards (Gorsevski and Jankowski, 2010; Gorsevski *et al.*, 2011). The role of GIS in spatial decision making is to aid the decision-maker in designating priority weights to the criteria, to evaluate the feasible alternatives and to visualize the results of the choice (Jankowski, 1995; Rojanamon *et al.*, 2009). A number of GIS methods and techniques have been also proposed to evaluate suitable site locations (Gorsevski *et al.*, 2011). GIS and Decision Support Systems (DSS) is one of them; however, GIS and the traditional DSS alone do not effectively facilitate the implementation of site selection, which are equally based on complex decision criteria and spatial information (Jun, 2000; Rahman *et al.*, 2012). Multiple MCDA techniques have been used to solve site selection problems in the literature. Approaches such as PROMETHEE, ELECTRE, and TOPSIS have been used to rank alternative sites, especially in the case of environmental problems (Salminen *et al.*, 1998; Cheng *et al.*, 2002; Corresponding, 2005; Vahidnia *et al.*, 2009). The AHP is a systematic decision approach first developed by Saaty (1980); (Bhushan and Rai, 2004). This technique provides a means of decomposing the problem into a hierarchy of sub-problems that can be more easily

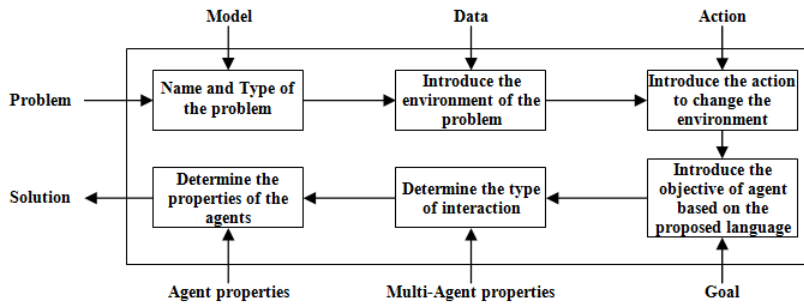
comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Bhushan and Rai, 2004; Sener *et al.*, 2010).

The combination of AHP with fuzzy set theory of (Zadeh, 1965; Zadeh, 1978) can provide a more effective and robust tool for spatial decision problems (Rahman *et al.*, 2012). Like AHP, it also provides a hierarchical structure, facilitates decomposition and pair-wise comparison, reduces inconsistency, and generates priority vectors (Vahidnia *et al.*, 2009). Boroushaki and Malczewski (2008) implemented AHP-Fuzzy operators using fuzzy linguistic quantifiers in the GIS environment, which has been proven to be effective (Rahman *et al.*, 2012). Although the research community has, over the last decade, developed methodologies such as GIS and predictive models to support decision-making for site selection, there is a pressing need for such tools to be more intelligible. Agent and multi agent system are modern intelligent tools, which have been used recently in a variety fields of science. 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 (Maes, 1994). However, developing agent-based model and relevant software for spatial issues is in the beginning, and it is still needed to be improved. In this paper, a novel software called Desktop GIAgentis introduces based on the BDI architecture of the agent. The purpose of Desktop GIAgent is to suggest a solution based on the imported data, action, and goal. So, hospital site selection is stated based on data, action, and goal, then the problem is imported to the software. The model does analyses on the problem; finally, a solution is offered by the model. This paper aims to develop and test an integrated approach of spatial and agent model to site selection of suitable hospital, with an emphasis on Belief-Desire-Intention (BDI) architecture of agent. The rest of the paper is organized as following: at first, the entire structure of the Desktop GIAgent is introduced, and then the concept of the model in the software is described based on the hospital site selection problem. In the next section, the model is implemented for hospital site selection, and finally the results and main conclusions of running agents for this problem are expressed in the last section.

Description of the Model

Figure 1 presents the flow of the process done in the proposed model. Each spatial problem can be partitioned in some components such as data, action, and goal. To be handled by the model. The purpose of the model is to understand the relation among imported data, to evaluate varieties of interaction and changes of the current state of the data, and finally to suggest a solution for the spatial problem.

Figure-1. The flow of the process done in Desktop GIAgent



Data

Most data contains spatial and attributes properties. Each data introduced for the model is shown as a tuple such as:

$$Layer = \{Pos, Attribute_1, Attribute_2, \dots, Attribute_N\} \quad (1)$$

Relation 1 presents a layer of spatial data, having some attributes. In the hospital site selection, we have four layers of data, so based on the proposed structure, each layer is represented as:

$$\begin{aligned}
 Env &= \{City, Road, Hospital, Contamination\} \\
 City &= \{Pos, Area, Population\} \\
 Road &= \{Pos, Weight\} \\
 Hospital &= \{Pos, Cost, Weight\} \\
 Contamination &= \{Pos, Density\}
 \end{aligned} \quad (2)$$

Relation 2 shows that four spatial data are imported into the model, while each layer has some attributes. Each layer happens in a specific time; therefore, a time value is assigned to each layer.

Action

The changes done on the current data are called Actions. Each action is represented by a set of four components $\{Time, Layer, Part, Domain\}$. *Time* shows the time when the layer happens. *Layer* shows the data layer on which the action is done. *Part* shows the specific part of the layer (spatial or attribute) on which the action is specifically done. *Domain* shows the range of variation. In the hospital site selection, the agents are asked to assign a value for each candidate hospital as its priority. Therefore, the action is defined as:

$$Action = \{1, 'Hospital', 'Weight', \{[01]\}\} \quad (3)$$

Relation 3 represents that each agent could assign a real value between 0 and 1 to the *Weight* attribute of each hospital in the hospital layer.

Goal

What the agents want to achieve is called its Goal. A novel language is introduced in the model for interacting with the agents. Each goal is stated in one sentence; it consists of some words. The words are categorized into four groups defined as:

1) **Grader Word**; each sentence starts with a word used for evaluating agents' action. The words such as: 'ifthen', 'model', 'morebetter', 'lessbetter', 'connect', 'minimize', 'maximize', etc. are samples of this group. Each *grader word* has a specific structure, which guides the arrangement of the other words in the sentence. The structure of some grader words in the model is shown as:

$$\begin{aligned}
 G &= \{ \text{'model'}, \{ \text{Time,Address,Name,Format,Part} \} \} \\
 G &= \{ \text{'ifthen'}, \{ \text{Time}, \{ \text{IF} \}, \{ \text{THEN} \} \} \} \\
 G &= \{ \text{'morebetter'}, \{ \text{Time}, \{ \text{MORE} \}, \{ \text{BETTER} \} \} \} \\
 G &= \{ \text{'lessbetter'}, \{ \text{Time}, \{ \text{LESS} \}, \{ \text{BETTER} \} \} \} \\
 G &= \{ \text{'connect'}, \{ \text{Time}, \{ \text{Network,Part} \}, \{ \text{StartNode ID}, \{ \text{EndNode, ID} \} \} \} \} \\
 G &= \{ \text{'minimize'}, \{ \text{Time, Value} \} \} \\
 G &= \{ \text{'maximize'}, \{ \text{Time, Value} \} \}
 \end{aligned} \tag{4}$$

2) **Mathematical Word**; mathematical relations, operations and functions are categorized in this group. The common words such as 'or' / 'and' are a sample of these worlds. They are used to correlate the other words to each other. The words such as '+', '-', '≤', '<', '=', '≠', '>' and '≥' are samples of mathematical operations, while 'sum', 'mean', are samples of mathematical functions.

3) **Spatial Word**; word related to spatial perspective such as: 'distance', 'buffer' are samples of spatial word. In this case, most spatial words, which are used as a tool, are defined as a function. The name related to these function are used in the proposed language.

4) **Common Word**; the words which show the name of a layer, time, spatial and attribute information are considered as the ones in the group. The words such as 'city', 'Cost', 'Density', '200', '2.1', 'A', are samples of these words.

In the hospital site selection, the process of selecting the suitable site must be done based on four goals: 1) the more contaminated the area is, the better location of the hospital is in the area; 2) the more population around the hospital is, the better location of the hospital is in the area; 3) the less the cost of the candidate land is, the better location of the hospital is in the area; and 4) the less the distance of the hospital to the main road is, the better location of the hospital is in the area. All four conditions are told to the agents based on the proposed language, namely:

$$\begin{aligned}
 Goal_1 &= \{ \text{'morebetter'}, \{ '1', \{ \text{'extract'}, \{ \text{'Contaminaton'}, \text{'Density'}, \{ \text{'relation'}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Contaminaton'}, \text{'containedby'} \} \} \}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Weight'} \} \} \}; \tag{5} \\
 Goal_2 &= \{ \text{'morebetter'}, \{ '1', \{ \text{'sum'}, \{ \text{'extract'}, \{ \text{'City'}, \text{'Population'}, \{ \text{'buffer'}, \{ \text{'Hospital'}, \text{'G1'}, \text{'City'}, \text{'1200'} \} \} \}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Weight'} \} \} \}; \\
 Goal_3 &= \{ \text{'lessbetter'}, \{ '1', \{ \text{'Hospital'}, \text{'G1'}, \text{'Cost'} \}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Weight'} \} \} \}; \\
 Goal_4 &= \{ \text{'lessbetter'}, \{ '1', \{ \text{'distance'}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Road'}, \{ \text{'buffer'}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Road'}, \text{'Nearest'} \} \} \}, \{ \text{'Hospital'}, \text{'G1'}, \text{'Weight'} \} \} \};
 \end{aligned}$$

Each goal consists of three parts: the first part is *more-better* or *less-better*, the second part is related to *more/less*, and the third part is related to the *better*. Most vocabularies of GIS are defined for our agents; however in this paper only some of them are used. In *Goal* and *Goals*, the first part is the more-better. In *Goal*, the second part determines the amount of population in the place in which the hospital is located. In *Goals*, the second part determines the sum of the population in the area in the specific distance of the hospital. In *Goal*, and *Goal*, the first part is less-better. In *Goal*, the second part determines the cost of the land. In *Goal*, the second part determines the

distance of hospital to the nearest road. For all goals the third part is the same and it is the weight of the hospital. All these four goals are defined for agents based on the proposed language.

Multi-Agent properties

In multi-agent system, a problem is divided into some manageable sub-problems. A sub-problem is assigned to an agent to be solved. In our proposal, sub-problems are created based on agents' actions and goals. Each agent finds some solution for its problem, so they interact with each other optimally (Dunin-Keplicz and Verbrugge, 2010). Three common strategies are used for interaction in our model. They are: Rational, Nash-Equilibria, and Tit-For-Tat. After interaction, each agent understands its best solution which is compatible with the other solutions. So all agent implement the optimal solution on the environment.

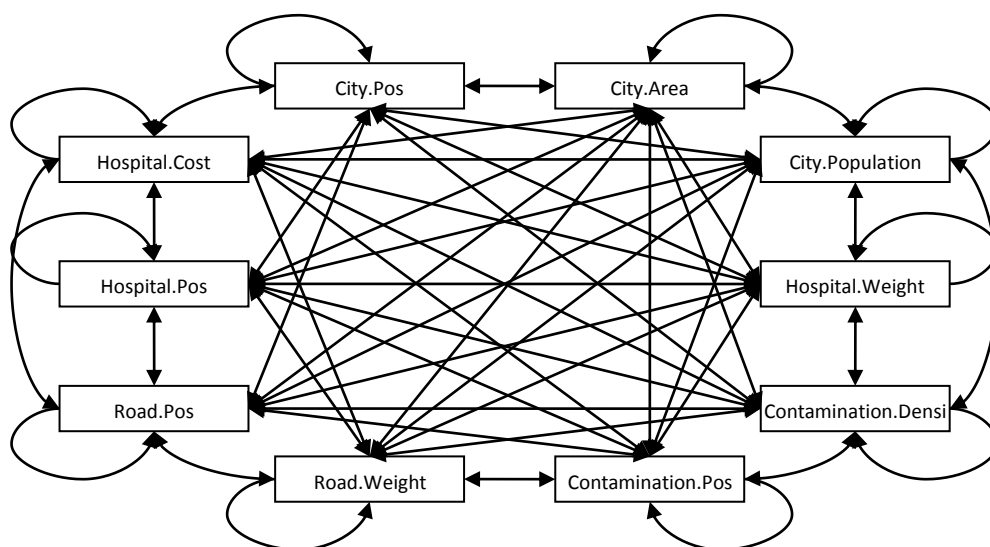
Agent properties

In our proposed model, an agent is an entity, which is aware of its action and goal. It senses the environment, and does some action to achieve its goal. In the hospital site selection, one action and four goals are defined; therefore, four agents are generated to solve the problem, while each agent has one action and one goal. The analyses done by each agent is stated as Observation, Belief, Desire, Intention, and Commitment.

Observation

The agent observes the environment (relation 1); each component of each layer is considered as one node in a complete graph. The generated graph is considered as the observation of the agent. Figure 2 represents the generated graph from the environment of the hospital site selection problem.

Figure-2. The graph generated from the environment of the hospital site selection case



Belief

The current state of the spatial environment is considered as the belief of the agent (Ligtenberg, 2004). Each agent observes the environment; as a result, a complete graph is generated. The agent knows its action which is corresponding to a node in the observation graph (for example “*Hospital.Weigh*”). This node is considered as the action node in graph, and the position related to the action node (“*Hospital.Pos*” in hospital site selection) is considered as the start node. The combination of the observation graph, start node, and action node presents the whole structure of the belief. Each edge of the belief graph has a specific name, which is driven from the name of its related nodes. For example, the set $\{Layer_1, Part_1, Layer_2, Part_2\}$ is the name of the edge which connects node $\{Layer_1, Part_1\}$ to node $\{Layer_2, Part_2\}$. Based on the definition of the belief, each edge stores the current state of the environment, which is related to its nodes. So, the edges in belief graph are categorized into four groups: the edges connect position nodes to position nodes, position nodes to attribute nodes, attribute nodes to attribute nodes, and finally attribute nodes to position nodes. The structure of storing data in each edge depends on the type of its related nodes; thus, the belief in each group of edges is different.

In position-position edges, the current spatial relationship among entities of the two layers is considered as the belief; topology, angle, and distance among entities of two layers are considered as the belief in these edges. For example, the edge, connecting *City.Pos* to *Road.Pos*, stores all spatial relationships among land parcels and road segments.

Desire

In agent architecture, the desire is named as option generator which is defined as (Hall *et al.*, 2005; Tweedale *et al.*, 2007):

$$\wp(\text{Bel}) \times \wp(\text{Int}) \rightarrow \wp(\text{Des}) \quad (6)$$

The definition of the desire depends on the analysis done by intention and belief, and also the structure of the belief which is defined as a graph along with their start and action nodes. So, the identical graph of the belief is generated and named intention graph. The process done in edges of the intention graph is implemented on the corresponding edges in belief graph. The combination of these two graphs generates the desire of the agent. Similar to the belief graph, the edges of the intention graph are categorized into four groups.

In position-position edges, the intention determines which entity of the first layer is related to the ones of the second layer. Two spatial operations play the role of the intention: topology and buffer. Topological relationships between two entities can be one of the disjoint, meet, overlap, covers, covered by, equal, contains, or contained by. Buffer operation shows the Euclidean relationship between two entities. The combination of the distance and angle increases the flexibility of buffer operation. A specific topological relationship and buffer area determines which entity of the second layer is related to the selected entity of the first layer.

The implementation of the intention graph on the belief graph generates the desire. The process is defined as: 1) the edges of the belief and intention graphs, having connection to the start node are triggered. They start the process by importing the data related to their $\{Layer_1, Part_1\}$, and they export the data related to $\{Layer_2, Part_2\}$. 2) The edges related to the output nodes of the previous edges are triggered, and they implement their analyses, 3) this process continues until the selected edges are connected to the action node. In this case, the action is implemented on the environment. The result of the action is some changes on the environment; the environment-evaluator assesses the changes based on the agent's goal and it gives the agent the percentage of the achieving the goal and this value is considered as the value of the desire.

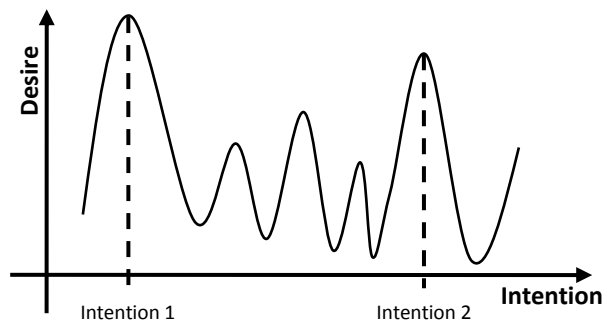
Intention

The intention graph is considered as the intention of agent, but this intention is not the one which the agent wants to intend; the agent intends to the intention which passes successfully through the intention function defined as:

$$\wp(\text{Bel}) \times \wp(\text{Des}) \times \wp(\text{Int}) \rightarrow \wp(\text{Int}) \tag{7}$$

Based on the function 7, the intention which has the acceptable desire value is implemented on the belief. The more desire the value is, the more acceptable the intention is; however, the highest value is not sometimes achievable because of the confliction of intention with the other agent's intention. Therefore, the other intentions with high desire values are stored in the data base. Genetic Algorithm (GA) is a practical procedure to find a set of acceptable intention. GA can find the absolute maximum of a desire function. Rerunning GA finds the new intention in the area, while the area around the previously selected intention is omitted. Figure 3 shows two different intentions of the agent obtained by optimization algorithm related to the desire function.

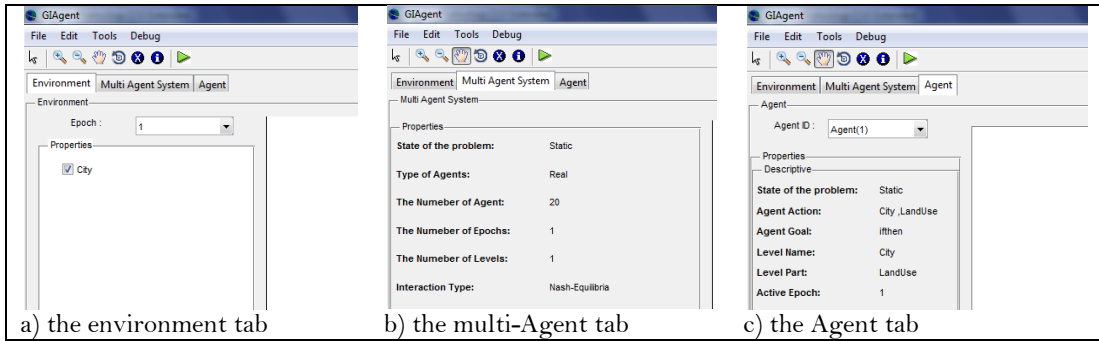
Figure-3. The intention of the agent obtained from desire



Implementation

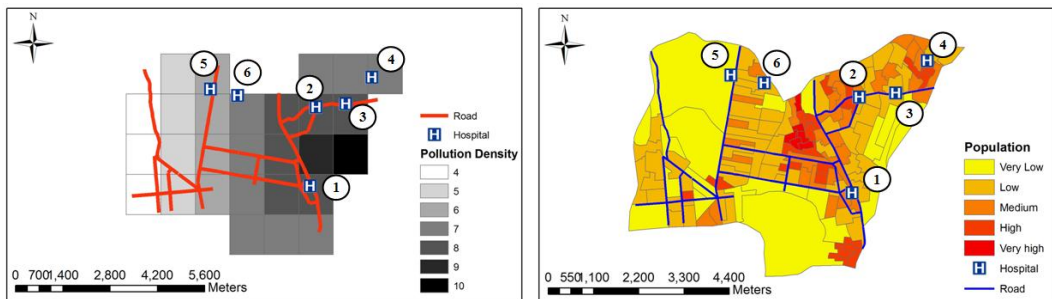
Desktop GIAgent is Geospatial Information Agent software that exposes a framework having three areas: Environment, Multi-Agent System, and Agent (Figure 4).

Figure-4. The interfaces of different steps in the Desktop GIAgent



In hospital site selection, all layers of data related to the computation of selecting the suitable site are considered as the environment. The study area is located in Tehran, the capital of Iran. The area extends from 51°23' to 51°29' east and from 35°44' to 35°48' north. Figure 5 depicts the study area, labeling existing hospitals and candidate sites for a new hospital.

Figure-5. The study area and the candidate locations for hospital construction

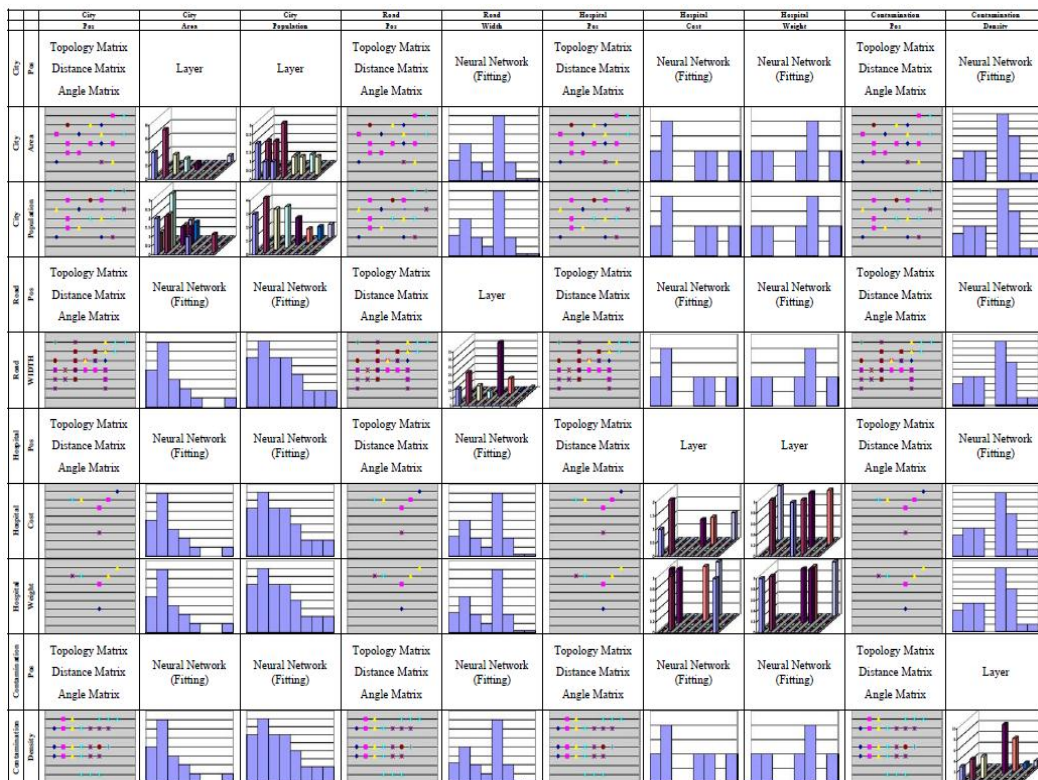


The goals and action needed for the problem are stated in section 2. As one action and four goals are defined for this problem, four (1 action × 4 goals) agents are generated to solve the issue. Each agent has only one action and one goal, and it starts with the observation of the environment. Environment graph is generated as the result of the observation. The actions of all agents are the same and it generates the start and action nodes of the belief graph. Figure 6 shows the current data stored in the edges of the belief graph. Each cell of the matrix corresponds to one edge of the belief graph based on the names of its row and column. Figure 7 shows one intention of an agent on the belief.

As seen in Figure 6, each cell corresponds to an edge in the belief graph, so the cells are categorized into four groups: 1) the cells which show the position-position relation. In this case, all information about topology, distance, and angle among entities of the related row and column are extracted and stored; 2) the cells which connect position to attribute; the data layer or neural network shows this type of the relation; 3) the cells which connect attribute to position. In this case, the distribution of attribute value in the area is shown; and 4) the cells which show the

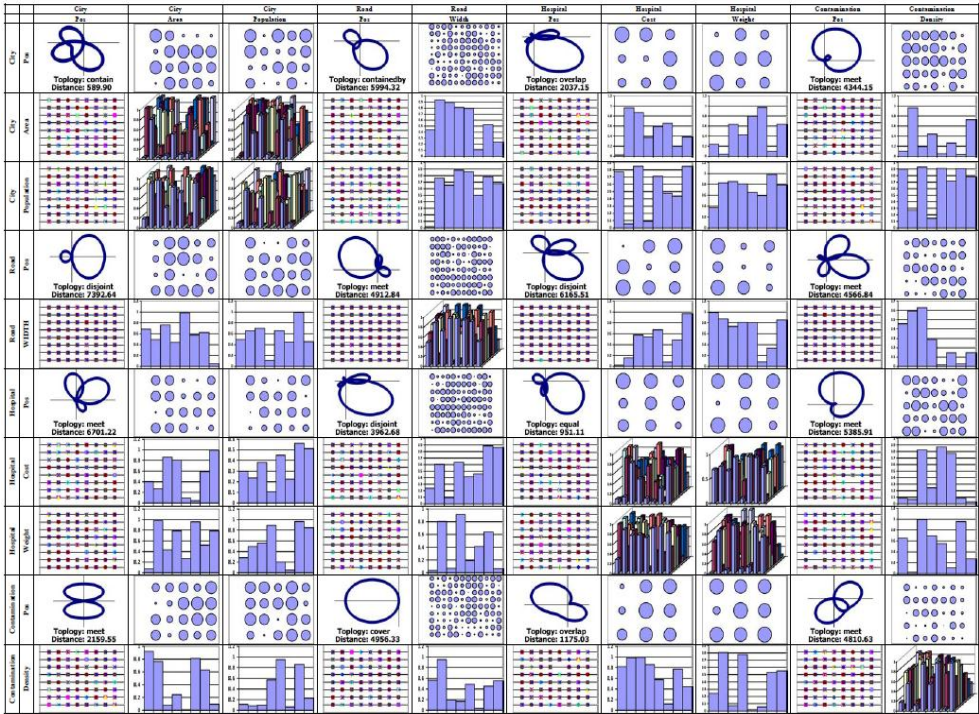
attribute-attribute relation. In this case, the histograms show the frequency of the second attribute (related to the column) based on the value of the first attribute (related to the row).

Figure-6. The current data stored in the edges of the belief graph



As seen in Figure 7, each cell stores the analysis done in related edge of the intention graph, so the cells are also categorized into four groups: 1) the cells related to position-position relation. In this case, a specific value is determined for topology and distance. The magnitude of the orientation in different angles is also shown in these cells; 2) the cells related to the position-attribute relation. In this case, the magnitude of changing the attribute is shown as some bubbles, and the distribution of bubbles are shown in these cells; 3) the cells related to the attribute-position relation. In this case, the changes done on the related cells in belief are shown. In these cells, the distribution of changes is shown for each group of the attribute; and 4) the cell related to attribute-attribute relation. These cells show the changes done on histograms in corresponding cells in belief. Each agent generates 10 intentions with high desire, and then they interact with each other based on their different types of commitments and interactions. In this problem, four agents are generated, each of which has three commitments. Three strategies are set for interaction. Therefore, 243 ($3^4 \times 3$) scenarios are introduced.

Figure-7. One intention of the agent on the belief



For each scenario, a value is assigned to each hospital, which shows the priority of that hospital. These assigned values (priorities) depend on the behavior of agent and interaction among them. Figure 8 shows the percentage of goal achieving based on the commitments and interactions.

Figure 8 shows that the behaviors of all four goals are approximately depend on the commitments and interaction. As seen in this figure, in 'Tit-For-Tat' commitment, the values of achieving Goal 1, Goal 2 and Goal 3 are higher than the other interactions, while Goal 4 is achieved better in 'Nash-Equilibria' interaction. When agent1 has 'single-minded' commitment, agent2 has 'blinded' commitment, and both agent3 and agent4 have 'open-minded' commitments, the achieving Goal 1 is higher than the other scenarios. When agent1 has 'blinded' commitment, both agent2 and agent3 have 'open-minded' commitment, and agent4 has 'single-minded' commitment, the achieving Goal 2 is higher than the other scenarios. When agent1, agent2 and agent3 have 'open-minded' commitment, and agent4 has 'single-minded' commitment, the achieving Goal 3 is higher than the other scenarios. When both agent1 and agent3 have 'single-minded' commitment, and both agent2 and agent4 have 'open-minded' commitment, the achieving Goal 4 is higher than the other scenarios. As a result, it can be concluded that when agent 1 has 'single-minded' commitment, agents 2, 3, and 4 have 'open-minded' commitments. 'Tit-For-Tat' is the type of the interaction (scenario no. 216) in which the achievement of all goals are higher than the other scenarios. Figure 9 shows the percentage of achieving goals in scenario no. 216.

Figure-8. The percentage of achievement of Goal1, Goal2, Goal3, and Goal4 based on their interaction and commitments

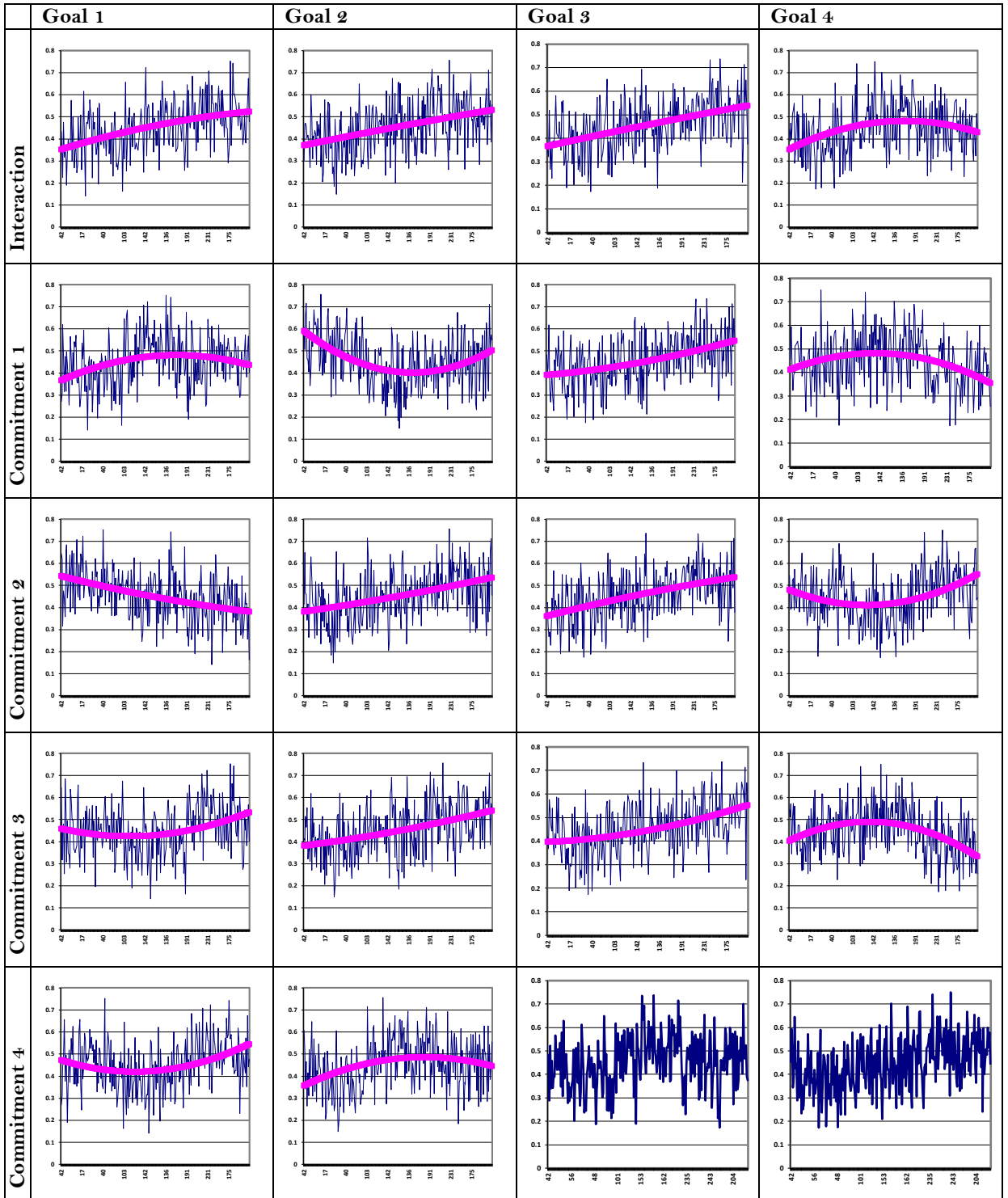
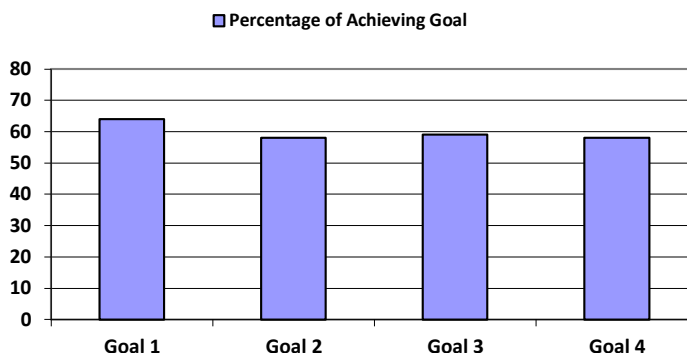
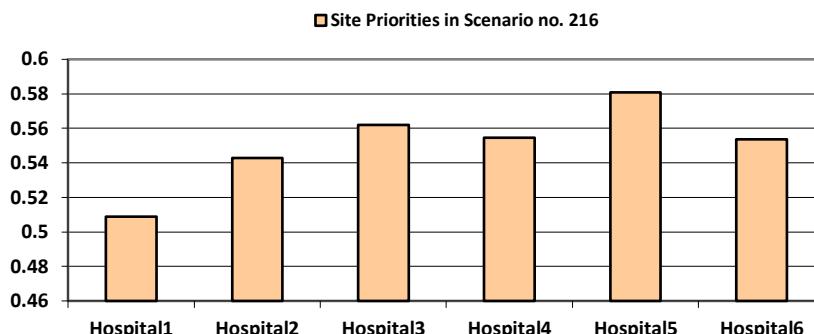


Figure-9. Percentage of achieving goals in scenario no. 216



In this scenario, a value is assigned to each hospital as the priority of the hospital. Figure 10 shows the priority (weighting) of each hospital in scenario no. 216.

Figure-10. Ranking of each hospital in scenario no. 216



As seen, the hospital number 5 has the highest ranking among the other hospitals and hospital number 1 has the lowest ranking.

CONCLUSIONS

During the last decade, site selection has been handled by traditional decision making methods such as GIS, AHP, and fuzzy-AHP. In this paper BDI agent concept is used to solve the hospital site selection problem. Novel software, named Desktop GIAgent, is presented based on the concept of agent for challenging the site selection issue. A combination of spatial and non-spatial data is defined as an environment for the agent, and also a novel language is specified for interacting between human and agents. When the rules and conditions are told to agents, they try to adjust their structure to their goals. Each agent is responsible for its goal; the interaction among agent determines the weight assigned to candidate sites. In our model, each agent has one goal, and it tries to accomplish its goal along with the other agents' goals. The interaction among agents is done to overcome the confliction of the goals. In hospital site selection, four goals were defined, and four agents were responsible for achieving these goals. They try to match their

structures to their goals, and as a result, some intentions are generated. The interactions among agents are done based on 243 scenarios. For each scenario, a specific value is obtained as the weight of the hospital site. However, the satisfaction of each agent is different for the assigned weights. Among these interactions, the scenario no. 216 is the most acceptable one because all agents achieve more than 50% of their goals.

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