Perception-Based Multi-Agent Geo-Simulation in the Service of Retail Location Decision-Making in a Shopping Mall*

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Introduction

The world of shopping malls has been changing dramatically in the last decade, buffeted by, among other things, the introduction of electronic commerce, the saturation of locations, and changes in customers' shopping behaviour (Ruiz et al 2004). Competition from category killers, discount stores, and factory outlet centres represents a challenge for shopping mall managers. According to Wakefield et al (1998) there are essentially three factors which explain the mall's declining role. First, consumers are increasingly busy, have less time for shopping, and therefore reduce the frequency of their visits to the mall. Moreover, too many malls are alike, and customers will go to the shopping centre that offers the most product and service variety and the most comfortable atmosphere. Finally, (Wakefield et al 1998) emphasize the fact that fewer consumers are going to the mall in

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order to "*enjoy their shopping experience*". These factors lead mall managers to develop strategies to differentiate their malls from the competition in order to enhance customer loyalty.

The shopping behaviour is influenced by several internal and external (or contextual) factors (Duhaime and Laroche 1996). While the former are related to shoppers' characteristics and preferences, the latter are linked to the mall environment and configuration as such (Deborah and Whan 1991) (Eroglu and Gilbert 1986). The literature reveals that the shopping behaviour rests upon several processes: perception, choice, navigation efficiency, visual memorization, buying, and consumption patterns, and post-consumption attitudes (Petrof et al 1978).

In a mall the interaction between people and the environment is an important issue (Norman 1988?). The environment can be characterized by its degree of complexity, mystery, coherence, and legibility (Kaplan and Kaplan 1989). Perception plays a key role in customers' activities in a mall (Sheridan 2002). Spatial legibility may be thought of as a way for mall managers and tenants to communicate information to customers. Hence, the importance of stores' locations, the perception of products, and shopping opportunities as well as signage when customers walk in the mall's corridors. Public buildings which are not legible often induce frustration and negative reactions on busy persons who cannot find their way easily. In shopping malls, spatial legibility is of great importance and one of the important related issues is the mall layout (Gärling et al 1982). Indeed, people have different abilities to find their ways in complex spatial environments, and to memorize particular locations and routes in information-rich environments such as malls. One important property of a legible space is to facilitate the creation of mental maps of its layout by the individuals who attend this space. Hence, the importance of adequately locating stores in a mall (Hernandez and Biasiotto 2001). During a shopping trip in a mall, a customer may have a precise idea of where he or she wants to purchase given items. But, discovering unexpected shopping opportunities also influences a customer's decision making and may result in a buying decision if the opportunity fits with the customer's needs and preferences. Creating buying opportunities for a large proportion of customers is an important goal for mall managers and tenants. To this end, mall managers must find for every store a location which will optimize the chances for customers to be attracted by this store and by the buying opportunities it may offer. Managers know very well the importance of 'anchor stores' such as Wal-Mart which attract certain categories of customers and favour 'proximity shopping' in stores which are located in corridors converging toward the anchor stores (Konishi and Standfort 2001).

Changing a mall configuration is a very important and expensive decision in terms of money and time. In order to guarantee the success of such a decision, mall managers should be able to better understand customers' behaviours and the way they may react to the changes in the mall's configuration. Certain traditional techniques may help mall managers to understand how customers interact with the mall environment. For example, they can use *questionnaires* to collect data about customers and analyze the collected data to try to understand how customers use the mall. Although surveys can help mall managers to understand how customers appreciate the current mall configuration (and it is well known that most customers are not keen to fill out questionnaires), they are not very useful in anticipating the reactions

of customers to future changes in the mall configuration. Hence, managers lack tools to anticipate customers' reactions to changes in mall configuration.

Indeed, optimizing the location of stores in a mall is a complex problem if a manager wants to take into account the factors which influence the customers' shopping and buying decisions in relation to the mall's spatial layout. They include: 1) relative locations of stores; 2) the store's location in relation to corridors, entrances and other services; 3) customers' preferences in relation to their needs and socio-economic profiles; 4) customers' perceptions of buying opportunities in the mall in an environment which is rapidly changing. Traditional statistical and data analysis methods are not able to take into account so many factors, and cannot encompass the spatial and perceptual characteristics of people's shopping behaviours.

An ideal solution would be to enable mall managers to try various mall configurations by changing the locations of certain stores and carrying out surveys in order to determine the impact of these changes on customers. Obviously, such a solution is not practical in a real setting because: 1) changing a store's location is a costly activity which cannot be undertaken often; and 2) it is not possible to try several locations for a store and to assess the reactions of customers for each of these locations before making a final decision about the store's location. An alternative solution would be to simulate on a computer the customers' behaviours in a virtual mall and enable managers to explore various scenarios by changing stores' locations in the virtual mall and by observing the reactions of customers to these changes. Until recently, such an approach was not feasible. However, thanks to recent progress in the areas of geo-simulation (Benenson and Torrens 2003) and multiagent systems simulation (Moss and Davidson 2000), and more specifically in multi-agent geo-simulations (Moulin et al 2003), simulating the behaviours of a large number of virtual agents in a georeferenced virtual world is now possible.

In this paper, we present a multi-agent geo-simulation approach and a software package, MallMAGS, which are used to model and simulate customers' shopping behaviours in virtual malls. Using such a geo-simulation, a manager can reproduce his mall layout, create a population of virtual shopper agents which mimic the behaviours of mall customers, observe how virtual shopper agents interact with the virtual mall and how they react to changes in the mall configuration. We also propose to use SOLAP techniques (Spatial On Line Analytical Processing) to systematically analyze the results of the multi-agent geo-simulations.

The paper is organized as follows. In the next section, our multi-agent geo-simulation approach is presented and we show why it is appropriate to simulate perception-based customer behaviours in a mall. The following section presents the main steps of our method which enable a designer to create a geo-simulation and we illustrate how it is applied in the creation of the shopper agents and the virtual environment to simulate customer's behaviours in a mall. Then, we present MallMAGS, our multi-agent geo-simulation system for malls, after which we present how we analyze the output of the geo-simulation and how a mall manager can assess the impact of changes in stores' locations in the virtual mall. Some limitations and constraints of our work are presented in the following section. Finally, some conclusions are presented and future research directions identified.

MAGS: A Perception-Based Multi-Agent Geo-Simulation Approach

Geo-Simulation (Benenson and Torrens 2004) is a new form of simulation that has become popular in geography and the social sciences in recent years. It is a useful tool to integrate the spatial dimension in models of interactions of different types (economics, political, social ...). Mandl (2000), Koch (2001) and Moulin et al (2003) presented MultiAgent Geo-Simulation as a coupling of two technologies: multi-agent based simulation (MABS) and geographic information systems (GIS). Based on the MABS technology the simulated entities are represented by software agents who autonomously carry out their activities. They can interact and communicate with other agents. Using the GIS technology, spatial features of geographic data can be introduced in the simulation. "*The simulation of human behavior in space is an extremely interesting and powerful research method to advance our understanding of human spatial cognition and the interaction of human beings with the environment*" (Frank et al 2001: 1). Several researchers haved used this paradigm to develop applications that simulate different kinds of behaviours in spatial environments. For example, Raubal (2001) and Frank et al (2001) presented an application which simulates a way-finding behaviour in an airport. Dijkstra et al (2002) used cellular automata to simulate pedestrian movements in a shopping mall. Koch (2001) simulated people movements in a large scale environment representing a town. In these applications, the spatial features of the simulation environment (SE) are represented using maps or cellular automata, but the agent capabilities are often limited. For example, they are not able to effectively perceive the environment and to react to these perceptions.

In contrast, in our multi-agent geo-simulation approach (Moulin et al 2003) the agents have several knowledge-based capabilities such as perception, navigation, memorization, communication and objective-based behaviour which allow them to display an autonomous behaviour within a 2D-3D geographic virtual environment. The MAGS System (MultiAgent Geo-Simulation) is a generic multi-agent geo-simulation platform which can be used to simulate, in real-time, thousands of knowledge-based agents navigating in a 2D or 3D virtual environment (Moulin et al 2003). MAGS agents are able to perceive the elements contained in the environment, to navigate autonomously inside it and to react to changes occurring in the environment. This is a reason why it is appropriate to use the MAGS Platform to simulate customers' behaviours in a mall when we want to take into account customers' reactions when changes occur in the mall environment (e.g. new or changed locations for kiosks of stores, and display of new products)

MAGS agents have several knowledge-based capabilities:

- *The agent perception process*: In MAGS agents can perceive (1) terrain characteristics such as elevation and slopes; (2) the elements contained in the landscape surrounding the agent including buildings and static objects; (3) other mobile agents navigating in the agent's range of perception; (4) dynamic areas or volumes whose shape changes during the simulation (e.g. smoky areas or zones having pleasant odours) (Moulin et al 2003). Each agent has

a perception field (a cone shaped area whose range and angle is parameterized) which enables the agent to perceive the agents as well as the environment's objects and terrain features in a realistic way.
- *The agent navigation process*: MAGS agents can have two navigation modes: *Following-a-path-mode* in which agents follow specific paths which are stored in a bitmap called ARIANE_MAP or *Obstacle-avoidance-mode* in which the agents move through open spaces avoiding obstacles. In MAGS the obstacles to be avoided are recoded in a specific bitmap called OBSTACLE_-MAP. The *Following-a-path-mode* enables MAGS to simulate pedestrians' movements on pavements or car movements on roads in an efficient way. The *Obstacle-avoidance-mode* enables an agent to go anywhere and to avoid other agents and obstacles that it perceives in its perception field.
- *The memorization process*: MAGS agents have three kinds of memory: *Perception memory* in which the agents store what they perceive during the last few simulation steps; *Working memory* in which the agents memorize what they perceive in one simulation and *Long-term memory* in which the agents store what they perceived in several simulations (Perron and Moulin 2004).
- *The agent's characteristics*: In MAGS an agent is characterized by a number of variables whose values describe the agent's state at any given time. We distinguish *static states* and *dynamic states*. A static state does not change during the simulation and is represented by a variable and its current value (e.g. gender, age group, occupation,and marital status). A dynamic state is a state which can possibly change during the simulation (e.g. hunger, tiredness, and stress). A dynamic state is represented by a variable associated with a function which computes how this variable changes values during the simulation. The variable is characterized by an initial value, a maximum value, an increase rate, a decrease rate, an upper threshold and a lower threshold which are used by the function. Using these parameters, the system can simulate the evolution of the agents' dynamic states and trigger the corresponding behaviours (Moulin et al 2003).
- *The objective-based behaviour*: In MAGS, an agent is associated with a set of objectives that it tries to reach. The objectives are organized in 'hierarchies' composed of nodes which represent composite objectives and 'leaves' that represent elementary objectives which are associated with actions that the agent can perform. Each agent possesses a set of objectives corresponding to its needs. An objective is associated with rules containing constraints on the activation and on the completion of the objective. Constraints are dependent on time, on the agent's states and on the environment's state. The selection of the current agent's behaviour relies on the priority of its objectives. Each need is associated with a priority which varies according to the agent's profile. An objective's priority is primarily a function of the corresponding need's priority. It is also subject to modifications brought about by the opportunities that the agent perceives or by temporal constraints (Moulin et al 2003).
- *The agent communication process*: MAGS agents can communicate with each other by exchanging messages using mailbox-based communication.

The spatial characteristics of the environment and static objects are generated from data stored in a geographic information system and in related databases. The spatial characteristics of the environment are recorded in a raster mode which enables agents to access the information contained in various bitmaps that encode different kinds of informatión about the virtual environment and the objects contained in it. The *AgentsMap* contains the information about the locations of agents and the static objects contained in the environment. The *ObstaclesMap* contains the locations of obstacles, the *AriadneMap* contains the paths that can be followed by mobile agents, and the *HeightMap* represents terrain elevations. The information contained in the different bitmaps is used by the agent's perception and navigation algorithms. In MAGS the simulation environment is not static and can change during the simulation. For example, we can add new obstacles, or gaseous phenomena such as smoke and dense gases which are represented using particle systems (Moulin et al 2003).

Because of all these characteristics, MAGS offers us the means to create plausible customer agents visiting a virtual mall, perceiving stores and objects contained in the mall and reacting to shopping opportunities that they perceive during the visit.

We also developed a systematic method to create multi-agent geo-simulations. The main steps of this approach are presented in Figure 1.

In the following sections we present the most important steps that can be carried out in order to create a simulation of customers' behaviours in a mall and to enable managers to explore various scenarios in which store locations are changed in the virtual mall.

Preparation of a Geo-Simulation of Customers' Behaviours in a Mall

We present in this section the main steps of the method that enabled us to create a geo-simulation of customers' behaviours in a virtual shopping mall. Some of the method's steps have been grouped together in the same sub-section. In order to emphasize the general characteristics of the method, we first propose a general description of the step (presented in italics). Then we show how we applied it to the shopping mall case.

Identify Users' Needs and Specify the General System's Characteristics

Simulation applications provide a support to the decision making process. In geo-simulation applications, decisions are influenced by the spatial characteristics of the simulated system and the geographic features of its environment. Before developing a multiagent geo-simulation application, we must study in detail the needs and goals of its future users.

In the case of the shopping behaviour geo-simulation application, the users are

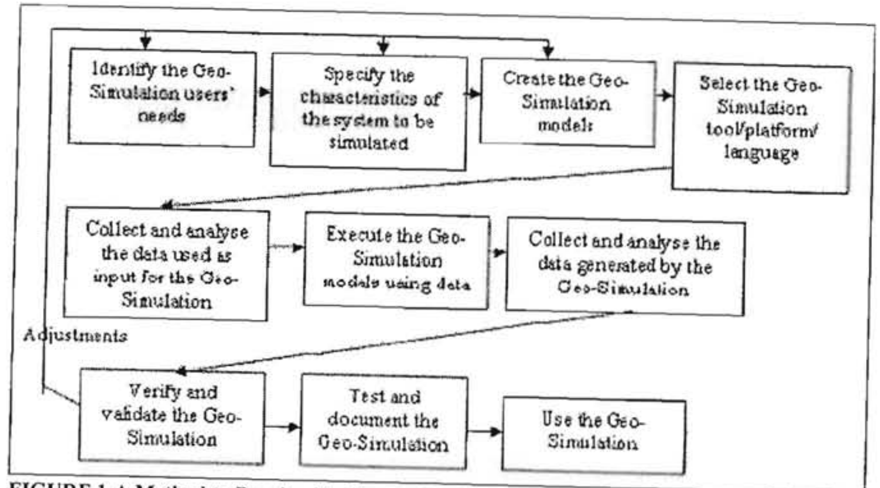

FIGURE 1 A Method to Develop Multiagent Geo-Simulation

mall managers who need to use the application to simulate and visualize customers' shopping behaviours in their shopping mall and to assess the influence of different store locations on customers' behaviours. Based on these needs we can limit the context of the geo-simulation application to the spatialized *shopping behaviour* of customers in a *shopping mall.*

Based on the users' needs, we must identify the characteristics of the system to be simulated as well as its environment, including all the relevant spatial and non-spatial features within the limits that were defined in the previous step.

In the shopping behaviour simulation case, we studied the shopping behaviour (the system to be simulated) of people in a mall (the environment). An extensive literature review in several disciplines (including consumer behaviour, marketing, and social psychology) provided the following results which must be taken into account when preparing agent's models.

According to several studies, shopping behaviour is influenced by several factors:

- *Internal factors*: Demographic (e.g. gender, sex, marital status, life-cycle, and sector of employment), personality, values, culture, attitudes, habits, preferences, and emotional factors. (Duhaime and Laroche 1996).
- *External factors*: Family, reference groups, social class, among others (Duhaime and Laroche 1996).
- *Situational and contextual factors*: The environment ambiance (e.g. music, odours, and temperature) (Deborah and Whan 1991), the spatial and geographic configuration of the environment (e.g. layout of the stores, textures, and colour), and the social aspect of the environment (e.g. attendance of other people and staff) (Eroglu and Gilbert 1986).
- *Other factors*: The temporal factor (e.g. period of time in the day, in the week, in the month, in the year), expected duration of shopping.

Shopping behaviour can be thought of as composed of several processes such as (Petrof 1978): 1) *recognizing shopping motivations*; 2) *retrieving information* used to search for stores where to shop (internal search from the memory or memorization process; and external search in the environment or perception process); 3) *evaluating alternatives* (choosing a particular store); 4) *decision making* before visiting a shop; 5) *post-decision process* (evaluation of the experience after visiting a store).

Create the Multiagent Geo-Simulation Models

In order to simulate the target system on a computer, we must model it as well as its environment, taking into account their spatial and non-spatial characteristics. Since our simulation approach is based on the agent technology, we use an agent-oriented design method to create the models and to represent the entities of the simulation. The Agent-Based Unified Modeling Language (AUML) (http://www.auml.org/) provides a formalism to specify such models.

In a simulation we can distinguish two categories of entities: passive and active agents. We describe here some of the passive and active agents found in the mall geo-simulation.

The Passive Agent model (PA) is used to specify entities which do not have behaviours. Usually, a large number of elements of the simulation environment belong to this category. We must characterize the *spatial* and *non-spatial structures* of the passive agents. In the shopping behaviour simulation case we represent the majority of the shopping mall entities as passive agents: stores, kiosks, toilets, doors, entertainment areas, rest areas, smoking areas and parking lots. We will only describe in this paper the spatial and non-spatial characteristics of some of these elements.

Non-spatial structure (example of the Store PA):

The non-spatial structure of a Store PA contains the information which is specific to a particular store in the virtual mall. For example, this structure contains the Store_Identification, the Store_Name, and the Store_Speciality. The details of the non-spatial structures of the others PA are not given in this paper.

Spatial structure (The PA of the spatial environment):

The 2D spatial (geographic) structure of the spatial environment PA is modeled using the GIS software GeoMedia (http://www.intergraph.com/). Figure 2a presents the 2D spatial structure (GIS) of the first floor of the Square One Mall. To create the 3D spatial structure of the PA, we use the software 3DStudioMax (http://www.techanim.com/). A portion of the 3D spatial structure of the first floor of the Square One Shopping Mall is displayed in Figure 2b. To make our simulation environment more realistic we used pictures of stores' windows as textures

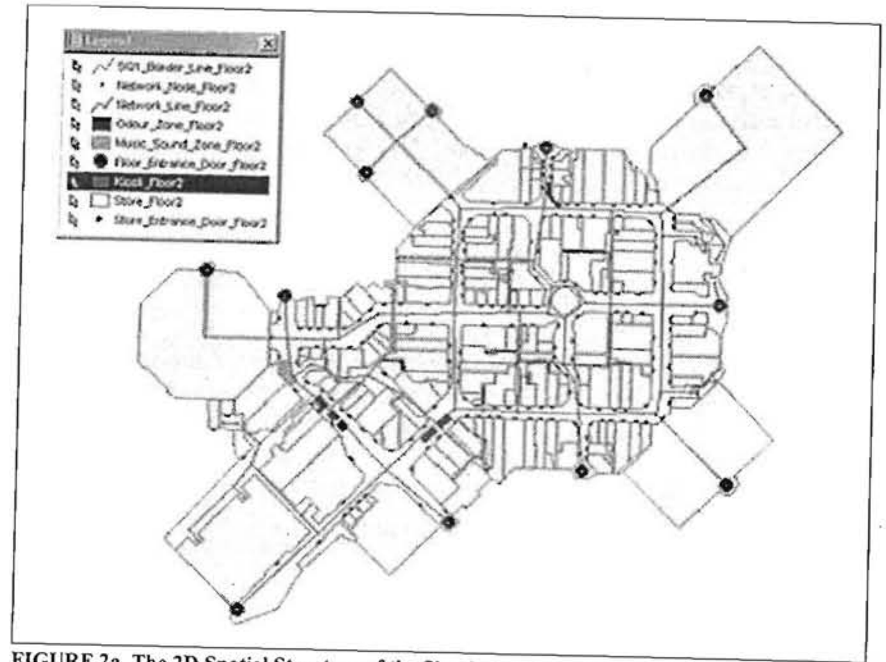

FIGURE 2a **The 2D Spatial Structure of the Simulation Environment Agents**

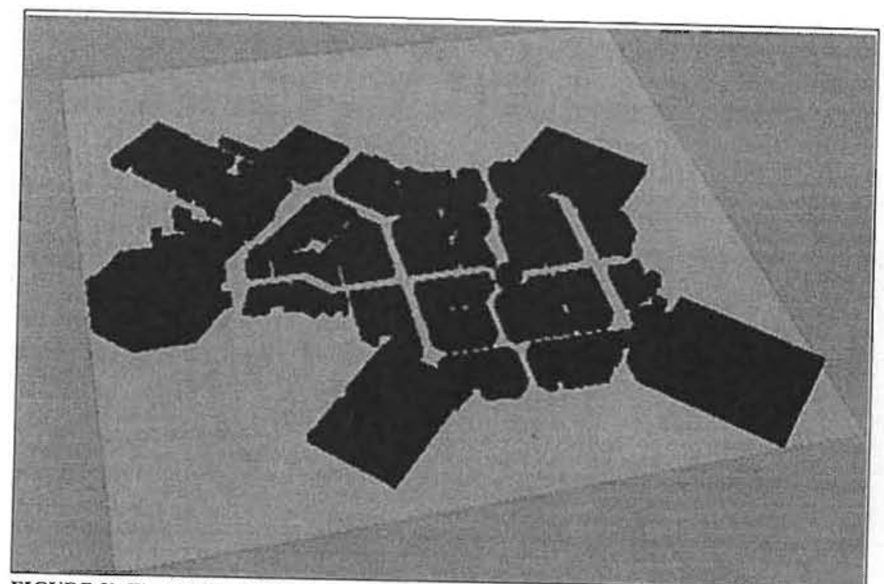

FIGURE 2b **The 3D Spatial Structure of the Simulation Environment Agents**

that were adjusted on the facades of the stores in the virtual environment.

The Active Agent model (AA) is used to specify entities having behaviours. These entities actively participate in the simulation. In this model we specify the *data structures* of the entities (spatial and non-spatial structures) as well as their *behaviours* (spatial and non-spatial behaviours). In the shopping behaviour case we only consider one category of agents which represents the shoppers: the *Shopper AA*.

The non-spatial structure (The Shopper AA):

The non-spatial structure of the Shopper agent includes variables which correspond to the factors that influence customers' shopping behaviours in a shopping mall. We specify, for instance, the agent's demographic profile (e.g. identification, name, gender, and age group), preferences, habits, shopping goals, emotional states, as well as dynamic variables (e.g. hunger and thirst), possession state (what the agent owns), and the agent's knowledge (what the agent knows in the mall: the stores, the toilets, etc.).

The spatial structure (The Shopper AA):

The spatial structure of the Shopper AA depicts the spatial representation of the agent in the simulation environment. For example, in the 2D simulation, the spatial structure of the Shopper AA can be a point, a circle or a square. In the 3D simulation, we represent the agents' spatial structure using a 3D shape (a 3D mesh) which represents a young man/woman, an old man/woman; we can also choose the colors of clothes or they may be randomly assigned to agents' shapes.

The non-spatial behaviour:

In the non-spatial behaviour of Shopper AA are included the main processes of shopping behaviour which are not related to the external environment such as the *needs detection process*, the *internal information retrieval process* and the *decision-making process*. These processes are defined using several models which result from the study of consumer behaviour in a mall (Petrof 1978).

The spatial behaviour:

The spatial behaviour of the shopper agent depicts the agent's interactions with the simulation environment (e.g. movement, obstacle avoidance and path finding) as explained earlier. For example, in a 2D spatial behaviour we can see the agent move from one location to another. In a 3D spatial behaviour, and using a 3D mesh animation, the agent "walks" in the 3D model of the shopping mall.

Collect and Analyze the Data Used as Input to the Geo-Simulation

During this step, we collect data and transform it in order to feed the simulation models. If it is acceptable to input random data in the simulation models, this step can be very simple but the simulation may be unrealistic. However, if we want to use real data, we must collect and analyze it before feeding it in the system. Since we deal with geo-simulations, we must collect and analyze both non-spatial and spatial data. In our approach we use OLAP and SOLAP techniques to analyze the input data.

This step is very relevant for a geo-simulation study for two reasons:

- to help the simulation users make efficient decisions using the simulation tool, the collected data which feed the simulation models need to be realist.
- in order to analyze the non-spatial and spatial collected data, we need techniques which can be easily and rapidly used by simulation users. The techniques need to present analysis results in a way which is close to the users' mental model. It has been shown that OLAP and SOLAP analysis techniques are the most appropriate techniques to do this kind of analysis (Bédard et al 2001).

For the shopping behaviour simulation case and in order to have a realistic simulation we used real data that our team collected in the Square One shopping mall. We now briefly explain how we collected the data and which techniques we used to analyze it. We present here the data collection process as well as the analysis process of the collected data.

Data collection: The data characterizing the spatial environment is recorded in a GIS and obtained after processing different documents such as maps and descriptions of stores. For the creation of the shopper agents we did not have any data. Consequently, we decided to build a survey to collect data about real shoppers visiting the shopping mall. Thanks to this survey that was conducted in the Square One mall in the Toronto area during October 2003, we collected about 390 completed questionnaires. We built a thirty-page questionnaire in order to collect most of the data needed to measure the factors characterizing the customer's characteristics, his or her knowledge of the mall and stores, as well as his or her goals and preferences. Thanks to this questionnaire, we collected a great deal of non-spatial data (customer's demographic profile, habits, interests and preferences) and spatial data about shopper spatial knowledge (preferred entrance doors, preferred parking lots, usual paths followed during the shopping trip, the shopping areas which are best known in the shopping mall). The data were recorded on paper questionnaires. In order to record this data in an electronic form we used Microsoft Visual Basic to input shoppers' non-spatial and spatial data into a Microsoft Access database.

Data analysis OLAP and SOLAP analysis: The survey provided a large number of non-spatial and spatial data which needed to be analyzed. We used a multidimensional analysis approach based on *On Line Analysis Processing* (OLAP) for the non-spatial data and on *Spatial On Line Analysis Processing* (SOLAP) to analyze the collected spatial data (Bédard et al 2001). OLAP-SOLAP approach is geared towards decision-support as it is designed from the start to be *easy* and *rapid* (Rivest et al 2001). OLAP-SOLAP is a multidimensional approach which is based on *dimensions* and *measures*. Dimensions represent the analysis axes, while measures are the numerical attributes being analyzed against the different dimensions (e.g., *age group* of a person can be considered as a dimension). A dimension contains member which are organized hierarchically into levels (e.g., *young*, *teenager*, and *old* can represent a hierarchy of the age group dimension), each level having a different level of intensity going from coarse at the most aggregated level to fine at the most detailed level. The members of one level can be aggregated (regrouped) to form the members of the next higher level. The measures at the finest level of granularity can be aggregated or summarized following this hierarchy and provide information at the higher levels according to the aggregation rules or algorithms (e.g., *13-17 years* and *18-25 years* are two measures of the *young* level of the *age group* dimension). A set of measures aggregated according to a set of dimensions forms what is often called a *data cube* or *hypercube* (Rivest et al 2001).

Here we show how we used the OLAP and SOLAP techniques and tools to analyze our survey data and to identify meaningful information for the creation of the shopper agent's models. Using OLAP-SOLAP we can see, based on the results, the influence of one or several variables (dimensions) on another. These variables can be spatial or not. Using these results, we can adjust the shopper agent's model (structure and behaviour). We can, for instance, determine which variables are more important for our model (the variable which influences enormously the shopping behaviour).

OLAP analysis: Using an OLAP analysis, we can analyze non-spatial variables or *Dimensions*. We can also determine the influence of one dimension on another. For example, we can determine the influence of the gender dimension on the color or music preferences dimensions. Actually, we analyzed results about all the dimensions of our model of the Shopper agent. We can further analyze the data by combining dimensions together.

SOLAP analysis: Using a SOLAP analysis, we can determine the relationship between a spatial dimension of the environment and the non-spatial dimension of the Shopper agent. For example, we can determine the relationship between the Gender dimension of a shopper and the choice of the shopping corridor or the entrance door in a shopping mall. Figure 3a presents the entrance doors of the first floor of the Square One shopping mall and Figure 3b presents the graphical representation of the distribution of the participants on the dimension Floor_Entrance_Door in the shopping mall. We can see in Figure 3b that the most frequented mall's doors are Door 0 (97 shoppers) and Door 10 (125 shoppers). The

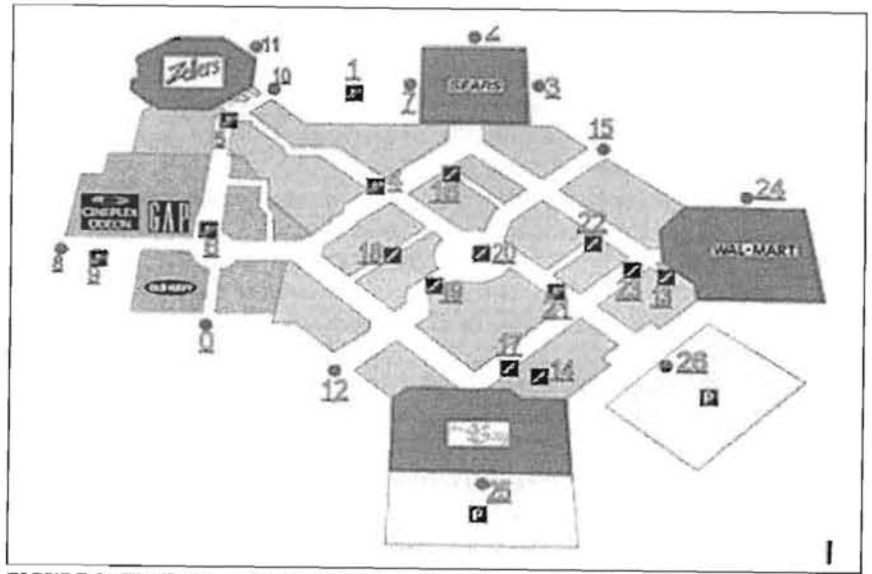

FIGURE 3a The Entrance Doors of the First Floor (Square One Mall)

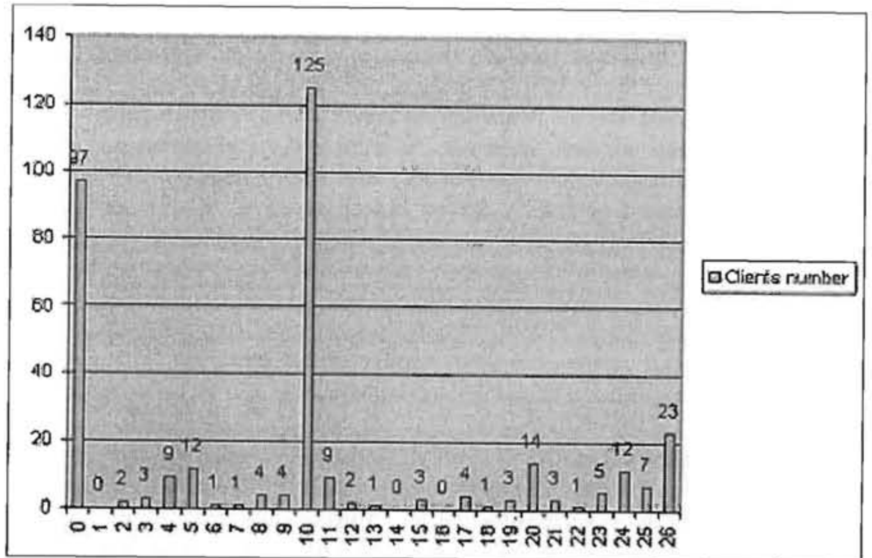

FIGURE 3b The Distribution on the Floor_Entrance_Door Dimension

multidimensionality aspect of the OLAP-SOLAP can tell us that among these 125 shoppers who enter by door 10, we have 65 females and 60 males. Among these females, we find that 31 are aged between 13 and 25 years old, 26 between 26 and 50 years and 8 aged over 51 years. The OLAP-SOLAP technique has the advantage of presenting these results rapidly (on line) and easily in a manner which is close to the mental model of its users.

Above, we presented the first steps of our approach which aimed to prepare the multiagent geo-simulation models, to collect empirical data in order to feed these models and to analyze the collected data in order to adjust the characteristics of these models. The OLAP-SOLAP approach is particularly suited to the analysis of data collected in a mall because mall managers are not computer scientists or data analysts.

In the following sections we present the remaining steps of our approach which aim to develop and run the simulation models in the MAGS platform and to generate simulation outputs which can be used by mall managers to explore various scenarios corresponding to different store locations.

Running the Simulation: the Mallmags Prototype

Using the MAGS platform we developed a multiagent geo-simulation prototype which simulates customers' shopping behaviour in a mall. For each simulation we must prepare a simulation scenario using the *scenario-manager*, a dedicated module that belongs to the MAGS platform. In such a scenario we must indicate the characteristics of the simulation environment (the mall), the characteristics of the passive and active agents in the simulation (e.g. shopper, stores, and kiosks) and the behaviour of the active agents in the simulation (shoppers). The behaviour specification is based on the concept of objectives which is supported by the MAGS platform. Using the same module we must: (1) feed the simulation data with the collected data about the shoppers as well as the mall; and (2) indicate for example which percentage of shopper agents (with specific characteristics) enter at each door at given times. It is important to note the ease with which this module can be used which is, again, close to the mental model of its users. All the specifications are then recorded in scenario files which are used to initialize the simulation.

In Figure 4a and Figure 4b we display 2D and 3D screenshots of a simulation that involved 390 software Shoppers agents navigating in the virtual shopping mall. These 390 shopper agents hold the data collected from the 390 real shoppers who were interviewed during the Square One survey in October 2003. In the simulation prototype the Shopper agent comes to the mall to visit a list of specific stores or kiosks that are chosen before the simulation on the basis of the agent's characteristics. These elements are determined using the collected data as explained above. The agent enters by a particular door and starts the shopping trip. Based on the agent's position in the mall, on the agent's knowledge (*memorization process*) and on what the agent perceives in the mall (*perception process*), the agent chooses the next store or kiosk to visit (*decision making process*). When the

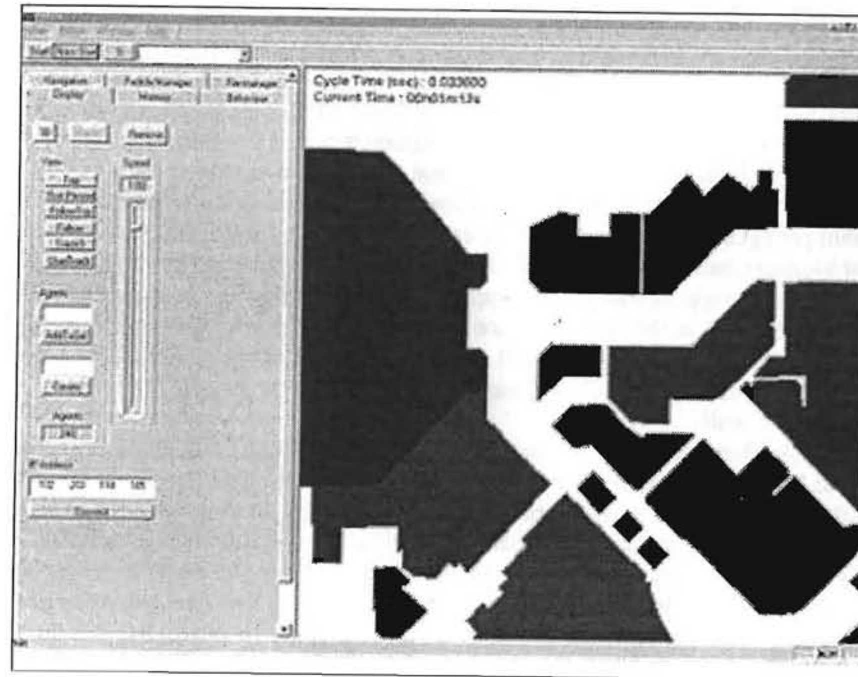

FIGURE 4a The 2D Simulation in MAGS Platform (Square One Mall)

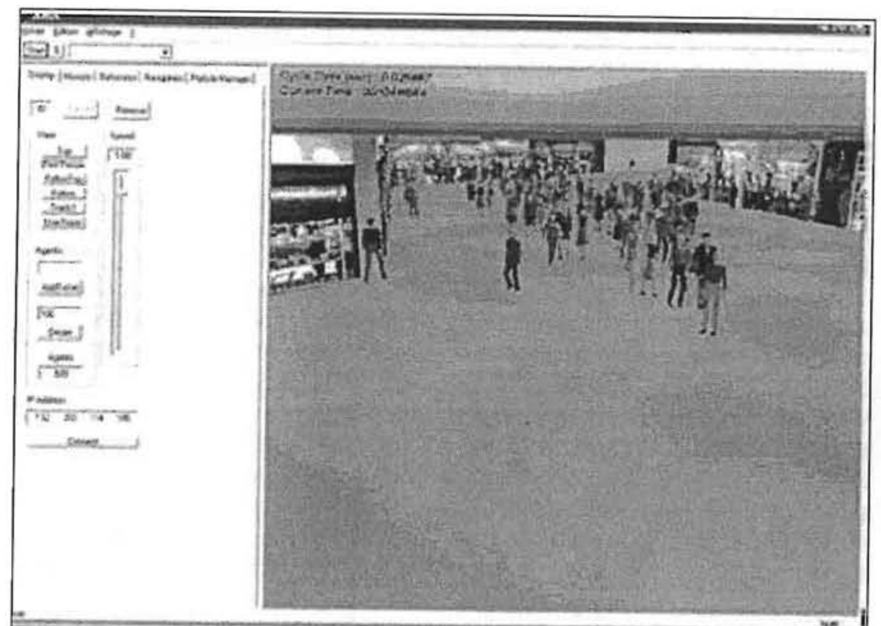

FIGURE 4b The 3D Simulation in MAGS Platform (Square One Mall)

agent chooses a store or kiosk, the agent moves in its direction (*navigation process*). Details about the memorization, perception, decision-making and navigation processes are presented in (Moulin et al 2003).

Sometimes, when the agent is moving to the chosen store or kiosk, the agent may perceive another store or kiosk (perception process) that is in its shopping list and that it did not know before. In this case, the Shopper agent moves to this store or kiosk and memorizes it (*memorization process*) for its next shopping trips. The shopper agent repeats this behaviour continually until he or she visits all the stores or kiosks remaining in the agent's shopping list or until the agent has no more time left for the shopping trip. If the shopper agent still has time for shopping and some stores or kiosks of the agent's list are in locations unknown by the agent, the agent starts to explore the shopping mall searching for these stores or kiosks. When the shopper agent reaches the maximum time allowed to the shopping trip, the agent leaves the mall.

The Shopper agent can also come to explore the mall without having a specific list of stores or kiosks to visit. In the exploration mode the Shopper agent takes his or her preferred paths in the shopping mall. In this mode the moving action of the Shopper agent to the stores, kiosks and particular areas (characterized by a specific music, odour or lighting) is directed by the agent's habits and preferences. For example, if the Shopper agent likes *cars* and the agent passes in front of a car exhibition, he or she can move to this exhibition. To extend our simulation prototype we can simulate the shopper reactions to the mall's atmosphere. We can insert special agents that broadcast music, lighting or odour. If the shopper agent is in the exploration mode and likes the music or the lighting or the odour broadcasted by these special agents, the shopper agent can move toward them and possibly enter the associated store.

During the agent's shopping trip, the Shopper agent can feel the need to eat or to go to the restroom (simulated by a dynamic variable reaching a given threshold). Since these needs have a bigger priority than the need to shop, the agent suspends temporarily its shopping trip and goes to the locations where it can eat something or to go to the restrooms. In our geo-simulation prototype the priorities of the activities of the shopping behaviour are defined based on Maslow's hierarchy of needs (Maslow 1970).

The current shopper agent's models and behaviours are significant enough to carry out meaningful simulations. However, the simulation environment could be enriched in order to associate products to stores. This can be done thanks to a data base relating products and stores. Consequently, the agents could come to the mall with a list of products to buy and opportunistically choose during the shopping trip the stores where to purchase these products. Having access to product information, the store agents may advertise shopping opportunities like product sales (advertisement is simulated by messages broadcast by the store agent to shopper agents moving in an area located in the store vicinity). We could then easily develop agents' behaviours which will enable them to react to shopping opportunities in relation to their needs and preferences.

Geo-Simulation for Efficient Decision-Making

In this section we present the two last steps that enable managers to analyze the geo-simulation results and to explore the impact on changing stores' locations in the virtual mall.

Collect and Analyze the Data Generated by the Geo-Simulation

The simulation output analysis is an important step to gather simulation data and to analyze it according to the user's needs. In our approach, this step is characterized by the following points:

- The simulation output data are collected using specific software agents called Observers. The mission of these agents is to gather data about the mobile agents which enter their perception area. This data is recorded in files and analyzed after the simulation.
- The data analysis of the geo-simulation output (non-spatial and spatial data) is implemented in an analysis tool that we developed using Microsoft Visual Basic 6.0. This user-friendly tool uses the data collected by the Observer agents in order to carry out multidimensional non-spatial and spatial analyzes using an OLAP (On Line analytical Processing) and SOLAP (Spatial On Line analytical Processing) approach.

In the example of the shopping behaviour simulation, the role of an observer agent is to collect data from the shopper agents who come nearby (in the observer agent's perception range) and to store these data in files or databases. When the simulation execution ends, we can analyze the contents of these files or databases in order to make a report about the simulation results. We can collect non-spatial and spatial results during the simulation. Using again our OLAP and SOLAP techniques and tools we can analyze these results. For the shopping behaviour simulation example, we located observer agents at the entrances of the virtual shopping mall in order to record the number of Shopper Agents entering and exiting the shopping mall. Other Observer Agents were positioned in corridors in order to count the number of Shopper Agents passing by. Other Observer Agents collect different data such as the Shopper Agents' satisfaction when exiting the shopping mall. The Observer agents' behaviour is similar to conducting a survey in the virtual environment, a survey of the same kind as the one we conducted in 2003 in the real shopping mall. Hence, we are able to use the same OLAP and SOLAP analyzes that we used to analyze the data obtained from the real shoppers. We can also compare the results of the simulation with the data collected in the real mall in order to verify the conformity of the virtual shopper agent population with respect to the real customer population.

In this step, we benefit again from the advantages of the OLAP-SOLAP analysis technique in order to analyze the simulation output. This is very important for two reasons: (1) the analytic results can be used rapidly and easily by users; (2) using the same technique to analyze input and output simulation data gives us the opportunity to compare several simulation scenarios using output data which have the same structure.

Experiment with Different Scenarios Using the Geo-Simulation

The last step of our approach is to exploit the results of the multiagent geo-simulations in order to for example:

- Understand the system to be simulated by observing various simulations carried out over long periods of time using the Geo-Simulation platform.
- Experiment with the system in new situations or contexts in order to assess the influence of different decisions.

Mall_MAGS can be used by shopping mall managers to explore different spatial configurations of the shopping mall by changing a store location, or closing a door or a corridor in the virtual mall. For each new configuration, the manager can launch the simulation with the same population of virtual shopper agents, collect the results and analyze them. By comparing these results he or she can make informed decisions about the impact of spatial changes in the mall.

To illustrate the use of the Shopping behaviour geo-simulation tool, we used two simulation scenarios. In the first scenario, we launch a simulation with a given configuration of the shopping mall (Figure 5a) and with a population of 390 shoppers. The simulation for this first scenario generates output data about the itineraries that the Shoppers agents take in the shopping mall. In scenario 2 we exchange the location of a two department stores: *Wal-Mart* and *Zellers* (Figure 5b). We launch the simulation again and MallMAGS generates the output data about the itineraries of the same population of Shoppers agents. By comparing the output data of the two scenarios we notice the differences between the paths that the Shopper agents followed to attend the department stores *Wal-Mart* and *Zellers* stores. The simulation output analysis shows that corridor X is less frequented in scenario 2 than in scenario 1 (Figure 5a). However, corridor Y is more frequented in scenario 2 than in scenario 1 (Figure 5b). In these figures, the flow of the Shopper agents which pass through a corridor is represented by a line which is attached to this corridor. The width and the colour of this line are proportional to the flow of Shoppers agents that pass through the corridor. If this flow grows, the width of the line grows and its colour becomes darker. Through a data analysis on the characteristics' dimension of the Shopper agent we can see that in scenario 2, most of the Shopper agents that go through corridor Y are female and they come to the mall to visit female clothing stores. If the mall manager chooses the mall configuration of scenario 2, he or she might think of renting the spaces along corridor Y to female clothing stores.

Deciding about stores' locations in a mall is widely recognized as the most decisive factor in determining a retail unit's success or failure. As noted many

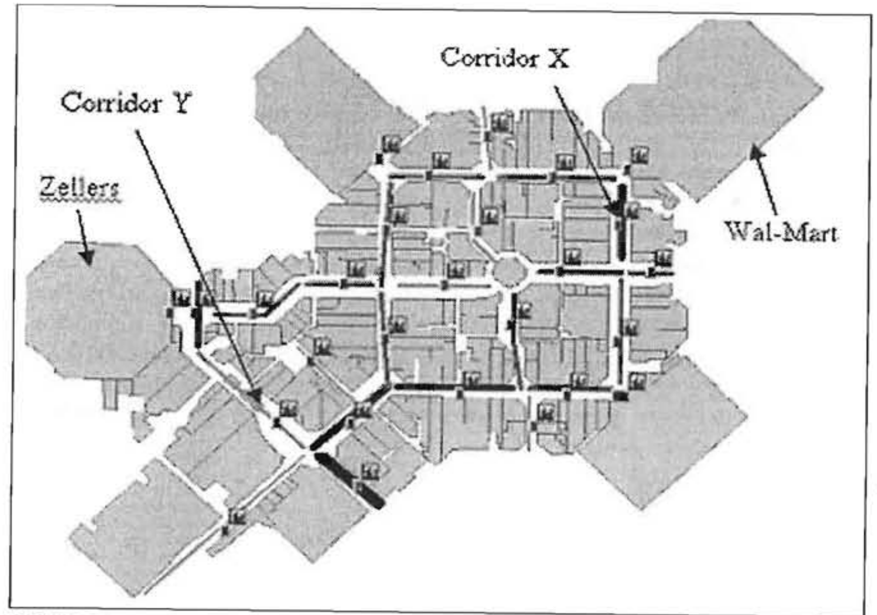

FIGURE 5a The Spatial Data Analysis in Scenario 2

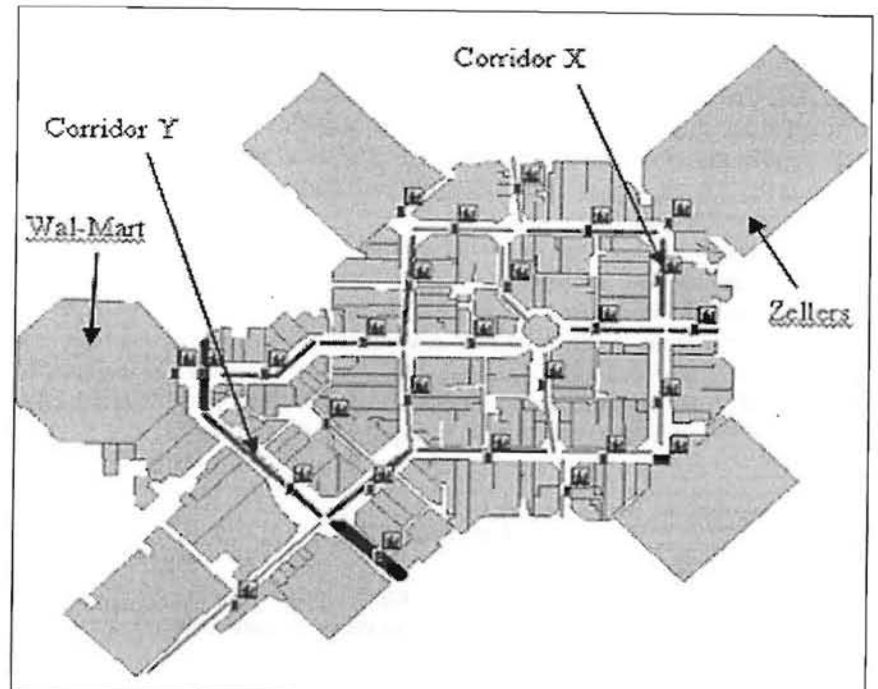

FIGURE 5b The Spatial Data Analysis in Scenario 2

times, good locations are 'the keystone to profitability' (Hernandez and Biasiotto 2001). They represent a point of major investment that needs to be managed. Once made, poor location decisions are difficult to remedy, and it is these factors that, in theory, 'compel the retailer to make the decision carefully' (Hernandez and Biasiotto 2001). Due to the increasing level of competition, the pressure placed on retailers to make 'good' decisions has risen markedly, as the consequences of 'bad' decisions have escalated. For the reasons mentioned above, retailers such as mall managers or store managers, who need to make decision about their retail location, need to be supported in their decision by efficient tools.

In this paper we presented an approach and a geo-simulation tool which can be used by mall managers to try various mall configurations by changing the locations of certain stores and to carry out surveys in order to determine the impact of these changes on customers. We beleive that this solution can help mall managers to make decisions about better store locations and their effect on customers' shopping behaviour in their mall.

Limits and Constraints of the Work: A Discussion

The geo-simulation prototype presented in this paper simulates efficiently the individual shopping behaviour in a mall. In this prototype however, there are some limitations:

- Lack of certain data, we were not able to collect data about groups of shoppers. Consequently, we were not able to simulate the shopping behaviour of groups in a mall. Since the social aspect of shopping behaviour is important, we plan to develop a new questionnaire in order to obtain new data to simulate the behaviour of groups of shoppers and to introduce it in the next version of the prototype.
- The prototype presented in this paper simulates the shopping behaviour of customers visiting one floor of the mall. Simulating the shopping behaviour on several floors will be tackled using the next version of the prototype.
- Shopper agents are equipped with several spatial and cognitive capabilities (e.g. perception and memorization). The memorization process prepares the ground for the development of a learning capability for agents. This is another area of investigation that we wish to explore in the future.

Conclusion

Our literature review showed that mall managers can currently use two techniques to assess the impact of store location changes on customers' behaviour:

- Surveys and questionnaires: They can collect data about customers and analyze it to try to understand how cutomers use the mall. One limit of this technique is the fact that it is not very useful in anticipating the reactions of customers to future changes in the mall configuration. Another limit is the difficulty in analyzing spatial data using such a technique.
- Geographic Information Systems (GIS): Using GIS represents a relatively new tool in retail field (Hernandez and Biasiotto 2001). The nature of GIS makes it an appropriate tool which facilitates the storage and analysis of spatial data. Unfortunately, GIS present the same problem as survey techniques because, the static nature of data stored in GIS means they are not very useful in anticipating the reactions of customers to future changes in the mall configuration.

In this paper we presented a generic approach and a geo-simulation tool to simulate and analyze customer shopping behaviour in a mall. We also noted how mall managers can use this tool in order to make informed decisions about their mall configuration. What distinguishes our approach and the geo-simulation tool from other techniques mentioned above is the fact that mall managers can use them to experiment with various mall configurations by changing the locations of certain stores in the virtual mall and analyzing the simulation results in order to determine the impact of these changes on virtual customers.

In the literature we found just one application which simulates the shopping behaviour in a mall. This application was developed by (Dijkstra et al 2002) and aimed to simulate the shopping behaviour in a virtual environment represent by cellular automata. What distinguishes our simulation from Didkstra's work and from other multiagent simulations of human behaviours in a geographic environment is that: (1) in our simulation the environment is represented by a georeferenced data set while in Dijkstra et al's application (the Amanda System) (2002) the environment is represented by cellular automata, which constrains substantially the shopper agents' movements; (2) our simulation is developed using the MAGS platform which gives our agents several cognitive and spatial capabilities which are not present in Dijkstra et al's simulation; and (3) our simulation generates output data in a form which facilitates the comparison of different simulation scenarios while Dijkstra et al's application (the Amanda System) is only used to visualize the simulation and does not generate any output. Finally, in MallMAGS the output data gathered by Observer Agents can be easily analyzed using OLAP/SOLAP tools.

Several new development and research directions are still open. Earlier, we already mentioned some possible improvements of our simulation by associating products with stores: this would enable the simulation of more sophisticated shopper agent behaviours, especially in relation to shopping opportunities such as product sales. Currently, our simulation runs on one floor of Square One. We could improve it by expanding it to all the floors of the shopping mall. We also conducted a similar survey in Place de la Cité, a shopping mall in Ste Foy (Quebec). An interesting study would be to compare the behaviours of the virtual shopper population of Ontario and of Quebec and examine whether differences appear in the agents' movement patterns if we used the Quebec virtual shopper population in the virtual Square One Mall.

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