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

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Abstract. In the very competitive retail world mall managers develop various strategies to differentiate their malls from their competitors in order to enhance customer loyalty. One possible strategy consists in changing the mall configuration and more specifically the stores’ locations. Deciding about stores’ locations is a very important decision which can be expensive in terms of money and time. In order to guarantee the success of such decision, mall managers should be able to better understand customers’ behaviors and the way they may react to changes of the mall’s configuration. Traditional techniques such as surveys and the use of geographic information systems may help to understand customers’ behaviors in an existing mall, but they are not adequate to anticipate customers’ reactions in a future layout of the mall. Thanks to recent progress in the areas of geosimulation and multiagent systems, simulating the behaviors of a large number of virtual agents in a georeferenced virtual world is now possible. We propose to apply these techniques in the shopping mall domain. In this paper we present a multi-agent geosimulation approach and a software, MallMAGS, which are used to model and simulate customers’ shopping behaviors in virtual malls. Using such a geosimulation, a

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manager can reproduce his mall layout, create a population of virtual shopper agents which mimic the behaviors of mall customers, observe how virtual shopper agents interact with the virtual mall and how they react to changes in the mall configuration. We propose to use SOLAP techniques (Spatial On Line Analytical Processing) to systematically analyse the results of these multi-agent geosimulations.

**KEYWORDS.** Shopping mall, Store location decision making, MultiAgent System, GeoSimulation, Shopping behavior, OLAP analysis.

### 1. 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 behavior (Ruiz et al., 2004). Competition from category killers, discount stores, and factory outlet centers represents a challenge for shopping mall managers. According to (Wakelfield 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 center that offers the most product and service variety and the most comfortable atmosphere. Finally, (Wakelfield et al., 1998) emphasize the fact that fewer consumers are going to the mall in 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 behavior is influenced by several internal and external (or contextual) factors (Duhaime et al 1996). While the former are related to shoppers’ characteristics and preferences, the latter are linked to the mall environment and configuration as such (Deborah et al 1991) (Eroglu and Gilbert 1986). The literature reveals that the shopping behavior rests upon several processes: perception, choice, navigation
efficiency, visual memorization, buying, and consumption patterns, 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, or shopping opportunities when customers walk in the mall’s corridors as well as signage. 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, 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 Wall Mart which attract certain categories of customers and favor ‘proximity shopping’ in stores which are located in corridors converging toward the anchor stores (Konishi H. and Standfort M., 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’ behaviors 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 up questionnaires), they are not very useful to anticipate the reactions of customers to future changes in the mall configuration. Hence, managers lack tools to anticipate customers’ reactions to changes of the 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: 1) relative locations of stores; 2) 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’ perception 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 behaviors.

An ideal solution would be to enable 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. 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 done often; 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’ behaviors 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 geosimulation (Benenson and Torrens 2004) and multiagent systems simulation (Moss and Davidson 2001), and more specifically in multi-agent geo-simulations (Moulin et al. 2003), simulating the
behaviors of a large number of virtual agents in a georeferenced virtual world is now possible.

In this paper we present a multi-agent geosimulation approach and a software, MallMAGS, which are used to model and simulate customers’ shopping behaviors in virtual malls. Using such a geosimulation, a manager can reproduce his mall layout, create a population of virtual shopper agents which mimic the behaviors 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 analyse the results of the multi-agent geosimulations.

The paper is organized as follows. Section 2 presents our multi-agent geosimulation approach and shows why it is appropriate to simulate perception-based customer behaviors in a mall. Section 3 presents the main steps of our method which enable a designer to create a geosimulation and we illustrate how it is applied for the creation of the shopper agents and the virtual environment to simulate customer behaviors in a mall. In Section 4 we present MallMAGS, our multi-agent geosimulation system for malls. Section 5 presents how we analyze the output of the geosimulation and how a mall manager can assess the impact of changes in stores’ locations in the virtual mall. Section 6 presents some limitations and contraints of our work. Finally, Section 7 is a discussion concluding the paper and identifying future research directions.

2. MAGS: a perception-based multi-agent geosimulation approach

Geo-Simulation (Benenson et al., 2004) is a new form of simulation that became popular in geography and 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, etc.). (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 which
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 and al. 2001). Several
researchers used this paradigm to develop applications that simulate different kinds of
behaviors in spatial environments. For example, (Raubal 2001) (Frank and al. 2001)
presented an application which simulates a wayfinding behavior 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 geosimulation approach (Moulin et al. 2003) the agents
have several knowledge-based capabilities such as perception, navigation,
memorization, communication and objective-based behavior which allow them to
display an autonomous behavior within a 2D-3D geographic virtual environment. The
MAGS System (MultiAgent Geo-Simulation) is a generic multi-agent geosimulation
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’
behaviors in a mall when we want to take into account customers’ reactions when
changes occur in the mall environment (new or changed locations for kiosks of stores,
display of new products, etc.)

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 (ex.: smoky areas or zones having pleasant odors) (Moulin et al. 2003). Each agent has a perception field (a cone shaped area whose range and angle is parameterized) which enables it 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 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 et al. 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 (ex.: gender, age group, occupation, marital status). A dynamic state is a state which can possibly change during the simulation (ex.: hunger, tiredness, 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 behaviors (Moulin et al. 2003).
- The objective-based behavior: 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 owns 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 behavior 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 information 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, 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 geosimulations. The main steps of this approach are presented in Fig 1.

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

3. Preparation of a geosimulation of customers’ behaviors in a mall

We present in this section the main steps of the method that enabled us to create a geosimulation of customers’ behaviors in a virtual shopping mall. Some of the method’s steps have been gathered 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.
3.1. Identify users’ needs and specify the general system’s characteristics

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

In the case of the shopping behavior geosimulation application, the users are mall managers who need to use the application to simulate and visualize customers’ shopping behaviors in their shopping mall and to assess the influence of different store locations on customers’ behaviors. Based on these needs we can limit the context of the geosimulation application to the spatialized shopping behavior 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 behavior simulation case we studied the shopping behavior (the system to be simulated) of people in a mall (the environment). An extensive literature review in several disciplines (consumer behavior, marketing, social psychology, etc.) provided the following results which must be taken into account when preparing agent’s models. According to several studies, the shopping behavior is influenced by several factors:

- **Internal factors**: Demographic (gender, sex, marital status, life-cycle, sector of employment, etc.), personality, values, culture, attitudes, habits, preferences, emotional factors. (Duhaime et al. 1996).

- **External factors**: Family, reference groups, social class, etc. (Duhaime et al. 1996).

- **Situational and contextual factors**: The environment ambiance (music, odors, temperature, etc.) (Deborah et al. 1991), the spatial and geographic configuration of the environment (layout of the stores, textures, color, etc.), and the social aspect of the environment (the attendance of other people, staff, etc.) (Eroglu and Gilbert 1986).
- Other factors: The temporal factor (period of time in the day, in the week, in the month, in the year, etc.), expected duration of shopping.

The shopping behavior can be thought of as composed of several processes such as (Petrof et al., 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 (choose a particular store), 4) decision making before visiting a shop, 5) post-decision process (evaluation of the experience after visiting a store).

3.2. Create the multiagent geosimulation 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/](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 geosimulation.

The Passive Agent model (PA) is used to specify entities which do not have behaviors. 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 behavior 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 of a particular store in the virtual mall. For example, this structure contains the Store_Identification, the Store_Name, the Store_Speciality, etc. 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/). Fig 2.a 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.technim.com/). A portion of the 3D spatial structure of the first floor of the Square One Shopping Mall is displayed in Fig 2.b. To make our simulation environment more realistic we used pictures of stores’ windows as textures that were adjusted on the facades of the stores in the virtual environment.

Fig 2.a: The 2D spatial structure of the simulation environment agents
The Active Agent model (AA) is used to specify entities having behaviors. 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 behaviors (spatial and non-spatial behaviors). In the shopping behavior 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 behaviors in a shopping mall (Section 3.1). We specify the agent’s demographic profile (identification, name, gender, age group, etc.), preferences, habits, shopping goals, emotional states, as well as dynamic variables (hunger, thirst, etc.), possession state (what the agent owns), agent’s knowledge (what the agent knows in the mall: the stores, the toilets, etc.), 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 behavior: In the non-spatial behavior of the Shopper AA are included the main processes of the shopping behavior which are not related to the external environment such as the needs detection process, the internal information retrieval process and the decision-making process (Section 3.1). These process are defined using several models which result from the study of consumer behavior in a mall (Petrof et al., 1978).

- The spatial behavior: The spatial behavior of the shopper agent depicts the agent’s interactions with the simulation environment (movement, obstacle avoidance, path finding, etc.) as explained in Section 2. For example, in a 2D spatial behavior we can see the agent move from one location to another. In a 3D spatial behavior, and using a 3D mesh animation, the agent “walks” in the 3D model of the shopping mall.

3.3. Collect and analyse 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 analyse it before feeding it in the system. Since we deal with geosimulations, we must collect and analyse both non-spatial and spatial data. In our approach we use OLAP and SOLAP techniques to analyse the input data. This step is very relevant for a geosimulation study for two reasons:

(1) to help the simulation users to make efficient decisions using the simulation tool, the collected data which feed the simulation models needs to be realist.

(2) in order to analyse 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 and al. 2001).

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

The data collection:
The data characterizing the spatial environment is recorded in a GIS and obtained after processing different documents: maps, descriptions of stores, etc. 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 Toronto area during October 2003, we collected about 390 filled questionnaires. We built a thirty-pages questionnaire in order to collect most of the data needed to measure the factors characterizing the customer’s characteristics, his knowledge of the mall and stores, as well as his goals and preferences (See Section 3.1 and 3.2). Thanks to this questionnaire, we collected a lot of non-spatial data (customer’s demographic profile, habits, interests and preferences) and spatial data about the 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 has been collected on paper questionnaires. In order to record this data in an electronic form we used Microsoft Visual Basic to program a software which inputs shoppers’ non-spatial and spatial data into a Microsoft Access database.

The data analysis: OLAP and SOLAP analysis:
The survey provided a large number of non-spatial and spatial data which needed to be analysed. 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) for the spatial data.
Processing (SOLAP) to analyse the collected spatial data (Bédard and 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 dimension age group), each level having a different granularity 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 analyse 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 analysis 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 behavior). We can, for instance, determine which variables are more important for our model (the variable which influences enormously the shopping behavior).

- **OLAP analysis**: Using an OLAP analysis we can analyse 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 analysed results about all the dimensions of our model of the Shopper agent. We can further analyse 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. Fig 3.a presents the entrance doors of the first floor of the Square One shopping mall and Fig 3.b presents the graphical representation of the distribution of the participants on the dimension Floor Entrance Door in the shopping mall. We can see in Fig 3.b that the most frequented mall’s doors are Door 0 (97 shoppers) and Door 10 (125 shoppers). The multidimensionality aspect of the OLAP-SOLAP can tell us that among these 125 shoppers who enter by the door 10 we have 65 females and 60 males. Among these females we can find that 31 have age between 13 and 25 years, 26 have an age between 26 and 50 years and 8 have are aged over than 51 years. The OLAP-SOLAP technique has the advantage to present these results rapidly (on line) and easily in a manner which is close to the mental model of its users.

![Diagram of entrance doors of the first floor (Square One Mall)](image-url)

*Fig. 3.a: The entrance doors of the first floor (Square One Mall)*
In this section we presented the first steps of our approach which aimed to prepare the multiagent geosimulation models, to collect empiric data in order to feed these models and to analyse 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.

4. Running the simulation: the MallMAGS prototype

Using the MAGS platform we developed a multiagent geosimulation prototype which simulates customers’ shopping behavior in a mall. For each simulation we must prepare a simulation scenario using the \textit{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

Fig. 3b: The distribution on the Floor Entrance Door dimension
passive and active agents in the simulation (shopper, stores, kiosks, etc.) and the behavior of the active agents in the simulation (shoppers). The behavior 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 easiness of the use of this module 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 Fig. 4.a and Fig. 4.b 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 (Section 3.3). It enters by a particular door and starts the shopping trip. Based on its position in the mall, on its knowledge (memorization process) and on what it perceives in the mall (perception process), the agent chooses the next store or kiosk to visit (decision making process).
When it chooses a store or kiosk, it 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 it 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
accomplishes this behavior continually until it visits all the stores or kiosks remaining in its shopping list or until it has not time left for the shopping trip. If the shopper agent has still time for shopping and some stores or kiosks of its list are in locations unknown by the agent, it starts to explore the shopping mall searching these stores or kiosks. When the shopper agent reaches the maximum time allowed to the shopping trip, it 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 its 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, odor or lighting) is directed by its habits and preferences. For example, if the Shopper agent likes cars and it passes in front of a car exhibition, it 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 odor. If the shopper agent is in the exploration mode and likes the music or the lighting or the odor broadcasted by these special agents, the shopper agent can move toward them and possibly enter the associated store.

During its 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 geosimulation prototype the priorities of the activities of the shopping behavior are defined based on Maslow’s hierarchy of needs (Maslow 1970).

The current shopper agent’s models and behaviors 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 broadcasted by the store agent to shopper agents moving in an
area located in the store vicinity. We could then easily develop agents’ behaviors which will enable them to react to shopping opportunities in relation to their needs and preferences.

5. Use the geosimulation for efficient decision-making

In this section we present the two last steps that enable managers to analyse the geosimulation results and to explore the impact on changing stores’ locations in the virtual mall.

5.1. Collect and analyse the data generated by the geosimulation

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

- The simulation output data is 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 analysed after the simulation.

- The data analysis of the geosimulation 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 Observers agents in order to carry out multidimensional non-spatial and spatial analyses using an OLAP (On Line analytical Processing) and SOLAP (Spatial On Line analytical Processing) approach.

In the example of the shopping behavior simulation, the role of an observer agent is to collect data from the shopper agents which come nearby (in the observer agent’s perception range) and to store this data in files or databases. When the simulation execution ends, we can analyse 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 analyse these results. For the shopping behavior 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 have been 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’ behavior 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 analyses 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 analyse the simulation output. This is very important for two reasons: (1) the analysis results can be used rapidly and easily by users; (2) using the same technique to analyse input and output simulation data gives us the opportunity to compare several simulation scenarios using output data which have the same structure.

5.2. Experiment different scenarios using the geosimulation

The last step of our approach is to exploit the results of the multiagent geosimulations 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 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, 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 analyse them. By comparing these results he can make informed decisions about the impact of spatial changes in the mall.

To illustrate the use of the Shopping behavior geosimulation tool we used 2 simulation scenarios. In the first scenario we launch a simulation with a given configuration of the shopping mall (Fig. 5.a) 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 (Fig. 5.b). 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 (Fig. 6.a). However, corridor Y is more frequented in scenario 2 than in scenario 1 (Fig. 6.b). In these figures the flow of the agents Shoppers which pass through a corridor is represented by a line which is attached to this corridor. The width and the color 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 color becomes darker. By 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 cloth stores. If the mall manager chooses the mall configuration of scenario 2, he may think of renting the spaces along corridor Y to female cloth stores.

Deciding about stores’ locations in a mall is widely recognized as the most decisive factor in determine retail success or failure. As it has been noted over many years, 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 geosimulation 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 think that this solution can help mall managers to make decision about better stores’ locations and their effect on customers’ shopping behavior in their mall.

6. Limits and constraints of our work: A discussion

The geosimulation prototype presented in this paper simulates efficiently the individual shopping behavior in a mall. Unfortunately, this prototype presents some limitations which are presented in the following points:
- Lack of certain data, we were not able to collect data about groups of shoppers. Consequently, we were not able to simulate the shopping behavior of groups in a mall. Since the social aspect of the shopping behavior is important, we will develop a new questionnaire in order to get new data to simulate the behavior of groups of shoppers and to introduce it in the next version of the prototype.
- The prototype presented in this paper simulates the shopping behavior of customers visiting one floor of the mall. Simulating the shopping behavior on several floors is one will be done using the next version of the prototype.
- Shopper agents are equipped with several spatial and cognitive capabilities (perception, memorization, etc.). The memorization process prepares the ground for the development of a learning capability for agents. This is another area of investigation that we want to explore in the coming years.

7. Conclusion

Our literature review showed that mall managers can currently use two techniques to assess the impact of stores’ location changes on customers’ behavior:
(1) Surveys and questionnaires: They can collect data about customers and analyze it to try to understand how customers use the mall. One limit of this technique is the fact that it is not very useful to anticipate the reactions of customers to future changes in the mall configuration. Another limit is the difficulty to analyze spatial data using such a technique.

(2) 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, make them not very useful to anticipate the reactions of customers to future changes in the mall configuration.

In this paper we presented a generic approach and a geosimulation tool to simulate and analyze customers’ shopping behaviors in a mall. We also mentioned how mall managers can use this tool in order to make informed decisions about their mall configuration. What distinguishes our approach and geosimulation tool from the techniques mentioned above is the fact that mall managers can use them to try various mall configurations by changing the locations of certain stores in the virtual mall and analyze 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 behavior in a mall. This application was developed by (Dijkstra, 2002) and aimed to simulate the shopping behavior in a virtual environment represent by cellular automata. What distinguishes our simulation from Dijkstra’s work and from other multiagent simulations of human behaviors in a geographic environment is that: (1) in our simulation the environment is represented by a georeferenced data while in Dijkstra’s application (the Amanda System) (2002) the environment is represented by cellular automata, which constrains a lot 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’s simulation; and (3) our simulation generates output data in a form which facilitates the comparison of
different simulation scenarios while Dijkstra’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 analysed using OLAP/SOLAP tools.

Several new development and research directions are still open. In Section 4, we already mentioned some possible improvements of our simulation by associating products to stores: this would enable the simulation of more sophisticated shopper agents’ behaviors, 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 behaviors of the virtual shopper population of Ontario and of Quebec and examine if some differences would appear in the agents’ movement patterns if we used the Quebec virtual shopper population in the virtual Square One Mall.

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