RETAIL STORES MODELING: COMPARISON BETWEEN SIMULATION AND VIRTUAL REALITY APPROACHES

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ABSTRACT
In large scale retail supply chain, stores are quite complex systems involving different actors (i.e. managers, customers, distribution centers, suppliers, etc.), each one with specific needs and problems (i.e. store layout, products assortment and inventory management, shelves display policies, marketing and promotional activities, customers' satisfaction, etc.). In this research work the authors describe the development of two architectures for virtual retail stores based on the integration of simulation and three-dimensional virtual environments. The first architecture simulates the evolution over the time of a real store and provides the user with different functionalities (including a 3D visualization). The second architecture, based on the X3D standard (an evolution of VRML), prevalently supports the online commerce in a 3D virtual environment. The paper presents and compares both the architectures, highlighting the main functionalities, differences, advantages, disadvantages and potentialities.

Keywords: logistics and retail stores, simulation, modeling, 3D virtual environments.

1. INTRODUCTION

Retail stores are part of a complex supply chain (large scale retail supply chain) that includes, among others, stores, customers, distribution centers, suppliers, production plants, retail companies headquarters (that usually suggest economic and operative objectives and strategic policies) and other external actors such as banks, insurance companies, State, etc. Therefore retail stores decisions are usually addressed to achieve the business results (decided at headquarters level) respecting needs and requirements of different stakeholders.

A retail store managers deals with different problems that usually require quick decision processes. Among others, the most important are personnel management, marketing management and promotional activities, items inventory management, space allocation on the shelves (items display), e-commerce and virtual stores.

Let us consider the human resources management: alienation and low performances due to repetitive jobs as well as workers turnaround among different stores departments strongly affect retail store efficiency. Store managers usually apply tasks enrichment and enlargement policies in order to obtain major workers (and customers) satisfaction enhancing, at the same time, working conditions. Store workload planning, refurbishment frequencies and refurbishment quantities for each item depend on store departments conditions. Furthermore, some store sectors are more critical than others in terms of frequency, quantity and items display (i.e. the general goods sector involves a huge number of items types and usually requires a greater number of workers). Workload planning requires accurate and real time overviews of the store conditions and the use of specific policies to optimize workers' assignment to store departments. In this case expected results are: down time elimination and higher customers' satisfaction levels.

Consider now marketing activities and decisions; among others, the following elements play a critical role for increasing customers' satisfaction: kindness and assistance within the store, parking facilities comfort, store layout, attractiveness, promotions and discounts, products quality, opening hours and products assortment (Ortega B. 2000; Piotrowski C. and Rogers E. A. 1998).

Retails store managers also deal, every day, with inventory management problems: they have to set correctly the space on the shelves for each item type and select the re-order policies to be used. The inventory management policy should monitor the following parameters: the cost for sale losses (total and for each department), the storage costs, the costs for shelves refurbishment as well as the revenues from effective sales.

Difficulties and problems also come up during data collection phase for store performance analysis. It is required to collect data about customers number, revenues from effective sales, loss sales, quantities ordered to suppliers, etc. Each store department is considered as a cost center with specific costs, such as employees, maintenance, hygiene and cleaning service. A correct data collection allows to calculate the economic report for the entire retail store as well as for each department. Moreover it is possible to analyze data for department-period, sector-period, family-period, product-period and make different statistic analysis to be used for improving promotional and marketing policies, work planning, logistics activities and, in general, the retail store management.

One of the most recently business for a retail store is the e-commerce. On line retail stores allows customers to interact, order and buy or simply have information about goods. This new form of business involves new critical issues for retail stores, such as information and service quality (Ahn and Ryu, 2007), design of the website, shopping navigation functionalities, (Liang and Lai, 2002), security and privacy of online transactions (Liao and Cheung, 2001). Note that a Modeling & Simulation (M&S) based approach is a powerful methodology for supporting the decision process within retail stores. Different tools based on M&S have been developed to support managers in solving and taking decisions about human resources management, logistic problems, inventory management, e-commerce, etc.

In this research work the authors present and describe the development of two virtual retail stores based on the integration of Simulation and three-dimensional virtual environments. The authors propose two different architectures for recreating a virtual store. The first architecture is capable of simulating the evolution over the time of a real store and provides the user with different functionalities (above all devoted to support the store decision process). The second architecture is based on the X3D standard (based on XML and developed as evolution of VRML) and its functionalities prevalently support the online commerce. The main goal of the paper is to compare both the architectures, highlighting main functionalities, differences, advantages, disadvantages and potentialities.

Before getting into details of the work, in the sequel a brief overview of the paper sections is presented. In Section 2 a state of the art about the use of M&S and Virtual Environment in retail stores design and management is presented. Section 3 proposes the first architecture called *Virtual Dynamic Store* (VDS). Section 4 presents and describes the second architecture called *Shopping Online CReated by Advances Three-dimensional Environments and Simulation* (SOCRATES). Section 5 compares the two virtual stores architectures and finally the last section summarizes conclusions and research activities still ongoing.

2. MODELING & SIMULATION AS SUPPORT TOOL IN THE LARGE SCALE RETAIL SECTOR

As mentioned into the introduction a retail store manager every day has to take in short time critical decisions that strongly affect the store efficiency. The authors believe that a Modeling & Simulation (M&S) based approach can effectively support retail stores design and management.

Consider human resources management within retail stores. Bruzzone et al. (2008) propose an innovative integrated works island model for retail stores: the model uses simulation for evaluating workload and number of workers required in each island (store sector) and it has been implemented in 14 retail stores of a leader brand in the Italian retail business.

Simulation tools are also used for supporting strategic decisions, such as the evaluation of different store management and logistics and distribution alternatives (Bruzzone et al. 2000).

Nielsen (1993) say that effective marketing strategies positively affect customers' satisfaction. Usually elements such as stochastic customers' behavior, inadequate data sources and uncertain market response make marketing strategies planning an exceeding difficult task. Also in this case M&S, by recreating the stochastic evolution of the market is an effective support for marketing strategies development and testing (some application examples of M&S for supporting marketing strategies are reported in Arinze and Burton, 1992; Bruzzone et al., 2000-c).

Moreover M&S is extensively used in retail stores for items inventory management: De Sensi et al. (2008) use M&S for testing different inventory control policies under demand and lead time constraints; Al-Rifai and Rossetti (2007) use M&S for calculating optimal inventory levels while Bertazza et al. (2005) calculates inventory levels that minimize the total costs in a vendor managed inventory system. Additional research works can be found in Chen and Krass (2001), Giannoccaro and Pontrandolfo (2002) Lee and Billington (1993) Lee and Wu (2006).

One of the most recent application fields for M&S (combined with three-dimensional visualization and environments) is the e-commerce (Briano et al., 2004). The main idea is to use simulation for supporting store management and a virtual three dimensional environment for supporting both the store design and management and provide the user with an advanced and interactive online shopping experience (virtual stores). In this last case a virtual store has to recreate exactly the sensation to be inside a real store (Briano et al., 2004; Gong et al., 2004).

In this research work two different architectures to recreating a virtual retail store are presented: the first one is based on the integration of different software tools (including 3D real time modeling tools, virtual environments and Visual C++) and the second one developed by using X3D standard, a description language of 3D scenes. X3D is an evolution of the VRML standard for web 3D scenes description.

The VRML standard has been extensively used in different domain of applications: from network resources management (Deri and Manikis, 1997) to reconstruction of 3D human organ in the medical field (Zheng-yang, 2005), from visualization of videoconference image sequences (Kompatsiaris and Strintzis, 2006), to design and implementation of virtual shopping systems (Lu et al., 2005).

In the next sections two architectures for recreating a virtual retail store (respectively called VDS and SOCRATES) are presented and described.

3. THE VIRTUAL DYNAMICS STORE

Some years ago, a prototype of a virtual retail store was developed by the authors (Briano et al., 2004). Recently the authors start to work again on the virtual store and implemented a fully functional version called VDS (*Virtual Dynamic Store*). The different steps to implement the VDS are as follows: creation of the 3D store layout, determination of the retail store areas involved in the simulation, definition, design and implementation of the virtual store functionalities (including analytical models combined with genetic algorithms for items inventory management and items optimal space allocation on the shelves). The VDS is able to recreate the evolution of the retail store over the time by using three different integrated modules: the Virtual Environment, the store Geometric Model and the Dynamic Processes Module. The Virtual Environment recreates the real environment that hosts the retail store; the Geometric Model realistically represents the store layout (including building, shelves, warehouses, items, etc.); the Dynamic Processes Module recreates all the interactions that evolve in the hosting environment and modify the store configuration as the time goes by (interactions generated by store workers and customers). Note that the Dynamic Process Module has been developed in Microsoft Visual C++. As a consequence, in order to guarantee a complete integration between the Dynamic Processes Module and the other two modules, the authors decided to use *Vega Prime* by *Presagis* for implementing the Virtual Environment (it provide a full interface with C++) and the modeling toolset *Creator* by *Presagis* (that can be easily interfaced with Vega Prime) for implementing the store Geometric Model.

The VDS recreates all the most important activities of a real retail store: (i) creation and arrangement of different items on the store shelves and items realistic representation; shelves emptying/filling process; (ii) inventory management and items optimal space allocation; (iii) store monitoring and controlling by real-time simulation; (iv) web virtual shop functionality for e-commerce.

To reproduce correctly the retail store activities, it was necessary to collect a set of information about shelves positions and dimensions, items positions and overall dimensions, area allocated on the shelves for each item type, items prices, items on hand inventory and consumption flows over the time.

Such information have been used for developing both the store Geometric Model and the Dynamic Processes Module. The Geometric Model includes 3D shelves (including classic shelves, refrigerators for fresh food, checks-out, etc.) with a dual graphic detail level. The implementation of a dual graphic detail level is strictly connected with the computational workload of the computer graphic card. A real store contains thousands of items that mean thousands of geometric models (i.e. a parallelepiped for each product). Each item geometric model should have minimum one texture mapped on it (in order to have a realistic item representation). Consequently, the computational workload could easily exceed the graphics card capabilities of a low cost hardware platform. To avoid computational overloads, high resolution and low resolution graphic detail levels have been implemented for all store sectors. The levels are activated (activating one excludes the other) according to whether the observer is close or far from the object being observed. In particular, each sector of the store Geometric Model has a dual graphic detail level in order to lighten the computational workload of the graphic card. Bounding boxes define the portions of space – within which the shelves of interest are located – whose confine, if crossed by the observer from inside to outside, leads to a switch from one texture for each item to a single texture for the entire shelf being observed.

The DPM recreates the items geometric models, disposes the items on the shelves and executes the emptying/filling process. The DPM recreates the shelves emptying process during the store business hours: by considering items sale rates, the DPM calculates dynamic stochastic sale flows based on daily/hourly rates. Analogously the DPM manages, outside the business hours, the shelves refurbishment process by considering the inventory costs, profits and optimal space allocation for each item. The items inventory management model and the approach proposed for items optimal space allocation are respectively based on Order-Point, Order-Up-to-Level (s, S) inventory policy and genetic algorithms.

Concerning the store controlling by real time simulation, the DPM has a specific function that modifies the number of items on the shelves. As soon as an item passes through the store checkouts (in the real store), the DPM updates the VDS animation. Therefore, the VDS is capable of monitoring, real time, the store giving an overview of the items inventory on the shelves by using a three-dimensional visualization.

Another additional aspect managed by the DPM regards the virtual shop for e-commerce: as soon as the customer (i.e. a person that use the virtual shop through internet) click on a specific item, the DPM creates a message box reporting all the information regarding the item: brand, price, best before dates, ingredients, etc. Figure 1 shows a panoramic view of the VDS, figure 2 shows the shelves emptying process managed by the DPM.

Figure 1: panoramic view of the virtual retail store

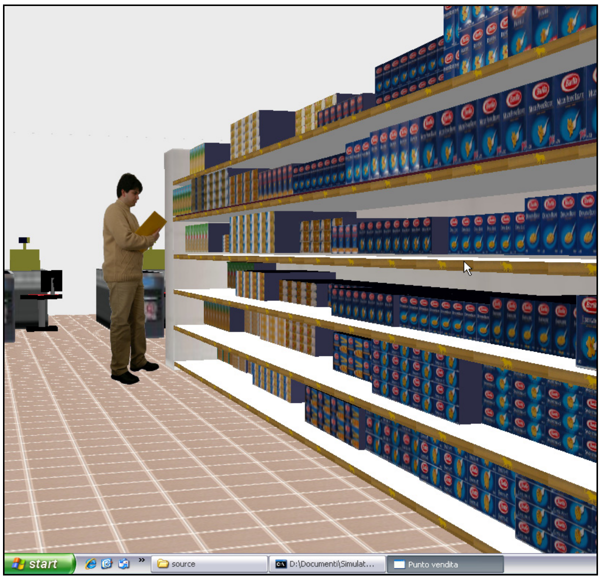

Figure 2: Shelves emptying process managed by the DPM

The DPM also implements two different types of movements: the first one reproduces the customers' movement among the shelves (the movement is controlled by an external input, for instance the keyboard), the second one is similar to the flight of a bird to have a general overview of the retail store.

SHOPPING ON LINE CREATED BY ADVANCED THREE-DIMENSIONAL ENVIRONMENT AND SIMULATION

The second architecture proposed by authors for developing a virtual retail store is based on X3D standard and it is called SOCRATES (*Shopping On Line CReated by Advanced Three-dimensional Environment and Simulation*).

SOCRATES is an useful application to support the e-commerce, indeed it is a virtual retail store in which users can navigate, interact with objects and eventually buy the products.

As for the VDS, the first step is the development of the retail store 3D environment. Data about store layout dimensions, departments number and dimensions, shelves number and dimensions, items position and overall dimensions, items position on the shelves, space allocated for each item type on the shelves, items prices, items general information (i.e. items description, ingredients, best before date, etc) have been collected. Figure 3 shows some information about the store layout, shelves dimensions and disposition.

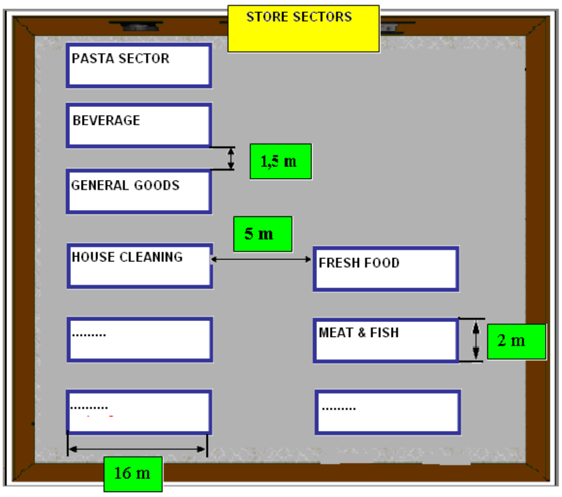

Figure 3: Departments layout and dimensions

The SOCRATES geometric model has been developed by using SketchUp, a Google tool to model and develop 3D environment. The 3D geometric models include the building that host the retail store, shelves, refrigerators, check outs, etc.. As last part of the geometric model development, items have been positioned on the shelves as shown in figure 4.

Figure 4: Virtual shelves with products

The second step after the SOCRATES geometric model creation, was to set-up SOCRATES interactivity. The store geometric model is exported in VRML format and successively edited by using X3D Vitality Studio editor files. X3D allows users to create the interactivity with the virtual retail store, to position cameras (a cameras positioned on customer overhead represents the starting point for the navigation) and to set light and shadow.

In particular the interactivity is created by using special X3D structures (Anchor node) that allow to link each product with a pop-up web page reporting all the information about the product and the possibility to add the product to a cart. The pop-up web page is activated simply by clicking on the item as shown in figure 5 and 6.

Figure 5: Click on product

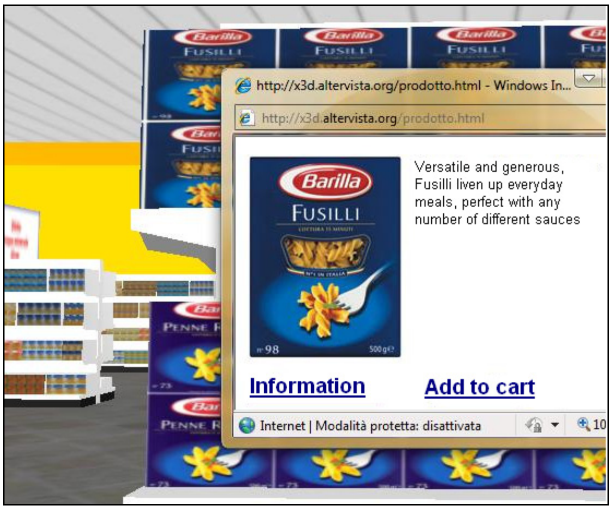

Figure 6: Information Page

The last functionality implemented in SOCRATES is the movement through the virtual environment. To this end the authors use BS Contact (by Bitmanagement Software), a player and a browser web plug-in that allows web visualization of real-time Virtual Reality. BS Contact provides the user with the following functionalities:

- Navigation speed: it possible to select five different navigation speeds, from very slow to very fast;
- Movement in the virtual environment: it is possible to walk, fly, examine and jump in the scene;
- Graphic: this option allow user to set some aspects of the visualization, (i.e. lights position);
- Look my Avatar: if user selects this option, an avatar is visualized within the virtual environment. The user can control avatar movements by using external inputs (i.e. keyboard, mouse).

The software also provides additional functionalities such as volume control, full screen modality, 3D scene saving, etc.

Figure 7 shows the navigation in the virtual environment without avatar, while figure 8 shows the navigation with avatar functionality activated.

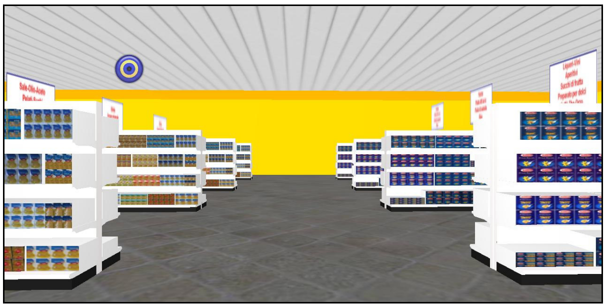
Figure 7: Navigation even avatar

Figure 8: Navigation with avatar

An interesting aspect of SOCRATES is the frame recreation. In particular to recreate a frame in X3D, the following steps are required:

- Frame development. To produce a frame the following elements are necessary: a 3D scene and objects, lights and cameras positioned on the scene;
- Imagine visualization;
- External input or simulation;
- Scene modification and camera repositioning;

It is a circular process, repeated about 16 times per second.

The interactivity in X3D it is implemented by using sensor nodes, that acquire users' input and provide appropriate responses (through events):

- Touch Sensor: supervise the actions of pointing device (PD);
- Plane Sensor: convert PD movement on XP plane into objects movement on 3D scene;
- CylinderSensor and SphereSensor: convert PD movement on XP plane to rotate objects in 3D scene;
- KeySensor: detect input by keyboard.

Therefore, the sensors detect different users' actions and produce events, that are send to others nodes. The PD (Pointing Device) in the case of SOCRATES is the mouse, but in general it could be a touch screen, a joystick, a game pad, etc.

The nodes allow to implement complex functions, such as store information, complex animation, geometries generate by algorithms. In this cases Script Nodes have to be used; for such nodes the behavior can be modeled by using java code. The script node contains different script function (java method). The function takes the input (the first argument of the function) from an event, then executes an algorithm and returns new events that modify the scene.

In SOCRATES the script nodes have been used to link the different goods to specific web page that report all the information about the product. Then, the customer can navigate within SOCRATES and by clicking on the item with the PD, can activate different events (information, add to cart, etc.).

4. VDS AND SOCRATES COMPARISON

The previous sections provide the user with a description of the VDS and SOCRATES, two different architectures developed by authors for implementing a virtual retail store. In the present section, the two architectures are compared and analyzed to point out advantages and disadvantages.

The first difference between the VDS and SOCRATES is in their scope. In effect, even if both architectures provide the user with a three-dimensional visualization of the retail store layout, the VDS has to be regarded as a decision support tool for retail store design and management, while SOCRATES is more devoted to shopping on-line and e-commerce functionalities.

The VDS simulator (implemented within the DPM) recreates the main activities of the retail store: shelves emptying/filling process, shelves refurbishment, items optimal space allocation on the shelves, real time store controlling for store departments workload planning. Moreover the DPM implements specific inventory control policies and genetic algorithms for optimal space allocation of items on the shelves. The VDS can also be used as support tool for store layout optimization: in fact the 3D visualization allows user to test and analyze different store layout (from grid layout to free form layout.

The second architecture, SOCRATES, recreates with high accuracy the retail store environment, the layout, the shelves disposition, the products display and allows users to interact with the 3D environment, to select products and obtain information or to buy products. Then SOCRATES is mostly devoted to e-commerce.

To provide SOCRATES with additional potentials in terms of web application, the authors decided to develop SOCRATES by using VRML language. The VRML is a standard language for internet applications; VRML files are machine readable independently from the platform (each user can visualize SOCRATES without technical problems). On the contrary, the VDS can be put on-line (i.e. by a remote desktop) but latency problems can easily occur.

However both VDS and SOCRATES present some disadvantages. The VDS scalability could be a problem in the case of very large number of items (low performances on low-cost hardware platforms). Some SOCRATES disadvantages are related to get used to interact with a virtual environment by using 2D tools (mouse or keyboard). Another problem could be the time for downloading the VRML file. A single VRML file contains the description of the entire 3D scene, then if the scene is complex the dimension file will grows as well as the downloading time (the VDS presents the same problems if the user has to download the VDS databases before using it). In both cases care must be taken when implementing the 3D geometric models (i.e. by using different graphic detail levels).

5. CONCLUSIONS

In the present research work two different architecture for virtual retail store have been presented. In the first part of the paper, the most important retail store problems have been described and then a state of the art about Modeling and Simulation and Virtual Environment tools to solve these problems have been presented.

In the second part of the paper the two architectures, respectively called VDS and SOCRATES have been presented and described. VDS is an advanced tool for supporting retail store design and management. SOCRATES, based on VRML standard successively edited by using X3D standard, is mostly devoted to support e-commerce. Some advantages and disadvantages of both architectures are finally presented and discussed.

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