A MODIFIED BEER GAME FOR SIMULATION AND OPTIMIZATION TEACHING

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ABSTRACT

A key aspect that should be considered when planning a simulation course is to develop students' skills for dealing with real cases such as conceptual modelling or validation. However, although desirable, providing real case studies is not always possible. To have a real system available for students to visit and analyze might not be possible due to time or budget constraints. In this circumstances, educational games provide with a suitable means for facing students with realistic case studies. This paper presents a modified version of the classic "Beer Game" developed by the MIT adapted for discrete events simulation (DES) and optimization teaching. The game is played using four computer applications connected through a local area network (LAN). Some aspects of a supply chain that are simplified in the original game are introduced in the game in order to provide with a complex case study in which M&S methodologies application is necessary. Students of a master in industrial engineering participated in this teaching activity achieving in general good results after designing decision making rules by means of simulation.

Keywords: simulation, education, logistics, supply chain, optimization.

1. INTRODUCTION AND PREVIOUS WORKS

Modelling and Simulation (M&S) is nowadays a popular tool which finds many applications in various fields, from being a general purpose research methodology (Powers et al., 2012) to a tool for decision making and planning (Cimino et al., 2010). Simulation courses can be found in various educational levels from undergraduate to doctorate studies. It has also been employed as a tool for education, providing a way to design realistic case studies within a controlled environment. One remarkable area of application is operations management since simulation can demonstrate the complexity of a real world scenario (Cleophas, 2012; Costantino et al., 2012).

Although M&S is generally viewed as an accurate and powerful analytic methodology which provides with a deep insight into a system and raises high expectations, misusing it can lead to project failure, economic loses and a loose of confidence on it as a tool. Thus some authors have analyzed possible causes of failure in simulation practice (McHaney et al., 2002) and provided tips for successful simulation practice (Sturrock, 2011; Clark & Krahl, 2011; Sharda & Bury, 2011; Sadowski, 2007; Schmeiser, 2001). (Robinson, 2002) provides an interesting quality management approach to simulation projects. In this paper, he groups quality features in three categories:

- Content quality, referred to technical aspects of the model and whether it has been properly verified and validated.
- Process quality, referred to how the simulation project is carried out, customer's expectations are fulfilled and there is a fluid communication between the modelers and the customer.
- Results quality, referred to whether simulation results are actually implemented and lead to improvements that can be perceived by the customer.

Although we are not aware of any rigorous study that provides statistics on how often simulation projects fail due to those reasons, (Robinson, 2002) suggests that many projects may fail due to issues from the "process" or "results" category, more than methodological aspects. Many introductory papers (Clark & Krahl, 2011; Shannon, 1998) or simulation textbooks (Banks et al., 2010; Sokolowski & Banks, 2010; Robinson, 2004) remark the importance of project planning, managing the information exchange with process experts, raising reasonable expectations and successful implementation of the proposed measures.

In this regard, simulation teaching must create awareness about possible causes of failure and explain students how to face these problems in a real project. A mistake that must be avoided is to center the course exclusively in coding issues. Coding should ideally represent only a 20% of the simulation time according to the 40-20-40 rule enounced by (Shannon, 1998) that stands for a 40% of effort in data acquisition and conceptual modelling, 20% coding and 40% validation, experimentation and implementation. However, students are often new to simulation software and the time devoted to model implementation teaching can easily overcome the time allotted for other simulation issues.

The educational game presented in this paper intends to provide with a case study that focuses on the following simulation issues:

- Conceptual modelling.
- Model coding and verification.
- Experimentation and optimization.
- Results implementation.
- Teamwork.

The game rules are described in section 2.

2. GAME DESCRIPTION

2.1. Rules

The game is based on the classical beer developed by the MIT (Sterman, 1984; Hammond, 1994). This game is intended to demonstrate the bullwhip effect in supply chains and how coordination among the different echelons can help to improve overall profits. The game has become quite popular because it is easy to setup and fast to play (only 45min) but also provides a deep insight in supply chain dynamics. It is so powerful indeed for reproducing the bullwhip effect that it has led to numerous research studies on its causes and its relation to human behavior and cognitive biases (Ancarani et al., 2013; Liu et al., 2009; Bendoly et al., 2006; Bendoly et al., 2009).

The original beer game has been modified and enriched for the purpose of this educational activity. The supply chain in this case is formed by four agents as seen on Figure 1. There is a manufacturer that produces items of a certain product. The manufacturer provides an intermediate warehouse which, in turn, distributes the items between two retailers that receive orders from a set of customers. The flow of orders in the chain is opposite to the flow of products and a rule is imposed so that no item can be sent if there is no supply order issued.

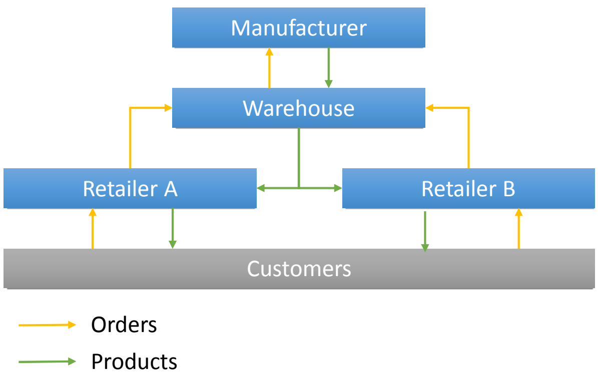

Figure 1. Supply chain diagram for the game.

Each agent has a buffer for storing items with a limited capacity and a list of pending orders received from the next echelon of the supply chain. The manufacturer also has a constrained production capacity that limits the number of items produced in each turn. Transport capacity among agents is constrained as well but there is no limit imposed on how many orders can be issued.

The decisions to be made by the agents are:

- The manufactures decides how many items to produce in each term. The pending orders are assumed to be served automatically as stock is available.
- The intermediate warehouse decides how many orders to place to the manufacturer and how many items to serve to retailers A and B.
- The retailers decide upon how many orders to place to the warehouse. Items are automatically served to the customers.

The game is run in 50 turns. A delay of one turn is assumed for transportation and order placement. Thus, for instance, an item served in turn 1 will be received in the next echelon of the supply chain in turn 2. An order issued in turn 1 by a retailer will be received by the warehouse in turn 2. Manufacture is assumed to require a delay of 1 turn with 85% probability and 2 turns with 15% probability. Demand from the final customers is generated randomly according to a certain stochastic process. The mean demand is varied in order to reproduce different possible market trends such as a growing or diminishing demand (Figure 2).

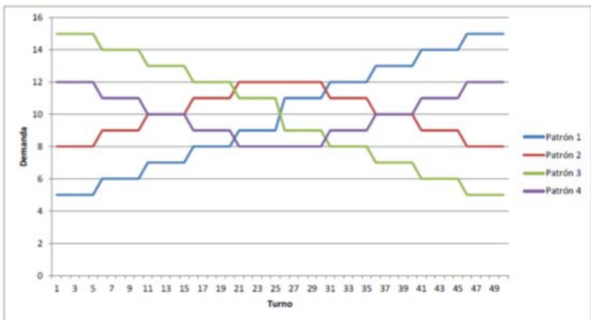

Figure 2. Demand patterns.

2.2. Setting

The game has been implemented in four applications developed in Visual Basic, each one for managing each one of the agents. The graphical user interface of each application displays the relevant information for each agent and allows for placing orders or serving customers. The applications are connected via sockets through a local area network using the TCP protocol.

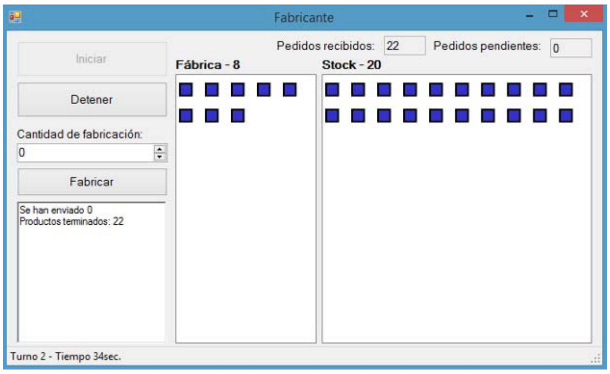

Figure 3. Manufacturer application.

Figure 3 shows the application for the manufacturer. It can decide how many items to produce at each turn. The stock of finished products is displayed as well as the work in progress. Information on the pending orders and incoming orders is provided as well.

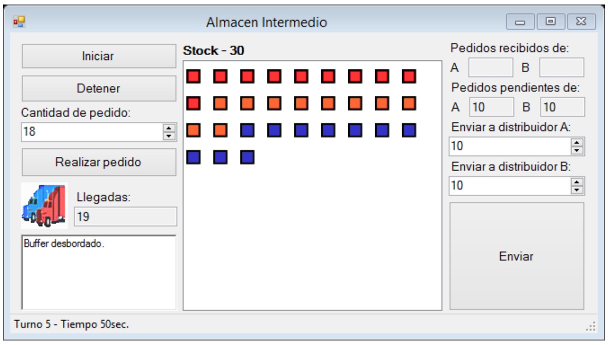

Figure 4. Intermediate warehouse application.

Figure 4 shows the application for the warehouse. It can decide how many items to request to the manufacturer and how many items to serve to each retailer. The stock of products is displayed as well as the number of items received from the manufacturer. Information on the pending orders and incoming orders is provided as well.

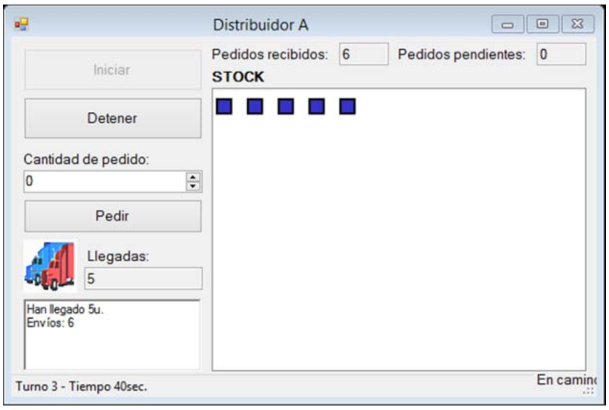

Figure 5. Retailer application.

Figure 5 shows the application for the retailer. It can decide how many items to request to warehouse only. The stock of products is displayed as well as the number of items received from the warehouse. Information on the pending orders and incoming orders is provided as well.

At each turn, a maximum of 60 seconds is allowed for decision making. Past this time the applications automatically move to the next turn.

2.3. Goal

The game goal is to minimize a cost function that depends on the stored items, the back orders and the manufacturer's capacity, transport capacity and buffers capacity. These costs are aggregated by the following equation:

$$
\begin{aligned}
COST = {} & 23MC + 5\cdot(B_M + B_W + B_{RA} + B_{RB}) \\
& + 12(T_{M\to W} + 2T_{W\to R}) \\
& + 50(\overline{S_M} + \overline{S_W} + \overline{S_{RA}} + \overline{S_{RB}}) + 2.4 \\
& \cdot 50(\overline{BO_M} + \overline{BO_W} + \overline{BO_{RA}} + \overline{BO_{RB}})
\end{aligned}
$$

Where MC stands for the capacity of the manufacturer, B the buffers, T the transporter, S the average stock and BO the average back orders. The subscript M refers to the manufacturer, W to the warehouse and RA and RB to the retailers A and B respectively.

3. TEACHING ACTIVITY

The teaching activity consists of developing a simulation model by teams of four and using it to design decision rules and minimize costs competing with other teams. The activity is carried out in the following steps:

1. Students, prior to been given information about the case, participate in a first gameplay in which they make their decisions intuitively. They are explained the basic rules of the game and the established constraints.
2. Project planning. Members of each team must identify the required activities to carry out the work and assign tasks to each member as well as estimate task durations and set up intermediate deadlines which are then supervised by the teachers.
3. The students develop a conceptual model of the game based on their experience and the information provided.
4. Model coding. Extendsim was used as the simulation software in this course, although other software could be employed.
5. The students must plan a set of simulation experiments in order to analyze the sensitivity of the cost function to the different variables that can be modified (such as the capacities) and the parameters used in the ordering policies adopted. These experiments are intended to guide a following optimization step in which they search for a good solution to the problem.

6. The students implement their solutions in a final gameplay and their results compared among teams.

For both the initial and the final gameplay it is required that the team members do not talk among themselves so that information cannot be shared.

Final scores are given taking into account various aspects:

- Technical quality of a report describing the conceptual model, implemented model, experimentation and optimization (50% of total mark).
- Presentation of the work carried out and the solutions implemented (30% of total mark).
- The ranking obtained in the final gameplay compared to the rest of the teams (20% of total mark).

3.1. ExtendSim model implementation.

Teams implemented their simulation model using ExtendSim. One unit of time was assumed to represent 1 turn of the game. Both backorders and products are represented by model items. The simulation advances in steps of 1 unit of time and the different numbers of products and backorders are sent from one echelon of the supply chain to another.

Each echelon of the supply chain is introduced in the model by the following elements:

- A queue of backorders.
- A queue of stocked products.
- A batch element that matches a backorder and a product when both are available and thus the product can be shipped to the next echelon.
- A create block that generates the orders to be sent to the next echelon.
- An activity with 1 unit of time delay that represents the transport to the next echelon.
- An activity with 1 unit of time delay that represents the delay when sending an order to the previous echelon.

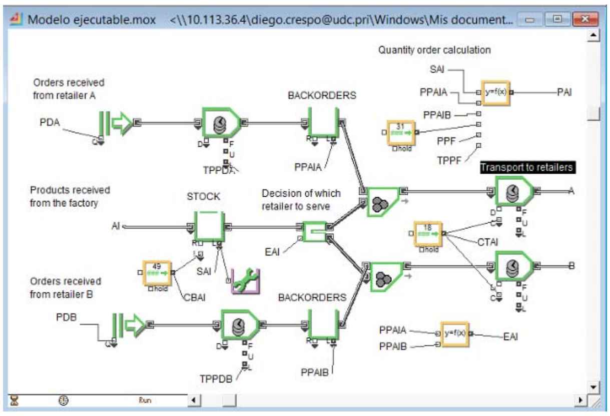

Figure 6. Screenshot of the simulation model for the intermediate wareshouse.

Equation blocks are used for calculating order quantities and controlling the flow of orders in the model.

4. RESULTS

The game was first applied in the course "Simulation and Optimization" for 3rd year students in the Industrial Engineering Master-Degree at University of A Coruña. The teaching activity weighted 50% of the student's final scores and the remaining 50% corresponded to the scores obtained in exams. 13 teams joined the activity at the beginning of the course although one team abandoned due the absence of some of its members.

The scores obtained in the initial gameplay can be seen in Figure 7. Not all the teams had time to complete the game in the given time, although completing the game in this session is not a necessary requirement. The goal is that students get familiar with the rules.

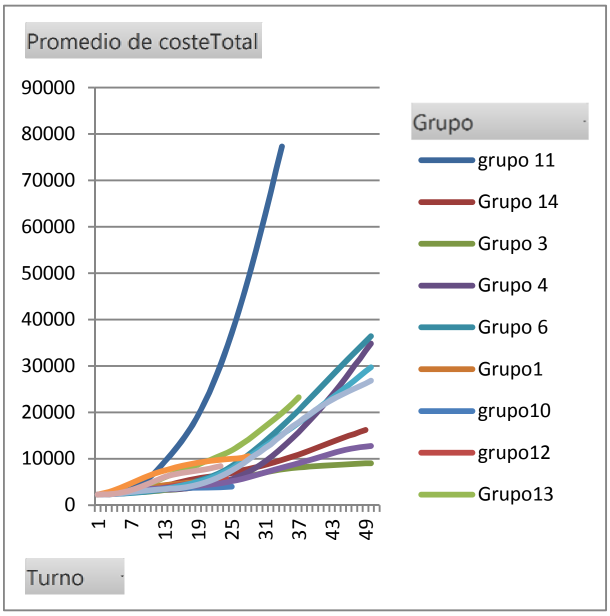

Figure 7. Scores in the initial gameplay as a function of turn number.

Students developed their simulation models and obtained results that were implemented in the final gameplay. In this last session all the demand patterns were the same for all the teams so that their results can be compared. Results are shown in Figure 8. The groups' scores were in general lower than in the first gameplay, although there were some exceptions. The lowest score in the first session was 9,047. In the last session, 7 groups out of 12 got a lower score, being 5,962 the best one.

This result shows that M&S helped in general to improve and optimize the supply chain performance. The improvement achieved by the teams from the first session to the final session also helped to reinforce the idea that simulation is a useful and practical tool for solving real problems. Students could assess the effect of implementing their simulation results.

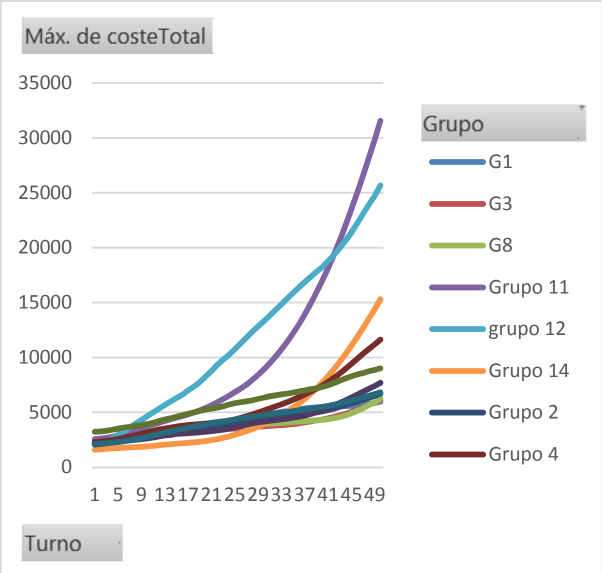

Figure 8. Scores in the final gameplay as a function of turn number.

5. CONCLUSION

The educational game described in this paper constitutes a tool for teaching the practical use of M&S technologies as well as optimization techniques. Students had to develop the conceptual model of a system that they had experienced, code it and design decision rules, conduct experiments to test them and optimize. Their results had to be put into practice in a final gameplay in which they were scored upon their results. Most teams achieved great improvements compared to the initial gameplay, thus successfully applying M&S technology in a realistic environment.

Teams competed intensely for achieving the highest score, being motivated by the score by ranking reward. Students' involvement in the activity was higher than expected and led in general to an enriching experience for both the teachers and the students.

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