Game Theory and Operations Research to Learn Performance Management Concepts in Industrial Engineering Courses

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Index Terms: Game Theory, Operations Research, Performance Management.

Abstract

Increasing competition within their areas of influence has changed organisational structure and pedagogical characteristics of educational institutions, which obligates them to adopt a choice of innovative approaches to improve performance of learning processes. In this context, simulation games have successfully amplified their use as an effective instrument to provide a pleasant environment for learning and education in Industrial Engineering Courses. A simulation game – which is presented in this paper – was developed as an operations research model and was used in an undergraduate performance and cost management course. This action has given to the students an interactive tool to provide a better understanding of the managerial aspects involved in a decision making process when a network of companies is established. In this paper it will be exposed how learning using simulation games differ from traditional learning approach, which involves, for instance, dynamics of interaction and time consumption by lecturers. Finally, some questions like 'in what ways did the games improved learning among the students?' and 'how was this measured?' are going to be discussed throughout the paper, together with an evaluation of the used game and ideas for further development.

1. Introduction to Simulation Games for Learning and Education

According to Ruohomäki [1], simulation games are expanding its use as a learning tool, including business and management games, which normally involves economics and production aspects. In this way, a simulation game, to be an effective instrument for learning, must include several related actions to provide a concrete experience, allowing observations and reflections to conduct towards abstract concepts and generalizations and to formulate hypotheses to be tested which, consecutively, lead to new experiences.

A simulation game, in order to be a useful tool in an educational environment, must be appropriately introduced to participants, with rules and directives clearly stated [1]. Also organisational and running aspects must be carefully defined because it would have an important role on participants' learning processes.

Following, to turn experience into learning, abstract conceptualisation must be carried out to integrate observations and to create various insights for future applications. Finally, as a key activity of an application of simulation games for learning, a debriefing must be realised to summarize the essential aspects of experiences conducted.

2. Applying Game Theory to Design Simulation Games

Game theory, used as a tool to evaluate situations in which the decisions of multiple agents affect each agent's payoff, could be applied to design simulation games for learning in industrial engineering. Hence, some basic concepts emerge from the game theory [2] [3], like non-cooperative versus cooperative games, existence of multiple equilibria or a unique equilibrium, games with perfect versus imperfect information, games based on static or dynamic characteristics, and games involving auctions and bidding [4].

According to Cachon and Netessine [5], non-cooperative static games are particularly relevant to experience industrial engineering aspects, mainly for supply chain management [6]. Under this circumstance, players need to choose strategies at the same time and are, thereafter, committed to their chosen strategies in a market involving synchronized movements. Also non-cooperative dynamic games are appropriate to simulate production management problems, particularly in situations involving sequential or simultaneous moves over multiple periods of time, which conducts to a design of games with stochastic characteristics.

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Another class of simulation games, the cooperative ones, has recently emerged in the market, almost certainly due to the predominance of bargaining and negotiations in supply chain relationships [5]. This kind of games, in your own way, tend to use a different approach to be designed, focusing on human aspects, including topics which take into account psychological and emotional behaviours of game participants [7].

3. Using Operations Research Models to Design Simulation Games

On the last years, increased availability in tools for business management has permitted modelling and evaluation of logistical processes [8]. The development of the simulation game was based on supply chain management principles [9], cost management concepts [10] [11] and operations research models. This game presents the simulation of cost management in supply chains [12], where rival companies attempt to maximize profits through optimisation of available resources.

In an industrial environment, managers are responsible for the planning and control of production systems to reach the objectives of the company. In that situation, operations research is a useful tool to solve such problems [13] [14], requiring some assumptions to be efficiently used: focus on decision-making aspects; process evaluation based on economical effectiveness criteria; use of a formal mathematical model; and dependence of computerized systems.

The first and the second statements are present in an industrial environment. The third one is also represented when objectives and constraints of the production system are defined in a mathematical form. In industry, the goal could be to produce a given quantity of products in a specific period of time and the constraints are the equipment and personnel available, the time to transform raw material in finished goods, the money to invest in inventories and quality improvement, and the available cash flow.

As mentioned above, to solve management problems using operations research techniques, it is often essential to engage computerized systems, since the logistics and the production planning and control in the industry increased their complexity [8]. For this reason, the representation of a manufacturing system in a computational model, as a simulation game [15], could be useful to allow the understanding of the managerial environment.

4. Network Configuration of the Simulation Game

The simulation game – see network configuration on Fig. 1 – was designed as a multi-player game where manufacturing companies compete to deliver different products to a single retailer.

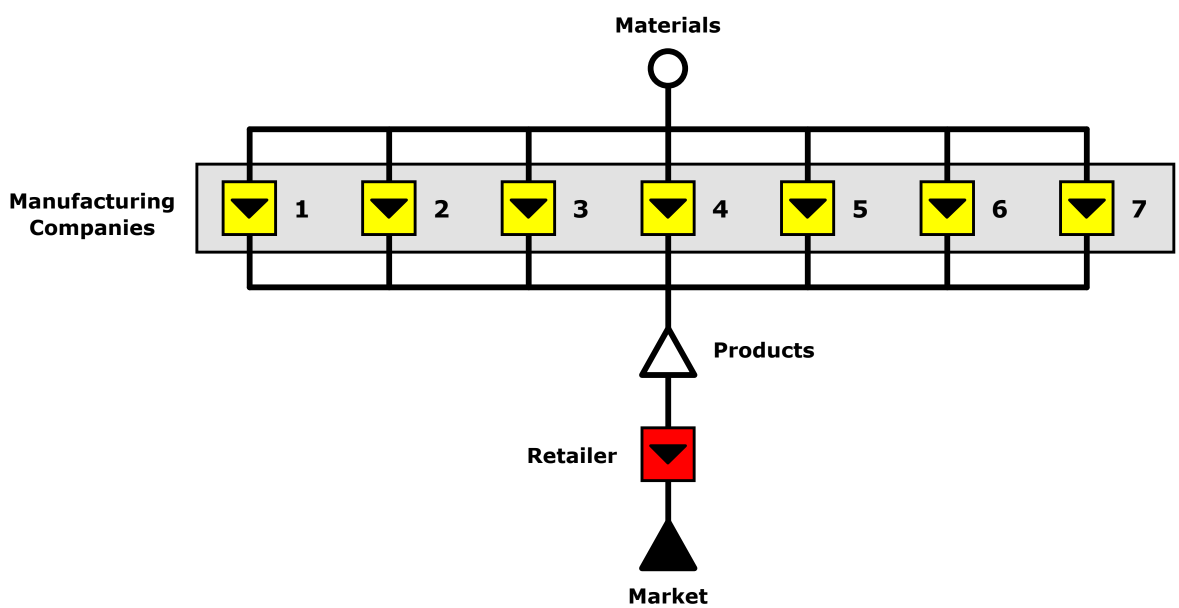
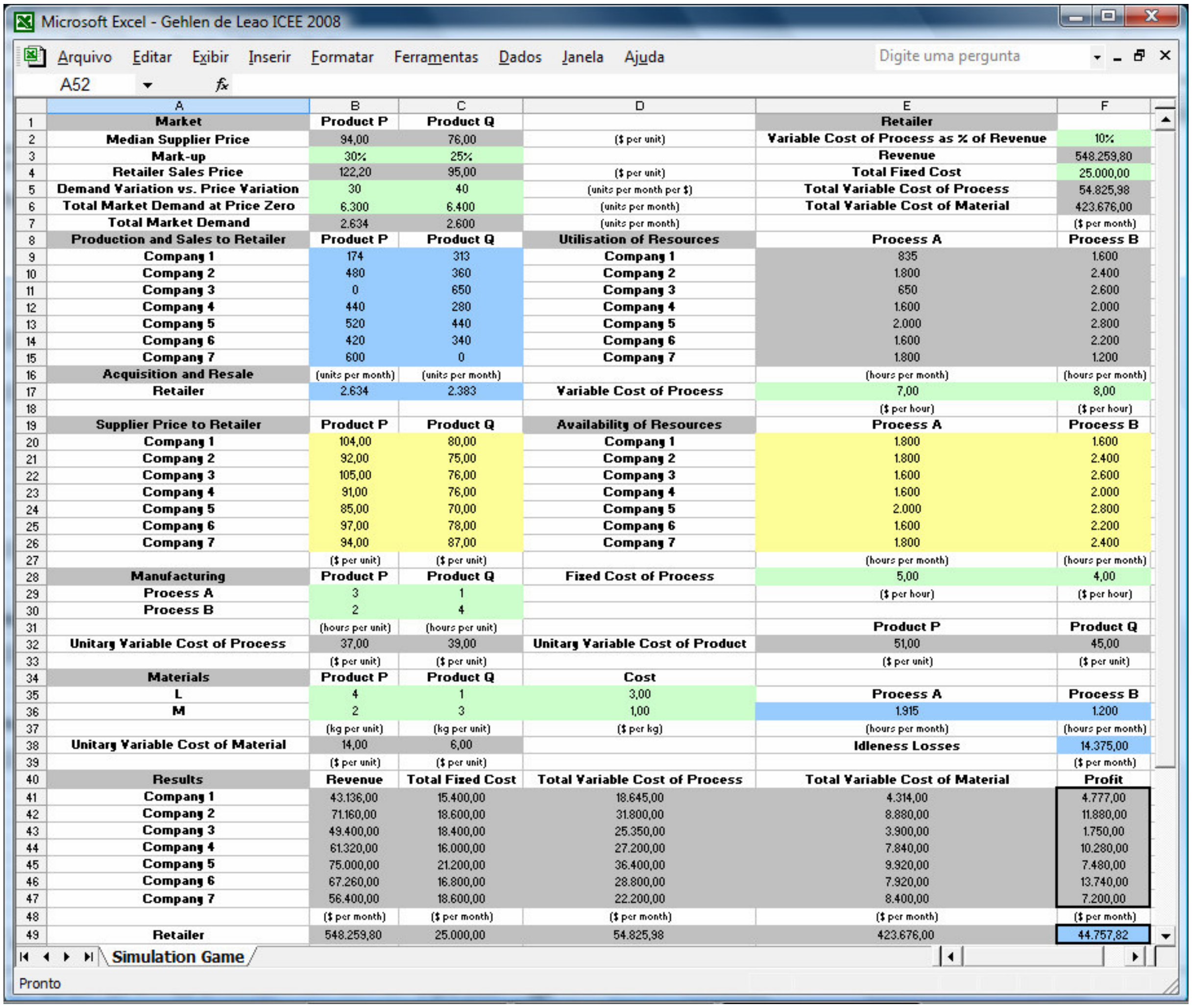


Fig. 1. Network Configuration of the Simulation Game.

The simulation game – see computer spreadsheet on Fig. 2 – was developed as an operations research model, comprising an objective function – maximisation of the retailer profit – and a set of constraints, which includes availability of manufacturing resources and total market demand for products.



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	A	B	C	D	E	F
1	Market	Product P	Product Q		Retailer	
2	Median Supplier Price	94,00	76,00	($ per unit)	Variable Cost of Process as % of Revenue	10%
3	Mark-up	30%	25%		Revenue	548.259,80
4	Retailer Sales Price	122,20	95,00	($ per unit)	Total Fixed Cost	25.000,00
5	Demand Variation vs. Price Variation	30	40	(units per month per $)	Total Variable Cost of Process	54.825,98
6	Total Market Demand at Price Zero	6.300	6.400	(units per month)	Total Variable Cost of Material	423.676,00
7	Total Market Demand	2.634	2.600	(units per month)		($ per month)
8	Production and Sales to Retailer	Product P	Product Q	Utilisation of Resources	Process A	Process B
9	Company 1	174	313	Company 1	835	1.600
10	Company 2	480	360	Company 2	1.800	2.400
11	Company 3	0	650	Company 3	650	2.600
12	Company 4	440	280	Company 4	1.600	2.000
13	Company 5	520	440	Company 5	2.000	2.800
14	Company 6	420	340	Company 6	1.600	2.200
15	Company 7	600	0	Company 7	1.800	1.200
16	Acquisition and Resale	(units per month)	(units per month)		(hours per month)	(hours per month)
17	Retailer	2.634	2.383	Variable Cost of Process	7,00	8,00
18					($ per hour)	($ per hour)
19	Supplier Price to Retailer	Product P	Product Q	Availability of Resources	Process A	Process B
20	Company 1	104,00	80,00	Company 1	1.800	1.600
21	Company 2	92,00	75,00	Company 2	1.800	2.400
22	Company 3	105,00	76,00	Company 3	1.600	2.600
23	Company 4	91,00	76,00	Company 4	1.600	2.000
24	Company 5	85,00	70,00	Company 5	2.000	2.800
25	Company 6	97,00	78,00	Company 6	1.600	2.200
26	Company 7	94,00	87,00	Company 7	1.800	2.400
27		($ per unit)	($ per unit)		(hours per month)	(hours per month)
28	Manufacturing	Product P	Product Q	Fixed Cost of Process	5,00	4,00
29	Process A	3	1		($ per hour)	($ per hour)
30	Process B	2	4			
31		(hours per unit)	(hours per unit)		Product P	Product Q
32	Unitary Variable Cost of Process	37,00	39,00	Unitary Variable Cost of Product	51,00	45,00
33		($ per unit)	($ per unit)		($ per unit)	($ per unit)
34	Materials	Product P	Product Q	Cost		
35	L	4	1	3,00	Process A	Process B
36	M	2	3	1,00	1.915	1.200
37		(kg per unit)	(kg per unit)	($ per kg)	(hours per month)	(hours per month)
38	Unitary Variable Cost of Material	14,00	6,00		Idleness Losses	14.375,00
39		($ per unit)	($ per unit)			($ per month)
40	Results	Revenue	Total Fixed Cost	Total Variable Cost of Process	Total Variable Cost of Material	Profit
41	Company 1	43.136,00	15.400,00	18.645,00	4.314,00	4.777,00
42	Company 2	71.160,00	18.600,00	31.800,00	8.880,00	11.880,00
43	Company 3	49.400,00	18.400,00	25.350,00	3.900,00	1.750,00
44	Company 4	61.320,00	16.000,00	27.200,00	7.840,00	10.280,00
45	Company 5	75.000,00	21.200,00	36.400,00	9.920,00	7.480,00
46	Company 6	67.260,00	16.800,00	28.800,00	7.920,00	13.740,00
47	Company 7	56.400,00	18.600,00	22.200,00	8.400,00	7.200,00
48		($ per month)	($ per month)	($ per month)	($ per month)	($ per month)
49	Retailer	548.259,80	25.000,00	54.825,98	423.676,00	44.757,82

Simulation Game

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Fig. 2. Computer Spreadsheet of the Simulation Game.

Products P and Q are produced on processes A and B – see configuration of the manufacturing processes on Fig. 3 –, which are identical in specification for each company, as shown on manufacturing processes data computer spreadsheet – see Fig. 4.

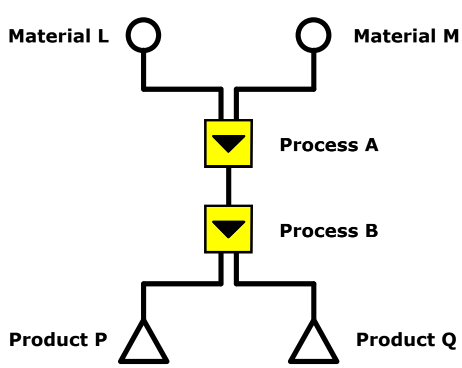
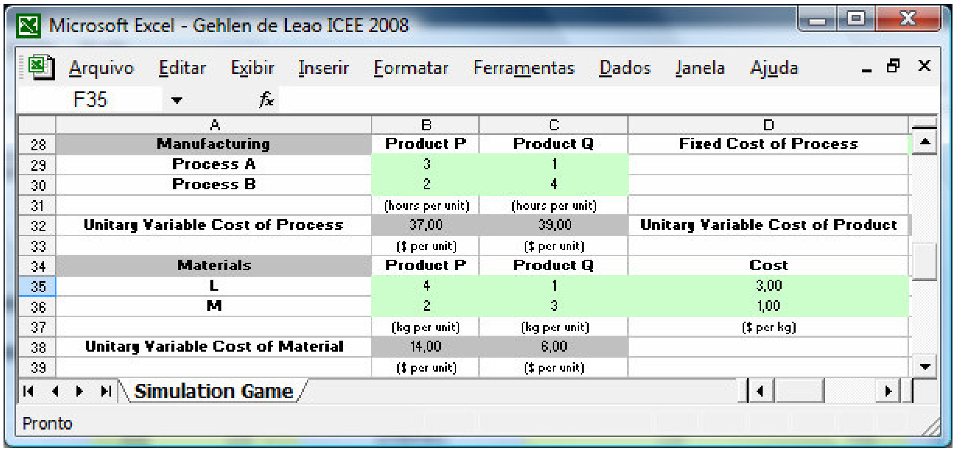


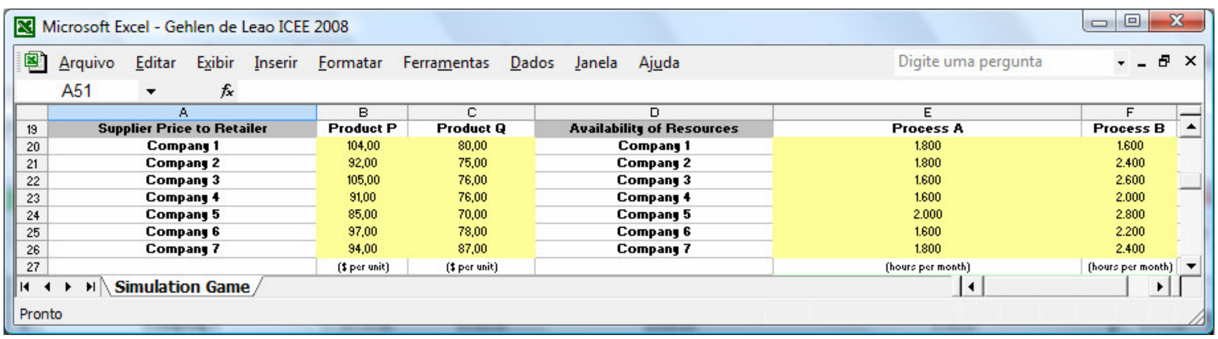
Fig. 3. Configuration of the Manufacturing Processes.



	A	B	C	D
28	Manufacturing	Product P	Product Q	Fixed Cost of Process
29	Process A	3	1	
30	Process B	2	4	
31		(hours per unit)	(hours per unit)	
32	Unitary Variable Cost of Process	37,00	39,00	Unitary Variable Cost of Product
33		($ per unit)	($ per unit)	
34	Materials	Product P	Product Q	Cost
35	L	4	1	3,00
36	M	2	3	1,00
37		(kg per unit)	(kg per unit)	($ per kg)
38	Unitary Variable Cost of Material	14,00	6,00	
39		($ per unit)	($ per unit)	

Fig. 4. Computer Spreadsheet: Manufacturing Processes Data.

The only parameters that the companies can control is the price of products and the availability of resources to execute manufacturing processes – see Fig. 5 –, which, in turn, could periodically fluctuate only in a smooth basis.



	A	B	C	D	E	F
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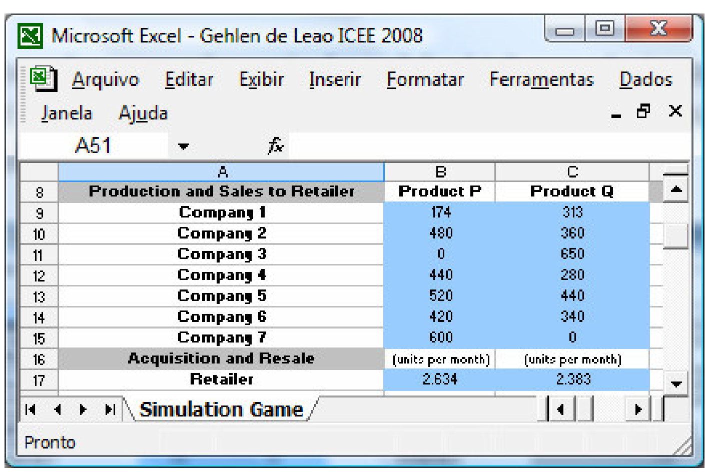
24	Company 5	85,00	70,00	Company 5	2.000	2.800
25	Company 6	97,00	78,00	Company 6	1.600	2.200
26	Company 7	94,00	87,00	Company 7	1.800	2.400
27		($ per unit)	($ per unit)		(hours per month)	(hours per month)

Fig. 5. Computer Spreadsheet: Supplier Price to Retailer and Availability of Resources.

4.1. Mathematical Model of the Simulation Game

The simulation game is based on a mathematical model which was designed by using, as decision variables, the quantity of each product – P and Q – to be manufactured by the companies – 1 through 7 – and to be sold to the retailer – see exhibit on Fig. 6.



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11	Company 3	0	650
12	Company 4	440	280
13	Company 5	520	440
14	Company 6	420	340
15	Company 7	600	0
16	Acquisition and Resale	(units per month)	(units per month)
17	Retailer	2.634	2.383

Fig. 6. Computer Spreadsheet: Suppliers Production and Sales – Decision Variables – and Retailer Acquisition and Resale.

As a demand constraint, it must be considered the total market demand for each product which, in turn, is dependent on the sales price calculated with a mark-up over the median supplier price.

For instance, as shown on Fig. 7, to a median supplier price of $ 76 per unit for the product Q and a retailer sales price of $ 95 per unit, considering a mark-up of 25%, the total market demand for product Q would be equal to 2600 units per month; it could be estimated using as calculation parameters the total market demand at price zero – 6400 units of product Q per month – and the demand variation versus price variation – 40 units of product Q per month per $.

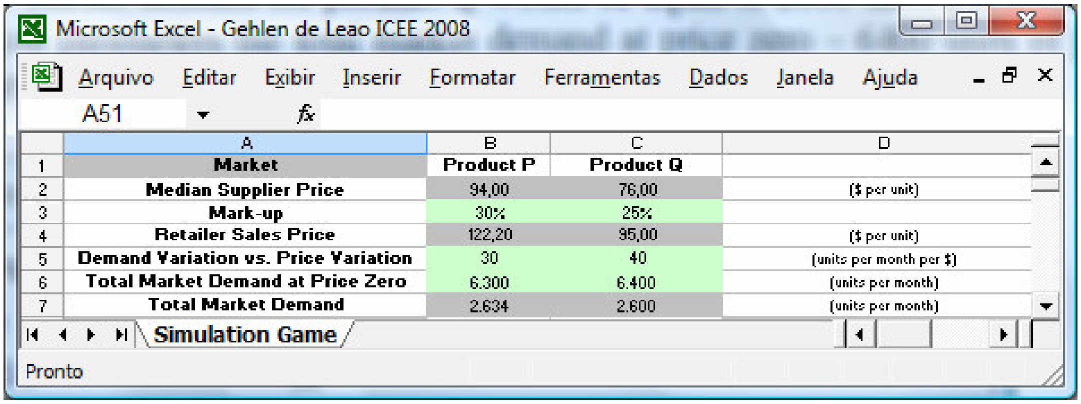

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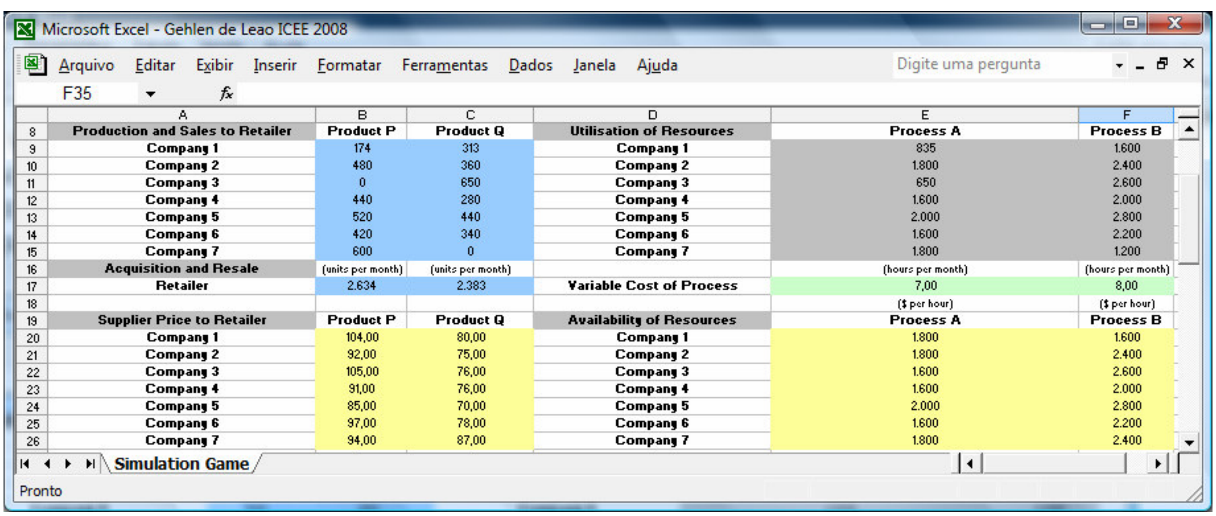
Fig. 7. Computer Spreadsheet: Market Data.

As manufacturing resources constraints, it must be taken into account the resources available in each company and the consumption of the manufacturing resources – processes A and B – to make products P and Q.

For example – see Fig. 8 – the company 5 has manufactured and sold 520 units of product P and 440 units of product Q, using the entire availability of process A – 2000 hours per month – and every 2800 hours available in process B.

By contrast, company 3 has produced and sold merely 650 units of product Q, using 650 hours out of 1600 hours per month available in process A and the full availability – 2600 hours per month – of process B.



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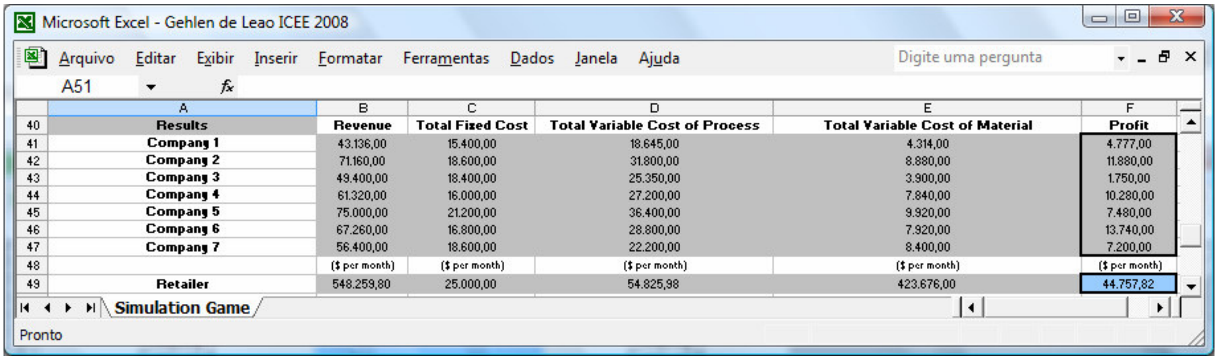
24	Company 5	85,00	70,00	Company 5	2.000	2.800
25	Company 6	97,00	78,00	Company 6	1.600	2.200
26	Company 7	94,00	87,00	Company 7	1.800	2.400

Fig. 8. Production Sales to Retailer and Utilisation of Resources versus Availability of Resources.

The final decision – how many products should be manufactured on each company – is taken based on maximisation of the retailer profit – see Fig. 9.



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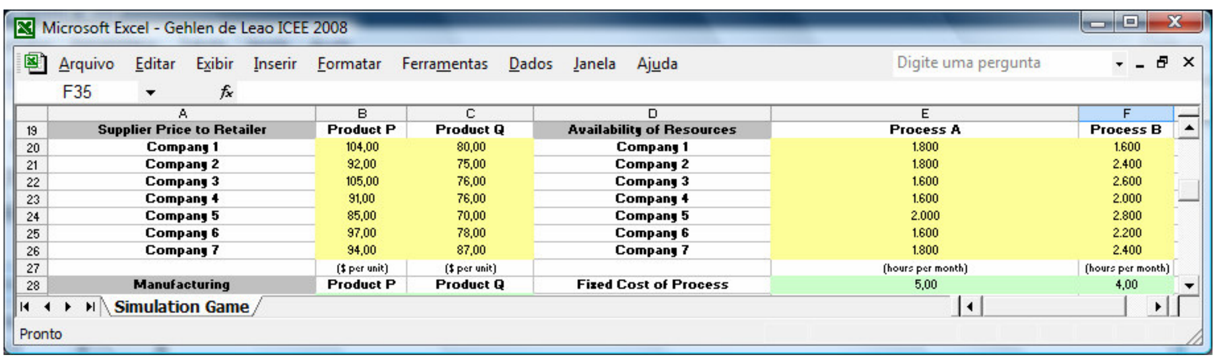
48		($ per month)	($ per month)	($ per month)	($ per month)	($ per month)
49	Retailer	548.259,80	25.000,00	54.825,98	423.676,00	44.757,82

Fig. 9. Computer Spreadsheet: Monetary Results.

So, it depends, ultimately and simultaneously, on product price offered by the companies and on the manufacturing resources available in each company.

4.2. Dynamics of the Simulation Game

The dynamics of the simulation game, for each player, consists on presenting bids – in terms of price of products and availability of manufacturing resources – in a monthly auction – see Fig. 10 –, trying to achieve maximum accumulated profit in a long term basis – usually one or two years.



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24	Company 5	85,00	70,00	Company 5	2.000	2.800
25	Company 6	97,00	78,00	Company 6	1.600	2.200
26	Company 7	94,00	87,00	Company 7	1.800	2.400
27		($ per unit)	($ per unit)		(hours per month)	(hours per month)
28	Manufacturing	Product P	Product Q	Fixed Cost of Process	5,00	4,00

Fig. 10. Computer Spreadsheet: Suppliers Bids – Price to Retailer and Availability of Resources.

As a main decision principle, on each round, the strategy for each player consists on offering a particular price for the products and to set the right capacity of the manufacturing processes – the second one affecting fixed costs –, in order to maximise economical benefits [16].

Then, after a round of bids from each company, the retailer takes a purchase decision based on maximisation of its own profit.

As stated by Wisner et al. [9], "suppliers must be able to accurately forecast demand so they can produce and deliver the right quantities demanded by their customers in a timely and cost-effective fashion".

Also Vollmann et al. [17] state that a key element of the demand management is a systematic search for equilibrium between supply of products and its demand, through monitoring of actual conditions of the marketplace, providing an information basis for decision-making in a manufacturing environment.

5. Educational Experiences Emerging from Game Application

The simulation game was used in class and its development was benefited from contributions presented by students. Some experiences have shown that the accomplishment of the goals for each company depends on strategic plan – including accurate demand forecasting – and tactical plan – to define the short time actions in terms of product prices and availability of resources [18]. As the result of the manufacturing companies is directly affected by the decision of the customers, players need to choose between cooperation and competition with other players, in order to maximise their own benefits.

This simulation game was used in an undergraduate performance management course, giving to the students an interactive tool to provide a better understanding of the managerial aspects involved in a decision making process when a network of companies is established. Also simulations over internet were conducted, almost on a daily basis, allowing more time for reflections before students state their decisions.

Preliminary results emerging from game application have shown that students with high grades in conventional evaluation methods have demonstrated additional enthusiasm to participate and, therefore, have also achieved superior results in the simulation game.

6. Concluding Remarks

The next step in the development of this simulation game include its implementation with more detailed aspects, in order to allow a more complete perception of its mechanism and to explore all its potentialities as a simulation model.

New experiments have been continuously performed – including the use of a Data Envelopment Analysis approach to evaluate efficiency and productivity of supply chains [14] [19] – and improvements emerging from these applications will be also included in future versions of the simulation game.

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