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Simulation Gaming in Construction: ER, The *E*quipment *R*eplacement Game

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Simulation gaming has been used to add an exciting feature to classroom instructions in a variety of disciplines. Generally, simulation games mimic real life situations in order to develop a wide array of professional skills. This paper firstly surveys simulation games used in the construction management domain including, estimating, bidding, and negotiation. A brief description of the surveyed games and the learning objectives are provided. Secondly, the paper describes the EQUIPMENT REPLACEMENT (ER) game. ER is a multi-player game that can be used in teaching and explaining the different effects of various equipment buy/sell strategies on the economic performance of construction companies. The game is aimed at simulating the buy and sells decisions of construction equipment and can be used to simulate various strategies for equipment with different cost magnitudes. The probabilistic aspect of demand in the construction market is incorporated and the pedagogical aspects of the ER game are also discussed. The game is implemented as an Excel add-in using Visual Basic for Applications (VBA).

Key Words: Construction Equipment, Game, Cost Models, Simulation, Replacement Analysis, Construction Management

Introduction

Simulation games are an excellent way to provide practical decision-making and management experiences. Their teaching effectiveness is usually very high as they provide a unique way to reinforce the theory discussed in the classroom environment (Frazer, 1975). As the players generally become deeply involved in the gaming situation, they develop a desire in doing well in the game and therefore the simulation becomes closer to reality. These games provide a chance to experiment with, or test, ideas and theories acquired elsewhere. Obviously simulation gaming is not a substitute for more formal approaches to teaching the theories and methods of the particular topics, however, it complements these approaches. Integrating the standard formal teaching methods and simulation games as a laboratory to test and reinforce the relevance of theories, can be a very effective teaching method. In this paper, we discuss simulation games in general and survey the construction-specific simulation games. Next, we focus specifically on the Equipment Replacement (ER) game, which emphasizes the replacement decisions of construction equipment. Finally, we present the computer implementation and go through a brief sample run of the game.

Simulation Game in Construction

In the construction domain a number of simulation games have been proposed. These games demonstrate a multitude of concepts important to the construction professional ranging from bidding practices to negotiation.

Construction Management Game

The Construction Management Game is one of the earliest games developed in the construction domain by Au, et al (1969). The Construction Management game is an example of simulating the bidding process in the construction industry. Teams of players are cast in the roles of managers in construction companies. Each company is a general contractor that subcontracts and coordinates all portions of a building construction project either to individual subcontractors or to its own operational divisions when awarded a general contract. The goal is to maximize the company's net worth. The teams' performances are calculated in an income statement such as that shown in Table 1.

Table 1

Evaluating A Company's Performance In A Construction Management Game (Au, et al 1969)

	Income statement	
A.	Income from construction contract	$412,510.00
	Cost of contracts	
B.	Subcontracts and supervision of subcontractors	347,891.00
C.	Field overhead	2,063.00
D.	Gross profit	$62,556.00
	Administrative and general expenses	
E.	Office operating cost	10,921.00
F.	Information costs	650.00
G.	Bidding costs	1,733.00
H.	Interest on existing loans	900.00
I.	Earning before federal learning taxes	$48,352.00
J.	Federal income taxes	17,411.00
K.	Net earnings	30,941.00
L.	Retained earnings at beginning of period	208,422.00
M.	Liquid assets	$239,363.00
	Loans	
N.	Existing loans	60,000.00
O.	New loans (one year notes)	25,000.00
P.	Loans due this time period	10,000.00
Q.	Total cash-on-hand	314,363.00
R.	Retained earnings at end of period	$239,363.00
S.	Percentage gain or loss up to end of period	+19.7%

CONSTRUCTO

The CONSTRUCTO project management game was developed at the University of Illinois by Halpin to integrate the effects of weather and labor productivity into the management of projects in a network format (Halpin, 1973). A simulation approach was adopted using the CYCLONE simulation language to build a real life construction project situation including some of the environmental and economic parameters facing managers. The players are presented with a construction project. In turn, the players are asked to input the activities and crews required among other variables.

SuperBid

SuperBid is a computer simulation model developed in the University of Alberta, that can be used to improve the bidding skills of construction managers (AbouRizk 1992). The SuperBid game is similar to CONSTRUCTO and the project management games, in that a bidding situation is created automatically by the computer using stochastic techniques. However, SuperBid is geared specifically at introducing the concepts of the bidding in the construction management domain using a game format. The players try to increase the profitability of their companies by mainly optimizing their bidding decisions. Similar to the Project Management and CONSTRUCTO games, SuperBid is implemented as a computer program.

Negotiation Game

Another construction related game is the Negotiation Game (Dubziak 1988). The construction Negotiation Game simulates a contract negotiation between a utility and a design/build firm. The negotiation involves only two parties but implies there are several issues to be resolved. Players in the game are assigned to represent one of the two parties and to negotiate the various issues, which include duration, penalties, bonuses, frequency of reports, contract types, percentage profits and legislation. A final contract generally requires an agreement on each of these issues, presented on a form signed by both parties (Table 2).

Table 2

A Negotiated Contract Between CMG Gas And Pipeline Constructors, Inc (Dubziak 1988)

Duration	38 weeks
Penalty for late completion	$6,800 per day
Bonus for early completion	$0 per day
Report format	Traditional CMG form
Frequency of progress report	Weekly
Conform to pending pipeline marking legislation	Yes
Contract type	Fixed fee
Amount of fixed fee	$5,050,000.
Percentage of profit	Not applicable
CMG Gas clerk on site	Yes
Penalty for late starting date	$3,000 per day
Signed:	
CMG Gas representative	
Pipeline Constructors, Inc.	

Parade of Trade Game

The main learning objective of the parade of trade game by Choo et al (1999) is to explain the impact of workflow variability on succeeding trade performance. The game demonstrates to the players how small changes in the variability of tasks and dependence can influence the construction environment. In the game, multiple trades follow each other in a linear sequence and work output by one trade is handed off to the next trade. This can be simulated using dice or using a developed computer program.

Lego Bridge Game

Beliveau (1991a) has developed an interesting construction simulation game using Legos. The game presents the players with a multitude of real life issues in a simplified way. The game involves building one of two bridges using Legos. The players have to decide which bridge to build, prepare an estimate for the bridge (in terms of how many Lego) pieces and finally build the bridge. The teams are rewarded for lower cost due to short building time and are penalized for over or underestimating. As can be seen there are a number of simulation games developed for the construction industry.

Road Building Negotiation Game

The road-building-negotiation game is a group negotiation game that can effectively demonstrate the impact of a well-developed strategy in negotiations (Beliveau, 1991b). In the game, two teams of negotiators are given the objective to build the longest continuous road that passes through a number of plots of land. The plots are assigned equally between the players but the players can trade the plots between them to increase their road's length. The teams are given a few minutes before negotiation to come up with a defined strategy for negotiation. Further, the negotiation time is limited. The team with the longest continuous road is declared the winner. Often two teams do not reach an agreement in the allocated time and both fail to build any roads at all. The moral of the game is to try to negotiate a win-win situation in order to reach beneficial agreements in the allocated time.

The Marketing Game

The Marketing game is developed at Bradley University (Bichot, 2001) and is aimed at enhancing the awareness of construction managers about the importance of marketing in the construction industry. The various marketing techniques that can be used in the construction industry are first presented to the players. Then the players are asked to develop and perform a simulated marketing plan over a number of simulated years (periods) and the players are assessed based on the effectiveness of their marketing strategies and techniques. A comparison of the games described above is seen in Table 3.

Table 3

A Comparison Chart of the Simulation Games Available for the Construction Management Field

	Game	Focus Area	Time Frame Required	Computer Implementation Needed	Limit on Number of Players/Teams	Main Construction Courses Where Applicable
1	***Construction Management Game***	*General Management skills*	*1.5hr to 1 semester*	*YES*	*Optimum 4-6 teams*	*Construction Management*
2	***Negotiation Game***	*Tradeoffs and Negotiation skill*	*1.5hr*	*NO*	*NO*	*Contract Management and Administration Courses*
3	***Parade of Trade Game***	*Effect of variability on construction productivity*	*1hr*	*YES*	*NO*	*Construction Productivity Improvement*
4	***CONSTRUCTO***	*General Management skills*	*NA*	*YES*	*NA*	*Construction Management*
5	***Super-Bid***	*Bidding skills*	*1hr*	*YES*	*NO*	*Estimating and Construction Management*
6	***Lego Game***	*Estimating and Construction Planning*	*1.5hr*	*NO*	*Optimum 4-6 teams*	*Scheduling, Company Management*
7	***Road Building Negotiation Game***	*Group Negotiation and planning*	*1hr*	*NO*	*Optimum 4-6 teams*	*Construction Management*
8	***Equipment Replacement Game***	*Equipment and resource management with market demand*	*1.5hr to 1 semester*	*Yes*	*Optimum 4 teams*	*Construction and Company Management*
9	***The Marketing Game***	*Construction Marketing, Company management.*	*1hr*	*Yes*	*4*	*Introduction to construction, Marketing Courses*

Description of the Equipment Replacement Problem

Equipment management is becoming a major role in the everyday practice for construction professionals. Equipment costs are a major cost item in projects and the correct management of the construction equipment is a significant factor in the success of any construction company. The longer a piece of construction equipment stays in service the higher will be its maintenance cost and the lower the productivity. When a machine reaches a certain age, it may be more economical to replace it. The equipment replacement problem thus is to determine the most economical age of a machine. Generally, we study the replacement policy over n years. At the start of each year, we decide whether to keep the machine in service for 1 more year, or sell and buy new machines. Let $r(t)$ and $c(t)$ represent the yearly revenue and the total operating cost of a t-year-old machine. Also, let $s(t)$ be the salvage value of the machines that have been in service for t years. The total cost of acquiring new machines at year t is $I(t)$.

Therefore the goal is to find the decisions that maximize *f(t)*,

$$f(t) = r(t) + s(t) - I(t) - c(t) + f(t-1)$$

We limit the number of machines that can be bought each period to *k* and the periods are limited to *n* periods. The winner therefore is the team with the highest *f(n).* At the end of the game, each team will have a matrix whose elements represent the equipment purchasing decisions for each machine for each quarter. For example for team b,

$$D_b = \begin{vmatrix} x_{11} & x_{12} & x_{1j} & .. & x_{1k} \\ x_{21} & x_{22} & x_{tj} & .. & .. \\ .. & .. & .. & & x_{nk} \end{vmatrix}$$

Such that for period *t*

$$x_{tj} = \begin{cases} 0 & \text{if no machine is purchased} \\ 1 & \text{if machine A} \\ 2 & \text{if machine B} \\ 3 & \text{if machine C} \end{cases}$$

Each team will also have *n* vectors representing the selling decisions for each quarter,

$$S_{bt} = \begin{vmatrix} y_{t,1} & y_{t,2} & y_{t,i} & .. & y_{t,t*k} \end{vmatrix}$$

$$\text{Such that for } \forall t,\ y_i = \begin{cases} 0 & \text{if no sell} \\ 1 & \text{if sell} \end{cases}$$

$$\text{Subject to } \forall i,\ \sum_{t=0}^{n} y_{t,i} = (0,1)$$

The elements of this matrix and vectors are the decision variables. Here we define that the market demand *d(t)* is stochastic. Although, forecasting the market demand in real life is a complex problem we simplify the problem by assuming that the demand follows a beta distribution such that the probability at time t of a market demand *d(t)* is,

$$P[d(t)] = \left\{ \frac{(\alpha + \beta - 1)!}{(\alpha - 1)!(\beta - 1)!} \left(\frac{d(t)}{w} \right)^{\alpha - 1} \left(1 - \frac{d(t)}{w} \right)^{\beta - 1} if\ 0 < x < w \right.$$

where *w* is set to equal the maximum demand and is equal to $d_{(t-1)}+I$, where I is the expected increase in demand and $d_{(t=0)} = I_o$. The shape parameters α and β are used to control the demand profile, either to increase or reduce the expected demand.

Although any model can be used for market demand, this model provides for the necessary variability for the simulation game, such that the revenue for each team is not fixed. The revenue is determined from one period to the other by the teams' production capacity and the market demand by the following formula,

$$r(t) = \begin{cases} p(t) * P & \text{when } d(t) > p(t) \\ d(t) * P & \text{when } p(t) < d(t) \end{cases}$$

And, $p(t)=N_1 \text{ x } P_1 + N_2 \text{ X } P_2 + N_3 \text{ x } P_3$, where N_1, N_2, N_3 are the number of machines types 1,2,3 respectively and P_1, P_2, P_3 are the production capacities of machines types 1,2,3 respectively, where $p(t)$ and $d(t)$ is the production capacity and the demand at time t and P is the price per unit. When the demand is less than the production capacity the program selects the machines with the lower variable cost to do the work. This might not be the best alternative, but this is set as a rule of the game and is made known to all teams. This is an example of striping the real life situation, discussed earlier, to concentrate more on the equipment buy/sell decisions. Although the exact mathematical optimum solution to this problem is not considered here, it would be useful to understand how a solution to this problem can be obtained. The equipment replacement problem has been traditionally formulated as a dynamic programming (DP) problem and solved using standard DP techniques. However, because we are considering different machines types and the different buy/sell strategies and not just replacement, the problem has been formulated above an integer-programming problem. These kinds of problems are usually solved using techniques like branch and bound. The added complexity here is the stochastic demand and that fact that the objective function is discontinuous. Therefore, to find a solution (or optimum strategy) to this problem we have to resort to simulation techniques and optimization methods that are suitable for discontinuous problems like genetic algorithms. Even then, using these techniques a global optimum solution is not guaranteed. The next section describes the simulation game version of this problem.

Description of the ER game

EQUIPMENT REPLACEMENT game is optimally played with four teams, although other team sizes are possible. Each team is responsible for managing the excavator fleet of an excavating contractor. The game is played in 12 simulated quarters. At each quarter, the teams can decide to buy new excavators or sell existing ones depending on the efficiency of the machines and the expected production demand in the future. The production units are considered to be cubic yards of work. The price per cubic yard is fixed at $50 and the market demand or number of jobs is independent of the decisions made by the teams.

Three types of machines are available to satisfy the demand. Suggested data for each type of machine is shown in table 1.

Rules of the Game

- In the game, we will assume that any advancement in the technology and the quality of the excavators is equated by inflation. This means that all new machines will always have the same initial cost and variable costs in spite of when they were purchased. However there is an increase in the variable cost per quarter due to inflation and decreased efficiency. Machines A are less automated than Machines B and Machines C are less automated than machine B and therefore the variable costs with Machines A increase at a faster rate. Salvage value at retirement is calculated using the double declining balance. Other depreciating methods can be also be used by making minor modification to the game. The double declining balance depreciation was used to emphasize the effect of depreciation on the decisions made.

- The number of jobs available is approximated by the demand per quarter in terms of cubic yards/ quarter. The demand begins at 20,000cubic yards/year for each team and increases each year. The size of each year's increase is randomly generated between 0 and 40,000 cubic yard according to a beta distribution as described above. This range allows the moderator to change the variability of the market demand. If a team does not have enough machines to satisfy the demand, then their sales will be determined by the capacity of the machines they have. If a team has excess capacity, then the full demand will be satisfied by using machines in the order of their variable costs with the machine having the lowest variable cost per unit being used first.

- Teams cannot change buy or sell decisions after they are made, and the teams are also not allowed to make future buy or sell decisions.

- A company can only buy a maximum of 5 machines of each type, in each quarter. Each team begins with $200,000 in cash. Machines can be bought on margin with an interest rate of 15%.

- For the purpose of the game, retiring a machine is considered a tax benefit. Machines will be identified for each team sequentially in the order in which they were purchased.

- Cash balances earn an interest of 12%. The cash position of each team is evaluated after all costs are paid and before the income is received. (Negative cash balances incur a 15% charge.) Taxes on profits are calculated at 10%.

- Teams will make decisions for 10 quarters but the game will last for 12. At the end of the 12^{th} quarter, the team with the highest book value is the winner.

All the variables discussed above can be changed to explore different effects and scenarios. Modifying all these variables is made possible in the computer implementation described below.

Computer Implementation

The game was implemented as an add-in to Excel in Visual Basic for Applications. Implementing the game as an Excel add-in is beneficial because most students are already familiar with the interface and also because that allows the student to build their own spreadsheet models, during the simulation game, for verification and analysis of their decisions. Visual Basic was used to program the macros responsible for the different calculations and for administering the game. The application consists of four identical workbooks (one for each team) and a separate workbook for the moderator. The moderator workbook is where the global variables of the simulation game can be changed, such as the initial cash for each team, the prices of the machines the depreciation method used or the life and variable costs of the machines. The player's workbooks are where each team enters the decisions for each quarter.

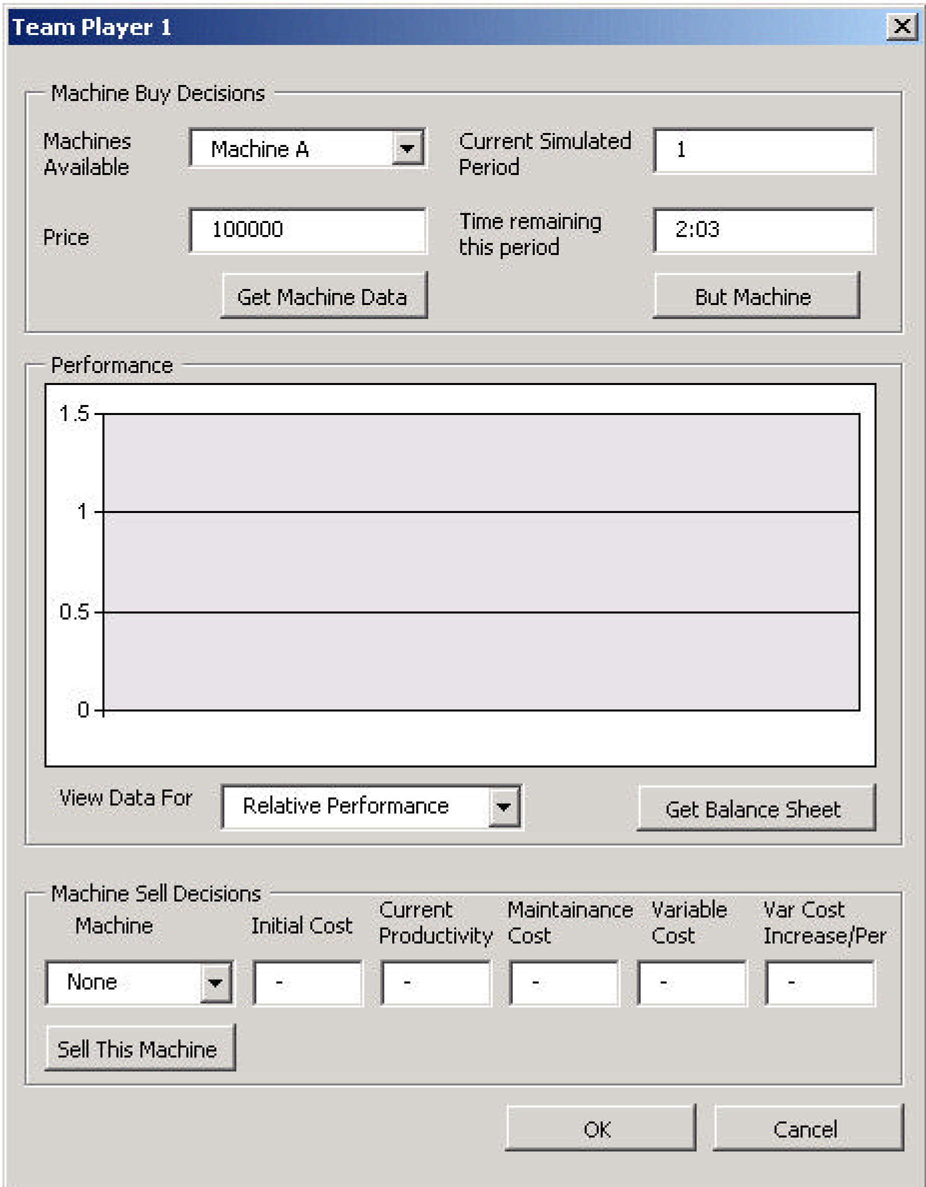

Figure 1: The Players Interface

Furthermore, the players' workbook is where each team can track its financial statement and its current position. The formulae are all predefined and protected, so although each team can see how it is doing they cannot change the rules of the game. Each team enters the number of each machine kind to buy for each quarter and this is added to their database of machines, which can be view on a separate sheet. Each team can select a specific machine at any time and hit the sell button to sell the machine. This updates their financial position automatically. Also each team can select any machine they own from the database and get a complete report on that particular machine including its book value its current production, its current variable cost etc.

The players also get a chart showing how the different attributes of the game are progressing with time like their cash and income. The different teams also get an index chart showing their current positions with respect to each of the other teams. The workbooks for the various teams are linked to the moderator workbook who in turn sets the future demand. The moderator can also reset the game and set the simulated time for each quarter as can be seen in figure 2. Although generally not recommended, the moderator can adjust the program so that certain teams get either an advantage or a handicap by changing variables like their initial cash. At the end of the game, charts are generated to show what decisions each team made and how that affected their position. These can be used in post-game discussions.

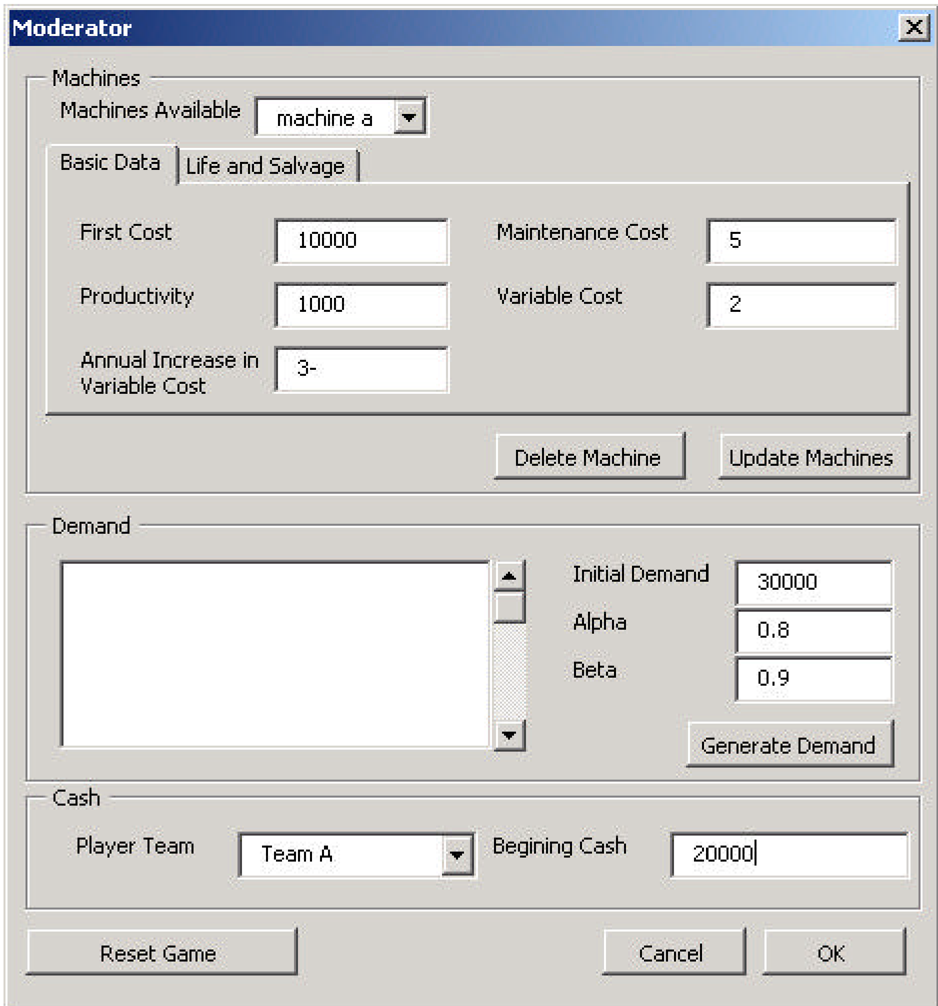

Figure 1: The Moderator Interface

A Sample Run

In this section, we will describe a typical run of the replacement game. The game here was played with four groups of students. The groups had members ranging from 2 to 4 students each. The game took about one whole class session of about an hour and twenty minutes. Alternatively, this game can be played over extended period. In this case, students can conduct more detailed risk analysis of market demand (i.e. Monte Carlo Simulations) using add-ins to excel like @Risk or Crystal Ball. That included the time for discussion of the results and the various strategies. An effective method to make these games more realistic is to add some sort of added incentive for the winner. This can range from small percentage grade points to simple prizes such as books or even a symbolic amount of waged money! A 1% grade point was offered to the winning team members.

The production demand is seen in figure 3. The actual demand for each simulation quarter was generated using the beta distribution as described above and was revealed at the beginning of each quarter. This added the challenge for the different teams to try to predict the future demand and but the increase trend was disclosed to all teams to take out the task of forecasting whether or not a particular demand trend will continue. A limitation here is the number of quarters of the simulation was limited to 12 quarters, which meant that also the number of demand trends was limited.

Table 4

The Position of Team A after two quarters

REVENUE from selling machines	$68,326.25
REVENUE from production	80,000
Total Expenditures	3,300
NET INCOME	125,026
INTEREST	9,754
TAXES	64890.094
TOTAL	69,890
BOOK VALUE ON MACHINES	160,000
CURRENT BOOK VALUE	229,89

Table 5

Data for the sample run

Machines A	***Machines B***	***Machines C***
Initial Cost of Machines	Initial Cost of Machines	Initial Cost of Machines
$100,000	$220,000	$250,000
Production Capacity	Production Capacity	Production Capacity
5000 cubic yards/quarter	6000 cubic yards/quarter	7000/quarter
Maintenance Cost	Maintenance Cost	Maintenance Cost
$8000/year	$8000/year	$8000/year
Variable Cost (first year)	Variable Cost (first year)	Variable Cost (first year)
$7/ cubic yard with a $7/year	$8/ cubic yard with a $3/year	$7/ cubic yard with a $7/year

It is important to note that different predefined demand curves can be experimented with resulting obviously in different strategies. In addition, the demand trend can be shown at the start of the simulation to allow the teams to formulate a strategy accordingly. Alternatively, a projected and an actual demand curves can be used with the projected demand curve being shown before the simulation and the actual demand being shown at the beginning of every quarter only.

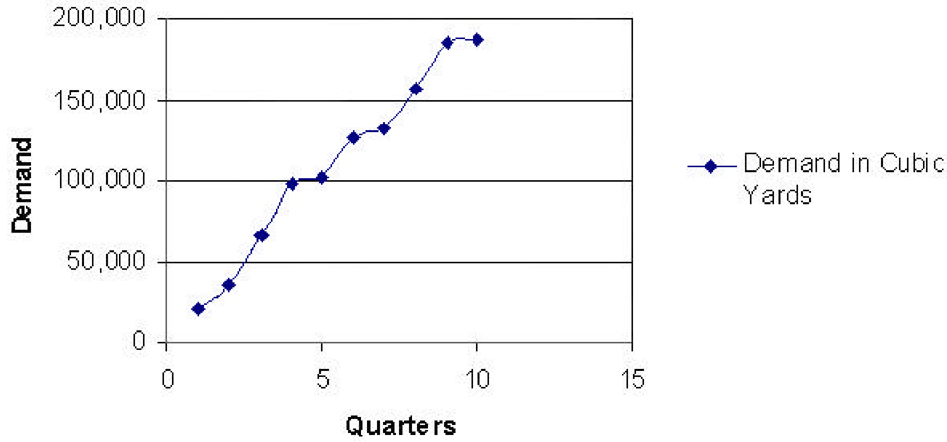

Figure 3: The Production Demand

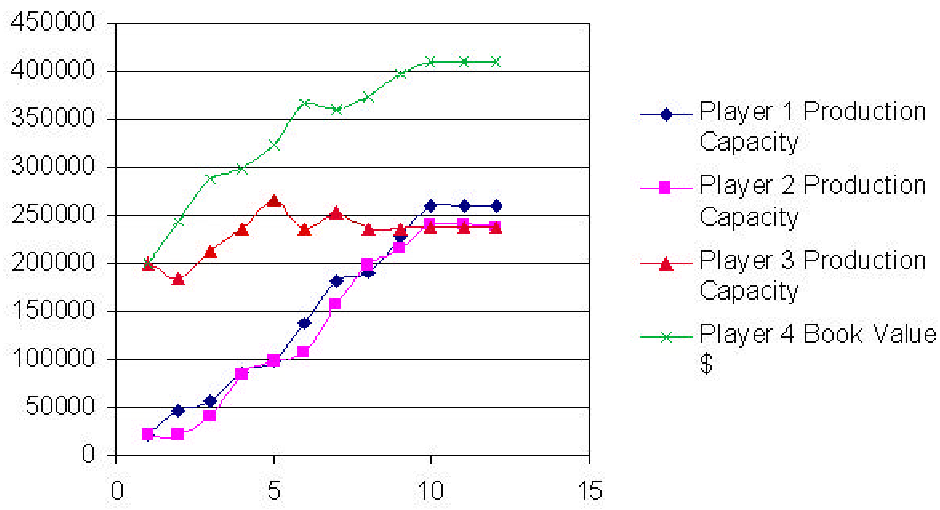

Figure 4: The Production Capacity of the Four Teams

The data used for this simulation game is shown in table 5. This data can be easily changed to reflect different situations. Changing this data will have an effect on the number of expected buy and sell decisions to be made by each team. For example, by increasing the production capacity of the machines while keeping the demand constant, the number of buy sell decisions will decrease as single purchases will be able to cover more production demand.

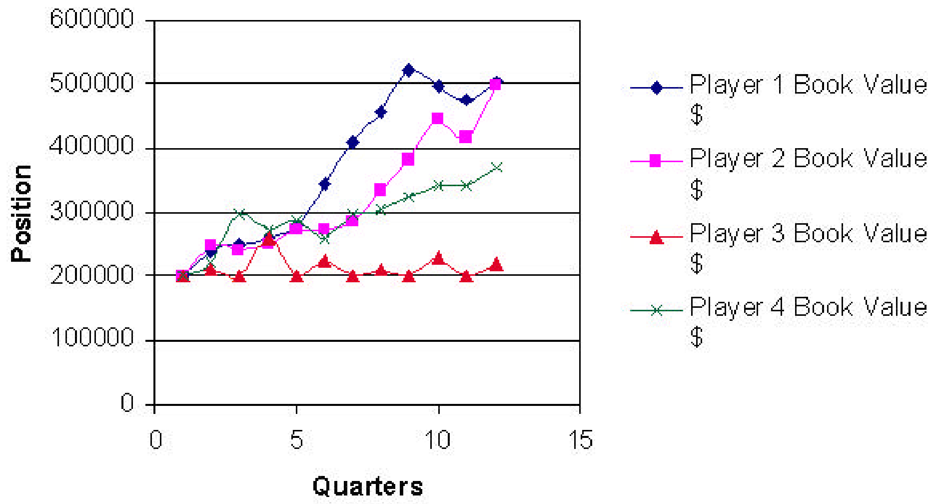

Figure 5: The Performance of the Four Teams

The production capacity (in cubic yards) of the four teams is shown in figure 4, and their financial position (net worth in $) is shown in figure 5. Although several factors will affect who wins the game, the correct production capacity is a critical factor. As can be seen form the charts, the simulation ended with teams one and two almost in a tie. Team 4 had over estimated the market demand and even though a sell decision was made at the end of the game (as can be seen from the flat potion at periods 11 to 15), the team ended with an excess of production capacity to which maintenance and variable costs had to be charged. The performance of team 3 on the other hand was shadowed by the abrupt and jerky buy/sell decisions.

Teams one and two mimicked the demand curve and tried to follow the trend in a tit-for-tat strategy. Quick responses to the market changes and following the expected market demand change are some of the important lessons learned. Group decision-making within the various teams is another. Teams were encouraged to build their own spreadsheets to verify the calculations. As the teams participating in this game indicated, managing the company's inventory of machines and how much cost is incurred was an important issue. . Team one calculated the ratio of their inventory costs (variable cost + maintenance) to their revenues as a measure to manage their inventory.

The overall combined performance of the teams and their strategies were recorded for future discussions and study. After the simulation was run some questions where set forward for discussion like,

- Did you plan for a strategy before the game? What was your strategy?
- How did you project the demand for the next quarter?
- Who keyed in the decisions in the computer?

In addition, a student survey was conducted at the end of the session to try and evaluate the teaching effectiveness of the game and the results are shown in Figure 6. Although, most students agreed that the quality and teaching effectiveness of the game was superior, the lowest score was given to the reality of the game. This may be an indication that we can add more complexity to the game without sacrificing the teaching effectiveness. Also, the program and the interface were seen to be effective.

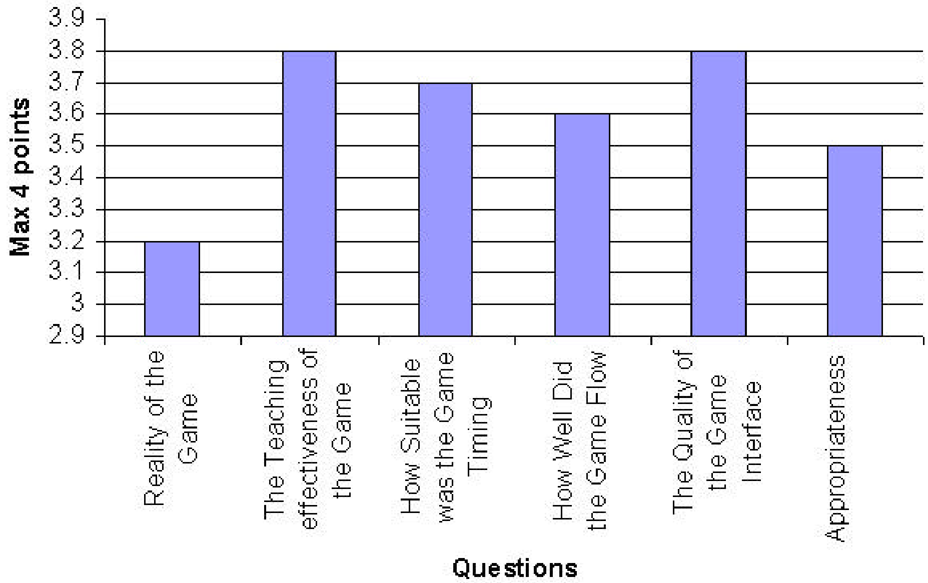

Figure 6: Results of the student survey

Conclusion and Future Research

This paper presented the construction EQUIPEMNT REPLACEMENT game, which was developed as a tool for learning about the effect of buy/sell decisions on the financial performance of a construction company. A formulation of the equipment replacement problem was presented along with the computer implementation of the game. The lessons that can be learned about how the students operate in a team and particularly the interaction of opinions is a valuable element of this simulation game. In addition to the educational features of the game, probably the most important lesson that is learned is the leadership role and that the usually effective leaders are vigilant to make sure that the ideas of all players are considered and that a winning strategy is usually one that the whole team is behind.

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