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USING SIMULATION AS A TEACHING TOOL IN AN INTRODUCTORY OPERATIONS MANAGEMENT COURSE

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ABSTRACT

We discuss the use of two online simulations as a part of our core undergraduate and graduate business operations classes. We have found the games, Littlefield Technologies, to be of pedagogical value, as they can engage students in the material due to the competitive nature of the game, as well as the ability to see consequences of their actions. Students are able to apply what they have learned in the class to a more realistic scenario than textbook problems. Despite the additional work and challenges associated with ensuring all students register on time and engaging everyone, we feel the games are worthwhile. We provide some strategies for facilitating the smooth and successful execution of the simulations.

1 INTRODUCTION

Most simulation academics in business schools must, at some point in their careers, teach a core operations/operations management class, either at the undergraduate or graduate level. Simulation *per se* is not often a topic in these classes, which (rightly) focus more on the basics such as inventory management or forecasting.

In this paper, we discuss the use of Responsive.net's Littlefield Technologies simulations in these core classes. Over the last 10+ years, thousands of undergraduate and graduate students have competed with one another to apply the material they learned in class to a more realistic setting than standard textbook problems.

Section 2 provides background information on our students and university, as well as a brief review of the use of games in Operations Research (O.R.) education. Section 3 introduces Littlefield Technologies. In Section 4, we outline strategies for improving student success in the game. Section 5 discusses the benefits and Section 6 the challenges of using the games in the class. Section 7 summarizes student response to the game. Section 8 concludes the paper.

2 BACKGROUND

2.1 San Francisco State University

San Francisco State University (SFSU) is an urban, public 4-year university serving approximately 30,000 students (SFSU 2015a). As part of the California State University (CSU) system, the SFSU mission includes a "commitment to quality teaching and broad access to undergraduate and graduate education" (SFSU 2015b). One of the CSU's core values is accessibility, as stated in its mission: "To encourage and provide access to an excellent education to all who are prepared for and wish to participate in collegiate study" (CSU 2015). This means that students at a CSU campus come from all walks of life, at varying levels of academic preparedness, and with varying levels of parental or economic support.

The College of Business (COB) at SFSU is the largest college on campus, with approximately 6,000 undergraduate students. Each student is required to pass a junior-level core operations class, DS 412. The required topics in the course are forecasting; capacity planning; inventory management; linear programming; project management; and quality management. The standard class size is 55 students/section, and most instructors teach 1-2 sections/semester. At the graduate level, approximately 25 students/semester take the graduate equivalent course, BUS 786.

Instructors of DS 412 are faced with two main challenges: The first is the general apprehension with which most students approach "mathy" classes. Many students have had unpleasant experiences in previous quantitative courses, and DS 412 has the reputation of being one of the two hardest classes in the COB. The second challenge is that the majority of students work, some full-time, in order to put themselves through school. The combination of this and taking a full load of classes leaves students with little time to devote to their studies and to the practice necessary for most to master quantitative material.

As a result of these challenges, instructors try to find "fun" ways to engage students, both to capture their attention and to overcome their fear of quantitative analysis. One such way is the use of simulations and games in the classroom.

2.2 Teaching O.R. Using Games

Games and simulation have been used to teach O.R. for decades. Ezz et al. (2012) provide an extensive overview of the history of management education using simulation and games. The earliest and perhaps most well-known game is the beer game, introduced in the early 1960s at MIT, based on work introduced in Forrester (1958). New games are being developed every day, for example (Costantino et al. 2012; Lee 2011); most of these games likely do not make it to the literature. The Production and Operations Management Society (POMS) maintains a list of teaching simulations (2015), including (descriptions taken directly from the POMS site):

- LINKS, "a sophisticated, team-based, competitive management simulation designed in a modular fashion to permit application in a variety of educational/instructional contexts. (…) Examples of simulations include: supply chain management, service operations management, and enterprise management."
- SimQuick, "an Excel spreadsheet (with some macros) that allows the user to model simple processes including waiting lines, inventory, supply chains, manufacturing, and projects with uncertain task times."
- BusSim, "three simulations that relate Operations Management content to real world applications": "a manufacturing based simulation that focuses on the operations function, (…) a manufacturing based simulation that teaches broader management responsibilities (…and) a service based trucking industry simulation."

One of the more popular games used in teaching O.R. is Littlefield Technologies (or Littlefield Laboratories), which won the 2004 Production and Operations Management Society (POMS) 2004 Wickham Skinner Teaching Innovation award (Wood 2004). It has received a fair amount of attention in the literature in the intervening years (Mehrotra 2007; Miyaoka 2005; Snider and Balakrishnan 2013; Wood 2007). We have been using this game in our courses for over a decade because of its relative simplicity, effectiveness, and low cost ($15-20/student). Unfortunately, we have not used any other simulations and are therefore unable to provide a comparison between them.

3 LITTLEFIELD TECHNOLOGIES

3.1 The Basic Games

We use two games in our core classes, Capacity Management and Managing Customer Responsiveness. Both rely on the same system setup, a simplified Digital Satellite System receiver manufacturing facility. Figure 1 shows a screenshot of the home screen students are taken to upon login. It depicts the 3-station, 4-stage process through which jobs move. Upon arrival, boards are stuffed at Station 1 and then proceed to Station 2 for testing. At Station 3, they are tuned, and then go back to Station 2 for final testing before being shipped to the customer.

Revenues are based on how quickly orders can be fulfilled. If they are met within a certain minimum guaranteed time, Littlefield receives full compensation. The compensation decreases linearly up until a pre-defined maximum time, at which point Littlefield earns nothing.

Students gain control over the system after a warmup period of 50 simulated days. They are in control for 168 simulated days (*i.e.*, through day 218), at which point the simulation executes another 50 days. The entire facility is shut down after simulated day 268. The goal is to end the simulation (on day 268) with the most on-hand cash (compared to the other teams). Each team starts with a cash balance of $1M, which it can use to purchase inventory and machines. Unused capital earns interest at a compounded annual rate of 10%.

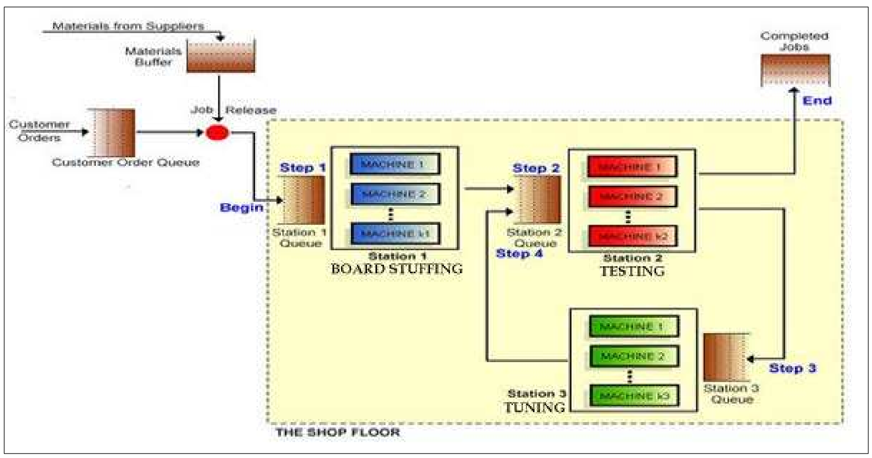

Figure 1: Screenshot of Littlefield Technologies home screen.

The system parameters students over which students have control depend on the game being played, and are discussed in Sections 3.1.1 and 3.1.2. In both cases, students are given access to graphs and downloadable time series data for:

- Job arrival data
- Raw materials inventory
- The queue size and utilization for each station
- Number of completed jobs
- Average revenue earned/day

3.1.1 Capacity Management

The Capacity Management game is typically played after we have covered forecasting, capacity planning, and queueing theory. Students are responsible for purchasing the correct number of machines for each station to ensure customers receive orders within the quoted lead time. In order to do so, students should forecast the peak demand for the system; determine the service rates at each station using system utilization and job arrivals; and use a combination of queueing theory and breakeven analysis to determine how many machines to purchase, given purchase prices and the amount of time remaining.

Students are told that the job arrival rate will be increasing linearly for the first five months. After a month of stable demand, it will decrease linearly until the end of the simulation. Each station begins with only one machine. When students gain control of the factory, station 1 is nearing 100% utilization, causing increasing delays in delivering product on time.

Students are able to purchase and sell machines at each station, and to change the service priority on Station 2 between FIFO and favoring jobs at steps 2 (initial testing) or 4 (final testing). The sales price of machines is less than 10% of the purchase price, making indiscriminate buying and selling of machines a costly experiment. The ideal course of action is to immediately forecast peak demand and determine the required capacity. Purchasing the capacity before it is necessary is worthwhile as the revenues gained by being able to meet demand far outweigh the opportunity cost of lost interest on capital.

The following topics are taught prior to playing this game. In forecasting, we teach linear trend regression and smoothing models. In capacity management, we cover how to calculate capacity needs from demand and processing times. And in queuing theory, we cover utilization and the nonlinear relationship between utilization and waiting time.

3.1.2 Managing Customer Responsiveness

Managing Customer Responsiveness is played after we have completed the Capacity Management game and covered inventory management and Just-in-Time. In addition to determining the capacity at each station, students are now also responsible for setting the reorder point and reorder quantities for raw materials; choosing between three customer contracts that offer different levels of lead times and prices; batch sizes; and borrowing cash, should the need arise. (We typically do not use the latter two options for our undergraduate courses.)

In contrast to the Capacity Management game, the expected job arrival rate in this version of the game is constant, making forecasting straightforward. In return, students must execute more complex analysis to determine the capacity required for the different contract levels – including whether it is financially viable to increase capacity to those levels, given the remaining system time. They must compare the potential increase in revenue against the cost of the machines required to achieve the promised delivery time.

Students must also find an appropriate reorder point and reorder quantity; hence we cover the Economic Order Quantity (EOQ) and reorder point models prior to playing this game. With the initial settings, the system runs out of inventory each order cycle, which has significant financial implications for the factory if students have chosen a more aggressive contract for their customers. Each order has a fixed ordering cost of $1,000, which makes placing frequent orders (*i.e.*, setting too low a reorder quantity) a costly undertaking.

3.2 Administration

There is some administrative overhead associated with playing these games. Students must either be assigned to groups, for example based on schedule (Roeder and Saltzman 2014), or self-select into groups. Each student must then purchase an access code online and register for the game, as a member of his/her group.

The instructor is able to change system parameters including:

- Job arrival rates
- Initial number of machines at each station
- Service rates
- Machine purchase and salvage prices
- Rate of simulated time. Typically, 1 simulated day = 1 real hour; this means that the simulation runs for exactly one calendar week.

Alternatively, the instructor can select from several prepared scenarios offered by Responsive.net. The authors find it useful run different versions of the simulation from semester to semester so that students who seek out solutions from previous semesters are less likely to be successful than if the same scenario was run every semester. The versions differ in the service rates at the three stations, which leads to different optimal capacity levels. (Responsive.net also offers a version of the game identical to Littlefield Technologies in all but name, Littlefield Laboratories. All system processes and parameters are the same, but the product is different.)

In an ideal case, students can be taken to a computer lab for the beginning of the simulation. This ensures that groups are able to meet in person at least one time, and that everyone is able to understand how the game works. Depending on the course's schedule, this may not be possible.

4 STRATEGIES FOR IMPROVING STUDENT SUCCESS

Given the busy nature of our students, we have developed a few strategies to facilitate their success in the simulation. Many of the strategies dovetail with those described in Snider and Balakrishnan (2013).

4.1 Grade Not Based on Performance in Simulation

While students' grades can be based on a variety of measures, depending on instructor preference, we choose to grade students not directly on their performance in managing the factory. Rather, we base their evaluation on a report the group turns in a week after the simulation has finished. Individual student grades may be adjusted based on team member feedback, for example using the online tool CATME (Ohland et al. 2012).

We have students turn in different types of reports in our classes. The first author requires a higher-level executive summary, the second a report based on the template outlined in Snider and Balakrishnan (2013). In both cases, students are given templates or grading rubrics to help in writing an effective report. The first author awards 0.5 of 10 points for the simulation for students completing the grading rubric as part of their deliverables. Students are graded not only based on the content of their reports but also on the grammar and writing. Where necessary, we provide students with information on campus writing resources.

While students' performance on the simulation is of secondary importance, as we consider it a learning tool not an assessment mechanism, it can be useful to provide some incentive to students to try to achieve good results. For example, the top team in the class may earn an extra point (out of 10) for "winning" the game.

4.2 Setting Early Deadlines

The main administrative task associated with running the simulation is having students purchase their access codes, form groups, and register each group member. To ensure students complete each step before the simulation begins, we try to set early deadlines so missing a deadline does not immediately imply significant consequences. The first author also awards extra credit points for students meeting the earliest deadline for registration.

4.3 Preparing for the Game

In addition to reviewing the purpose and mechanics of the game before playing it, we have found it useful to have students prepare beforehand by completing a homework assignment in which they forecast demand (for the Capacity Management game). To do this, they are given demand data from the first 50 days of the simulation and are asked to plot the data, identify any data pattern present in the data, select an appropriate forecasting method, and forecast out a number of periods. We have found that this pre-assignment helps the students get started with analysis of the data immediately after the game begins.

4.4 Group Dynamics

Because students are working in groups, we have found it helpful to provide students tips on how to interact with their groups in order to improve the group's effectiveness. These tips include determining:

- The process for making decisions (deciding as group or assigning certain members to make certain decisions).
- The means of communication (meet physically or via phone/chat or email).
- The frequency of checking the factory and making decisions.

In addition, we review general communication courtesy, such as acknowledging receipt of messages even if one has nothing to contribute to the conversation. We have found that this process is valuable for students, as many have not considered the implications of effectively working in groups, despite being required to do so in many of their business classes. Because of the limited time available, we do not have the opportunity to devote (more) time to teaching students explicitly about group work and maximizing the team's effectiveness.

4.5 Debriefing After Game

After the simulation has ended, students are eager to hear the strategies other teams have employed, especially the winning team. We have 2-3 teams describe the approach they took, and discuss as a class what did and did not work. In the future, we might consider a more formal approach to debriefing, such as the one suggested in Pavlov et al. (2015).

Some common lessons that come out during the debriefing session and during less formal conversations with students are:

- The importance of taking action early and proactively, rather than reactively. Especially for the first game, it is critical to have sufficient capacity in place before it becomes necessary. The teams that did not do so are never able to catch up to those that did.
- The danger of operating at 100% utilization.
- Good team communication is a significant factor in the team's ability to succeed.
- Even though more machines are necessary, it may not make financial sense if there is not enough time left to recoup the capital investment.
- If a system is "in trouble," (*e.g.*, operating at capacity), it must be stabilized before other changes are made: For the second game, teams often choose the contract with the shortest lead time (and highest possible revenues) before addressing the stockout and additional capacity problems. This results in a prolonged period of time in which the factory is not making any money.

5 BENEFITS

The literature has shown many benefits from using games in the classroom (Wood 2007). In our specific case, there are two main advantages.

5.1 Increased Engagement

Because of the competitive nature of the game, some students find themselves strongly drawn to the game, compulsively checking their status. Especially in the second game, many of them actively try to apply the material they have learned in class to improving their system's performance.

Anecdotally, students have reported liking the ability to see the consequences of their actions. Rather than just being marked "correct" or "incorrect," they experience what the result of a less-than-ideal decision was. Because other teams are also competing, they can compare their current status with that of other teams. The simulation also includes a default "do nothing" team, so students can see whether their actions have been more or less beneficial than a hands-off approach.

5.2 More Realistic Application

One of the challenges in an overview class is that there are many required topics, which leaves little room to go into depth. Textbook problems, especially if using online homework systems, can be very simplistic – and thus quite unrealistic.

The simulation allows a direct application of material learned, but in a more realistic setting: Rather than being presented with equation parameters, students must independently derive them. This can be nontrivial: To find the service rate at station 1, students must estimate the arrival rate and utilization, solve the utilization formula for the service rate, and do the calculation. Some students struggle with these seemingly simple tasks because they are not accustomed to having to download (messy) data and use a spreadsheet to do calculations. Because the simulation is not being presented in a specific chapter (for example, the Inventory Management Chapter), students must also first determine the type of problem(s) facing them. This in itself requires a level of curiosity and proactiveness that we do not ask of our students often enough.

While students are grappling with determining the right model and applying the appropriate formulas, they are also faced with having to think more deeply about the possible consequences of their actions. Groups have overpurchased machinery, leaving them with insufficient money to buy raw materials. They have stabilized the bottleneck at one station, not realizing that it may shift the bottleneck to elsewhere in the facility. One very common mistake in the first game is to notice the problem with job lead times and purchase additional machines at station 2, because each job goes through the station twice for testing. They do not consider that multiple visits *per se* do not imply a problem; indeed, station 2's utilization is quite low, at around 50%, before the unnecessary additional capacity is purchased.

6 CHALLENGES

While there are benefits to using simulation in a class like this, there are also challenges.

6.1 Administrative Overhead

The administrative overhead of running the simulation can be significant. At the beginning of the semester, students are confronted with a variety of different "codes" (simulation access code, simulation course code, online textbook code, add code) and can become confused. Ensuring students *both* purchase the access code and register with their team can require patience.

As is often the case with student groups, some team members are more engaged than others are. This can become frustrating when groups are trying to coordinate meeting times to play the game or write their reports.

6.2 Student Engagement

While many students become enthusiastic players, a not insignificant number are too busy and fail to "see the point" of playing. This can lead to discontent within the group, especially if some members feel they are contributing more than others in the group are.

6.3 Increased Instructor Workload

The final challenge is that of increased workload for the instructor. In addition to the administrative tasks, the simulations generate additional deliverables from students, deliverables that must be graded. This can be especially onerous for instructors that do not have the support of teaching assistants or graders.

7 STUDENT RESPONSE

While there are always students who do not feel the activity worthwhile (from course evaluations, "Getting rid of the simulations. I didnt [sic] get much from them"), the students that engage develop a much deeper and richer understanding of the course material, and are glad to have had the opportunity to apply what they learned in this way. From the course evaluations at the end of the semester, in response to the prompt "The most effective attributes (characteristics) of the instructor's teaching were," students wrote: "She had us use simulations that helped us understand how each new thing she taught was used and everything was clearly explained," "the simulations assignment which really got us involved in the activities of Operations Management by being participants," and "the Littlefield Labs simulations were excellent exercises that helped incorporate each topic learned in the course."

We have not recently conducted formal surveys to systematically assess students' perceptions of the games. Miyaoka (2005) reports on the results of a survey conducted in 2004:

> The students were asked to indicate how strongly they agreed with three statements with 5 representing "strongly agree" and 1 representing "strongly disagree." The three statements and the average results of 67 evaluations are listed in [Table 1].

Table 1: Average of student ratings in response to survey questions, from Miyaoka (2005).

Question	**Average response**
These games contributed to my understanding of capacity management and inventory management.	4.1
In these games, I frequently found myself actively thinking about the simulation game and what decisions I should make.	4.2
As a result of these simulation games, my interest and curiosity about operations management has increased.	3.9

8 CONCLUSION

Despite the additional administrative overhead and the additional grading, we feel that the benefits outweigh the drawbacks of using the simulation in our operations classes. While Littlefield Technologies might not be the right choice for every operations class, we encourage instructors to consider it and other ways to engage students in the classroom.

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REFERENCES

Costantino, F., G. Di Gravio, A. Shaban, and M. Tronci. 2012. "A Simulation Based Game Approach for Teaching Operations Management Topics." In *Proceedings of the 2012 Winter Simulation Conference*, edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, 1564-1575. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

CSU. 2015. "The California State University Mission." Accessed accessed May 2, 2015. http://www.calstate.edu/PA/info/mission.shtml.

Ezz, I., C. Loureiro-Koechlin, and L. Stergioulas. 2012. "An Investigation of the Use of Simulation Tools in Management Education." In *Proceedings of the 2012 Winter Simulation Conference (WSC)*, edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, 1-14. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Forrester, J. W. 1958. "Industrial Dynamics." *Harvard Business Review* 36 (4):37-66.

Lee, W.-L. 2011. Spreadsheet Based Experiential Learning Environment for Project Management. Proceedings of the 2011 Winter Simulation Conference.

Mehrotra, V. 2007. "Living (and Learning) in the Digital World." *OR-MS Today* 34 (6):14.

Miyaoka, J. 2005. "Making Operations Management Fun: Littlefield Technologies." *INFORMS Transactions on Education* 5 (2):80-83.

Ohland, M., M. Loughry, D. Woehr, C. Finelli, L. Bullard, R. Felder, R. Layton, H. Pomeranz, and D. Schmucker. 2012. "The Comprehensive Assessment of Team Member Effectiveness: Development of a Behaviorally Anchored Rating Scale for Self and Peer Evaluation." *Academy of Management Learning & Education* 11 (4):609-630.

Pavlov, O. V., K. Saeed, and L. W. Robinson. 2015. "Improving Instructional Simulation with Structural Debriefing." *Simulation & Gaming*.

POMS. 2015. "POMS Education Resources." Accessed June 30, 2015. http://www.poms.org/education/.

Roeder, T. M., and R. M. Saltzman. 2014. "Schedule-Based Group Assignment Using Constraint Programming." *INFORMS Transactions on Education* 14 (2):63-72.

SFSU. 2015a. "SFSU Enrollment Facts." Accessed accessed May 2, 2015. http://www.sfsu.edu/~puboff/sfsufact/archive/1415/students.htm.

SFSU. 2015b. "SFSU Mission." Accessed accessed May 2, 2015. http://www.sfsu.edu/~puboff/mission.html.

Snider, B., and J. Balakrishnan. 2013. "Lessons Learned from Implementing Web-Based Simulations to Teach Operations Management Concepts." *INFORMS Transactions on Education* 13 (3):152-161.

Wood, S. C. 2004. "2004 Skinner Teaching Award Winner: Littlefield Technologies." *POMS Chronicle* 11 (3-4):7-8.

Wood, S. C. 2007. "Online Games to Teach Operations." *INFORMS Transactions on Education* 8 (1):3-9.

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