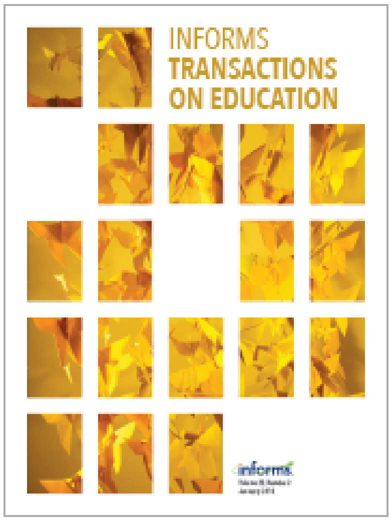

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Game

The Zu Zitter Game: A Course-Long Tool for Teaching Operations Management

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The mix of quantitative and qualitative material covered in most introductory operations management (OM) courses proves particularly challenging for many business majors and MBA students as well as for their instructors. Additionally, students with less work experience may struggle to see how topics such as process design and layout, capacity planning, quality management and control, inventory management, process improvement, and lean principles are integrated in a "big picture" way when applied in practice. In this paper, I describe the Zu Zitter Game, which places student teams in charge of all aspects of a production process and encourages them to actively integrate new material as the course progresses. It culminates in a fun, hands-on experiential learning "game day" event that brings the concepts taught in the course together and illustrates how they must be managed cohesively. Students' feedback has been very positive; in particular, they rate it very highly for improving their "big picture" understanding of OM topics.

Keywords: operations management; games; experiential learning; production; active learning
History: Received August 2013; accepted November 2014.

1. Introduction

Many business students, at both the undergraduate and MBA levels, struggle with quantitative courses such as statistics, calculus, accounting, and finance. Others struggle with more qualitative courses such as marketing, strategy, and governance. The difficult challenge faced by instructors of operations management (OM) courses is the mix of both qualitative and quantitative material that they cover.

Additionally, learning to design, maintain, and improve operational processes requires not only mastery of a varying array of techniques but also the ability to see and apply them together in a "big picture" way. Much as individual courses cannot be viewed as separate knowledge silos, the methods within an OM course cannot be viewed as distinct and disjointed. Instructors must provide a way for students, especially those with little work experience, to get a feel for how these pieces fit together in practice.

Many instructors, practitioners, and researchers have developed games to illustrate individual concepts in courses on OM and related fields like supply chain management, operations research, and management science. Probably the best known is the classic Beer Game developed at MIT (Sterman 1989) that illustrates the importance of information sharing within supply chains. However, although beneficial for understanding individual concepts, few of these games represent course-encompassing activities designed to bring the material within a course together.

In this paper, I describe the Zu Zitter[1] Game that I have developed for my MBA-level Production and Operations Management course. It provides students the opportunity to make decisions in a more hands-on environment and shows them that the principles covered in the course can be applied to effectively manage the situation faced, just as they can in the "real world." Although the graded portion, a 2-1/2 to 3 hour game, is played at the end of the course, additional time (typically, 3 to 4 hours, in total) is also provided during the course for teams to actively incorporate new knowledge and to test their initial ideas.

Concepts considered by teams will depend on the material covered in a particular course, but a typical OM course would include topics such as process

[1] Zu Zitter Carzay is copyrighted by Turner Entertainment Co. in the 1966 animated television version of Dr. Seuss' *How the Grinch Stole Christmas*. Grinch® and Mount Crumpit, as well as any other similarly silly terms used throughout this paper, are copyrighted by Random House, Inc., in the original 1957 text. Their use here is merely for fun and is not intended to provide any additional real value to students or readers.

design and layout, capacity planning, quality management and control, inventory management, process improvement, and lean principles. Students' ability to apply some of these concepts may be more limited than their ability to apply others, requiring some creative solutions. However, the options are almost unlimited and there are many "right" answers.

The target participants for this game are upper-level undergraduate or first-year MBA students enrolled in an introductory OM course. In particular, students with little working experience would stand to benefit the most from the hands-on experiences. It should be noted that the game has not been run in an executive MBA setting, in which students would be expected to have considerable experience. Even in such courses, though, the students' experiences may be in areas other than OM, such as finance, accounting, or marketing, so instructors would have to determine the applicability themselves.

Although, to date, it has only been run with classes of fewer than 40 students, the game is reasonably scalable for larger classes. The biggest limitations are the cost to acquire or time to produce sufficient raw materials as well as the physical space requirements. The latter can be mitigated by splitting larger classes into smaller game sessions, as is commonly done with the Beer Game.

An important strength of the Zu Zitter Game is that it immerses students in a "real" process. They get to see or even participate in the conversion of materials into finished goods and watch the flow of product through the system. Unfortunately, although it would be possible to simulate the process for online courses (including massive open online courses), the actual experience would be less effective. Instructors of those courses should consider other alternatives.

The remainder of the paper is organized as follows: In §2, I provide a brief survey of the relevant literature. Next, I outline the Zu Zitter Game in §3, detailing the basic product, materials ordering, and resource decisions. In §4, I describe the work done throughout the semester to prepare for the final game, which I describe in §5. Experience and feedback from previous runs is summarized in §6. I finish with conclusions and suggestions for future extensions in §7. Several supplemental documents are provided, but in particular, an instructor-only file provides more sensitive material that students should not view (available as supplemental material at http://dx.doi.org/10.1287/ited.2015.0138).

2. Literature Review

In the 1963 edition of *The Handbook of Research on Teaching* (Gage 1963, p. 1125), McKeachie made the now well-known observation that "college teaching and lecturing have been so long associated that when one pictures a college professor in the classroom, he almost inevitably pictures him as lecturing." Similarly, on encouraging active learning—their third principle of good practice in undergraduate education—Chickering and Gamson (1987, p. 5) noted that "learning is not a spectator sport. Students do not learn much just by sitting in classes listening to teachers, memorizing prepackaged assignments, and spitting out answers." The authors recommend that students be actively engaged in problem solving and analysis. Prince (2004, p. 223) defines "the core elements of active learning [as] introducing activities into the traditional lecture and promoting student engagement." The game described herein is a way to accomplish both of these elements.

Experiential learning, which one could consider a subset of active learning (see Snider and Balakrishnan 2013, Figure 2, for a compiled breakdown of student learning), originates with Kolb (1984, p. 38), who states that "learning is the process whereby knowledge is created through the transformation of experience." The author details the cycle by which students learn through and from experience. The four phases of this cycle are: concrete experience, reflective observation, abstract conceptualization, and active experimentation.

In Gentry (1990), the editor expands on this process, incorporating three works—Carter et al. (1986), Wolfe and Byrne (1975), and Hoover and Whitehead (1975)—to define the critical components of experiential learning for schools of business: business curriculum-related; applied; participative; interactive; whole-person emphasis; contact with environment (may be "surrogate" experience, which is "real-world-like"); variability and uncertainty; structured exercise; student evaluation of experience; and feedback. The Zu Zitter Game meets each of these requirements in an attempt to improve learning of OM methods.

The benefits of games in courses for the related fields of operations management, operations research (OR), and management science (MS) have been discussed by several authors. Sniedovich (2002), for example, notes the lack of attention given to games in the OR/MS literature despite their clear educational benefit and then makes the case for why these fields are particularly well suited for them. Griffin (2007), in an introduction to a special issue on OR/MS games, likewise makes the case for their inclusion and then characterizes what makes a successful game: easy to implement, encourages interaction around OR/MS principles, and generates discussion once completed. The game I present here has shown to achieve the latter two and, though slightly more complicated than the Beer Game given as an example, requires only staples, staplers, and paper strips to play. Ben-Zvi and Carton (2007) also discuss the benefits of simulation games in teaching MS, specifically referencing existing learning taxonomies, and then describe their experience with a specific game course given at the end of an MBA program. Wood (2008) discusses some of the advantages of online games (and, implicitly, the disadvantages of in-class games). Although the listed advantages, such as the reduced setup for instructor and learning curve for students, are certainly worth consideration, in the case of the Zu Zitter game, the ability of students to see the progression of physical goods from the supplier to the production process to the customer seems to provide sufficient benefit to students to outweigh any disadvantages (see the students' comments in §6).

In addition to the aforementioned Beer Game, other examples of games designed for OM (and related) courses include the following: Robinson and Robinson (1994) describe a set of tabletop experiments widely utilized in both courses and corporate training in Japan to provide managers with insight into work-related (experiments attributed to Frank and Lillian Gilbreth) and process-related (experiments attributed to Taiichi Ohno and Akira Totoki) issues. Heineke (1997) discusses how games provide operations courses with a theme and then gives an example of such an exercise, the Paper Puppets game. Pendegraft (1997) illustrates the process of linear programming by fabricating tables and chairs from Lego® parts. Anderson and Morrice (2000) demonstrate the value of information sharing in service supply chains with a game. Chen and Samroengraja (2000) provide a stationary version of the Beer Game. Kumar and Wood (see, for example, Wood 2004) developed a web-based, real-time production game in which teams compete in running a plant, including making ordering and capacity decisions. Drake and Mawhinney (2006) use another Lego-based game to reveal the benefits of cooperation in supply chains. Polito et al. (2009) present an opening-day simulated factory demonstration, Zarco Incorporated. Talluri (2009) uses "customer" (student) valuations of a desirable product (e.g., a cruise) to demonstrate several facets of revenue management. Wright and Ammar (2009) summarize several OM games, including some of their own design. Allon and Van Mieghem (2010) illustrate the concept of dual-sourcing with a game in which students source a product from both Mexico—responsive, but expensive—and China—slow, but inexpensive. Finally, D'Amours and Rönnqvist (2013) describe a collaborative logistics game focused on negotiations and coalitions in transportation. As noted in the Introduction, unlike most of these games, the Zu Zitter Game is designed as a course-long, hands-on activity in which the material is brought together.

One exception worth noting is Gray (2011), who also describes a course-long, hands-on activity. In particular, teams of four or five students must design a simple product and then work on improving the production process from the starting point of a craft shop. Although the intent is similar to the Zu Zitter Game, the implementation is quite different. In that game, the teams work independently on their own product and process, making a final presentation at the end of the course. In the Zu Zitter Game, teams work on developing the process for the same product, ultimately competing head-to-head to satisfy actual (simulated) demand in (compressed) real time. The nature of the Zu Zitter Game, however, allows for easy incorporation of new elements, and so any of these works can serve as a source for instructors to generate new ideas.

3. Game Description

In the Zu Zitter Game, each team of students takes on the role of a manufacturing team at Grinchy Manufacturing Incorporated (GMI), a for-profit manufacturer located on snowy Mount Crumpit. GMI's President and CEO, played by the instructor, has selected them for their (soon to be acquired) extensive knowledge of OM principles and tasked them with producing the highly demanded Zu Zitters. As with all for-profit corporations, GMI's goal is to maximize profits, and students are given carte blanche (full authority) to make decisions about process design and layout, scheduling, product mix, quality management, and material ordering in order to achieve this goal.

3.1. Product Variants

The basic product (see Figure 1), the Zu Zitter, is composed of two blue rings, each constructed from a rolled 8-1/2" × 3/4" strip of "steel" (paper),[2] assembled perpendicular to each other and "welded" (stapled) in the area where the ends overlap. Additionally, one 5-1/2" × 3/4" strip of yellow steel is folded and then welded in perpendicular to one of the primary rings (and, thus, in line with the other primary ring).

In addition to the basic Zu Zitters, there is a market for the special Zu Zitter Carzays. These high-end models include an additional ring, the Carzay, which is constructed from a rolled 5-1/2" × 3/4" strip of either red or green steel (depending on customer requirements). This special ring is attached inside of and in line with the primary blue ring that does *not* contain the folded yellow strip using one (and only one) color-coded welding wire.

Although there are numerous technical specifications that must be met (see §3.4 for details), the order of the production steps is not specified. In particular, though each ring and folded strip must be

[2] For information on paper selection and for metric equivalent strip sizes, please see the game teaching note.

Figure 1 Zu Zitter Product Variants

attached to another element at the connection point, the order and number of welds (with the exception of the Carzay's color requirement) is not limited. For example, one could theoretically bend all of the strips necessary to complete a Zu Zitter Carzay and then use one color-coded staple to attach them all together. However, this would be extremely difficult to do quickly while maintaining quality, so productivity would suffer. Conversely, additional welds may facilitate a more efficient process design but come at additional material cost.

The design of the product has been selected to allow students to utilize any one of numerous possible variations in process design as well as in product mix strategy. This provides flexibility in planning and eliminates the "one right answer" scenario. Certain elements have also been chosen for a particular desired effect. For example, the yellow strips were added because their orientation is less intuitive, requiring students to consider how they may ensure that they are installed correctly. Similarly, the color-coded stripes require a changeover in the welder. In general, however, it has been designed so as not to be overly complicated to construct, allowing students to focus on the many other operational decisions that they will need to make, such as inventory management.

3.2. Customer Demand

The market for Zu Zitters is in the maturity phase of its life cycle, so the prices are fixed and the demand is relatively constant over time. However, from week to week, realized demand does fluctuate. Means and standard deviations for the distributions of demand for individual products (see Table 1 for an example)—assumed to be independent—are provided to students at the beginning of the course (see §7 for an alternative approach). Inventory (works in progress or finished goods) may be carried over from period to period to satisfy future demand, but units produced in subsequent periods may not be used to satisfy previous periods' unfilled demand. Although the possibility of backorders is not precluded by the game design, incorporating a system for students to track and satisfy previously unfilled demand would add another layer of complexity.

Table 1 Sample Values for Demand Process

Item	Weekly demand: Average	Weekly demand: Std. dev.	Selling price ($)	Pr[accept base]
Base Zu Zitter	14	3.8	200	1
Zu Zitter Carzay (red)	7	2.7	275	0.25
Zu Zitter Carzay (green)	8	2.9	275	0.30

Customers in the high-end market are very particular and will only accept the correct color Carzay (e.g., a green Zu Zitter Carzay cannot be used to satisfy demand for a red Zu Zitter Carzay). However, some customers may be willing to accept a base Zu Zitter, if the correct color is not available, at the lower associated price and, by design, margin. The probability of a random Carzay customer accepting a base model is also provided for each color (see Table 1). This possibility allows students to consider strategies based on high volume at lower margins. The instructor could choose to further emphasize the effect that this possibility would have by selecting a larger difference in the probabilities for the two colors.

3.3. Materials and Resources

Materials are ordered from two suppliers. Steel strips are ordered from Whoville Steel and can be ordered in any quantity with a guaranteed short lead time (typically, one week, though a Beer Game like Shipping Delay could be used to simulate longer lead times). In addition to the unit purchasing cost, a unit shipping cost is incurred.

There is also a fixed processing fee that is charged to place an order, regardless of quantity or mix. Furthermore, since the manufacturer cuts the strips specifically for each order, there is an additional fixed setup fee for each color in the order (see Table 2 for sample costs).

Welding supplies are sourced from Max Welker Welding Supplies. The basic (silver) welding wire

Table 2 Sample Values for Materials Ordering

Item	Order processing fee* ($)	Color setup fee ($)	Unit price ($)	Unit shipping cost ($)
Steel strip—Blue, 8-1/2" × 3/4"	10	40	20	5
Steel strip—Yellow, 5-1/2" × 3/4"	10	40	15	5
Steel strip—Red, 5-1/2" × 3/4"	10	40	35	5
Steel strip—Green, 5-1/2" × 3/4"	10	40	35	5
Basic welding wire—50 count	100	—	75	15
Red welding wire—100 count	100	—	200	30
Green welding wire—100 count	100	—	200	30
Welder (stapler)	—	—	50/week	—

*Paid once per order, regardless of number of colors ordered.

(staple) required to complete most welds is sold in 50-count strips (the usual size in the boxes provided with mini staplers). Color-coded welding wires, in red and green, are also sold in strips, though the number in each will depend on which brand the instructor purchases (for example, Swingline® sells "color bright staples" in packs that include red, green and blue staples in strips of 100; note that this also gives the instructor the option of requiring a blue staple in each base model). Order processing fees, setup fees (if applicable), unit costs, shipping costs, and lead time are provided (see Table 2 for an example) for this supplier as well.

The ordering and setup fees for the raw materials can be selected to focus students' attention on certain aspects of the decision process. For example, a small order processing fee and large setup fees are usually used for ordering steel in order to *almost* separate the ordering decisions for the individual colors. This allows teams to initially focus on how they would order each separately (the basic problem) and then start to look at how combining orders might affect the decision processes (a more advanced step). Conversely, to avoid overcomplicating the whole process, welding wires might simply be charged a single order processing fee without any individual fees. Since the relatively low usage of red and green wires means that they might only be ordered once throughout the horizon, the ordering decision is then largely driven by the base wires.

Each team must also decide the number of welders (staplers) to rent from Max Welker at the provided weekly rental rate. Although the supplier will replace malfunctioning welders at no cost, replacements will not be available until the end of the current week. Teams must, therefore, consider renting not only the number that will be necessary to run their processes but also as many spares they may need to handle midweek breakdowns. Typically, the instructor will provide the staplers to be used (the "mini" style staplers available from several retailers seem to work best and are relatively inexpensive); students are not allowed to bring their own. Time permitting, a discussion of the use and calibration of employee-owned tools can be used to demonstrate the value of such a requirement.

Finally, teams have the flexibility to assign two to four members to their production process, but each student so assigned is paid a weekly salary rate (e.g., \$300/wk). Since there is an inherent hiring lead time in most production processes, this number is fixed over the horizon of the game. Students assigned as nonproduction personnel (see §5.2 for typical nonproduction roles) are assumed to be part of a larger management team with a combined fixed overhead cost (e.g., \$500/wk) independent of the number so assigned. This focuses students on the resource decision associated with production capacity, requiring them to justify the additional workers' wages with a sufficient increase in expected revenue. It is important, therefore, that the instructor not choose demand levels that are so high that "as much as possible" is the obvious choice of capacity.

GMI is assumed to have access to sufficient cash to cover any inventory purchases, wages and rental fees. However, GMI's cost of capital (e.g., 20% annually) is provided, so students must consider the opportunity cost associated with holding any inventory (materials, work in progress, and finished goods). Additional carrying costs (e.g., insurance, warehousing, theft, damage, etc.) should be also included in order to provide a more realistic cost of holding inventory.

3.4. Defective Units

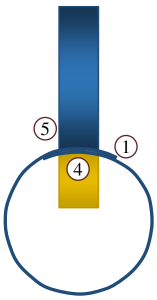
Determining how to manage product quality is an important aspect of the game. Teams are provided with detailed specifications to which the Zu Zitters must be produced, and units not meeting these requirements will be considered defective. Evaluation and rejection of defective units is done by the instructor following the game. Whereas units with small deviations from the specifications may or may not be rejected, noticeably defective units will be returned for a full refund of the selling price with no opportunity to be replaced. Additionally, teams will be assessed a good will lost penalty (for example, \$3) for each rejected unit. Therefore, effective quality management is critical for success.

In particular, the specifications[3] require that the circumference of each blue ring be 7-1/2" and the circumference of each Carzay ring be 4-3/4". The tolerance of each measurement is ±1/8", meaning that the overlap of material at the weld should be between 7/8" and 1-1/8" on the blue rings and between 5/8" and 7/8" on the Carzay rings. Notice that the strips are 3/4" wide, which is outside of the specification limits for the overlap on the blue rings, so there must be a noticeable difference (longer) between the overlap of each ring and the width of the opposing ring. The first mistake made by many teams is using the width of the first ring to guide the overlap of the second, and pointing it out serves as the initial signal to them that the specifications must actually be adhered to.

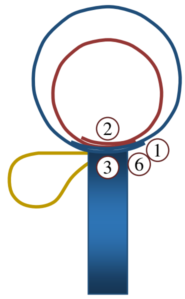
Further, the specifications call for the two blue rings to be perpendicular (90° angle of intersection) to each other, for the folded yellow strip to be perpendicular (again a 90° angle of intersection) to one primary ring, and for any Carzay ring to be in line (0° angle

[3] For metric equivalent specifications, please see the game teaching note.

Figure 2 **Inspection Checks**



(1) Overlap in blue rings within spec?
(2) Overlap in Carzay ring within spec?
(3) Blue rings perpendicular to each other?
(4) Yellow strip perpendicular to blue ring?
(5) Edge of Carzay ring aligned with edge of blue ring?
(6) Yellow strip end aligned with edge of blue ring?



of intersection) with the other primary ring. Each of these angles has a tolerance of ±3°.

Finally, each Carzay ring is required to line up, edgewise, with the blue ring in which it is installed. Likewise, the end of the folded strip must also line up with the edge of the primary ring in which it is installed. The edge-to-edge difference may not exceed 1/16". Figure 2 summarizes the technical quality checks.

In addition to violations of these technical specifications, any Carzay model without a color-coded welding wire, with more than one color-coded welding wire, or with the wrong color welding wire will be consider defective. Base units, of course, should not have any color-coded welding wires (unless the instructor adds the requirement of a blue staple in each one).

4. In-Class Activities

The Zu Zitter Game is first introduced to students during the initial class of the course. As an opening to the breadth of OM concepts that will be covered, the instructor shows a completed unit to the students and poses the question "If we wanted to produce these, then what decisions would we need to make?"

After the general discussion of OM that follows, an overview of the game similar to the one provided above is presented to the class (see Example-Handout.doc in the online supplement). Introducing the game to students early in the course has several advantages, including allowing students to see the direction in which they are headed and preventing them from settling too quickly on a final set of strategies, as they might do were it introduced later in the course when they would be faced with greater time constraints.

4.1. Team Selection

The teams are also formed very early in the course so that they may work together throughout the semester. Numerous methods exist for forming teams, including student selection; random assignment; grouping based on personality (e.g., Rutherfoord 2006); or even, as Borges et al. (2009) describe, algorithmically for simultaneous optimization of intra-group heterogeneity and inter-group homogeneity. Assigning students to teams also forces them to figure out how to work together for a common business objective, as they will be when they are members of a management team in the "real world." However, the different methods have their own strengths and weaknesses (see Scott and Cross 2005, for example), which should be considered.

Depending on the size of the class, teams of six students usually work best, providing sufficient students to effectively cover both production and nonproduction tasks. For very small classes, teams with as few as four members could be utilized, but compromises would need to be made. For example, some nonproduction roles might need to be combined or excluded. Additional time would also need to be given between production windows for teams to handle all of the nonproduction activities.

Frequently, it is not possible to create teams of equal size. In such cases, the "extra" members from larger teams may be utilized as floaters to help count orders for smaller teams in addition to helping their own team.

Once the teams have been formed, they should be encouraged to select team names, which adds to the spirit of team competition. In the game example given in §5, the teams were named *Mission Possible*; *All Things Rings*; *Zoom*; *Cupcake*; and *Red Fish, Blue Fish*.

4.2. Incorporating New Material

As new material is introduced throughout the course, time is allotted for teams to discuss how it may be applied in the game. Hints and suggestions may be provided by the instructor, but remember that the purpose is to allow students to think about the material for themselves. See the game teaching note for examples of what students have done in previous sessions.

Depending on the topics covered in the particular course, questions may arise that will force students to look "outside the box" for solutions. A big advantage of the game is that outside of a few key methods, it is very flexible as to the inclusion of various OM concepts.

In addition to the time allotted for team discussion, an abbreviated run (four or five simulated weeks) of the game day experience described in the next section is run mid-course, when sufficient material has been covered for students to have a rough plan in place, but with enough time left to work on ways to improve their process based on their experiences. Extra time should be given to allow teams to consider and implement changes during these weeks. The results of this run are not factored in the performance portion of the grade but instead are meant to familiarize students with how the game is actually played as well as to give them a baseline for their process from which improvements can be made. This latter part may be included in the full strategy report as part of teams' justification for their final process.

5. Game Day

The game, itself, occurs at or near the end of the course and is used to determine the performance portion of the grade. Students implement their final process strategies over an extended horizon. This final run requires a couple of hours for the students to play as well as an additional hour for the instructor—preferably aided by a teaching assistant (TA)—to verify the output and assess the quality. For classes with shorter scheduled durations (e.g., 75 minutes twice per week), the game horizon could be split over two sessions or the instructor could choose to run it outside of the normal class time (allowing at least three hours to play the game and to assess quality).

5.1. Prepared Materials

Prior to the final session, teams are instructed to email an initial (pre)order for inventory that will be available for use in week 1. Normal ordering costs apply, but there is no lead time. Alternatively (and for the midterm practice round), the instructor may choose to provide all teams with the same level of starting inventory, about which the teams would be informed ahead of time. This inventory, as well as the requested staplers and a sufficient stack of blank order forms (see Figure 4 and ExampleDemandOrderForms.doc for a sample order form) to cover any reasonable game length, will be placed at each team's table by the instructor during the initial setup.

In addition, teams should plan whether or not they will need to place an order at the start of week 1, which will be available for use at the start of week 2. The corresponding order form—even if no order is to be placed—must be filed before the game may begin.

Finally, teams must turn in a strategy report that outlines their plans for running the game. This should include an overview of their production process, resource/capacity (labor and welders) planning, inventory ordering process, quality management/control strategies, and risk management approach. When the time remaining in the semester allows, teams may be asked for simply a summary report at this time, saving a full report for after the game is run. In such cases, bullet points may be allowed; however, sufficient detail should be required to ensure that students have put the necessary effort into planning their strategies and are not simply "winging it" during the game. As with a real production facility, teams are free to adjust their strategies as the game progresses, but a well-planned set of initial strategies is still critical for success. If time does not allow for students to turn in a report after the game (for example, if the game is run at the very end of the course with final grades due shortly thereafter), then teams must turn in a complete, detailed analysis prior to the start of the game.

5.2. Team Roles

Within the report, each team should also clearly define the roles that its members will be playing during the game. Though some flexibility in roles must be provided to account for teams of different sizes and to allow teams to select differing number of production workers, they should generally be derived from the typical roles provided to the students:

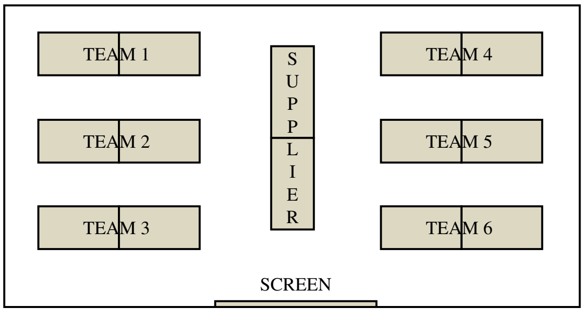
- *Line Supervisor*—monitors demand, directs the production staff, determines the final order fulfillment, and files the purchase orders and demand slips. May also serve as team leader during the semester.
- *Production Worker*—participant in the actual production process.
- *Quality Manager*—responsible for quality control in the production process. The quality manager may inspect materials or units, disassemble units (partially or fully) for scrap or rework, assist in investigating the root cause of defects, and direct production personnel to complete such rework or implement process changes. The Quality Manager may *not* participate in production itself or completing rework.
- *Inventory Manager*—responsible for "receiving" orders (including counting out inventory at the supplier table), releasing materials to production, monitoring inventory levels, determining order quantities, and filling out the purchase orders.

Even if their selected roles are not exactly as described above, teams must adhere to the spirit of the limitations in the list. Additionally, although students are allowed to swap into production to give teammates a break, there should be a clear delineation between production and nonproduction members within a given simulated week. Both requirements are critical to fairly and accurately calculating each team's production cost.

5.3. Game Setup

A large room with movable tables works best so that each team may be given a dedicated area in which to work. Raw materials (e.g., paper strips) should be placed in a central supplier location, easily accessible by all teams (see Figure 3 for a sample layout, where each team is given two 72" × 30" tables). Additionally, a screen displaying a countdown clock (http://www.online-stopwatch.com, for example, provides such a clock with an audible alarm) should be visible to all teams. In the game, each production "week" will be

Figure 3 Sample Room Layout for Six Teams



a timed interval, and it is critically important that all teams are aware of the start and end of each interval.

Teams should be given some time to set up their production facilities (tables) as they see fit. One area must be dedicated for raw materials receiving/storage, another for the production process, and a final one for finished goods storage (see the game teaching note for some discussion of potential layouts). When physically possible, teams should be allowed to move their assigned tables around to facilitate the layout of their choosing.

Any jigs, bins (fixed or rolling), rulers, or other such devices selected by teams to improve the quantity and quality of production may also be installed during setup. Lastly, the instructor may provide or require to teams to bring bags or bins for holding shipped goods.

5.4. Game Play

Once the teams have their "factories" set up and their reports/orders have been turned in, the game progresses as follows:

At the start of each week, after verifying that the previous week's shipments have been made and that new inventory orders have been placed, the instructor indicates that the production window for the week is beginning and then initiates a two-and-a-half minute countdown clock. During this time, while the Production Workers work on producing units, the Inventory Manager should release material to the floor and count out the order being filled at the supplier table. Likewise, the Quality Manager may check any raw material, work-in-process, or finished goods inventory; assist in investigating any quality issues; and direct the production members to complete any rework or make any process changes that may be needed.

The production period ends when the countdown clock reaches 0:00, usually with an associated alarm. No production work may be completed after this point until the next week's window begins. Any work-in-process inventory must remain where it is in the production process until work recommences. Only

Figure 4 Sample Demand Slip Completed with Shipped Units

Team: Red Fish, Blue Fish Week: 20

Product	Weekly demand	Will accept base	Units shipped		
			Base	Red	Green
Zu Zitter (base)	15	15	16		
w/Red Carzay	8	2	1	4	
w/Green Carzay	6	1			6
	Total shipped:		17	4	6

units that are totally completed will be available to fulfill orders.

Each team is then provided with a Customer Order Slip (see Figure 4 and ExampleDemandOrderForms.doc) for the week, which provides the realized demand for each of the three product variants during that week, randomly generated from the provided distributions. For each of the two Carzay models, the number of customers willing to accept the base model at the lower profit margin is also provided; it is randomly generated using an inverse binomial distribution function on the realized demands.

For the game to be as fair as possible, all teams face the same demand in a given week. An exception would be if concurrent sections of the same course were playing the game at different times. To avoid potential cheating, the instructor might consider giving each section a similar but distinct stream in such cases.

A reasonable amount of time (usually, a few minutes) is provided to allow for the Line Supervisor to determine and record the number of units shipped (see the red/script markings in Figure 4); for the Inventory Manager to deliver the previous order into the raw materials storage area and to determine what, if any, orders need to be placed (see Figure 5); and for team members to discuss their production plans (including adjustments) for the following week. Prebuilt spreadsheets may be used to help manage any of these decisions.

Figure 5 Sample Completed Weekly Order Form

Team: Red Fish, Blue Fish Week: 8

☒ Whoville steel order ($10 processing fee)

Order	Setup fee ($)	Product	Unit price ($)	Shipping ($)	Quantity
☒	40	Steel strip–blue, 8-1/2″ × 3/4″	20	5	100
☒	40	Steel strip–yellow, 5-1/2″ × 3/4″	15	5	50
☐	40	Steel strip–red, 5-1/2″ × 3/4″	35	5	
☐	40	Steel strip–green, 5-1/2″ × 3/4″	35	5	

☒ Max Welker welding order ($100 processing fee)

Order	Setup fee	Product	Unit price ($)	Shipping ($)	Quantity
☒	–	Basic welding wire–50 count	75	15	4
☐	–	Red welding wire–100 count	200	30	
☐	–	Green welding wire–100 count	200	30	
		Welder (one week rental)	50	–	5

The Line Supervisor signals that the team is ready for the next week to begin, either by filing the demand slip and order form onto the designated piles or, for larger classes, by some other visual indicator (e.g., holding up a brightly colored flag) that is easier for the instructor to see. When all teams signal that they are ready to proceed, the next week begins.

The game continues in this fashion for an undisclosed number of weeks, though the instructor may provide a range of durations (e.g., 12 to 20 weeks). The unspecified length—along with the salvage values described below—prevents teams from gaming the end of the horizon, especially with their inventory decisions. This is a similar approach to the one taken by Sterman (1989) for the Beer Game.

When the production window of the second-to-last week is finished, the instructor announces that the following week will be the last and, therefore, no orders need to be placed (since they would not arrive in time to be used). The final week is then run, as usual, and the last units are shipped.

After filing the final Customer Order Slip, teams count up the remaining raw materials (strips and staples), including those already built into works in progress and unshipped finished goods inventory, and record the quantities on a final order form with "Salvage" marked as the week. This salvaged inventory is returned for a full refund of its materials purchasing costs in order to reduce the impact on teams who have just received a large order when the game ends since the game is meant to simulate a continuing process. Once completed, the salvage sheet is added to the other order slips, which are left with the demand slips and shipped units (in three distinct piles for easier counting/inspection) at the team's factory for the instructor.

5.5. Follow-Up Analysis

After the game, the instructor should lead a discussion of what students learned from their experiences. Teams should be encouraged to share unexpected challenges that they faced and likewise to share solutions that they found. The instructor can plan some talking points (e.g., how the different costs should affect ordering), but the spontaneous interaction between the teams is often more engaging at the end of the day.

After the students are dismissed, the instructor counts the shipped units and checks the quality in order to determine the number of defects. Detailed discussion of the quality check may be found in the game teaching note.

These values, along with those from the order and demand slips, are entered into an input spreadsheet (see Table 3 and ExampleSpreadheet.xls), which is then used to determine ordering, shipping, holding, purchasing and defect costs, gross revenues, and profit. Defects costs are determined by multiplying the aggregate number of defects by the finished units' selling prices, plus the good will lost penalty. Salvage costs are determined by multiplying the remaining inventory by the unit purchasing costs from the supplier. Summary charts (see Figure 6) are then produced to compare the teams' performance levels. More detailed breakdown tables and charts, such as (simplified) financial statements (see Table 4), may also be provided.

As mentioned in §5.1, when time allows, a complete report—including detailed analysis and explanation of strategies selected as well as lessons learned—should be turned in approximately one week after the game. This allows students time to digest the experience, including the post-game discussion, and formulate stronger conclusions. Even when time does not allow for a full report to be turned in after the game, the instructor may require students to turn in a short follow-up reflection on what they learned, including what they would do differently if the game were played again, a short time later. Either way, in an effort for continuous improvement, teams may be asked to recommend improvements to the game. A small incentive (bonus) may be offered for particularly strong suggestions.

In the end, the students' final grades are largely determined by the analysis provided in their reports. However, in the spirit of competition, some points ($\sim$20% of the total) should be awarded for overall performance in the game itself.

6. Feedback and Experience

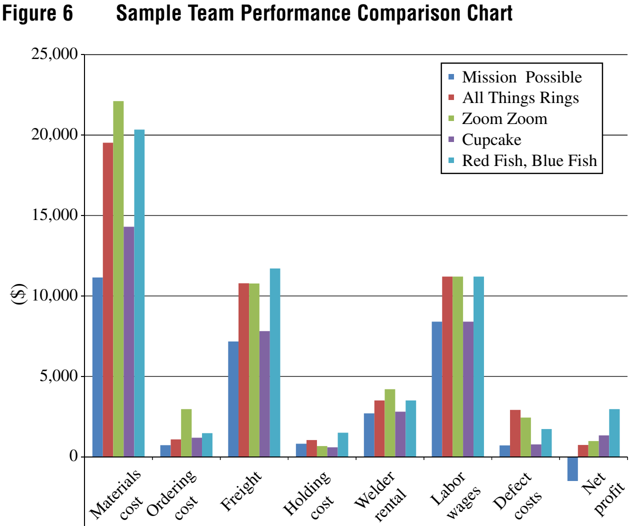
To date, variants of this game have been run with one undergraduate class of 32 students and nine MBA classes ranging from 18 to 34 students. The undergraduate class served as the proverbial guinea pig for the initial version of the game before rolling it out in my MBA course. While the undergraduate students seemed to enjoy the game and demonstrated that they had learned from the experience, they showed less self-motivation than expected. Some comments from the course evaluations complained "[*the instructor*] didn't tell us exactly what to do," which, paradoxically, was supposed to be a major point of the whole exercise. In response, the documentation for the game was greatly expanded, more time was dedicated to activities throughout the semester, and expectations were more clearly explained, all of which seemed to have positive results in the next section (note: since all subsequent sections have been MBA classes, it is impossible to separate the direct effect of the changes from the relative motivation level of the two types of students; however, the response to and use of materials provided after the first section

Table 3 Sample Team Input Sheet

	Week															Salvage/	
	Pre	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Defects	
Orders quantities																	
Steel strips																	
Blue	174	0	0	0	0	150	0	0	0	150	0	0	150	0			
Yellow	87	0	0	0	0	75	0	0	0	75	0	0	75	0			
Red	48	0	0	0	0	0	0	0	0	0	0	0	0	0			
Green	51	0	0	0	0	0	0	0	0	20	0	0	0	0			
Wire																	
Basic	3	0	0	0	0	2	0	2	0	0	4	0	0	0			
Red	1	0	0	0	0	0	0	0	0	0	0	0	0	0			
Green	1	0	0	0	0	0	0	0	0	0	0	0	0	0			
Welder rentals	5	5	5	5	5	5	5	5	5	5	5	5	5	5			
Production workers		4	4	4	4	4	4	4	4	4	4	4	4	4	4		
Units shipped																	Staples
Base models		9	8	13	19	10	10	13	2	13	14	13	15	11	18	3	2
Red Carzay		3	4	1	0	2	3	2	7	5	3	0	6	4	6	4	3
Green Carzay		3	2	2	0	5	7	6	5	5	8	7	6	6	6	6	3
Order placed																	
Steel strips																	
Blue	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0		
Yellow	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0		
Red	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Green	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Wire																	
Basic	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0		
Red	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Green	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Starting inventory																	
Steel strips																	
Blue	0	174	144	116	84	46	162	122	80	52	156	106	66	162	120	60	
Yellow	0	87	72	58	42	23	81	61	40	26	78	53	33	81	60	30	
Red	0	48	45	41	40	40	38	35	33	26	21	18	18	12	8	2	
Green	0	51	48	46	44	44	39	32	26	21	36	28	21	15	9	3	
Wire																	
Basic	0	150	120	92	60	22	88	48	106	78	32	182	142	88	46	0	
Red	0	100	97	93	92	92	90	87	85	78	73	70	70	64	60	54	
Green	0	100	97	95	93	93	88	81	75	70	65	57	50	44	38	32	

suggest the differences were meaningful, if not measureable). Additionally, several incremental but significant improvements to the game itself have been made since then, including some proposed by students in their follow-up reports.

Figure 6 Sample Team Performance Comparison Chart



The subsequent experiences with the MBA students have been starkly better, with most teams spending a great deal of time at the end of—and even outside of—several classes working on incorporating the new material into their plans. Their efforts have also shown in their strategy and final reports, where they demonstrate detailed analysis for many of the operational decisions. See the game teaching note for a description of the students' usual progression, as well as some detailed examples of their methods.

Even when teams fail to apply specific concepts themselves in their initial strategies, they often see the advantages of them through their own experiences playing the game as well as by watching what others teams do. This additional layer of learning is expressed in their follow-up reports. Examples of this type of learning are also provided in the game teaching note.

In general, the game-day experience for all sections has been jovial, with teammates joking about their own abilities, or lack thereof, and boisterously exchanging challenges and taunts with rival teams. Comments during and after the game have generally

Table 4 **Sample (Simplified) Financial Statements**

Week	1 ($)	2 ($)	3 ($)	4 ($)	5 ($)	6 ($)	7 ($)	8 ($)	9 ($)	10 ($)	11 ($)	12 ($)	13 ($)	14 ($)	Salv./Def. ($)
COGS worksheet															
Starting inventory	0	11,336	9,774	8,175	6,449	4,565	9,043	6,733	5,158	2,513	7,109	5,420	2,324	6,403	3,105
Inventory purchases	9,270	0	0	0	0	4,515	0	300	0	4,955	450	0	4,215	0	
Freight in	3,720	0	0	0	0	2,280	0	30	0	2,450	60	0	2,250	0	
Materials available for use	12,990	11,336	9,774	8,175	6,449	11,360	9,043	7,063	5,158	9,918	7,619	5,420	8,789	6,403	
Ending inventory	11,336	9,774	8,175	6,449	4,565	9,043	6,733	5,158	2,513	7,109	5,420	2,324	6,403	3,105	
Direct materials used	1,654	1,563	1,599	1,726	1,884	2,317	2,311	1,905	2,645	2,808	2,200	3,096	2,386	3,298	
Direct labor expense	800	800	800	800	800	800	800	800	800	800	800	800	800	800	
Rental expense, production equipment	250	250	250	250	250	250	250	250	250	250	250	250	250	250	
Warehousing	62	55	47	39	31	55	43	34	25	48	37	26	42	31	
Manufacturing overhead	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
Total manufacturing costs	3,166	3,067	3,096	3,215	3,365	3,822	3,804	3,389	4,120	4,306	3,686	4,572	3,878	4,778	
Income statement															
Gross sales	2,985	2,810	2,980	3,325	3,395	4,100	4,155	3,170	4,625	5,035	3,920	5,445	4,275	5,970	
Sales returns and allowances															(2,914)
Net sales	2,985	2,810	2,980	3,325	3,395	4,100	4,155	3,170	4,625	5,035	3,920	5,445	4,275	5,970	(2,914)
Cost of goods sold	(3,166)	(3,067)	(3,096)	(3,215)	(3,365)	(3,822)	(3,804)	(3,389)	(4,120)	(4,306)	(3,686)	(4,572)	(3,878)	(4,778)	3,105
Gross profit (loss)	(181)	(257)	(116)	110	30	278	351	(219)	505	729	234	873	397	1,192	191
Interest income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Interest expense	(22)	(41)	(36)	(29)	(22)	(26)	(29)	(21)	(12)	(13)	(17)	(5)	(5)	(3)	0
Net operating profit (loss)	(203)	(299)	(152)	81	9	253	322	(240)	493	716	217	868	392	1,188	3,303
Cash flow statement—Operations															
Starting cash	0	(11,473)	(10,085)	(8,530)	(6,636)	(4,679)	(8,826)	(6,107)	(4,710)	(1,536)	(5,377)	(3,419)	560	(3,112)	1,384
Cash receipts from															
Customer sales	2,985	2,810	2,980	3,325	3,395	4,100	4,155	3,170	4,625	5,035	3,920	5,445	4,275	5,970	(2,914)
Inventory salvage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,105
Interest income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Cash paid for															
Inventory purchases	(12,990)	0	0	0	0	(6,795)	0	(330)	0	(7,405)	(510)	0	(6,465)	0	0
Wage expenses	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	(800)	0
Rental fees	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	(250)	0
Warehousing (admin. and insur.)	(62)	(55)	(47)	(39)	(31)	(55)	(43)	(34)	(25)	(48)	(37)	(26)	(42)	(31)	
Administrative overhead	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	0
Interest expense	(22)	(41)	(36)	(29)	(22)	(26)	(29)	(21)	(12)	(13)	(17)	(5)	(5)	(3)	0
Net cash flows from operations	(11,473)	1,388	1,555	1,894	1,958	(4,148)	2,719	1,398	3,174	(3,841)	1,957	3,980	(3,672)	4,496	180
Ending cash	(11,473)	(10,085)	(8,530)	(6,636)	(4,679)	(8,826)	(6,107)	(4,710)	(1,536)	(5,377)	(3,419)	560	(3,112)	1,384	1,564

Table 5 Responses to Student Survey

How would you rate the helpfulness of the __________ in understanding key individual concepts in the course?

	Responses				
Content element	Not at all helpful	Slightly helpful	Somewhat helpful	Very helpful	Extremely helpful
Lectures	0 (0%)	0 (0%)	4 (9%)	18 (42%)	21 (49%)
Homework	0 (0%)	1 (2%)	6 (14%)	22 (51%)	14 (33%)
Case discussions	1 (2%)	3 (7%)	13 (30%)	18 (42%)	8 (19%)
Production game	0 (0%)	1 (2%)	7 (16%)	20 (47%)	15 (35%)

How would you rate the helpfulness of the __________ in understanding the way in which the course material works together ("big picture")?

	Responses				
Content element	Not at all helpful	Slightly helpful	Somewhat helpful	Very helpful	Extremely helpful
Lectures	0 (0%)	1 (2%)	7 (16%)	19 (44%)	16 (37%)
Homework	1 (2%)	10 (23%)	15 (35%)	8 (19%)	9 (21%)
Case discussions	0 (0%)	6 (14%)	17 (40%)	13 (30%)	7 (16%)
Production game	0 (0%)	0 (0%)	5 (12%)	17 (40%)	21 (49%)

been very favorable and specifically praised the way the game "puts things together" and "makes it real."

For example, one student commented that the game "showed how production really works and that it is complex with many different important factors all put together into creating one product. I thought it was a great hands-on experience." One team's report stated, "The game taught us the scope of production management and how to apply its principles… [*it*] taught us the importance of strategizing and planning before initiation of a process. It was important to look at all angles to fulfill the desire of the customers, assign duties so as to fulfill all the requirements, avoid conflicts, and come up with crisis mitigation processes that were essential for the survival of our company." Another team, citing Abraham Lincoln's famous quote "*Give me six hours to chop down a tree and I will spend the first four sharpening the axe*," wrote, "The first and foremost conclusion is the importance of planning. This team project came together long before the game was begun when [the *team leader*] began recruiting people for his team the first week of class. This planning carried forward with the design for construction of the ideal Zu Zitters, the layout of the assembly line, the creation of an MRP system, the writing of job plans and implementation of Lean techniques in all area of the project. In addition, the team created the open and relaxed culture necessary to implement a successful continuous improvement program. These two approaches gave the team the strong background to meet the challenges of the project right out of the gate, while maintaining enough flexibility to make mid-stream corrections and hopefully resulted in our the winning of the game." Finally, a member of one top team wrote, "The game itself is energizing. Students benefit not only from an experience of building an assembly line, they get to be a part of it—an invaluable experience for the future. Many classes utilize on-line simulations which have a predictable pattern. In many cases the experience feels intangible. The hands-on simulation game in [*this class*] allows students to see the results of their labor right away. The fact that we saw the final product and were able to assess our performance stimulated the production. It was up to us to either sink or swim with pressure to produce in a short amount of time. This requires quite a bit of preparation, calculation, and collaboration amongst the team."

As further evidence of student perception of the game, an online survey was given to two recent sections. For each of the major content areas of the course, they were asked to rate how helpful it was in understanding individual concepts and in seeing how they work together. The results of the survey (43 of 54 students responded anonymously) are given in Table 5.

The answers to the first set of questions indicate that students felt the game's helpfulness in understanding individual concepts was on par with the homework because both had approximately half of students rating it *very helpful* and another one third of students rating it as *extremely helpful*. Though the game was rated behind the lectures, which nearly half the students found *extremely helpful*, it is worth noting that students who have already been helped by the lecture are less likely to rate any subsequent source as highly.

The second set shows that students found the game to be the most helpful in seeing how the concepts fit together. The responses for the game and lectures are virtually reversed from the first set, with nearly half of students rating the game *extremely helpful*. Thus, although students may have perceived the lectures to be their best source for learning each topic, the game put them together.

7. Conclusions and Future Extensions

Because of the complex and often seemingly disjointed mix of quantitative and qualitative material covered by most introductory operations management courses, a course-long exercise that allows students to continually incorporate new material can be particularly valuable. The Zu Zitter game described in this paper provides such a vehicle for student learning. It is fun, active, and hands-on, representing the type of experiential learning that has been advocated by so many.

As noted, the game has inherent flexibility with regard to incorporating new material and, therefore, also allows for interesting extensions or variations. I describe a few specific extensions here that have clear potential benefit, but instructors are encouraged to investigate others that they may imagine.

Product Variants. The product has been designed to be simple to construct while still allowing for variations in production methods. As such, additional elements could be added to allow for an even greater number of potential solutions. This could also be useful for larger classes because additional production personnel could be added to each team.

Real-Time Demand and Quality Checks. The demand stream for a given week could arrive as individual buyers throughout the production window. This change could have interesting effects on the production planning by the students but could prove difficult to control for larger groups. The presence of TAs would help facilitate such a process.

Likewise, TAs could be used to check quality during the game so that teams might have the opportunity to rework units rather than suffering the penalty of a defect. In smaller classes, the instructor could do random checks of some shipped units from each team during the subsequent production window.

Negotiable Terms. Teams could be given the opportunity to negotiate with the suppliers (i.e., the instructor) to select more favorable terms for a specific strategy. For example, a team may offer a higher per-unit purchasing cost in exchange for lower ordering costs so that they may make smaller, more frequent orders.

Forecasting. For courses with a strong forecasting element, the parameterized demand processes could be replaced with a sample of historical realized demands. Students could then track and incorporate the realized demands as the game progresses. This would also allow for nonstationary demand processes.

In-Game Changes. Instructors can include the possibility of design and/or order modification during the game. This forces students to plan for such possibilities, including how to handle potential obsolescence. An example added in a recent section, along with some other possible ideas, is provided in the game teaching note. Response to this event was positive, including one team suggesting that another similar one would be beneficial.

Nonproduction Elements. Finally, since many OM courses have a heavy service component and class rosters often include students with majors/concentrations in areas such as accounting, instructors could expand the tasks of the nonproduction workers to include other activities required in a real production facility. However, care would need to be taken to ensure that these activities are still related to the OM material and are not simply providing such students with a comfortable escape from the activities of the rest of the team.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/ited.2015.0138.

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