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TEACHING BRIEF

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The Hunger Chain: A competitive simulation for teaching supply chain management

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ABSTRACT
Shortage gaming, supply chain competition, and supply rationing are important and timely topics in operations management and supply chain management curricula. We introduce an online instructional game, the Hunger Chain, that provides an action-based, competitive simulation for engagement of students in experiential learning of these topics. We discuss how instructors can use the game to stimulate students' learning about panic orders and hoarding (shortage gaming), decision dependencies (supply chain competition), and efficient and/or fair allocation of limited supplies (supply rationing). A comparison of test results from students who played the game to those from a control group showed significantly improved learning outcomes. In addition, sentiment analysis of student feedback was overwhelmingly positive.

KEYWORDS
Active Learning, Instructional Simulation, Online Games, Rationing, Shortage Gaming, and Supply Chain Competition

INTRODUCTION AND MOTIVATION

In this article, we describe an online instructional game, the Hunger Chain, to simulate companies' behaviors under supply shortage, shortage gaming, supply chain competition, and supply rationing. The game can be easily implemented in either a classroom or an online setting. Through this simulation, students can acquire first-hand experience with real-life examples to see how competition in supply chains can drive companies into irrational behaviors, such as panic orders and hoarding (i.e., the Prisoners' Dilemma), that can potentially break down a supply chain. The game-playing process then provides an opportunity for students to learn how to ration supply to achieve efficiency and/or fairness.

Examples of supply shortage

Supply shortages are a major topic in operations and supply chain management curricula, as demonstrated by the shortages of essential commodities during the COVID-19 pandemic. A well-known example is the worldwide shortages of medical and grocery supplies in the COVID-19 pandemic, shown in Figure 1 and described in the following articles: "As we struggle to come to terms with the scale of the COVID-19 pandemic, one of the most frustrating sights is witnessing front-line health-care workers begging for more masks, protective gowns, testing kits, ventilators and intensive-care beds … We prepare for shortages of oil and weapons in times of crisis. It is now painfully obvious that medical supplies are just as critical" (Sheffi, 2020); "Popular items such as flour, canned soup, pasta and rice remain in short supply" (Gasparro & Kang, 2020); and "Paper towels remain in higher demand as people clean more amid the pandemic, exacerbated by an even more severe shortage of sanitizing wipes" (Terlep & Gasparro, 2020).

There is abundant evidence on panic buying and hoarding caused by the Coronavirus outbreak (D'Innocenzio and The Associated Press, Mar 6, 2020): "COVID-19, the disease that has sickened more than 100,000 people worldwide …, has created legions of nervous hoarders who are loading up on canned goods, frozen dinners, toilet paper, and cleaning products." and "Italians engaged in *panic buying* … Such *hoarding* resembles typical behavior in the days leading up to a hurricane or other natural disasters." This situation has forced supplying companies to impose rationing rules, for example, for masks (Berzon et al., 2020): "Suppliers had started limiting orders to the amount of a typical purchase or slightly more, to prevent *hoarding* and make sure each got at least part of its order." For example, Home Depot

FIGURE 1 Photos of panic buying and hoarding caused by the Coronavirus in 2020

limited each customer to buying at most 10 masks at a time.

Although a pandemic like COVID-19 is rare, the short supply of flu vaccine is not. If there is a flu outbreak or an unexpected production issue, vaccines will likely be in short supply. Similar to what happened in the 2004–2005 period in the United States, when there was a severe shortage of supplies due to contamination, rationing was imposed to limit vaccinations only to priority groups, such as the elderly, young children, and healthcare professionals. Around that time, the United States had approximately 90 million high-risk people (elderly and healthcare workers); thus, rationing had a significant impact on the fatalities caused by the outbreak.

In general, supply rationing becomes essential under a supply shortage. If, however, such rationing rules are not implemented or are not well designed, then what could happen? As we observed in the examples above, competition for limited supplies can lead to behaviors, such as panic orders and hoarding, which result in supply chain breakdown (or meltdown) where some people hold excessive supplies, while others suffer from a scarcity. Thus, knowledge and understanding of shortage gaming, supply chain competition, and rationing are important in operations management.

Learning objectives

Shortage gaming, supply chain competition, and inventory rationing can be difficult topics to teach in a lecture format, but easy to learn by experiential game playing. Therefore, the objectives of using the Hunger Chain simulation are as follows:

1. Develop student understanding of the causes of the panic orders and hoarding under supply shortages.
2. Give students hands-on experience with supply chain competition and how one team's performance depends on other teams' decisions.
3. Gain a better understanding of the importance of supply rationing rules in terms of efficiency and fairness.

This game has been used in a variety of operations management courses, including supply chain management, procurement/sourcing, distribution, and logistics. Feedback from audiences of undergraduate, graduate (MS, MBA), and executive students in business schools at multiple universities has been positive. In the remainder of the paper, we first review related literature and show how use of the Hunger Chain simulation fits into the spectrum of these works. Then, we introduce the overall learning approach of the game and present student data for assessment of its effectiveness. Lastly, we summarize administrative details on game adoption, teaching plans, and instructions for instructors and students to use the simulation.

LITERATURE REVIEW

Business schools are under increasing pressure to engage students effectively in both online and face-to-face teaching settings. One popular way to do this is through action-based experiential learning or instructional gaming (Isabelle, 2020; Wideman et al., 2007). This is true, especially for online instruction where students can be easily distracted, and the key challenge is to retain students' attention in this environment. Learning by doing via gaming and simulation is one strategy to address this challenge.

There are several relevant studies on instructional games or exercises in the fields of operations and supply chain management. DuHadway and Dreyfus (2017) develop an inventory and forecasting simulation to demonstrate sales and operations planning processes in the classroom with a hands-on learning component. Surti and Celani (2019) introduce a simulation exercise for the Newsvendor model and emphasize the importance of behavioral factors in human decision-making processes where the students learn the concepts and ideas of traditional operations management and supply chain management concepts. Day and Kumar (2010) discuss the benefits of using SMS text messaging through an automated Beer Game in large classes. Reyes (2007) develops a Parallel Interaction Supply Chain Game as a modified version of the Beer Game, where the supply chain network consists of two customers, two retailers, one distributor, two manufacturers, and three vendors. This game enables learning of both the Bullwhip effect and rationing.

We introduce a new online instructional game, the Hunger Chain simulation, to teach three important supply chain management topics: shortage gaming, supply chain competition, and supply rationing. Supply chain competition has not been covered in the literature to date. Our work expands and enhances the rationing component of Reyes (2007) into a general multiretailer single-supplier game, where (any number of) student teams can play the retailers competing for a limited supply (as set by the instructor). The implementation of the Hunger Chain allows the instructor to visualize the game trajectory (e.g., order inflation over time, mismatch of demand and supply) and to set up different scenarios by varying demand distributions, cost parameters, the intensity of shortage, and synchronized or asynchronized demand. Availability of alternative demand distributions allows instructors to choose the nature of demand variability (e.g., normal vs. uniform demand). Instructors can also control whether demand is synchronized (i.e., all retailers face the same demand realizations) to make the competition fair or asynchronized for more realistic experiences.

Jacobs (2021) introduces an online shortage game with a centralized decision-maker (i.e., allocating inventories to different locations). In comparison, the Hunger Chain simulates the behaviors of multiple decision-makers (i.e., retailers) and their competition for limited supply in a decentralized setting, as observed in the examples cited earlier. Our research is also relevant to recent literature on teaching supply chain risk management in the COVID-19. To help instructors incorporate supply chain risk management concepts into their curriculum, Ferguson and Drake (2021) discussed the impact of the COVID-19 pandemic on the supply chain, including the widespread shortage of toilet paper that happened in the United States in Spring 2020, which is an example of shortage gaming as discussed in this paper.

GAME-BASED LEARNING APPROACH

Allocation rules

There are many different rationing rules available for supply chain management. The most popular one (used in this game) is the proportional allocation rule: if the sum of all retailers' orders is less than or equal to the supply, then each retailer gets her order fulfilled; otherwise, the allocation of the supply to a retailer equals to the proportion of their order quantity in the sum of all retailers' orders. This rule is popular in practice because it is simple and easy to use. It is also intuitive because it allows each retailer to specify their own needs, while being fair and equitable to everyone. However, under this rationing rule, if a retailer orders a large quantity, she can get a proportionally large allocation. Hence, the rule may encourage retailers to inflate their orders beyond their actual needs to ensure a sufficient allocation, especially when supply is short. For this reason, the proportional allocation rule is one of the "order-inflating" mechanisms. This is in contrast to the linear allocation rule, another "order-inflating" mechanism where, intuitively, each retailer gets an equal share of the shortage (calculated as the difference between total quantity ordered and capacity divided by the number of retailers and subtracted from each retailer's order).

Example game results

A sample teaching plan and detailed instructions on how to play the game are provided in the Appendix. Figure 2 shows a sample game trajectory (via the complete game information table) over six periods. The chart on the left illustrates total quantity ordered in comparison to total supply and demand. Lost sales and surplus inventory over time (summed over all retailers) are shown on the right.

We can clearly see significant order inflation over time from the left graph of Figure 2, where supply remains constant, demand is random but relatively stable, but the total quantity ordered skyrockets (i.e., these are *panic orders*). At the end of the game (in period 6), the students' orders became completely irrelevant to their demands but depended only on their conjectures of how much other teams may order. The chart on the right of Figure 2 shows the corresponding lost sales and surplus inventory over these time periods. Toward the end of the game, we can see a large surplus inventory and lost sales coexisting, which indicates *hoarding*, a highly inefficient allocation in the supply chain, or a supply chain breakdown (mismatch between the demand and supply due to the wrong allocation of the supply).

The Prisoner's Dilemma and game theory basics

The Hunger Chain game provides a live example of the Prisoner's Dilemma which explains why order inflation is inevitable. Figure 3 shows a table for two players with the four cases of telling the truth or inflating the order. Despite the benefits of the win-win case (both telling the truth), the players will eventually choose the lose-lose case (both inflating the order) because regardless of the other's action, inflating the order always provides a better pay-off than telling the truth for each player.

The students learn to use the Prisoner's Dilemma to explain what they experienced (i.e., the order inflation) in the game, which leads to a supply chain breakdown (the lose-lose situation). They learn the painful fact that it is not in the retailers' best interest to tell the truth, but lying (i.e., order inflation) is a better choice. They also learn how other competing retailers' orders may affect their profits and the impact of information (i.e., the need to watch out the competing retailers' actions).

From proportional rule to fair sharing

Through playing the Hunger Chain game, the class discovers and experiences a real-life disaster in supply chain management. To complete this class session, we recommend offering some solutions to resolve the supply chain breakdown (at least partially), so that students can leave with some practical approaches to address supply problems. To this end, the instructor can first suggest FCFS (First Come, First Served)

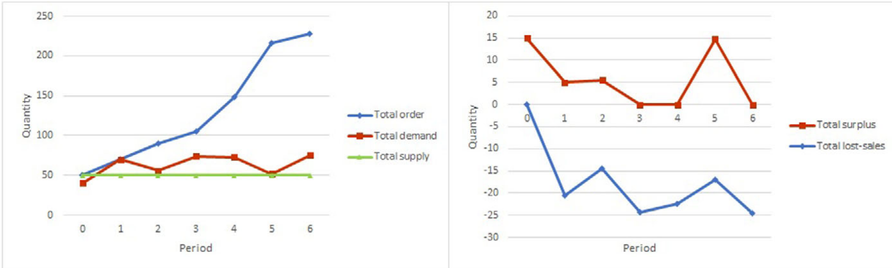

FIGURE 2 Game trajectory indicating panic orders and hoarding

FIGURE 3 Prisoner's Dilemma

without imposing any other allocation rule. However, if FCFS is implemented, then the last few customers may get nothing. Thus, some kind of rationing rule is necessary because it provides a minimum guarantee and prevents disaster. The natural question is how to allocate supply for efficiency and/or fairness?

We suggest that the instructor introduces the fair sharing allocation rule, which uses past sales to allocate the supply (Lu & Lariviere, 2012). Specifically, the supplier allocates limited supply among customers by their percentage of past shipments. For instance, if CVS accounts for 10% of the last 13 weeks of total shipments to all customers, then the supplier reserves 10% of the supply for CVS. In the case of COVID-19 supplies, we can apply this rule after we collect sales history data. The fair sharing rule completely removes order inflation because the retailers do not need to order at all, thus improving overall supply chain efficiency. In addition, the fair sharing rule provides a clear incentive for the retailers to sell more because they can only get more supplies if they sell more. The rule also likely results in the supply being sent to the markets where they are mostly needed.

However, the fair sharing rule may have some side effects. First, it may intensify competition among retailers and encourage them to increase sales aggressively. Order competition can be so intense that the retailers might increase their sales in ways that lead to a deterioration in profits. Second, the fair sharing rule is not really "fair" because larger retailers will get more supplies, making it more likely for them to maintain their size and be more competitive than the smaller ones. Thus, it may lock in market shares for the retailers. A retailer with a small allocation cannot sell more without boosting its supply, but the only way to increase its supply and therefore its allocation is to sell more. Consequently, a sales laggard cannot catch up unless a sales leader reduces their sales rate. Finally, the fair sharing rule eliminates retailers' forecast and future events, and so may still result in significant mismatches between demand and supply.

Fair sharing also requires historical sales data for implementation. However, sometimes we do not have historical data available to base allocations (e.g., flu vaccines). In such cases, governments often design sophisticated rationing rules to prioritize high-risk people, such as healthcare workers, chronically ill patients, and the elderly (see Zhao, 2014) for a detailed description of a tiered approach to allocate influenza vaccines during a shortage.

TEACHING EFFECTIVENESS ASSESSMENT

Evidence of teaching effectiveness

To assess the teaching effectiveness of Hunger Chain simulation, we compared the student performance on short-answer test questions for shortage gaming, supply chain competition (the Prisoner's Dilemma), and inventory rationing. We established two groups: (1) the experiment group (where the Hunger Chain simulation was played before taking the test in Fall 2020), and (2) the control group (where the Hunger Chain simulation was not used in Spring 2020 class and students only received a lecture on these topics). Identical test problems were given to these groups by the same instructor in the same online course, and there were no students who retook this course.

We provide a list of the test questions, organized by learning objectives, and report results in Table 1. Test score results in the experimental group who played the simulation (13 students) were higher on average than those in the control group who did not play the simulation (16 students). To check for the difference in the group means, the Mann–Whitney U test, a nonparametric statistical approach for small samples, is used (Belohlav et al., 2004). The results show a statistically significant difference in mean test performance between the two groups on each question (Q1: $p = 0.026$, Q2: $p = 0.003$, and Q3: $p = 0.037$). Although sample sizes are small, these

TABLE 1 Sample test questions and test score results between the experiment group and the control group

Sample Questions Imagine a situation in which the supply is limited and multiple retailers facing random demand must compete for the supply. The supplier allocates the supply among the retailers using the proportional allocation rule that you learned in the class.

Items	Learning objectives	Experimental group (n = 13)		Control group (n = 16)		Mann–Whitney U test p-values
		Mean	SD	Mean	SD	
Q1: Why might this shortage of supply lead to panic orders or hoarding? (10 points)	This game helps students understand the causes of the panic orders and hoarding under supply shortages.	7.96	1.11	6.25	1.22	0.026
Q2: Does the retailer's outcome depend on the actions of others? How? (10 points)	This game provides students the hands-on experience of supply chain competition and how one team's performance depends on other teams' decisions.	8.03	1.03	5.80	0.70	0.003
Q3. Which of the allocation rules that you learned in the class allocates the supply among retailers more efficiently and/or fairly? Why? (10 points)	After playing the game, students have a better understanding of the importance of supply rationing rules in terms of efficiency and fairness.	8.00	1.11	6.63	1.25	0.037

findings suggest that classroom use of the Hunger Chain simulation improved students' understanding of relevant supply chain management topics.

Students' feedback analysis

To date, the Hunger Chain simulation has been played by 50+ instructors at more than 30 universities in the United States, Germany, China, Hong Kong, Taiwan, and South Korea, with 1000+ student teams. We collected 75 undergraduate students' comments after playing the Hunger Chain simulation in supply chain management-related classes at two US universities during 2018 and 2020. The students provided feedback in response to the question of "What is your most compelling learning from the Hunger Chain simulation?" Text mining analysis was performed in Python to summarize student comments about the game. After preprocessing and tokenization, we used a bag-of-words approach (Li et al., 2010) to calculate the frequency of words in student comments. Figure 4 shows that the words "game" or "hunger" had the highest frequency. The most commonly used words also included several positive adjectives, such as "fun" or "like." Because the Hunger Chain simulation requires students to determine the order quantity, the words "order," "make," and "profit" also had a high frequency.

To further assess student attitudes toward playing the game, we calculated sentiment scores using VADER (Valence Aware Dictionary and Sentiment Reasoner), a lexicon- and rule-based tool for text analysis (Hutto & Gilbert, 2014). These results are shown in Figure 5. Approximately 90% of student comments were classified as positive sentiment, with only 8% of the feedback after playing the Hunger Chain gain being negative.

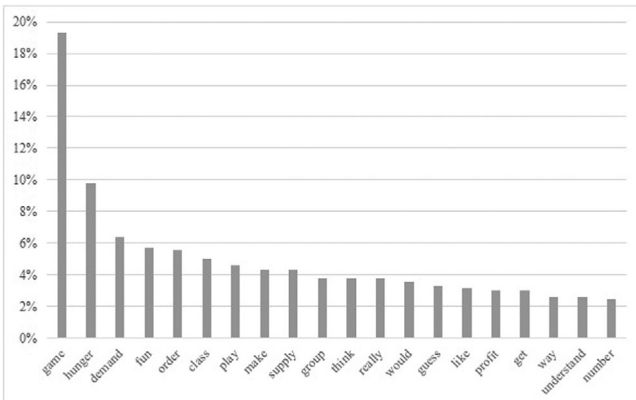

FIGURE 4 Frequency of words

A qualitative review of student comments provided the following insights:

- A majority of students liked the game, especially during the stressful end-of-semester rush.
- Some students were confused about the rules of the game and also the background story. This suggests that the instructor should provide motivating examples (e.g., shortages during the COVID-19 pandemic) and play a few test rounds before the formal game.
- Smaller groups (less than four students a group) appeared to work better because everyone has the chance to participate.

Overall, the game was well received by students and their feedback was very positive. One representative student comment was "The [Hunger Chain] Game was very interactive and brought critical thinking to the activity. I really enjoyed it

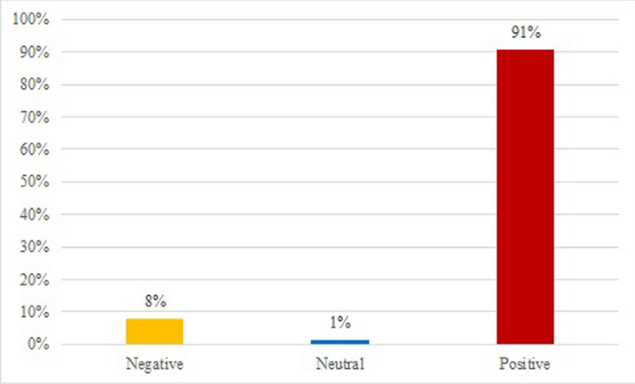

FIGURE 5 Sentiment analysis of student feedback

as we got to work in groups while being inclusive enough to work together as a class. The competition aspect of the activity pushes each group to become more proactive with critical thinking which broadens everyone's perspective and reflection of real-world competition." Instructors also like the game and have reported that it worked well in their classes.

CONCLUDING REMARKS

This paper presents an online competitive game, the Hunger Chain simulation, for teaching supply chain management topics. Specifically, the Hunger Chain game provides students hands-on experience with the following concepts:

- Shortage gaming can induce panic order, hoarding, and a significant supply chain breakdown.
- Supply shortage can induce competitive games among the retailers and one retailer's performance depends on others' actions.
- Information plays a critical role in the shortage gaming (either inflaming or extinguishing order inflation).
- Fair sharing eliminates the gaming behaviors and is more efficient than proportional allocation, although it is biased in favor of large retailers.

These are popular and timely topics in operations management and supply chain management classrooms, given recent events in COVID-19, but not easy to teach by lecture. The Hunger Chain simulation provides an active-learning exercise to support engaged instruction and learning.

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APPENDIX: TEACHING PLAN AND HOW TO PLAY

How to adopt

The game is designed, developed, and maintained by the third author as a web application, as shown in Figure 6. Instructors who would like to adopt the game for their courses can obtain permission and sample teaching slides from yaozhao@business.rutgers.edu .

Game setup

In the Hunger Chain Simulation, the instructor plays the supplier, and the student teams play the retailers competing for a limited supply, as shown in Figure 7. The retailers place orders to the supplier, and the supplier decides on how to allocate the supply among the retailers. The supplier has limited supply, and when the orders from the retailers exceed the supplier's capacity, the supplier must employ a rationing rule to allocate the supply among the retailers. The retailers start with the exact same financial status, the same initial share of the supply, and have the same chance to win.

Instructor sets the game and demand

Figure 8 shows an example of the instructor's page. The instructor enters the number of student teams (at least two teams), the number of periods (typically six periods), and one email address for each team (separated by), then the student teams will receive a password via this email once instructor

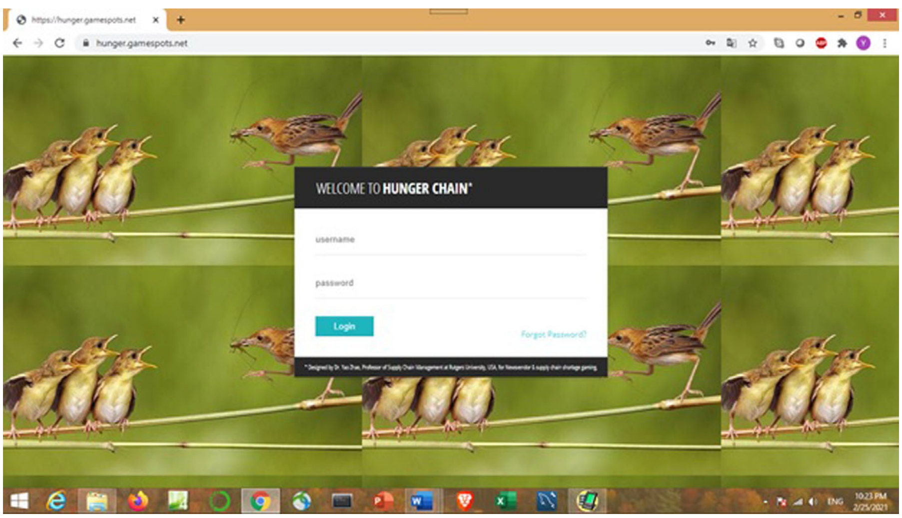

FIGURE 6 Hunger Chain simulation

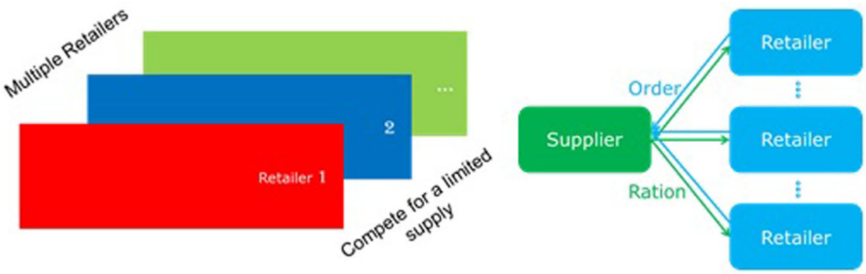

FIGURE 7 The supply chain with one supplier and multiple retailers

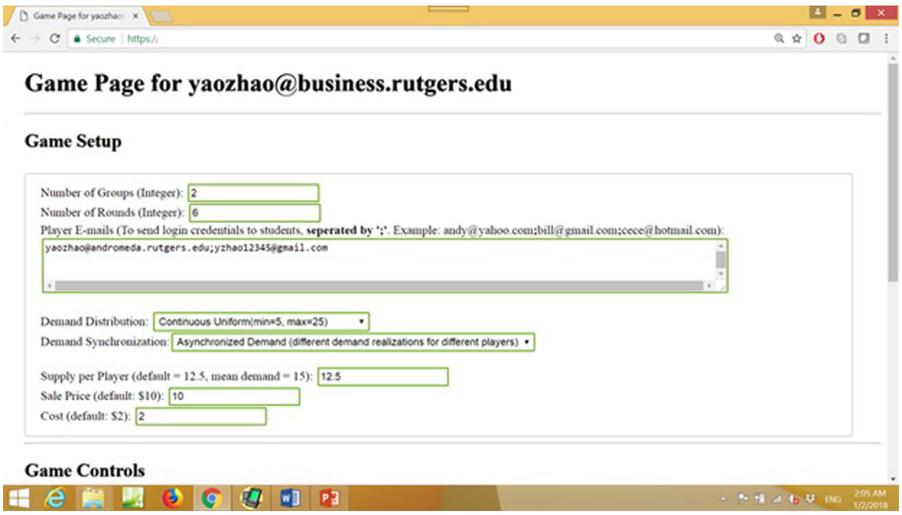

FIGURE 8 Instructor game page 1

clicks “Start Game” button (the instructor can also restart the game from scratch, or reset the game if the instructor changes game setup, etc.).

The retailers are Newsvendors facing random but statistically independent and identically distributed demand. The retailers are competing against each other because they all order from the same supplier with a limited supply. The instructor can choose a demand distribution from continuous normal, continuous uniform, and discrete uniform options where the average demand per period is set to be 15 for all demand distributions (this ensures the robustness of the experiment results). The type of demand can be either “synchronized” or “asynchronized” for the retailers. “Synchronized” means that every retailer will face the same demand realization, and “asynchronized” means that the retailers have different demand realization, although their demand distributions are the same.

Instructor sets supply and cost parameters

The instructor can set the supply per player to determine the supplier’s total supply per period which equals to the supply per player multiplying the number of groups (retailers). If the instructor sets the supply per player smaller than the average demand per period (i.e., less than 15), then the supply will likely be in short and the game is a shortage game. The instructor can change the supply per player to control the competition intensity: the smaller the supply per player is, the more intensive the competition will be. If the instructor sets the supply per player large enough, for instance, greater than 25, then a retailer’s demand will rarely exceed the supply per player and the game returns to a Newsvendor game where the supplier has ample supplies to meet all demand of the retailers.

The instructor can also change the cost parameters, the sale price, and purchasing cost for the students to learn the impact of the overage and underage costs. In the example of Figure 8, retailers’ sale price = \$10, cost (per unit of product) = \$2, then the overage cost = cost = \$2, the underage cost = sale price – cost = \$8. There is no input for salvage value as it is set to zero.

Students submit order and receive results

In each period of the game, each student team must place a new order by entering the order in the form provided, as shown in Figure 9, then click “Submit.”

After all teams submit their orders, the instructor can generate the results for this period by clicking the button of “Calculate,” then all student teams receive results for this period, as shown in Figure 10. A team only sees its own results but not the results of other teams. To proceed to the next period,

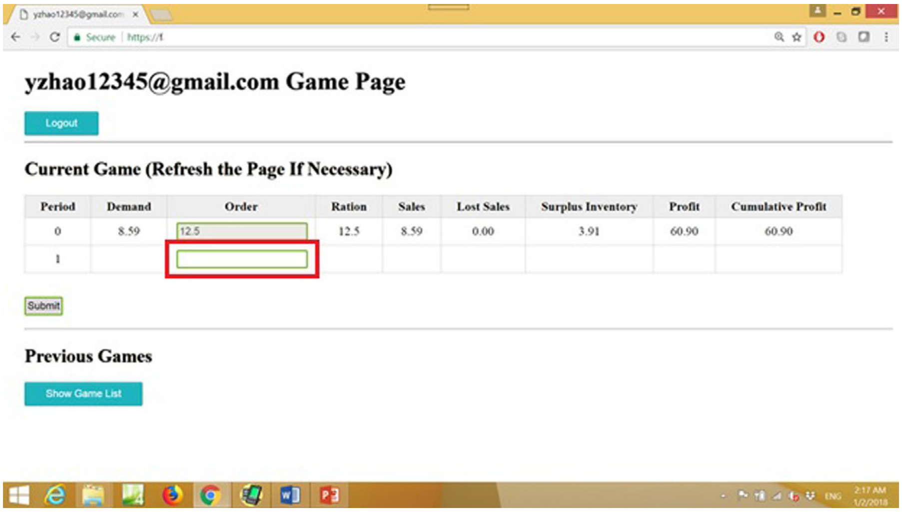

FIGURE 9 Student game page 1

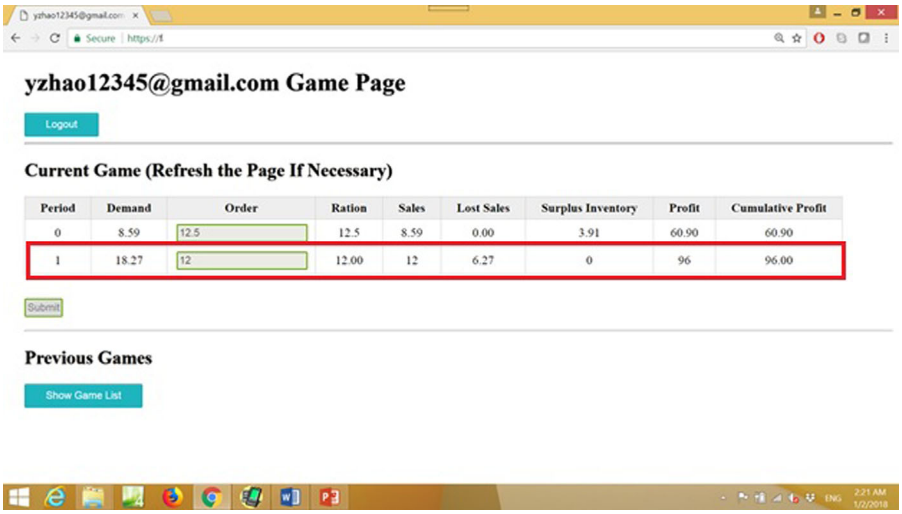

FIGURE 10 Student game page 2

the instructor clicks the button of "Next Round" until reaching the target number of periods.

Impact of information

The instructors can disclose competitive information (and game trajectory) to influence students' gaming behaviors in the middle of the game, as shown in Figure 11. Such information includes the total demand, total order, and the total supply (sum over all retailers). This information corresponds to market intelligence in the real world and can significantly change the retailers' gaming behaviors. The instructors may hide it initially (in 1–3 periods of a 6-period game) and show it after the game runs half-way through (in 4–6 periods of a 6-period game) to demonstrate the impact of information.

Sample teaching plan

We suggest the instructor to play out the shortage game first so the students can experience the supply chain breakdown, then connect the gaming experience with real-world examples and lecture about supply chain competition theory (the Prisoner's Dilemma), and finally present a more efficient supply rationing rule to solve the problems. Specifically, the instructor can

1. Introduce business problems under supply shortage.
2. Play the Hunger Chain simulation.
3. Connect the game experience to real-life business cases and use supply chain competition theory to explain the business problems observed in the game.

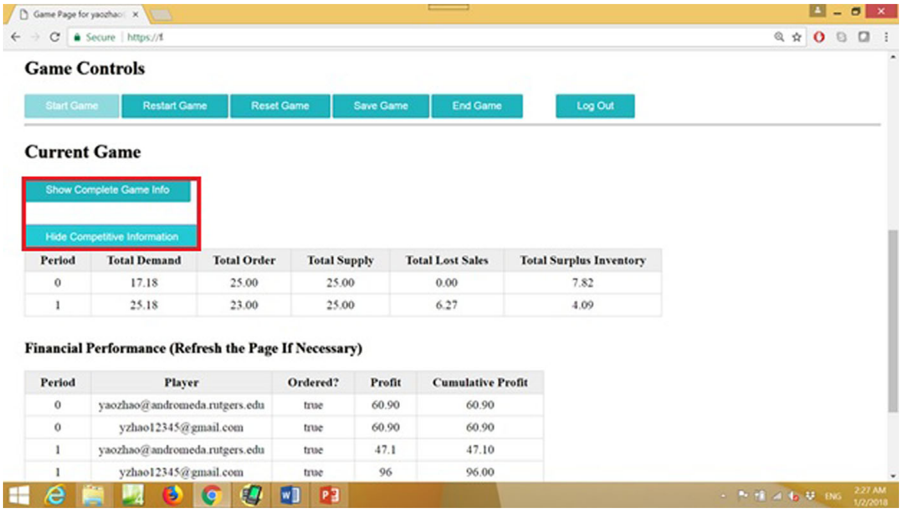

FIGURE 11 Instructor game page 2

4. Present various rationing rules to mitigate and resolve the business problems under supply shortage.

The teaching plan can cover one 90-min session or two 45-min sessions. Sample teaching slides are available upon request at yaozhao@business.rutgers.edu .

Suggested screen play

1. Preparation: Check the technical environment (laptop, browsers, and Internet) and form student teams (10 min).
2. Introducing the business problems under supply shortage (20 min)
3. Hunger Chain simulation (30 min)
4. The instructor sets Supply per Player < average demand (15). The suggested value is 12.5 or 10, depending on how intensive the instructor wants the competition to be.
5. Choose the game parameters but be sure to make sales price > cost.
6. Inform all students of the game parameters, especially the total supply capacity, to create a competitive mindset.
7. Discussion (30 min)
8. Use the game trajectory to show the panic orders, hoarding, and supply chain breakdown.
9. Use the Prisoner's Dilemma to explain order inflation.
10. Link game experience to real-life events.
11. Introducing the fair sharing rule for supply rationing, and discuss its pros and cons.