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Game

Rolling the Dice on Global Supply Chain Sustainability: A Total Cost of Ownership Simulation

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Abstract. Sustainability in management education is a potential solution to societal challenges, influencing students' worldviews and attitudes to contribute to a more profound social change. Through this innovative dice-based classroom simulation, students are exposed to supply chain sustainability, total cost of ownership (TCO), and risk management while also understanding their linkages through effective instructor debrief. Student teams compete by selecting sourcing options such as supplier location, transportation methods, and sustainability reputation from a menu, then see how their decisions fare as the product-line life cycle is simulated with a dice. The debrief facilitated by the instructor compares and contrasts results across the teams, generating insights into the interrelationships between supply chain sustainability choices, TCO, and risk management. Successfully conducted by multiple instructors, in multiple countries, and across all levels of management education (undergraduate, master of science, and executive master of business administration), survey results ($n = 350$) plus a pilot study ($n = 31$) confirm that this dice-based simulation accomplishes multiple learning objectives while also providing a highly engaging experiential learning classroom environment for this sample.



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Keywords: classroom games • teaching supply chain management • evaluating students • active learning • sustainability

1. Introduction

Literature is increasingly being published on integrating sustainability into the management curricula (Steiner and Posch 2006, Carew and Mitchell 2008, Lozano 2010, Segalàs et al. 2010, Lozano et al. 2015) and getting higher education institutions to become more sustainable overall (Wals 2014, del Mar Alonso-Almeida et al. 2015, Disterheft et al. 2015, Blanco-Portela et al. 2017). Business schools have particular responsibilities to prepare their graduates to make ethical and responsible economic and management decisions, yet also face challenges of integrating sustainability into their curricula (Stubbs and Cocklin 2008, Wu et al. 2010, Figueiró and Raufflet 2015, Mulà et al. 2017).

This paper describes a dice-based classroom simulation originally made popular by Goldratt and Cox (1992), but many variations have evolved in operations management teaching—for example, Johnson and Drougas (2002), Umble and Umble (2005), Hilmola (2006), and Lambrecht et al. (2012). The simulation enables supply chain students to learn about and experience the interrelation between sustainability,

total cost of ownership (TCO), and risk management in a high-energy, 45- to 60-minute experiential learning activity. The first of three phases provides student teams with a "menu" from which they select a supplier location, transportation method, supplier environmental, and social reputation, and how they will manage the supplier relationship over the life of a clothing product line. Their chosen supply chain design (largely encompassing the sourcing decision) provides their initial direct costs. In phase 2, four corresponding indirect costs are then revealed, while phase 3 involves students rolling a dice to simulate seven potential supply chain uncertainties that can occur over the life of the product line. The additional costs that result in phases 2 and 3 are influenced (extent, probability, severity) by their original supply chain design selections from phase 1. All teams' initial choices and corresponding ending TCO results are then contrasted and compared during the simulation debrief.

Survey results ($n = 350$) show that the simulation successfully accomplishes multiple learning objectives while providing a highly engaging experiential

learning classroom environment for this sample. The simulation is developed in response to positive effects of experiential learning (Kolb 1984), where groups are given tasks to complete in the form of decisions, in real time, and in competition with others (Piercy et al. 2012) to consider the impact of the trade-off of global business sustainability decisions. Students benefit from integrating supply chain sustainability in the form of supplier choices, risk management, and TCO concepts for an overall life-cycle approach to decision making. Our contribution addresses a lack of assessment of learning outcomes in sustainability teaching (Figueiró and Raufflet (2015) found no paper in their sustainability education literature review sample had done this), while also providing an effective learning simulation for students and managers alike.

The rest of the paper is constructed as follows. Firstly, a literature review assessing published works on the array of tools available to teach sustainability in management education, the benefits of simulations, and the importance of TCO in sustainability are presented. Then, an in-depth explanation of the exercise is provided, followed by the survey methodology and results analysis, limitations of the study, and future research directions. We conclude with the simulation's contribution.

2. Literature Review

2.1. Operations Simulations and Sustainability

Simulations provide both active and experiential learning for students (Piercy et al. 2012). Kolb (1984) defines experiential learning as “the process whereby knowledge is created through the transformation of experience” (p. 38), while Itin (1999) defines it as “the change in an individual that results from reflection on a direct experience” (p. 92). Although the case study teaching approach continues to be very popular in business education and within operations management specifically (Drake 2019), McCarthy and McCarthy (2006) contend that experiential learning techniques provide superior learning, with the authors advocating that experiential learning programs be mandatory in the major areas of a business curriculum. Fortunately, the field of operations and supply chain management has many classroom exercises for various topics such as inventory management (Robb et al. 2010), forecasting (Snider and Eliasson 2013), assembly line balancing (Fish 2005), and, of course, the classic beer distribution supply chain simulation of Sterman (1989). Many online operations simulations are also available (Snider and Balakrishnan 2013). Interestingly, although sustainability has been growing in prominence for management education, there appears to be a dearth of games and simulations developed for in-class use to date. The review of pedagogical tools, games, and simulations in the sustainability classroom

by Simmers and Soderstrom (2017) reveals that passive approaches (articles, books, cases, and videos) represent over 85% of the current resources, and only two online activity games and one finance based simulation were among the 77 listed. Barth and Rieckmann (2012) argue that sustainability education not only requires innovation in teaching and learning, but that it also challenges the capabilities of academics to generate, bring about, and adopt the innovative practices necessary to teach sustainability.

Considering that sustainability requires business students to think differently about business, historical approaches of management education such as lecture and cases may not be the most effective (Stough et al. 2018), although transdisciplinary, global, real-world cases could be developed to stimulate enhanced learning (Steiner and Posch 2006). The review by Figueiró and Raufflet (2015) of the sustainability management education literature stated that action and experiential learning is emerging as a very promising approach for teaching sustainability. Erskine and Johnson (2012) state that, “because sustainability is, by its nature, a concept and topic that calls for action, the active learning approaches preferred by students may be more valuable in this emerging focus of business inquiry” (p. 204).

Overall, activities in which students learn by doing (Collins and Kearins 2007, Shrivastava 2010, Springett 2005, Ortega-Sánchez et al. 2018) are emerging as a very promising method for teaching sustainability. First, students become active knowledge producers instead of passive recipients (Welsh and Murray 2003) because they work through the problems of an issue. Second, by including realistic global problems (e.g., the implications of environmental and social sustainability risks in the supply chain), the curriculum can foster responsible citizens, as the role of business managers is argued to be a crucial social activity (Khurana and Nohria 2008), with bad management blamed for damage to society and business schools castigated for poorly educating managers (Amann et al. 2011). Sustainability in management education is a potential solution to societal challenges, a force for good and for the transformation of managerial as well as business conduct (Painter-Morland 2015). Figueiró and Raufflet (2015) explain that experiential learning involves the students' participation in problematization, research, problem solving, and critical reflection, using tools such as teamwork, case studies, projects, discussions, and games. The objective is to generate cognitive engagement, which can increase students' motivation and develop their critical thinking skills (MacVaugh and Norton 2012). The literature review by Figueiró and Raufflet (2015) found a consensus on the need to revise classic teaching methods for sustainability education.

2.2. Total Cost of Ownership (TCO) and Sustainability

Given the importance of sustainability in management education, there is a need for a classroom simulation that can provide supply chain students with sustainability-based experiential learning opportunities. Investigation into classroom exercises focusing on supply chain sustainability and TCO found similar scarcity. On the sustainability side, classroom exercises often have a modeling focus (Godfrey and Manikas 2012, Beliën et al. 2013, Frommer and Day 2017), while there are even fewer TCO classroom exercises available. Although the concept of TCO is well developed and widely used in business (Ellram and Siferd 1993), especially in some industries where the initial outlay of a product or service is low compared with maintenance and other costs occurring during the lifetime of the system, TCO teaching literature is not so prevalent. Yet, its application and complexity is important because of the emergence of globally dispersed supply chains (Trent and Monczka 2003) and pressure to be sustainable. The evaluation of TCO is a complex and delicate task, which requires efforts to both understand the costs implied and gather enough data to estimate them when transactions often involve both goods and services, thus requiring the simultaneous evaluation of both (Caniato et al. 2015). In terms of TCO action learning, only Bevilacqua et al. (2015) provide a “cook and teach” 3-hour exercise where engineering students prepare a meal while also measuring the food supply chain environmental and social implications of that meal. Unfortunately, the existing literature does not provide a classroom exercise that incorporates both supply chain sustainability and TCO, two emerging and highly critical concepts for today’s supply chain managers.

2.3. Measuring Sustainability Education

Measuring sustainability education has also proven challenging to date. Figueiró and Raufflet’s (2015) literature review of sustainability in management education found that no article contributed assessment of learning outcomes. Simmers and Soderstrom (2017) suggest some direct and indirect methods, but conclude that value-added assessment is recommended “because the goal of sustainability education is not solely about knowledge acquisition but about knowledge usage to change the world” (p. 211).

The dice simulation addresses untapped opportunities in current supply chain education by providing students with a sustainability-based experiential learning opportunity that also integrates TCO and risk management concepts. Furthermore, the survey results also provide assessment of learning

outcomes within supply chain sustainability education across undergraduate- and graduate-level courses.

3. Exercise Description and Delivery

This in-class 45- to 60-minute simulation requires no preclass preparation for students and can be conducted at any point of the supply chain curriculum. Instructors are expected to have some sustainable supply chain knowledge to make the necessary connections between sustainability risk and TCO during decision making and debrief activities. Students compete in small teams and can be incentivized by awarding a prize to the team with the lowest resulting TCO at the end of the simulation. While the simulation was conducted in classes of up to 60 students, there is no limit to the number of teams that can participate. The simulation has three phases: (1) direct cost selection from a supplier “menu,” (2) associated indirect costs that result, and (3) dice rolling to simulate seven business environment risk/uncertainty events over the life cycle of the product line. Although online randomizers are available, humans have been rolling dice for 8,000 years. The high levels of classroom engagement and excitement during the dice rolling phase of the simulation appears to be tapping into something primordial for us.

3.1. Phase 1: Direct Costs (Approximately 20 minutes)

An introduction slide (Figure 1) is first shown explaining the scenario and the phases.

Student teams are then provided a form with a “menu” of supply chain design options and their associated direct costs from which to choose (Figure 2). Their primary choice is supplier location (local, next shore, or developing country) and transportation method. The term “developing country” indicates a low-cost production country for textile manufacture. The combination of country and transportation method provides their direct cost of materials and direct cost of transportation over the life of the product line in a single value. Secondly, the level of sustainability reputation (environmental and social) they desire and the way in which they will manage the relationship over the life of the product line are selected. Just like a restaurant menu, some options are more expensive than others. Choosing “low” for supplier inspection level would mean primarily trusting the supplier on their sustainability rather than funding more frequent independent inspections. While saving direct costs initially, such an approach could increase risks over the life of the product line. A high level of supplier collaboration on product design and production processes would have higher direct costs to administer but should lower potential risks over the life of the product line. While time would tell in the real world how such decisions would play out, dice will

Figure 1. Exercise Introduction Slide

- You work in supply chain management for a major clothing company and you are looking to source the manufacturing of a new product line
- You must decide on a supplier, transportation method, and how you will manage the supplier relationship over the life of the product line
- Your goal is to have the lowest Total Cost of Ownership (TCO) over the life of the product line
- Three phases to the competition:
 1. Direct Costs (you choose from 'menu')
 2. Indirect Costs (will result from your choices)
 3. Simulation (rolling dice)
- Team with the lowest TCO at the end wins...

be rolled in phase 3 to simulate seven supply chain risks. Figure 2 is an example of a team's supply chain design and associated costs as selected from the menu. The simulation values are non-currency specific to enable international usage, and menu costs are designed so that a supply chain designed entirely with medium levels of sustainability would result in a direct cost of 100. This benchmark enables a quick categorization of a team's supply chain sustainability levels during the simulation (e.g., low: 68–89, medium: 91–111, high: 112–132) while also enabling an efficient comparison of TCO results during the eventual debrief.

3.2. Phase 2: Resulting Lifecycle Indirect Costs (Approximately 10 minutes)

The instructor reveals, one slide at a time, the four resulting lifecycle indirect costs: inventory holding, purchase administration, quality validation, and customer service impact. For each one, each team fills in their cost-tracking worksheet for the type of indirect cost and their resulting value. All indirect costs are based on their menu choice of supplier location and transportation method. Once each indirect cost table is displayed, the instructor should ask the teams the question, "What is the rationale for these table values?"—challenging students to explain why some are high while others are low, to understand impacts. For example, Figure 3's holding cost table reveals a relationship between the delivery lead time and the required levels of inventory in the supply chain. Fast transportation from a local supplier would add indirect inventory holding costs of only 4 toward a team's eventual TCO, whereas choosing slow transportation from a low-cost production country triples those holding costs to 12 due to the required high inventory levels with such a sourcing choice. Figure 3's purchase administration costs reveals that frequent small purchases from a developing country would incur high levels of indirect purchase administration costs (12), whereas less-frequent larger orders from a local supplier would incur minimal

such costs (4). Similar indirect cost tables are revealed for quality validation costs (e.g., higher costs for large batches of inventory sourced from a developing country) and customer service impact (e.g., fast delivery from a local supplier would improve TCO performance).

For each indirect cost, the instructor can ask students if a corporation's accounting department would receive and invoice for such costs. Students typically answer that even though these costs are real and potentially significant, they would not appear as supply chain costs in an accounting system. This can help slowly reduce the deference for accounting information solely, encouraging them to adopt TCO concepts and sustainability concerns into their supply chain decision making.

3.3. Phase 3: Roll the Dice for Seven Lifecycle Risks (Approximately 15 minutes)

Prior to revealing the seven supply chain risks that will be simulated by dice rolling, the class should be asked to speculate the risks for which they think the dice will be rolled. While some suggest risks that will be simulated, others suggest things like natural disasters, trade wars, and conflict/social unrest that are not currently incorporated because of their extremely low probability (but could be incorporated if required). Such suggestions expose to fellow students that even more supply chain risks could occur than the seven upcoming in the simulation. Mirroring risk management, each risk has two components that are simulated by rolling the dice: probability and severity. Their menu choices from phase 1 influence their impacts on foreign currency fluctuation, inflation, environmental incident, social incident, inspection incident, quality recall incident, and market demand for sustainable products. For example, if a team chose a local supply chain, they would not be exposed to a foreign currency risk. Rather than the instructor rolling, having various students roll the dice each time creates an even more interactive classroom environment and absolves the instructor of any responsibility for the dice-roll

Figure 2. (Color online) Supplier “Menu” and Sample Student Group Selections

		Lifetime Unit Cost & Transport Cost		
		Slow	Medium	Fast
Supplier Location	Local	50	60	70
	Next Shore	40	50	60
	Developing Country	30	40	50

		Supplier Sustainability Reputation - Environmental		
		Low	Medium	High
Supplier Location	Local	15	18	21
	Next Shore	12	15	18
	Developing Country	9	12	15

		Supplier Sustainability Reputation - Social		
		Low	Medium	High
Supplier Location	Local	15	18	21
	Next Shore	12	15	18
	Developing Country	9	12	15

		Lifetime Supplier Inspection Level		
		Low	Medium	High
Supplier Location	Local	6	8	10
	Next Shore	8	10	12
	Developing Country	10	12	14

		Lifetime Supplier Collaboration Strategy Cost		
		Low	Medium	High
Supplier Location	Local	6	8	10
	Next Shore	8	10	12
	Developing Country	10	12	14

Supplier Location: Local Next Shore Developing Country				
Option	Selection			Cost
Transportation Method	Slow	Medium	Fast	30
Supplier Sustainability Reputation- Environmental	Low	Medium	High	9
Supplier Sustainability Reputation - Social	Low	Medium	High	15
Supplier Inspection Level	Low	Medium	High	10
Supplier Collaboration Level	Low	Medium	High	12
Total Direct Cost of Ownership:				76

results. Figure 4 provides an example of how the probability and severity work for the environmental incident risk.

The first roll determines if the risk occurred or not for each team based on their selection of supplier location and supplier environmental reputation. Teams who

Figure 3. Indirect Inventory Holding and Purchase Administration Costs

		Lifetime Inventory Holding Costs		
		Slow	Medium	Fast
Supplier Location	Local	8	6	4
	Next Shore	10	8	6
	Developing Country	12	10	8

		Lifetime Purchase Administration Costs		
		Slow	Medium	Fast
Supplier Location	Local	4	6	8
	Next Shore	6	8	10
	Developing Country	8	10	12

have been more risky with low-sustainability selections increase the chances of the risk occurring and, if it does, also the subsequent severity of the risk. Groups nervously await the roll results, then react when the roll value reveals if the risk occurred for them and, if so, what their severity was. In this example, an occurrence roll result of “3” would only result in the risk occurring for teams that chose a supplier in a developing country and with a low environmental reputation (like our sample group did in Figure 2). The rest of the teams would have avoided this risk by their menu selections and then enjoyed watching the affected groups anticipate their fate as the severity impact roll occurs. If a subsequent severity dice roll result of a “4” occurred, the group would have to add 20 to their TCO value. The instructor records the numbers rolled on the instructor spreadsheet and the results filter on to the *Team Selections and Results* page. The seventh risk simulates the market demand for sustainable products impacting all teams. If the market demand roll is high, teams that chose high-sustainability supply chains would profit and thus are provided with a negative (offset) TCO value for this risk, while low teams incur additional costs. If, however, demand for sustainable products is low, the opposite results will occur.

3.4. Exercise Debriefing (Approximately 10 Minutes)

Contrasting and comparing each team’s original direct costs with their resulting TCO is critical for students to recognize the linkages between sustainability, risk management, and TCO. If no team chooses the extremes (68, 132), the instructor can have them running as the two final groups as they are preset in the teaching spreadsheet for comparison. The instructor should group the teams into low- (direct costs 68–90), medium- (91–111), and high-sustainability (112–132) supply chains, then highlight the resulting TCO values for each grouping. Low teams typically have higher increases and a wide range of possible TCO values, relative to medium and high teams, because their supply chain design has higher indirect costs and is exposed to more supply chain risks. The comparison can be done by quickly converting each group’s data (Figure 5) into the instructor spreadsheet (available as a supplementary file) and displayed on the screen.

Analysis of the results from 79 student teams over 8 simulations reveals that the design is pedagogically

robust. Table 1 compares results of the 14 teams who chose a low-direct-cost (sustainability) supply chain design against the 53 and 12 teams who chose medium- or high-sustainability supply chain design, respectively.

The simulation is designed to expose a low-direct-cost strategy to the most uncertainty (probability and severity) and the least uncertainty to a high-direct-cost strategy. As indicated by the standard deviation values in Table 1, teams who chose a low-direct-cost strategy will have the highest uncertainty of results and, on average, will also have the highest resulting indirect costs and risk costs. In contrast, high-direct-cost/sustainability teams typically are more highly insulated from the first six simulated supply chain risks, and if the roll result for the sustainability market demand (seventh risk) is favorable, their resulting increased profits, on average, will more than offset their six risk costs contributing to a lower net TCO value. As the data in Table 1 reveal, teams who chose a high-direct-cost strategy at the outset experience the least uncertainty surrounding their final TCO results, generally resulting in a negative percentage change. That is, their decisions were rewarded with a lower TCO as a result of what happened in the environment over the course of the product line being supplied. The instructor should debrief the students to this effect including reasons why, in the clothing industry, these occur.

Note that while the design of the simulation makes it possible for an extremely low (i.e., risky) direct cost/sustainability team to win, it would require a highly unlikely streak of good luck to occur, a fact recognized by students during the debrief discussion. Over the seven risks and related rolls, lucky or unlucky “streaks” tend to even out. Despite the randomness that can occur with the dice rolls, the simulation effectively illustrates that higher levels of sustainability in supply chain design provide higher predictability of TCO results while also providing supply chain risk mitigation.

4. Methodology for Measuring Effectiveness

The effectiveness of the simulation was measured via an optional, anonymous 11-question student survey that was conducted immediately after the exercise (Figure 6). The survey was comprised of 10 Likert

Figure 4. Probability and Severity for Environmental Incident Risk

Supplier Location		Supplier Environmental Reputation & Environmental Incident - Occurrence?		
		Low	Medium	High
Supplier Location	Local	if roll = 1	N/A	N/A
	Next Shore	if roll = 1/2	if roll = 1	N/A
	Developing Country	if roll = 1/2/3/4	if roll = 1/2	if roll = 1

Supplier Location		Supplier Environmental Incident - Severity TCO Impact					
		1	2	3	4	5	6
Supplier Location	Local	5	5	10	10	15	15
	Next Shore	10	10	15	15	20	20
	Developing Country	15	15	20	20	25	25

Figure 5. Sample Completed Cost-Tracking Worksheet

Total Cost of Ownership (TCO) DICE GAME
Student Worksheet

Phase 1: Direct Costs
Circle your selections. Enter the associated direct costs from selection tables.

Supplier Location: Developing Country Next Shore Local

Option	Selection			Cost
Transportation Method	Slow	<u>Medium</u>	Fast	50
Supplier Sustainability Reputation - Environmental	<u>Low</u>	Medium	High	12
Supplier Sustainability Reputation - Social	Low	<u>Medium</u>	High	15
Supplier Inspection Level	Low	Medium	<u>High</u>	12
Supplier Collaboration Level	Low	Medium	<u>High</u>	12
Total Direct Cost of Ownership:				101

Phase 2: Associated Indirect Costs

	TCO Impact
1. Lifetime Inventory Holding Costs	8
2. Lifetime Purchase Admin Costs	8
3. Lifetime Quality Validation Costs	8
4. Customer Service Impact	0
Total Indirect Costs:	24

Phase 3: Risks & Impacts

	Y/N?	TCO Impact
1. Foreign Currency Fluctuation	N	0
2. Inflation	N	0
3. Supplier Environ. Incident	N	0
4. Supplier Social (Labor) Incident	Y	15
5. Supplier Inspection Lvl & Environ./Social Incident	N	0
6. Supplier Quality Recall Incident	N	0
7. Market Demand for Sustainable Product	Y	15
Total Risk Costs:		30

Grand Total Cost of Ownership: 155

scale questions (−3 strongly disagree, +3 strongly agree) and 1 question for written comments. Some questions seek feedback on the simulation approach, while others were designed to provide an assessment of learning. The simulation and survey was first piloted in a required logistics course in a master of science (MSc) program in the United Kingdom. Survey results ($n = 31$) revealed support for the simulation and learnings across all questions, but recommended more clarity in how the simulation is administered. In response, additional slides were created to better facilitate students through the simulation, one slide for each indirect cost and risk. This improved process

was subsequently conducted in both an undergraduate business required course ($n = 309$) and an Executive MBA (EMBA) course ($n = 41$) in Canada with the same instructor, and using the same survey instrument. Curriculum-wise, in both instances, the simulation was conducted in the middle of supply chain content with inventory management having previously been covered in their courses. The undergraduate students were a mix of second- and third-year students, and the simulation was conducted in their first and only required course in operations and supply chain management during their 4-year degree program. Only 8% of the students were majors in operations or supply chain management, with the rest of the class primarily majoring in accounting, finance, or marketing, creating an inherent student engagement barrier in the course. The EMBA students had an average of 14 years of progressive work experience, and the simulation was conducted in their only course in operations and supply chain management, which occurred in their second semester of a four-semester degree program.

Statistical significance testing (Mann–Whitney U test) was conducted comparing the undergraduate survey results to the MSc pilot and the EMBA results. Relative to the pilot, significant positive differences were found in over half of the undergraduate metrics, indicating that the efforts to improve the clarity of the administration of the simulation were effective. Comparing the undergraduate responses to the EMBA, we found no significant differences for any of the survey questions at the $p < 0.05$ level. This finding allows the responses from these two groups to be combined for analysis purposes. Furthermore, it also reveals that EMBA students accrue the same experience as undergraduates from the simulation despite their significant work and life experience differences. Table 2 provides the mean scores for the MSc pilot study, undergraduate, and EMBA responses, while Table 3 provides combined undergraduate and EMBA response details that show largely positive Likert-scale results.

5. Evidence of Effectiveness

An assessment of the simulation's impact was conducted by analyzing the combined undergraduate and EMBA Likert-scale responses on the simulation approach and the learning outcomes. Written comments were collected and also analyzed separately.

Table 1. TCO Simulation Results Analysis by Direct Cost Category

Direct cost category	Direct costs range	Count	Average direct cost	Average indirect costs	Average risk costs	Average TCO	Average % change	Standard deviation
Low	68–90	14	83.0	36.9	43.2	163.1	100.7%	58.4%
Medium	91–111	53	101.3	23.2	6.6	131.1	30.1%	26.8%
High	112–132	12	118.3	7.6	−15.8	110.0	−6.7%	6.5%

Figure 6. Survey Instrument

1. The exercise was an interesting way to learn about the Total Cost of Ownership concept. (circle your answer)

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

2. There exercise made me aware of some Total Cost of Ownership components that I hadn't considered before.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

3. Awaiting the dice roll result was an effective way to simulate the worry / anxiety supply chain professionals feel about their sourcing decisions.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

4. Supply chains that are designed to incorporate a high level of sustainability are an effective way to reduce global supply chain TCO risks.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

5. Comparing each team's supply chain design and eventual Total Cost of Ownership results was a valuable learning experience.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

6. A company's accounting system will provide all the cost information that supply chain professionals need to make their sourcing decisions.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

7. Our group generally agreed on the final decisions after considering everyone's input.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

8. Supply chains that are designed to achieve low direct costs have a wider range of possible Total Cost of Ownership results than supply chains that incorporate a high level of sustainability.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

9. More university class exercises / cases should incorporate uncertainty (such as dice rolling) to simulate eventual real world impacts that are beyond a managers control.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

10. This exercise should continue to be included in this course.

Strongly Disagree			Neutral			Strongly Agree
-3	-2	-1	0	+1	+2	+3

11. Do you have any other comments about the exercise?

5.1. Simulation Approach

The questions relating to the simulation approach from the survey tool and corresponding Table 3 are questions 1, 3, 7, 9, and 10. The survey results indicate that using dice to simulate supply chain uncertainty was strongly supported across all groups of students. In addition to a very high mean value of +2.46, 98.4% of students rated the simulation positively (+1/+2/+3) as an interesting way to learn about TCO. Although they only had to wait briefly in the classroom for the roll of the dice, students experienced worry and anxiety surrounding that uncertainty (mean of +2.20, 92.3% positive ratings). Although it made them uncomfortable, they apparently valued the learning experience it provided as they strongly encouraged the expansion of simulating uncertainty with dice in other university classes (mean of +2.35, 96.6% positive ratings) and the continued use of the simulation in the course (mean of +2.56, 97.7% positive ratings).

5.2. Assessment of Learning Outcomes

The questions relating to the assessment of learning outcomes from the survey tool and corresponding Table 3 are questions 2, 4, 5, 6, and 8 (where questions 2 are 5 are "perceived" self-reporting). The simulation created high levels of awareness of TCO components not previously considered by the students (Question 2). Interestingly, the simulation generated slightly more new awareness for the EMBA's. Although these

executives possess more work and life experience, these results appear to indicate they have a similar level of incoming knowledge on sustainability and TCO concepts as undergraduates do (Cole and Snider 2019). Perhaps this is attributable to the topics emerging more recently as key management education concepts. Questions 4 and 8 provide multiple assessments of the primary intended learning objective of the simulation—the interrelationship between supply chain sustainability, TCO, and risk management. Question 4's results indicate that students experientially learned that sustainable supply chain decisions provide TCO risk mitigation (mean of +1.91, 88.0% positive), enabling increased business stability in a turbulent world. Question 8's results confirm these learnings as the students recognized that low-direct-cost supply chains will experience higher levels of TCO uncertainty (mean of +1.87, 87.1% positive). Question 6's results (mean of -1.29, 71.7% negative) indicate the simulation educates students on the limitations of relying on traditional accounting information for supply chain decision making. Considerations such as indirect costs and impacts on risk probability and severity need to be analyzed in addition to accounting provided cost information. Question 5 (mean of +2.26, 96.0% positive) also shows strong support for the pedagogical approach of the simulation debrief as they believe it enables expanded experiential learning reflection beyond their own team's performance.

Table 2. Survey Mean Scores

Course type	Survey size	Q1 Interesting way to learn TCO concept	Q2 Made me aware of components considered before	Q3 Awaiting dice roll simulated worry/anxiety	Q4 Sustainable supply chains are effective way to reduce TCO risks	Q5 Comparing each team's design and eventual results was valuable learning	Q6 Accounting system provides all cost info needed	Q7 Group agreed on decisions	Q8 Low cost Supply chains have wider range of results than sustainable ones	Q9 More university classes should simulate real world impacts with dice	Q10 Exercise should continue to be included in course
Miscellaneous (pilot)	31	2.33	1.80	1.37	1.63	2.00	0.43	2.03	1.63	1.97	2.23
Undergraduate	309	2.46	2.09	2.20	1.90	2.26	-1.29	2.10	1.86	2.38	2.58
EMBA	41	2.51	2.20	2.17	1.98	2.22	-1.27	2.07	1.90	2.17	2.37

Table 3. Combined Undergraduate and EMBA Survey Response Details

Q1 Interesting way to learn TCO concept	Q2 Made me aware of TCO components not considered before	Q3 Awaiting dice roll simulated worry/anxiety	Q4 Sustainable supply chains are effective way to reduce TCO risks	Q5 Comparing each team's design and eventual results was valuable learning	Q6 Accounting system provides all cost info needed	Q7 Group generally agreed on decisions	Q8 Low cost supply chains have wider range of results than sustainable ones	Q9 More university classes should simulate real world impacts with dice	Q10 Exercise should continue to be included in course
-3	0	1	0	0	139	1	8	0	1
-2	0	1	4	1	62	3	8	0	2
-1	0	5	8	0	50	7	5	1	0
0	5	22	30	13	32	16	24	11	5
+1	29	56	56	48	20	46	44	35	22
+2	115	105	127	120	22	126	129	119	80
+3	201	160	124	168	25	151	132	184	240
Total	350	350	349	350	350	350	350	350	350
Mean	2.46	2.10	1.91	2.26	-1.29	2.10	1.87	2.35	2.56
Negative	0.0%	2.0%	3.1%	0.3%	71.7%	3.1%	6.0%	0.3%	0.9%
0	1.4%	6.3%	8.6%	3.7%	9.1%	4.6%	6.9%	3.1%	1.4%
Positive	98.6%	91.7%	88.0%	96.0%	19.1%	92.3%	87.1%	96.6%	97.7%

5.3. Written Comments

Written comments were received on 172 of the 380 surveys (45%). To analyze the entire 1,984 comment words, a word cloud was generated. Word clouds display text in graphical form where font size represents frequency, and can be used to enable instructors to assess student learning and feedback (Miley and Read 2012). Settings of a minimum of three characters and five occurrences resulted in 42 most common words (Figure 7). “TCO” had 10 occurrences, while “fun” had 48.

Selected comments provide more insights into the impact the exercise had on students:

- A great exercise to bring awareness of the many considerations to take into account of a global supply chain.
- Best way to emphasize the considerations of indirect costs and risks that we completely overlooked when looking at our sourcing decisions.
- It was fun—made it clear sustainability (environmental & social) decisions are important
- I learned a lot about external factors to really consider before making final decisions. I now understand that even if it is the cheapest decision, it doesn’t mean that it’s the best.
- Good learning opportunity to understand all risks with uncertainty and importance of a high level of sustainability. Engaging and great!
- Fun way to learn about TCO and the risks involved with taking cheaper costs up front.
- I thought it was very valuable. It gave a world experience that we could relate the concept to.
- Randomness of dice roll is important because it proves it is not a perfect case scenario as most class

Figure 7. Student-Comment Word Cloud



material in business school teaches us/makes us think.

- Using dice to incorporate risk into the exercise makes it much more exciting.
- Letting others roll the dice was a fantastic idea!
- This was a great game—really got my heart racing! Next time I’d suggest more risks to include!

6. Limitations and Future Research Directions

A broader survey conducted across multiple instructors and multiple countries could provide stronger evidence of the global applicability of the simulation and ease of implementation for faculty members. Our simulation could be revised and tailored to incorporate current events by adding other risks such as global trade wars triggered by powerful political figures, or even natural disasters. This modularity of the simulation should enable it to continue to be relevant long into the future. The design of the game also provides options for changes to the product line, and thus the instructor can design specific country options—while it is currently designed as the flow from low-cost production countries to Western consumers, an option of China sourcing raw materials from Latin American countries (such as from Argentina and Venezuela to fuel their manufacturing economy) could quite easily be integrated. Finally, the success of this simulation should provide encouragement for further experiential learning exercises to be developed within sustainability education.

7. Conclusion

This innovative simulation and paper not only fills existing research gaps by providing a much-needed supply chain sustainability and TCO classroom experiential activity, it also is one of the first to provide assessment of learning outcomes for a sustainability simulation (a call made by Figueiró and Raufflet (2015)). Survey results confirm that this simulation successfully accomplished multiple learning objectives for this sample while also providing a highly engaging experiential learning classroom environment. The dice-based approach also provides ease of implementation for faculty relative to simulations that are based on online software programs, and also provides students the opportunity to discuss sustainability trade-offs among their peers. The simulation has been successfully conducted by multiple instructors, in multiple countries and across all levels of management education (undergraduate, master of science, and EMBA). To date, we have received requests for the simulation from multiple universities and from EMBA students who participated in the simulation for use with their own employees. This indicates interest and applicability in both educational and

corporate settings. Through this simulation, students are exposed to supply chain sustainability, risk management, and TCO while also experiencing and reflectively understanding the linkages between these important supply chain concepts. Finally, it illustrates an example of the perceived learning effectiveness enabled by using dice to simulate uncertainty for business students (similar to Heineke et al. (2010)) while also providing a call from these students for the dice approach to be expanded in their education.

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All electronic files for the simulation are available from the authors. The files are easily modifiable for adding or adjusting costs and risks. A video of the full simulation being conducted in a 60 student undergraduate class is also available. This paper was shortlisted for the Nigel Slack Teaching Innovation Award at the European Operations Management Association Conference in 2018. Thank you to colleagues Dr. Nancy Southin for providing statistical analysis support, Professor Nigel Caldwell and Dr. Katri Kauppi for trialling the simulation in Scotland and Finland, and Ben Carson from Viking Air for putting the educational tool into management practice with his supply chain team.

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