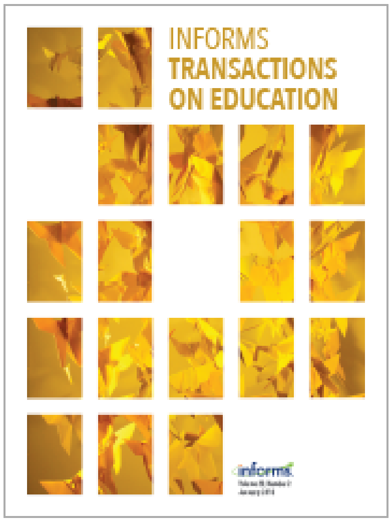

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Using a Monte Carlo Simulation Exercise to Teach Principles of Distribution: An Enhanced Version of the Classic Transportation Problem

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Abstract. This paper explains a Monte Carlo simulation workshop applied to an extended version of the classic transportation problem. It is designed to be conducted in a classroom or laboratory where students have access to a Monte Carlo simulation tool, such as Oracle Crystal Ball. The hands-on exercise builds on the classic transportation problem by allowing students to develop cost-efficient solutions when demands are uncertain and follow multiple types of patterns. Students develop a distribution plan by considering transportation, inventory-holding, and stock-out costs. Through simulation, students are able to see the consequences of their proposed policies and revise them until reaching a satisfactory solution. The Monte Carlo method is deployed because traditional deterministic optimization models do not exist for our scenario that we believe to be realistic and widely applicable. Students gain valuable experience using an important modeling tool applied to a classic operations-management problem.

Supplemental Material: Data are available at https://doi.org/10.1287/ited.2018.0200.

Keywords: transportation problem • Monte Carlo simulation • teaching operations management • teaching supply chain management

1. Introduction

The transportation problem was initially formulated decades ago by Hitchcock (1941) and has been one of the most important and successful applications of quantitative analysis (Reeb and Leavengood 2002). A streamlined version of the general-purpose simplex method to solve these types of problems was introduced by Dantzig (1951). The basic problem is characterized by a scenario in which an organization with multiple facilities, each having a limited capacity, distribute product to multiple locations, demand centers, or customers. The goal is to minimize the cost of shipping goods from sources to destinations; costs may be different along each route, and shipments from the sources cannot exceed their capacities.

Because of the specific mathematical structure of the transportation problem, when supplies and demands are fixed or certain, an optimal solution can be found using a variety of methodologies (Gass 1990). As a result of this characteristic as well as the critical issue addressed by the problem, it has been very widely studied and applied. However, as one begins to relax the assumptions about supply and demand, the problem becomes more difficult to optimize and has, thus, received less attention. Algorithms that address these real-world issues involving stochastic parameters are extremely complicated and difficult to solve (Laporte et al. 2002).

This paper addresses an aspect of this gap by using Monte Carlo simulation to solve a routing problem in which customer demands are uncertain. From our experience, we find the Monte Carlo simulation tactic described is easy for students (and practitioners) to use, understand, and interpret. Further, this approach does not require the assumption that demands follow a normal distribution or, for that matter, any particular type of distribution. The problem has also been enhanced to include the impacts of inventory-holding and stock-out costs in that solutions that deliver either more or less product than required at each customer location incur a cost.

In the exercise presented, the overall goal is to minimize total costs in a small supply chain network that consists of three manufacturing plants and four demand centers. Costs are incurred from the transportation of goods along routes as well as from penalties associated with either shipping too much or too little to the demand centers.

Participants in the exercise we conducted were 33 undergraduate business students of various majors enrolled in an introductory supply chain management course at the authors' home university, Texas Christian University in Fort Worth, Texas. The exercise took place in a computer laboratory outside of regular class hours but was designed to fit within the time frame of a typical class period (1 hour, 20 minutes). Students were offered a nominal bonus (two points) on their next exam for participating. The bonus points were given to incentivize students to participate in an outside-of-class activity. Each student had previously taken an introductory business statistics course, and it was assumed that they all had some basic background knowledge regarding histogram development and common probability distributions, in particular the normal and triangular distributions. We recommend that instructors attempting to implement this exercise ensure a similar level of experience among students and might consider a brief review of probability distributions to refamiliarize participants.

Prior to conducting the workshop, instructors should plan to train their students on the basic use of Monte Carlo simulation. Monte Carlo simulation is an iterative mathematical technique that is used to show the impact on total costs for thousands of different demand scenarios (or trials) at each tire-manufacturing plant or customer location. The technique numerically quantifies and graphically depicts potential total cost results (along with their associated likelihoods) based on provided uncertain inputs (i.e., estimated demand distributions at each of the four plants). Monte Carlo applications have evolved greatly over time and are now exceptionally powerful and easy to use, particularly with point-and-click software packages such as Oracle© Crystal Ball. Today, the technique is widely used in the field of operations management and numerous other business applications (Engle et al. 1989, Winston 2004, Kwak and Ingall 2007). Use of various simulation techniques have further expanded to innovative and effective teaching exercises (Evans 2000, Umble and Umble 2013, Weltman 2015).

Through our workshop, students gain a deeper understanding of a classic logistics issue, learn the basics of balancing multiple cost tradeoffs, use common probability distributions to model uncertain demands, and apply Monte Carlo analysis to see the total potential impact associated with their decisions. The workshop is easy to explain, and students are able to understand and interpret their solutions.

2. Workshop Scenario

As noted, our workshop is an extension of the classic transportation problem. In the exercise, students are presented with a network depicting three rubber-production facilities (located in Detroit, Pittsburgh, and Buffalo) that supply four automobile tire-manufacturing plants (Boston, New York, Chicago, and Indianapolis). The monthly capacity at each rubber-production facility is fixed and limited at 300 tons in Detroit, 180 tons in Pittsburgh, and 250 tons in Buffalo (although these quantities can be set to any amount desired by the instructor). On the customer side, demand for rubber is uncertain at each of the four locations, varying from month to month according to a set distribution. Complicating this uncertain demand is the fact that the monthly supply to each tire plant must be allocated before demand is realized. Thus, it is possible to either undersupply or oversupply a given plant in a given month. In this scenario, if the amount of rubber sent to a plant is insufficient to meet demand, stock-out costs are $60 per ton. Conversely, should the amount of rubber sent exceed demand, inventory-holding costs are $20 per ton. Any leftover inventory is assumed to be unsuitable for future use and does not carry over to the next period. These game-play parameters at the customer-location level create logistical conditions very similar to the classic newsvendor problem (Chen et al. 2016).

Regarding transportation cost, amounts vary between each production facility–customer pair and must be accounted for in a distribution plan. These costs, in dollars per ton shipped, are provided in Table 1.

To help illustrate the structure of this distribution network, Figure 1 shows a diagram that depicts not only the origins and destinations but also the capacity at each rubber-production facility and the cost of transportation (in dollars per ton) to a given tire manufacturer (demand center). Mean demand values at each tire manufacturer are listed, but these demands vary independently and in different ways at each location. These demand variabilities are discussed in the following section.

3. Conducting the Workshop

3.1. Worksheet

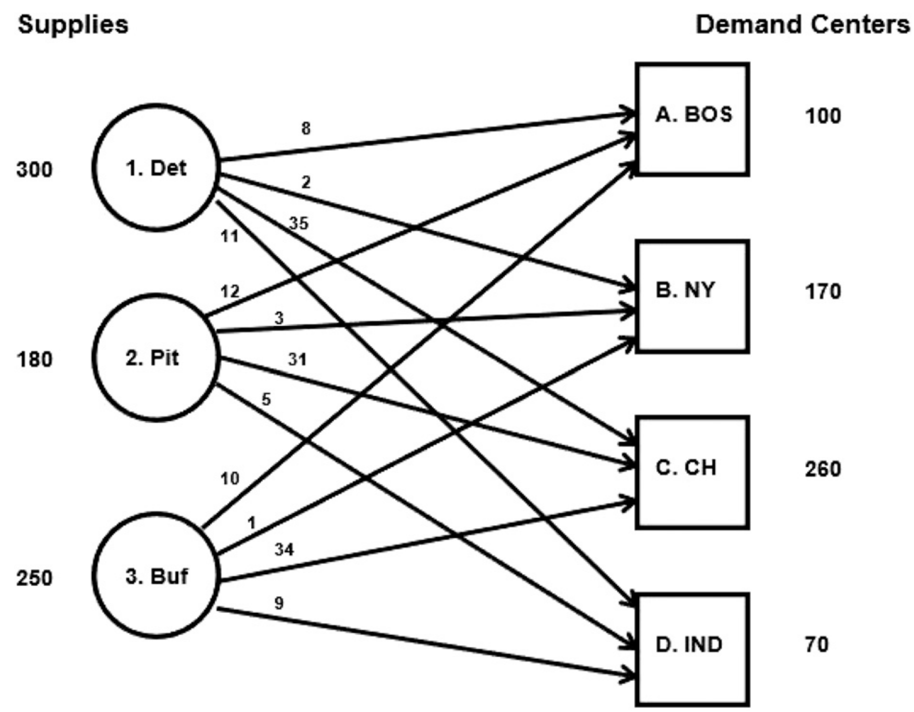
To begin the workshop, students are asked to form teams of three to five people and download an Excel

Table 1. Transportation Costs ($/ton)

From\to	A. Boston	B. New York	C. Chicago	D. Indianapolis
1. Detroit	8	2	35	11
2. Pittsburgh	12	3	31	5
3. Buffalo	10	1	34	9

Notes. To help illustrate the structure of this distribution network, Figure 1 shows a diagram that depicts not only the origins and destinations but also the capacity at each rubber production facility and the cost of transportation (in dollars per ton) to a given tire manufacturer (demand center). Mean demand values at each tire manufacturer are listed, but these demands vary independently and in different ways at each location. These demand variabilities are discussed in the following section.

Figure 1. Scenario Network Structure and Parameters



file (DistributionWorkshopStudent.xlsx, provided by the instructor) that contains a worksheet in which they will do all of their solution building. It should be noted that, in class, prior to the workshop, students were exposed to the "classic" transportation problem, in which both supply and demand are certain or fixed. Linear programing via Excel (solver) was applied to determine the optimal solution, and students develop some experience with both the problem and this optimization approach. For our workshop, which extends this problem by accounting for demands that are uncertain, we provide a spreadsheet template that contains an origin–destination matrix that is set up to make cost calculations for both transportation and inventory. The sheet is initially set with a solution of 40 unit shipments from each rubber plant to all four tire manufacturers and with demands at each customer equal to their stated means. The downloaded Excel worksheet (Figure 2) shows these initial settings along with associated costs.

The purpose of these initial settings is to provide students with an example in which both stock-out costs and holding costs are incurred, thus illustrating the financial impact of both inventory outcomes. In the example shown in Figure 2, the monthly inventory holding costs are $400 in Boston because the solution overshipped to that location by 20 units. Those 20 extra units incur a holding cost of $20 each for a total of $400. Stock-out costs in Chicago are $8,400 because it received 140 units less than required at a cost of $60 per unit. When introducing the workshop to the students, Figure 2 was shown to the class, and students were encouraged to think about the trade-offs to be made in the three

Figure 2. Initialized Distribution Plan and Associated Costs

	To	A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
From	1. Det	40.00	40.00	40.00	40.00	160	300	140
	2. Pit	40.00	40.00	40.00	40.00	160	180	20
	3. Buf	40.00	40.00	40.00	40.00	160	250	90
ShippedTo		120.00	120.00	120.00	120.00			
Actual Demand		100.00	170.00	260.00	70.00			
						Totals		
Stock-out costs		0.00	3000.00	8400.00	0.00	11400.00		
Warehouse costs		400.00	0.00	0.00	1000.00	1400.00		
Shipping Costs		1200.00	240.00	4000.00	1000.00	6440.00		
TOTAL COSTS		1600.00	3240.00	12400.00	2000.00	$19,240		

cost categories (stock-out, warehouse, and shipping) in developing a potential low-cost scenario.

3.2. Uncertain Demand

To help make a good transportation-solution decision, the downloaded Excel file also contains four separate worksheets (BOSDemand, NYDemand, CHDemand, and INDDemand) that show 36 months of prior demand at each tire manufacturer. Students are instructed to analyze this demand history, thinking of how it might best be characterized and how it is most likely to look over the next three months. It is emphasized to students that past demand patterns are indicative of future demand, but just like in actual business applications, demand at any center is not known with certainty. To aid in this assessment, students are encouraged to develop histograms of the demand data for each customer location as well as to determine means and measures of dispersion, or variability, such as standard deviations or coefficients of variation. Figure 3 shows examples of demand histograms students should develop in the workshop for each demand center.

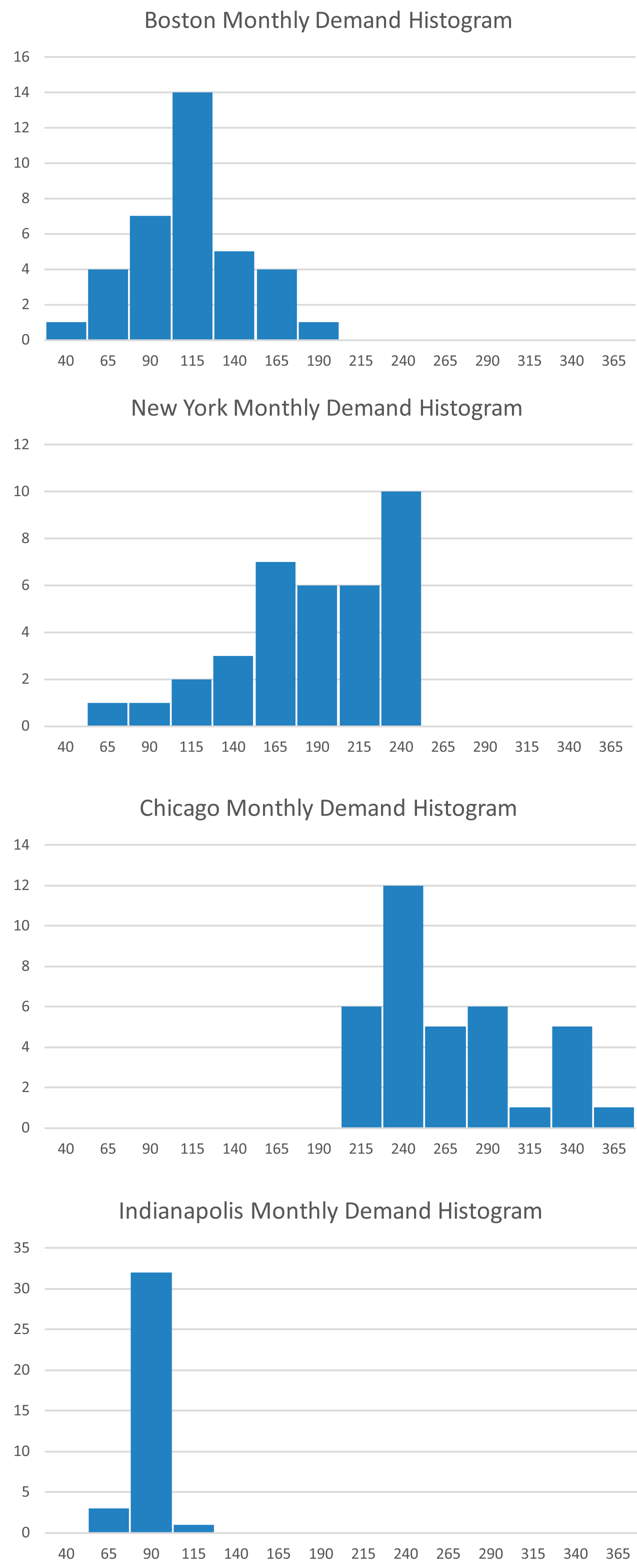
In these examples, Boston's demand is roughly normally distributed with a mean of 100 tons and standard deviation of 35 tons. New York's demand is triangularly distributed with a minimum of 50, maximum of 240, and most likely value of 220 tons. Demand in Chicago can be modeled as a triangular distribution with a minimum of 200, maximum of 360, and most likely value of 220. Finally, demand in Indianapolis can be modeled with a normal distribution with mean of 70 tons and a standard deviation of five tons.

In summary, there are two cases of normally distributed demand: Boston with a great deal of variability and Indianapolis with very little variability. The other two cases have skewed demands: New York's demand is left or negative skewed with a great deal of variability in demand, and Chicago's demand is right or positive skewed, also with a great deal of variability in demand.

It should be noted that the demand parameters are at the discretion of the instructor; these were simply the ones selected for this test exercise to provide a variety of means, dispersions, and distributions. Other demand distributions, such as uniform or Poisson, could alternatively be employed.

Further, in developing histograms, the choice of bin width and number of classes or bins is something of a judgment call although it is also an opportunity to inform students of best practice guidelines. Participants can be encouraged to strike a balance between having too many small bins (under-smoothing) and too few large bins (over-smoothing, over-summarizing the data) (Martin 2003). Using the approximate class width formula (Bowerman et al. 2017), we obtained a recommended width of 25 based on seven or eight classes

Figure 3. Demand Profile Histograms



for three of our four demand centers (Boston, New York, and Chicago):

$$\text{approximate class width} = \frac{\text{range}}{\text{approximate number of classes}}.$$

Figure 4. Example Student Distribution Plan Solution

	To	A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
From	1. Det	120.00	70.00	0.00	0.00	190	300	110
	2. Pit	0.00	0.00	105.00	75.00	180	180	0
	3. Buf	0.00	125.00	125.00	0.00	250	250	0
ShippedTo		120.00	195.00	230.00	75.00			
Actual Demand		100.00	170.00	260.00	70.00			
						Totals		
Stock-out costs		0.00	0.00	1800.00	0.00	1800		
Warehouse costs		400.00	500.00	0.00	100.00	1000		
Shipping Costs		960.00	265.00	7505.00	375.00	9105		
TOTAL COSTS		1360.00	765.00	9305.00	475.00	**$11,905**		

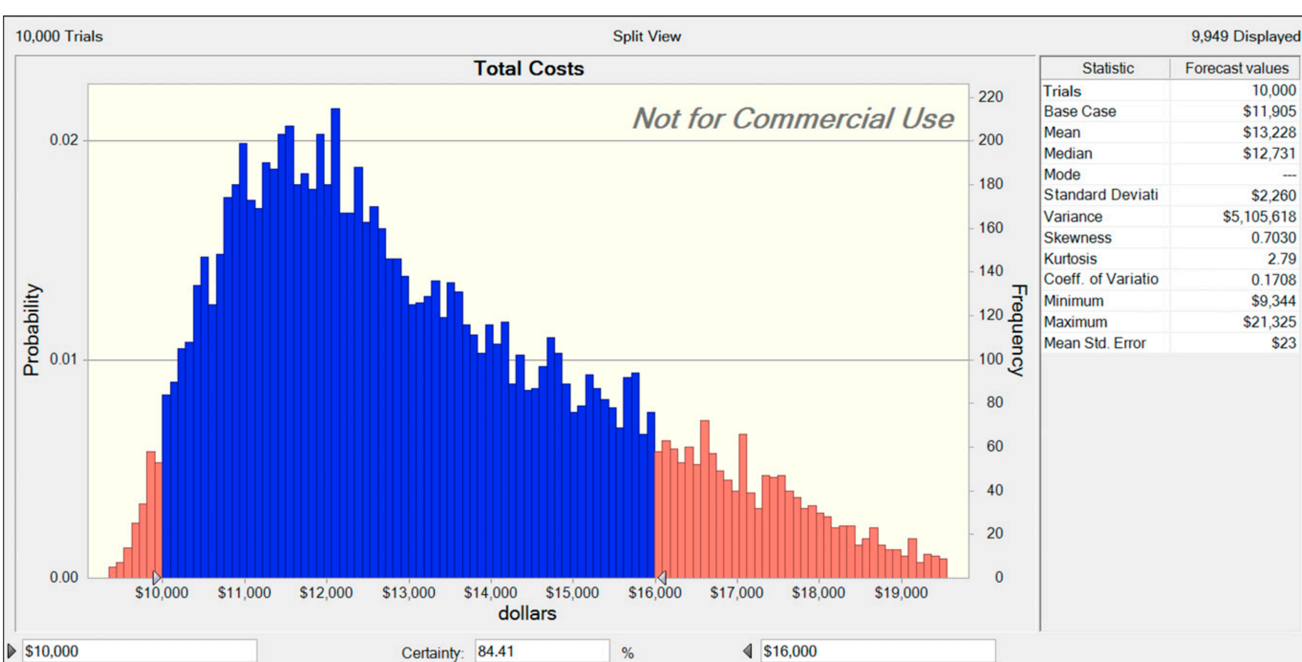
Because Indianapolis' demand has little variability, with this common scale, only three classes are able to be depicted. With the same scale used in our histograms for all four demand centers one can readily see and compare demand viabilities as shown in Figure 3.

3.3. Developing a Solution

Based on this historical demand analysis of each tire manufacturer, while keeping in mind the transportation cost and potential costs of oversupplying or undersupplying each location, student teams must now decide how many tons of rubber to ship along each route. A summary of an informed demand analysis and resulting distribution plan are provided in Appendix A. Teams can then examine their proposed solutions using Monte Carlo simulation. One such solution is shown in Figure 4.

Based on a run of 5,000 trials, this solution provides a mean total cost of $11,905, and it is quite likely (84.31%) that costs will be somewhere between $10,000 and $16,000 per month. The distribution of this total cost is shown in the histogram provided by the application (Figure 5). More trails can easily be run, but in our experience, trials of more than 5,000 produce very

Figure 5. Monte Carlo Total Cost Results for the Example Student Distribution Plan Solution



similar results (i.e., about 84% of the time, total costs are between $10,000 and $16,000 with a mean of $11,905 and standard deviation of $2,240).

After observing simulation results, student teams can make modifications to their distribution plan in an attempt to improve costs. For example, this team might consider attempting to reduce stock-out costs by shipping a larger amount of inventory to Chicago. Monte Carlo simulation would again be deployed to the modified solution to determine if, after another 5,000 rounds, a lower mean cost is obtained, perhaps with less variability. Various sets of routing quantities may be tested until student teams are satisfied that they have arrived at a reasonably low-cost distribution plan. As the simulation is applied to each proposal, students are allowed to see a full spectrum of possible total cost outcomes with their associated likelihoods. Instructors should allow approximately 45 minutes for this portion of the exercise.

With the 15 minutes remaining in the class, student teams provide their single best solution to the instructor by completing the three-by-four routing grid shown in Appendix B. The instructor then enters all teams' best solutions into a master spreadsheet (DistributionWorkshopMaster.xlsx, Appendix C, shown for three teams). A predetermined number of months (we used three) of demand are then generated by the instructor using the Excel application, and team total costs are calculated. At this point a winning team is identified, and the instructor leads a debrief discussion. A debrief will typically include some observations about the demand that was realized during these competition months as well as the opportunity for teams to explain their distribution strategy. Workshop points can be assigned, if desired, based on participation or competitively based on the total cost during this competition.

4. Assessment of Student Perceptions

In developing this exercise, our desire was to create something that illustrated the usefulness of Monte Carlo simulation as a decision aid or business analytics tool, conveyed some important supply chain management concepts, and, at the same time, was enjoyable for the students. To assess effectiveness in achieving these goals, we conducted a brief survey of the 33 undergraduate participants after completing the session. To avoid the potential of biasing the results, all surveys were completed anonymously (i.e., no identifying information was collected). Table 2 shows survey questions and provides a summary of responses.

Survey results show clear evidence of positive experiences and resulting attitudes toward the exercise in that all measures were highly rated. In particular, students found the simulation to be an enjoyable (average rating: 4.73/5.0) and effective method (average rating: 4.66/5.0) for teaching important issues related to the distribution exercise.

In addition to the survey, participants were given the opportunity to provide open-ended feedback regarding what they liked or found effective about the exercise as well as what they thought could be improved. Many of the positive comments centered around the applicability of the analytical technique and the effectiveness of the learning environment. For example, one participant reported,

> I found the problem to be applicable to life, which helped me better understand how Monte Carlo can be used to solve problems.

While another participant stated,

> I liked how this was fun to do and made the learning a lot more enjoyable. I thought it was a very hands-on

Table 2. Survey Results Regarding Students' Perceptions of the Workshop

With respect to the simulation exercise, I:	Strongly disagree (1), %	Disagree (2), %	Neither agree nor disagree (3), %	Agree (4), %	Strongly agree (5), %	Average rating
Felt able to work with the data and Monte Carlo analysis to come up with a good product-routing solution	0	0	0	33	67	4.67
Found the workshop enjoyable (as a learning activity)	0	0	0	27	73	4.73
Understood the usefulness and application of the Monte Carlo analysis tool	0	0	0	24	76	4.76
Felt the use of the workshop was motivation in learning the topic	0	0	0	36	64	4.64
Is an effective method for teaching important transportation and demand planning issues	0	0	0	34	66	4.66
The workshop was helpful in learning and applying the principles involved in transportation and demand planning	0	0	0	27	73	4.73

> experience to learn how to do transportation costs and how in the real world they figure this out.

Another positive statement echoing these themes was as follows:

> I enjoyed that I could actually see this information being used. This example is more applicable than some of the other examples have been. I did not really understand Monte Carlo analysis until this example, so I am very happy I participated in this workshop.

With regard to ways in which the exercise could be improved, most participants did not leave a response or simply stated, "nothing." A few others complained of slight computer glitches or Excel problems. Of those who left feedback for improvement (10 out of 33 participants), comments suggested that the exercise be expanded to include multiple problems, or greater detail of instruction regarding the development of a solution should be provided. Here are three example statements:

> Maybe have a couple more problems to do since this was very enjoyable, and I would have liked more problems to work with the Monte Carlo Analysis.

> I think the workshop worked really well. After it is set up, we could have more of a step-by-step process to complete the workshop.

> Less of an introduction, more step-by-step procedures.

5. Discussion and Limitations

Research has shown that interactive exercises are an effective way to enhance students' learning of modeling concepts, such as the transportation problem (Seal et al. 2010). Informal feedback from participants in our workshop overwhelmingly concurred. Students expressed excitement regarding participation in the hands-on exercise and enjoyed the competitive nature of the event. Students aggressively experimented with many potential routing schemes using the Monte Carlo simulator in an attempt to outperform their classmates. Further, with employers increasingly seeking graduates having strong quantitative skills, including Excel, students valued the chance to learn and apply a powerful Excel-based analytical tool to address a common operations-management issue.

As further validation of the usefulness of this tool, post hoc analysis shows that a good Monte Carlo–developed student solution provides better results than an optimized solution using mean demand for each customer. In a random set of 20 trials (20 sets of uncertain demands), the Monte Carlo–developed solution had a lower total cost than the optimized solution using customer mean demand in 16 instances (see Appendix D). When uncertainty is introduced in supply chain decisions, Monte Carlo analysis can lead students to better decisions than conventional approaches.

Given this potential for superior results, the ideas presented in this workshop could be expanded to develop a framework for addressing supply chain and operations-management problems under conditions of demand (or lead time) uncertainty. In this application, students could first be presented with the classic transportation problem with fixed supply and demand. Then students would be shown approaches to model and solve this problem, such as with linear programming and Excel solver. Finally, students would be asked to think about real-world conditions in which supplies and demands are uncertain and not known in advance. If some historical data are available, statistical methods, such as confidence intervals, could be engaged to plan around means and upper and lower limits. Ultimately, to plan through a very large set of possible scenarios, Monte Carlo analysis is required. Thus, a very basic problem is introduced, classic optimization approaches are provided, then complications are added (or assumptions relaxed), and additional tools (Monte Carlo simulation) are introduced and applied, creating an incremental learning approach.

A possible limitation of this current research is the fact that our sample size was somewhat small at 33 students. Although a larger number would certainly have been desirable, the positive feedback that we received on the student survey, along with the low variance, gives us confidence that the overall findings of our work would not change with more participants. (e.g., students generally enjoyed the exercise and found it to be an informative and effective learning experience).

Thinking of further opportunities for study in this area, interested instructors and researchers might consider comparing student comprehension of selected concepts between groups who have received instruction through this incremental learning approach using Monte Carlo simulation and those who have not. Those interested might also consider attempting this approach in other areas and reporting results. Drawing only on the fields of operations and supply chain management, a few examples of tasks in which this might be fruitful include demand planning (e.g., forecasting), inventory management (e.g., continuous review inventory policy), and project management. Further, researchers might consider additional adjustments to the distribution problem described in this paper. For example, the scenario could easily be expanded to include cases in which, in addition to customer demand, production capacity at each facility is uncertain. One could also create a model in which inventory left over at a customer location at the end of a period carries over to the next. With each adjustment, the model provides a truer reflection of reality, and the better students are trained in the classroom to account for these realistic conditions, the more effective they can be once they leave the classroom and begin making decisions in practice.

Appendix A. Sample Demand Analysis and Distribution Plan

Boston has a mean monthly rubber demand of about 100 tons with standard deviation of about 35 tons. There is quite a bit of variability in demand. A normal distribution could be used to model monthly rubber demand although one should probably ship above the mean given that stock-out costs heavily outweigh holding costs.

New York has a mean monthly rubber demand of about 170 tons. A triangular distribution could be used to model monthly rubber demand. Values of approximately 50, 220, and 240 tons for minimum, most likely, and maximum, respectively, are reasonable parameters for this distribution. The demand distribution is left skewed, meaning that more likely monthly demands are in the higher range of values. A good strategy might be to ship just a bit more than the mean to New York.

Chicago has a mean monthly rubber demand of about 260 tons. A triangular distribution could be used to model monthly rubber demand. Values of approximately 200, 220, and 360 tons for minimum, most likely, and maximum, respectively, are reasonable parameters for this distribution. The demand distribution is right skewed, meaning that more likely monthly demands are in the lower range of values. A good strategy might be to ship slightly less than the mean to Chicago.

Indianapolis has a mean monthly rubber demand of about 70 tons with standard deviation of about five tons. There is very little variability in demand. A normal distribution could be used to model monthly rubber demand and a good strategy might be to ship right around 70 tons to Indianapolis.

Appendix B. Student Team Deliverables

Assignment:
Use the format below to specify how many tons of rubber your logistics team will ship from each warehouse (source) to each tire manufacturer (destination). For each ton stock-out, costs are $60, for each ton left over for the month a $20 holding costs is assessed. Try to come up with a solution that will minimize total logistical costs (transportation, stock-outs, and holding) over 3 months of uncertain demands at each destination. A spreadsheet of 36 months of historical demands at each destination will be provided.

		To	A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
From	1. Det						0	300	300
	2. Pit						0	180	180
	3. Buf						0	250	250

Turn in the above grid with numbers in twelve blank cells. Include team member names.

Appendix C. Master Sheet for Live Team Results

Generator	A. BOS	B. NY	C. CH	D. IND
Demand	75.00	186.67	236.67	70.00

	Month1	Month2	Month3	TOTAL
Team1	$12,623			
Team2	$11,437			
Team3	$12,512			

	A. BOS	B. NY	C. CH	D. IND
1. Det	8	2	35	11
2. Pit	12	3	31	5
3. Buf	10	1	34	9

Per Unit	
Stock Out	60
Hold	20

Team1		A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
	1. Det	140	70	50	0	260	300	40
	2. Pit	0	0	105	75	180	180	0
	3. Buf	0	150	100	0	250	250	0
ShippedTo		140.00	220.00	255.00	75.00			
Actual Demand		75.00	186.67	236.67	70.00			
Stock-out costs		0.00	0.00	0.00	0.00			
Warehouse costs		1300.00	666.67	366.67	100.00			
Shipping Costs		1120.00	290.00	8405.00	375.00			
TOTAL COSTS		2420.00	956.67	8771.67	475.00	$12,623		

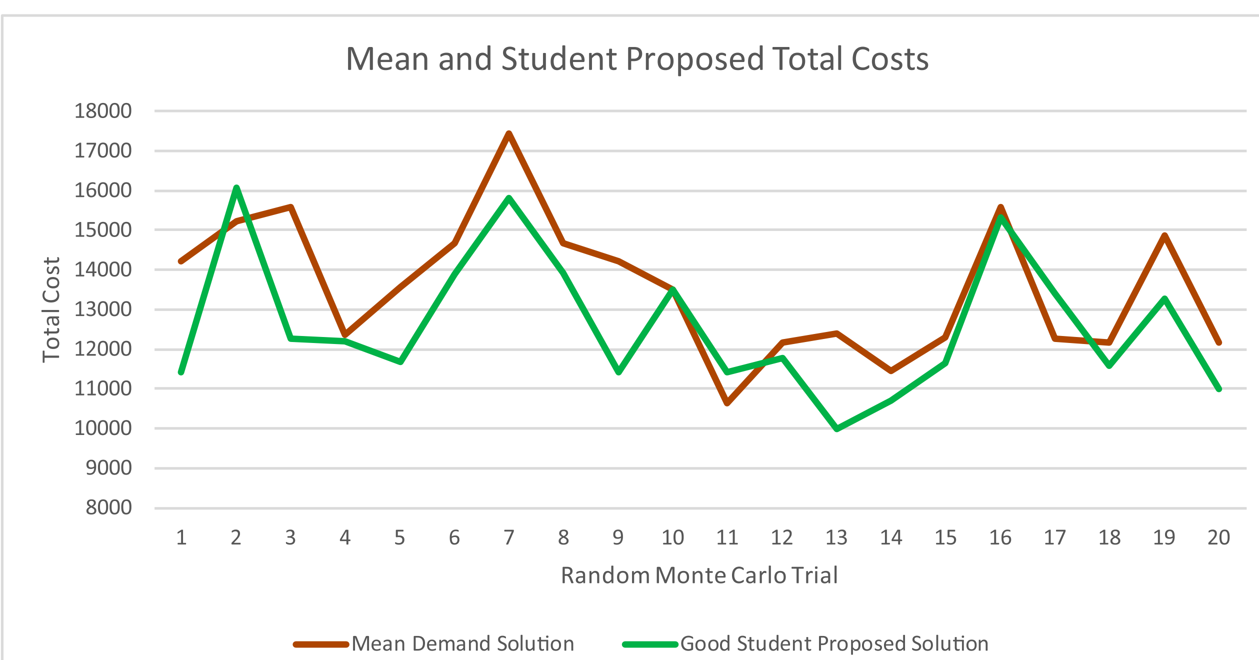
Team2		A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
	1. Det	90	10	50	0	150	300	150
	2. Pit	0	100	50	20	170	180	10
	3. Buf	0	90	100	60	250	250	0
ShippedTo		90.00	200.00	200.00	80.00			
Actual Demand		75.00	186.67	236.67	70.00			
Stock-out costs		0.00	0.00	2200.00	0.00			
Warehouse costs		300.00	266.67	0.00	200.00			
Shipping Costs		720.00	410.00	6700.00	640.00			
TOTAL COSTS		1020.00	676.67	8900.00	840.00	$11,437		

Team3		A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
	1. Det	120	50	0	75	245	300	55
	2. Pit	0	180	0	0	180	180	0
	3. Buf	0	0	230	0	230	250	20
ShippedTo		120.00	230.00	230.00	75.00			
Actual Demand		75.00	186.67	236.67	70.00			
Stock-out costs		0.00	0.00	400.00	0.00			
Warehouse costs		900.00	866.67	0.00	100.00			
Shipping Costs		960.00	640.00	7820.00	825.00			
TOTAL COSTS		1860.00	1506.67	8220.00	925.00	$12,512		

Appendix D. Comparing a Good Student Proposed Solution and the Mean Solution

Good		A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
	1. Det	120	70	0	0	190	300	110
	2. Pit	0	0	105	75	180	180	0
	3. Buf	0	125	125	0	250	250	0
ShippedTo		120.00	195.00	230.00	75.00			
Actual Demand		130.21	203.69	331.04	70.53			
Stock-out costs		612.63	521.47	6062.20	0.00			
Warehouse costs		0.00	0.00	0.00	89.31			
Shipping Costs		960.00	265.00	7505.00	375.00			
TOTAL COSTS		1572.63	786.47	13567.20	464.31	$16,391		

Means		A. BOS	B. NY	C. CH	D. IND	Shipped	MAX	Surplus
	1. Det	100	0	70	0	170	300	130
	2. Pit	0	0	110	70	180	180	0
	3. Buf	0	170	80	0	250	250	0
ShippedTo		100.00	170.00	260.00	70.00			
Actual Demand		130.21	203.69	331.04	70.53			
Stock-out costs		1812.63	2021.47	4262.20	32.08			
Warehouse costs		0.00	0.00	0.00	0.00			
Shipping Costs		800.00	170.00	8580.00	350.00			
TOTAL COSTS		2612.63	2191.47	12842.20	382.08	$18,028		



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