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TEACHING SUPPLY CHAIN COORDINATION WITHIN A NETWORK MODELING CONTEXT

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ABSTRACT

This article describes an educational exercise that demonstrates the value of coordination within a supply chain environment while exposing students to the conflict between locally and globally optimal supply chain decisions. This exercise allows students to formulate, model, and solve a problem relating to the design of a small supply chain network. The exercise begins with student teams developing a solution that is optimal from each team's local perspective. A solution that is globally optimal is then developed. As is often the case in a real-world supply chain, the solutions that are optimal for each team do not (when combined) yield the globally optimal solution. The student teams are then asked to negotiate to develop a solution that is amenable to all teams.

I. INTRODUCTION

This article describes a classroom exercise that can be used to teach the value of supply chain coordination. During the exercise, students are asked to make transportation decisions for a warehouse that must ship its products via a distribution center to a retailer. An important element of the exercise is the modeling of the supply chain network. This modeling process and the subsequent solving of the models in a spreadsheet environment allow students to hone their spreadsheet modeling skills and also gain insight into the problem. The coupling of modeling and the examination of supply chain coordination issues presents the students with a unique challenge and adds depth to the exercise.

II. LITERATURE REVIEW

In this section, a brief review of the literature related to supply chain coordination and existing educational exercises for the teaching of supply chain coordination concepts is provided.

1. SUPPLY CHAIN COORDINATION

Coordination between supply chain entities is essential for effective supply chain performance and has been a frequently occurring topic in academic research. Fugate, Sahin, and Mentzer, 2006 define supply chain coordination as "effective management of these flows [financial, information, and product/service] … creating synergistic relationships between the supply and distribution partners with the objective of maximizing customer value and providing a profit for each supply chain member" (2006). Note that this definition implies that the objective of supply chain coordination is not the maximization of the profits of each supply chain entity (local optimization). Rather, supply chain coordination seeks coordination that brings about performance that is optimal from the perspective of the entire supply chain.

Xe and Beamon (2006) suggest that supply chain coordination is particularly critical as the discipline of supply chain management itself is often defined in a context of coordination of goods and information flows. A coordinated supply chain is likely to provide benefits to all entities in the supply chain. Some of these benefits may include: "increased market share, inventory reductions, improved delivery service, improved quality, and shorter product development cycles" (Corbett, Blackburn, and Van Wassenhove, 1999).

Failure to coordinate supply chain activities can be detrimental. For example, Lee, Padmanabhan, and Whang (1997) describe how a distortion of order sizes known as the "bullwhip effect" can occur in poorly coordinated supply chains. Despite years of research focusing on counteracting the bullwhip effect, this problem remains. A recent example of the bullwhip effect was described in a Wall Street Journal article that appeared in January 2010 (Aeppel).

A number of academic works have been generated from practical applications related to supply chain coordination. A popular source for such academic articles is the Institute for Operations Research and Management Sciences' Interfaces journal. Articles in Interfaces tend to be approachable and interesting for undergraduate and graduate students. Several articles from Interfaces that relate to supply chain coordination include: the coordination of a semiconductor company's supply chain (De Kok, Janssen, Van Doremalen, Van Wachem, Clerkx, and Peeters, 2004), the facilitation of collaboration for a microchip manufacturer and its suppliers (Shirodkar and Kempf, 2006), and the synchronization of an automobile manufacturer's supply chain (Hahn, Duplaga, and Hartley, 2000).

2. SUPPLY CHAIN COORDINATION EDUCATIONAL EXERCISES

To help educate students on the topic of supply chain coordination, a variety of classroom exercises have been developed. Examples of such exercises appear in "The MIT Beer Game" (2009), Fawcett, Ritchie, Wallin, and Webb (2009), Fawcett and McCarter (2006), and Munson, Jianli, and Rosenblatt (2003). In these exercises' students are exposed to the potential pitfalls that may arise from a lack of supply chain coordination. These exercises also contain the common thread of allowing students to take on the responsibilities of decision makers. Students are then exposed (although not always immediately) to the successes and failures of their selected decisions. The exercise proposed in this article complements this existing literature, but also contributes to the literature by incorporating a network modeling element. This element adds an additional layer of complexity and interest to the exercise.

3. NETWORKING MODELING AND OPTIMIZATION

There are numerous examples in the literature that describe the modeling and optimization of supply chain networks. Example Interfaces journal articles that describe the optimization of diverse network modeling problems such as a company's raw resource supply chain (Ouhimmou, D'Amours, Beauregard, Ait-Kadi, and Chauhan 2009), United Parcel Service's air delivery network (Armacost, Barnhart, Ware, and Wilson, 2004), and military mobilization (Bausch, Brown, Hundley, Rapp, and Rosenthal, 1991). These articles, or others like them, can be presented to students to motivate the value of supply chain network modeling and optimization.

III. CLASSROOM EXERCISE

The exercise proposed in this article is intended for use in introductory or intermediate classes in supply chain management at either the undergraduate or graduate level. The author has tested this exercise in an undergraduate-level course that covers a number of contemporary supply chain management issues. Students in this course have typically been junior and senior-level (third and fourth year) undergraduate students majoring in Supply Chain Management. The typical enrollment in this course has been 20-25 students. Many of the students have significant work experience in the supply chain management or related industries. Approximately 90-120 minutes of class time should be allocated for the exercise, but this time commitment can be reduced by assigning portions of the exercise for completion outside of class.

1. COURSE AND CURRICULAR EXERCISE OBJECTIVES

This exercise contributes toward several course and curricular objectives. In the author's contemporary supply chain management course, the course's objectives include:

- Exposing students to "real-world" supply chain management problems and the difficulties associated with solving these problems. This exercise primarily focuses on the issues of supply chain coordination and local versus global optimization.

- The refinement of the students' analytical skills. The network modeling portion of the exercise requires the students to practice their analytical skills through the development and solving of spreadsheet optimization models.

- Providing students with an opportunity to orally defend their decision-making processes and engage in negotiation with others that have competing objectives. Both of these objectives are addressed in the exercise.

- Requiring students to work together in a team-based environment. The exercise requires that students work in teams.

This exercise also has the potential to contribute toward curricular objectives. The author's academic program (supply chain management) has developed a set of objectives that define the qualities that the program's graduating students should possess. These objectives are likely similar to those in place in other institutions and programs (e.g., operations management, etc.). This exercise specifically relates to five of these objectives:

1. Supply chain management graduates are expected to demonstrate competency in the delivery of oral presentations. As noted above, this exercise requires students to orally defend their decisions and engage in oral negotiations.
2. Supply chain management graduates are expected to exhibit knowledge of key supply chain management concepts. Supply chain coordination is a critical concept that is addressed in this exercise.
3. Supply chain management graduates are expected to be able to utilize business software applications and information technology to analyze information and make informed decisions. Spreadsheets are commonly used in industry and the ability to work effectively in a spreadsheet environment

is prized by employers. This exercise gives students an opportunity to model and optimize a supply chain network within a spreadsheet.

4. Supply chain management graduates are expected to become proficient in interpersonal skills and be able to work effectively in a team environment. During this exercise, students work in teams and must be able to effectively communicate with their teammates and with members of other teams.
5. Supply chain management graduates are expected to be analytical thinkers and effective problem solvers. A key component of this exercise is the analysis of a supply chain network problem.

2. PREPARATION

Prior to participation in this exercise, the students should have been exposed to basic supply chain management network models such as the transportation and transshipment problems. The students should also have experience in translating these formulations into spreadsheet models. A basic background in optimization techniques is also recommended. A brief discussion of supply chain coordination may be useful but is not required. Before beginning the exercise, the class is divided into teams. In the author's experience, a team size of three to five students appears to be ideal

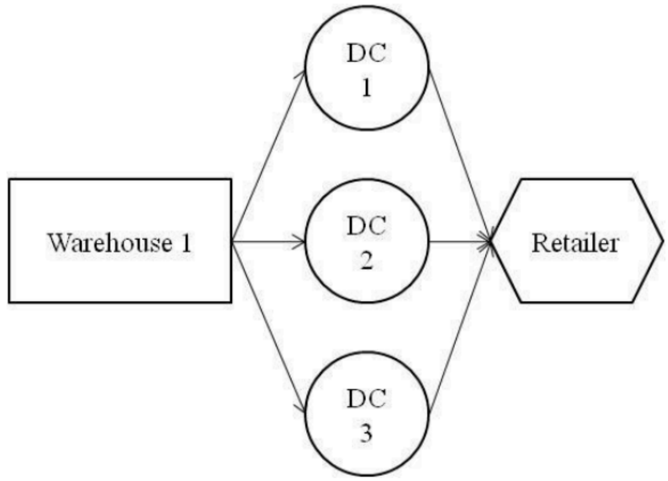
3. EXERCISE INTRODUCTION

The exercise begins with the class being told that each team is responsible for making transportation decisions for the distribution of a product from a warehouse to a retailer. The product (assume that all teams are shipping an identical product) is first transported directly from the team's warehouse to one or more of three distribution centers and is then shipped by a third-party logistics provider (3PL) to a single retail location. The 3PL offers both truckload (TL) (with a limited number of TL shipments available from each distribution center) and less-than-truckload (LTL) service from the distribution centers to the retailer. Each team is informed that they will bear all transportation costs associated with moving the product from their warehouse to the retailer. To increase the appearance of realism and potential for student engagement in the exercise, the instructor could choose to add names (either location or company names) to the warehouses, distribution centers, and the retailer.

4. INDIVIDUAL TEAM PROBLEM

At this point in the exercise, the students have not been informed that they are making transportation decisions in a competitive environment. Rather, the student teams are focused on developing a minimum cost transportation plan for the product located at their team's warehouse. To the students, the network to be modeled appears as in Figure 1. This network is referred to as the Individual Team Problem.

FIGURE 1:
INDIVIDUAL TEAM PROBLEM NETWORK DIAGRAM



After this basic introduction, an in-class presentation of the Individual Team Problem and its mathematical programming formulation is given by the instructor. This problem formulation takes on the appearance of a transshipment problem with additional constraints for limited warehouse capacity and the limited availability of TL shipments. The mathematical programming formulation for the Individual Team Problem is given below.

$$\text{minimize } \sum_{i=1}^{3}\left(c_i x_i + T t_i y_i + l_i z_i\right)$$

subject to

$$\sum_{i=1}^{3} x_i = s,$$

$$x_i \le C_i, \qquad \forall i \in \{1,2,3\}$$

$$Ty_i + z_i = x_i, \qquad \forall i \in \{1,2,3\}$$

$$y_i \le N_i, \qquad \forall i \in \{1,2,3\}$$

$$y_i \in Z^+, \qquad \forall i \in \{1,2,3\}$$

$$z_i \ge 0, \qquad \forall i \in \{1,2,3\}$$

In this formulation, s is the amount of product to be shipped from the warehouse, c_i is the cost (per unit of product) to ship from the warehouse to distribution center i, t_i is the cost (per truckload) for a TL shipment from each distribution center i to the retailer, l_i is the cost (per unit of product) for an LTL shipment from distribution center i to the retailer, and N_i is the total number of TL shipments available from each distribution center i to the retailer. The parameter T is the truckload capacity and C_i are the capacity of each distribution center i. The decision variables are x_i, the amount of product shipped from the warehouse to distribution center i, y_i, the number of TL shipments from distribution center i to the retailer, and z_i, the amount of product shipped by LTL shipment from distribution center i to the retailer.

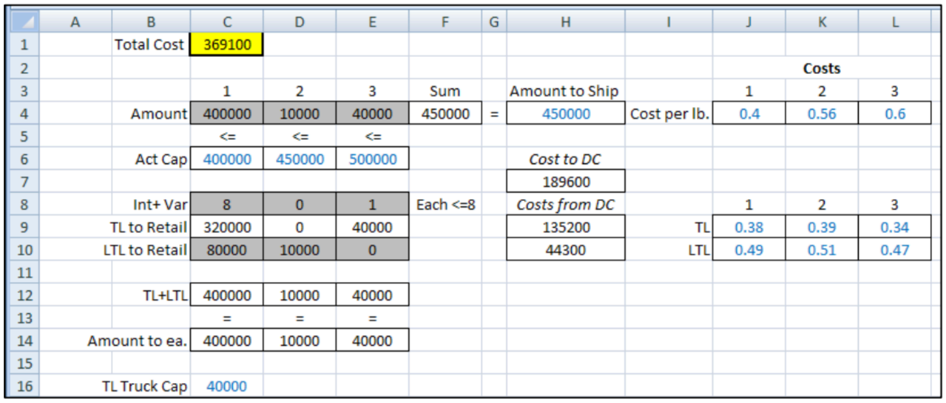
The first constraint set requires that the sum of the amount of product shipped from the warehouse to the distribution centers must be equal to the supply of product available at the warehouse. The second constraint set ensures that the amount shipped to any distribution center does not exceed the capacity of the distribution center. The third constraint set ensures flow balance across each distribution center. The amount of the product shipped into each distribution center must be equal to the amount shipped by TL and LTL shipments to the retailer. The fourth constraint set requires that the number of TL shipments from each distribution center does not exceed the number available.

If desired, additional constraints can be added to the problem to increase the complexity of the network modeling portion of the exercise. For example, a quantity discount structure utilizing binary variables could be incorporated. Other problem modifications, such as allowing direct shipment of product from the warehouses to the retailer could also be considered.

After introducing the problem, the teams are then provided with the transportation costs and other parameters for their Individual Team Problems (for each team, costs and parameters are different). See Appendix 1 for a listing of costs and parameters for each team (assuming a four-team exercise environment) and Appendix 2 for a sample handout of problem information that can be provided to the students. The teams are instructed to develop an Excel spreadsheet model of the problem and then use the Solver add-in to determine the optimal solution. For more information on installing and using the Solver add-in for Excel, refer to resources from Microsoft (2011).

Figure 2 displays a completed spreadsheet model for the Individual Team Problem. This spreadsheet is available for download from the author's webpage for this exercise (http://faculty.weber.edu/stephenhill/). Costs displayed in the spreadsheet are from Team 1's Individual Problem and would be different for the other teams. The screenshot in Figure 2 is taken from Microsoft Excel 2007. The spreadsheet may appear slightly different in other versions of Excel. Table 1 gives the total costs of the optimal solutions for each of the Individual Team Problems.

FIGURE 2:
SCREENSHOT OF INDIVIDUAL TEAM PROBLEM SPREADSHEET MODEL



	A	B	C	D	E	F	G	H	I	J	K	L
1		Total Cost	369100									
2											Costs	
3			1	2	3	Sum		Amount to Ship		1	2	3
4		Amount	400000	10000	40000	450000	=	450000	Cost per lb.	0.4	0.56	0.6
5			<=	<=	<=							
6		Act Cap	400000	450000	500000			*Cost to DC*				
7								189600				
8		Int+ Var	8	0	1	Each <=8		*Costs from DC*		1	2	3
9		TL to Retail	320000	0	40000			135200	TL	0.38	0.39	0.34
10		LTL to Retail	80000	10000	0			44300	LTL	0.49	0.51	0.47
11												
12		TL+LTL	400000	10000	40000							
13			=	=	=							
14		Amount to ea.	400000	10000	40000							
15												
16		TL Truck Cap	40000									

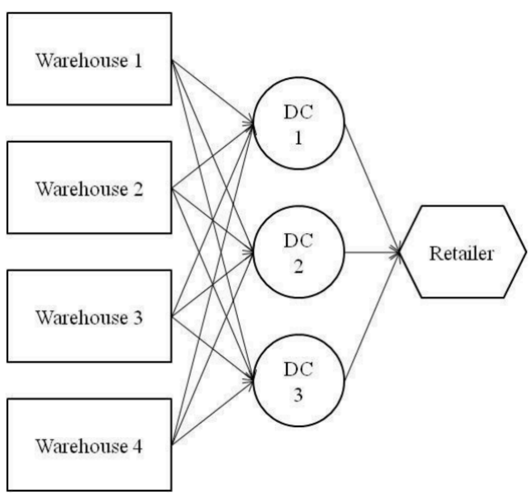
TABLE 1.
INDIVIDUAL TEAM OPTIMAL SOLUTION COSTS

Team	Total Cost	Cost WH to DC	Cost DC to Retail (TL)	Cost DC to Retail (LTL)
1	369,100	189,600	135,200	44,300
2	136,700	75,250	54,400	7,050
3	340,600	178,000	152,800	9,800
4	172,000	104,000	68,000	0
Total	1,018,400	546,850	410,400	61,150

5. GLOBAL PROBLEM

The teams are then presented with the Global Problem. This problem is a combination of each of the Individual Team Problems. Figure 3 shows the network diagram for the Global Problem.

FIGURE 3:
GLOBAL PROBLEM NETWORK DIAGRAM



The mathematical programming formulation for the Global Problem is given below.

$$\text{minimize} \quad \sum_{i=1}^{3}\sum_{t=1}^{4} c_{it}x_{it} + \sum_{i=1}^{3}(Tt_i y_i + l_i z_i)$$

subject to

$$\sum_{i=1}^{3} x_{it} = S_t, \qquad \forall t \in \{1,\ldots,4\}$$

$$\sum_{t=1}^{4} x_{it} \le C_i, \qquad \forall i \in \{1,2,3\}$$

$$Ty_i + z_i = \sum_{t=1}^{4} x_{it}, \qquad \forall i \in \{1,2,3\}$$

$$y_i \le N_i, \qquad \forall i \in \{1,2,3\}$$

$$y_i \in Z^+, \qquad \forall i \in \{1,2,3\}$$

$$z_i \ge 0, \qquad \forall i \in \{1,2,3\}$$

This problem formulation is similar to the Individual Team Problem. The x_i decision variables from the Individual Team Problem take on a second subscript and become x_{it} variables. These variables describe the amount of product that is shipped from warehouse t to distribution center i. The costs to ship product from the warehouses to the distribution centers also take on a second subscript and become c_{it}. A double summation is then needed for the first term in the objective function. Rather than having a single warehouse supply amount s, a supply amount S_t is identified for each warehouse. In the second constraint set, a summation of the amount shipped to each distribution center from the warehouses is needed. A similar summation is needed in the third constraint set. The remainder of the formulation is identical to the Individual Team Problem formulation.

Each team is then asked to independently develop and solve a spreadsheet model for the Global Problem. In solving the Global Problem, some students may suggest combining the Individual Team Problem optimal solutions to generate what may seem to be an optimal solution to the Global Problem. However, combining the optimal solutions from the Individual Team Problems results in an infeasible solution to the Global Problem. The infeasibility arises from the proposed use of more TL shipments than are available.

Students may, at this point, recognize the need to deviate from their team's best solution in order to achieve a global optimal solution (or even feasibility). Because the teams were instructed to seek out their team's lowest cost solution, some students may begin to resist accepting a solution that appears worse. Figure 4 displays a complete spreadsheet model for the Global Problem. This spreadsheet is available for download from the author's webpage for this exercise. As noted above, the combination of the

Individual Team Problems to produce a solution to the Global Problem results in infeasibility. A screenshot of this infeasible solution is given as Figure 5.

FIGURE 4:
SCREENSHOT OF GLOBAL SPREADSHEET MODEL
(GLOBAL OPTIMAL SOLUTION)

	A	B	C	D	E	F	G	H	I	J	K	L
1		Total Cost	1048800									
2											Costs	
3			1	2	3	Sum		Amount to Ship		1	2	3
4		T1	400000	0	50000	450000	=	450000	T1	0.4	0.56	0.6
5		T2	0	0	175000	175000	=	175000	T2	0.45	0.45	0.43
6		T3	0	420000	0	420000	=	420000	T3	0.42	0.44	0.5
7		T4	0	0	200000	200000	=	200000	T4	0.52	0.49	0.52
8		Sum	400000	420000	425000							
9			<=	<=	<=							
10		Act Cap	400000	450000	500000							
11											Costs	
12		Int+ Var	8	8	8	Each <= 8				1	2	3
13		TL to Retail	320000	320000	320000			54400	TL	0.38	0.39	0.34
14		LTL to Retail	80000	100000	105000			7050	LTL	0.49	0.51	0.47
15												
16		TL+LTL	400000	420000	425000							
17			=	=	=							
18		Amount to ea.	400000	420000	425000							
19												
20		TL Truck Cap	40000									

FIGURE 5:
SCREENSHOT OF GLOBAL SPREADSHEET MODEL
(INFEASIBLE COMBINATION OF INDIVIDUAL TEAM SOLUTIONS)

	A	B	C	D	E	F	G	H	I	J	K	L
1		Total Cost	1018400									
2											Costs	
3			1	2	3	Sum		Amount to Ship		1	2	3
4		T1	400000	10000	40000	450000	=	450000	T1	0.4	0.56	0.6
5		T2	0	0	175000	175000	=	175000	T2	0.45	0.45	0.43
6		T3	340000	80000	0	420000	=	420000	T3	0.42	0.44	0.5
7		T4	0	0	200000	200000	=	200000	T4	0.52	0.49	0.52
8		Sum	740000	90000	415000							
9			<=	<=	<=							
10		Cap	400000	450000	500000							
11											Costs	
12		Int+ Var	16	2	10	Each <= 8				1	2	3
13		TL to Retail	640000	80000	400000				TL	0.38	0.39	0.34
14		LTL to Retail	100000	10000	15000				LTL	0.49	0.51	0.47
15												
16		TL+LTL	740000	90000	415000							
17			=	=	=							
18		Amount to ea.	740000	90000	415000							
19												
20		TL Truck Cap	40000									

If desired, the Individual Team and Global Problems can be modeled in nonspreadsheet environments. For example, a software package such as IBM's ILOG OPL Studio could be utilized. Sample Individual Team and Global problem model and data files from ILOG OPL Studio version 6.3 are provided at the author's webpage for this exercise. These files can be adapted for another optimization software.

Table 2 gives a comparison of the costs of the teams' Individual Problem optimal solutions and the costs to the teams under the global optimal solution. Note that, in calculating the teams' costs in the Global Problem solution it is assumed that teams with larger shipment quantities through the distribution centers receive priority access to ship via TL. Because the TL service is a limited resource, this results in some teams having to use the more expensive LTL service to ship from the distribution centers to the retailer.

TABLE 2.
COMPARISON OF INDIVIDUAL TEAM AND GLOBAL PROBLEM OPTIMAL RESULTS

Team	Individual	Global	% Deviation
1	369,100	374,300	1.41
2	136,700	141,900	3.80
3	340,600	360,600	5.87
4	172,000	172,000	0.00
Total	1,018,400	1,048,800	2.99

6. NEGOTIATION

With optimal solutions to their Individual Team Problems and the Global Problem in hand, the teams are then asked to negotiate and develop a global solution that would be satisfactory to all of the teams. In the author's testing of this exercise, the teams were allowed to negotiate during a 50-minute class period before the exercise ended and a debriefing was held. The instructor should facilitate the negotiation but should attempt to avoid influencing the team's decisions. In large classes, it may be useful to appoint team leaders/negotiators to negotiate with the other teams. If the class is relatively small, an open discussion may be possible.

To represent internal managerial pressures, the students are told that a small portion of their grade on the exercise would be dependent upon their negotiated solution's deviation from their respective team's optimal solution (as deviation increases from the team's optimal solution, the students' grades decrease). Likewise, to represent supply chain performance pressures, the students are told that a small portion of their grade is based upon the negotiated global solution's deviation from the global optimal solution. Other incentives (free pizza, etc.) could be substituted if grade modification was not desired.

Because of these pressures, many students became adamantly opposed to allowing their team's cost to worsen. For example, Team 4 realized that they could maximize both the Individual Team and Global Problem portions of their grade by advocating acceptance of the Global Problem's optimal solution. In the optimal solution to the Global Problem, Team 4's optimal solution does not require a change from their Individual Team Problem's solution. Team 3, however, was reluctant to accept this solution. With this solution, they would receive a lower grade due to the deviation from their Individual Team Problem's optimal solution.

Based upon the author's experiences with this exercise, several possible outcomes of the negotiation process are:

1. Teams may refuse to allow their costs to increase. If all teams adopt this stance, the supply chain cannot operate due to the infeasibility of combining the solutions of the individual teams (as described earlier). If one or more teams adopt this strategy, the supply chain may become inoperable due to infeasibility, or other teams may be forced to accept increased costs. In this situation, the instructor should emphasize the infeasibility problem and suggest that student grades on the exercise may suffer due to the lack of cooperation.
2. Teams may agree to accept the optimal solution to the Global Problem. Doing so allows for the supply chain, as a whole, to operate at minimum cost, but three of the four teams experience deviations from their local optimal solution and in turn receive a reduced grade. While this solution may be desirable for the supply chain as a whole, the students should be reminded that their managers may question the need to deviate from their team's minimum cost solution.
3. Teams may propose a solution that "shares" equal or roughly equal deviations from local optimality. Such a solution requires a deviation from the global optimal solution but allows all teams to share what may only be small grade deductions. While such a solution may be equitable for the teams, it results in suboptimal supply chain cost. Higher supply chain costs are likely to be passed on to the retailer (and, ultimately, to the end customer). Therefore, such a solution may not be desirable.
4. Teams may propose altering the problem. For example, in the author's experience with the exercise, the members of Team 3 suggested negotiating with the 3PL provider to allow for more equitable access to the TL shipments. If such negotiation was not possible, the team suggested obtaining access to another 3PL that could, potentially, provide additional TL shipments from the distributor to the retailer. The instructor should use their discretion in allowing (or not allowing) approaches that result in changes to the problem.

7. LESSONS LEARNED

After completion of the exercise a debriefing was held. Approximately 20 minutes of class time was allocated for this purpose. During the debriefing phase of the exercise the students indicated that the primary lessons learned were:

1. Decisions that are locally optimal may not be optimal across the entire supply chain.
2. Without cooperation, the supply chain cannot perform optimally.
3. It may be necessary to align incentives (the grade assigned via deductions due to deviations from optimality, in the context of the exercise) to gain cooperation.

Further debriefing revealed extensive student interest in the exercise, although they expressed frustration with the efforts required to negotiate and to arrive at a solution agreeable to all teams.

8. FUTURE WORK

This exercise presents several opportunities for future work. The effect of the exercise on student achievement related to course and curricular objectives should be measured and analyzed. This analysis could be used to refine the exercise for future classes. Student impressions of the exercise should also be formally recorded via a survey and then studied to identify potential exercise improvements/modifications. Additionally, various iterations of the exercise could be developed that are appropriate for different target audiences (undergraduate versus graduate students, etc.). For example, use of this exercise in some graduate-level course environments may necessitate adding additional constraints that may make the problems in the exercise more difficult to model.

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APPENDIX 1: EXERCISE PARAMETERS AND COSTS

Each team's amount to ship (pounds of product):

Team 1: 450,000
Team 2: 175,000
Team 3: 420,000
Team 4: 200,000

Distribution center capacities (pounds of product):

DC 1: 400,000
DC 2: 450,000
DC 3: 500,000

Truckload capacity: 40,000 pounds
Maximum number of truckloads per distribution center: 8
Team costs to ship from warehouse to distribution centers ($/pound shipped):

	DC 1	DC 2	DC 3
Team 1	0.4	0.56	0.6
Team 2	0.45	0.45	0.43
Team 3	0.42	0.44	0.5
Team 4	0.52	0.49	0.52

Costs (by Truckload or Less than Truckload Service) from distribution centers to the retailer ($/pound shipped):

	DC 1	DC 2	DC 3
TL	0.38	0.39	0.34
LTL	0.49	0.51	0.47

APPENDIX 2: SAMPLE EXERCISE HANDOUT (MODIFY TO REFLECT EACH TEAM'S COSTS AND PROBLEM PARAMETERS)

TEAM 1

You have recently been named the Logistics Supervisor at a large warehouse. In this role, you are responsible for making distribution decisions related to the movement of your product from your warehouse, to an intermediate distribution center, and then on to a retail location.

You anticipate that you will ship 450,000 lbs. of product per month from your warehouse to a single retailer. When shipping the product to the retailer, you have a choice to use one or more of three distribution centers. The distribution centers can handle only a limited amount of product per month. The capacities of the distribution centers (in lbs.) are shown below:

DC 1 400,000
DC 2 450,000
DC 3 500,000

You will be using your own logistics fleet to ship from your warehouse to the DCs. The costs (per lb.) to ship to each DC are:

DC 1 $0.40
DC 2 $0.56
DC 3 $0.60

From each DC to the retailer you will rely on either truckload (TL) or less-thantruckload (LTL) shipments. Each TL shipment carries 40,000 lbs. of product and no more than eight TL shipments can operate out of any DC.

The cost to ship from the DCs to the retailer is dependent on the selected mode (TL vs. LTL) and on the DC from which the product is being shipped. The shipping costs are (per lb.):

	TL	LTL
DC 1	$0.38	$0.49
DC 2	$0.39	$0.51
DC 3	$0.34	$0.47

Determine the following:

1. The amount of product to ship to each DC
2. The amount of product to ship to the retailer from each DC by TL
3. The amount of product to ship to the retailer from each DC by LTL
4. The total cost of your solution