Collaborative Supply Chain Management Learning Using Web-Hosted Spreadsheet Models

Don N. Pope

Abilene Christian University, ACU Box 29309, Abilene, Texas 79699-9309
Phone: 325-674-2786 Fax: 325-674-2507
don.pope@coba.acu.edu

ABSTRACT

Methods for teaching and learning supply chain dynamics began with the now famous Beer Game simulation from MIT almost a half century ago. The advent of the internet enabled online collaborative implementations of the Beer Game and similar supply chain management simulations. The more recent development of web-hosted spreadsheets offers greater power and flexibility in developing supply chain instructional models with both the collaborative advantages of web-hosted applications and the modeling flexibility of spreadsheets. This paper presents an example web-hosted spreadsheet model and reports on classroom experience.

INTRODUCTION

The Beer Game was developed by Jay Forrester and colleagues at MIT (MIT Systems Dynamics Group, 2009) in the early1960s as an illustrative example of systems dynamics behavior and became a widely-used teaching tool in supply chain management courses. The game is played with several students making individual decisions by passing demand requirements (orders) back upstream in a supply chain and shipping physical goods downstream in response to customer demand as revealed by the class instructor. The inability to communicate with team members or know the retail demand forecast causes confusion, frustration, and increasing amplification of order quantity size variation back through the levels upstream. The business causes of this “bullwhip effect” behavior in multi-level supply chains were more fully studied by Lee et al. (1997). The interaction of multiple levels of supply chains is the defining frame of reference of the Supply Chain Operations Reference (SCOR) model (Supply Chain Council, 2009), and the Collaborative Planning, Forecasting & Replenishment (CPFR) initiative (Voluntary Interindustry Commerce Solutions Association, 2009).

The original Beer Game has been implemented and extended numerous times online (Beer Game sites online, 2009) The Supply Chain Game (Responsive Learning Technologies, 2009) is another web-based approach to team management of supply chains, given a series of system-generated customer demands and has more operational parameters to manage than the original Beer Game.

The emergence of web-hosted office applications, especially spreadsheets, offers supply chain management instructors a richer environment for developing supply chain simulations and collaborative team problem-solving exercises. Such exercises allow the students to collaborate from a decision-making perspective and provide hands-on experience with web-hosted applications representative of a larger phenomenon known as "Software as a Service (SaaS), "cloud computing" or "on-demand computing". Current literature is replete with discussions about the possibilities and issues with this computing model. (Levinson, 2007 and Snyder, 2008) Example web-hosted spreadsheets include Google Documents (Google, 2009) and Zoho Sheet (Zoho, 2009). Griffiths (2009) reviews several mobile spreadsheet apps developed for iPhones, describing the strengths and limitations of the apps within the context of a small device with limited user interface capabilities.

The following sections present an example supply chain management problem, a spreadsheet model for analysis and decision-making, and a team assignment, all of which are aimed at achievement of specified learning objectives.

EXAMPLE LEARNING EXERCISE

The learning objectives of the web-hosted spreadsheet supply chain management exercise are:

- Students will discover systems dynamics behavior of supply chains and appreciate the value of a common demand forecast and communication between supply chain levels.
- Students will experience the collaborative power of web-hosted office applications in business.

The first step in developing an exercise to achieve these learning objectives is to present an example problem to be solved.

Problem Definition

The problem is defined for a supply chain having four levels as shown in Figure 1. (The approach is easily modified to include more levels by simply adding worksheets in the spreadsheet.)

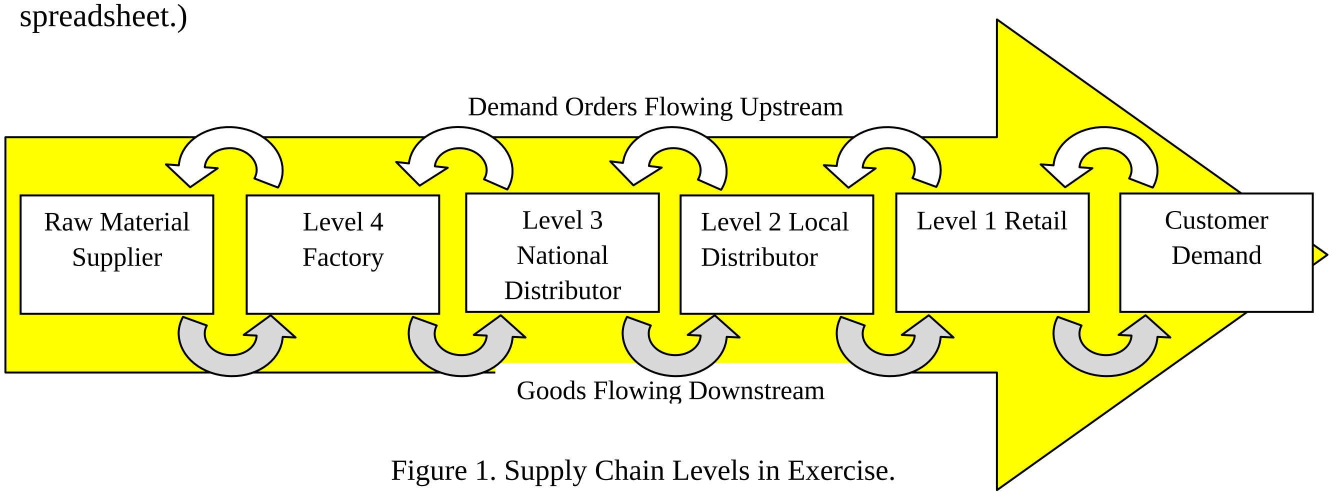

Figure 1. Supply Chain Levels in Exercise.

Table 1 defines system data parameters:

- The internal cost of the item being sold to retail customers is $2000 per unit.
- The profit at level one (retail) of any item sold is $600 per unit.
- The cost-of-having inventory is 35% of the cost of the item per year.
- Therefore, the weekly inventory carrying cost per unit is $2000*.35/52 = $13.46.
- The weekly cost of an item in backorder status is assumed to be $40 per week.

All of these parameters are user-defined and can be changed.

Data Parameter	**Cost**
Cost of Item	$2,000
Profit per unit at Retail	$600
Cost of Holding Inventory per year	35%
Inventory Holding Cost per unit per Week	$13.46
Weekly cost of item on backlog	$40

Table 1. Overall System Data Parameters.

Table 2 provides data for each level:

- **Order Cost** - The cost to order more supply from the next level upstream. In this example problem, these costs increase under an assumption that the physical locations of the levels of supply tend to be farther apart in the higher levels of the supply chain – national distribution, factory, and raw materials supply.
- **Lead Time Weeks –** This is the time in weeks to receive an order at any level n after it is ordered and shipped from level n+1 upstream. These resupply lead times increase in the higher levels of the supply chain in this example.
- **Initial Stock on Hand –** This is the inventory on hand at each level that is immediately available to meet demand in week one.
- **Customer Wait for Backorder? –** This parameter, set either to "Yes" or "No", indicates whether this level wishes to retain a stock out as a backorder and consider this demand volume in determining order quantities to the next supplying level upstream. In this example problem, the retail customer at level one is not willing to wait for the retailer to put the amount of stock out on backorder and provide these amounts in future deliveries. Thus, a stock out at the retail results in lost sales and profit and there is no need to attempt to meet this backordered demand with orders to the next supplying level. Other levels in the supply chain retain the amount of a stock out in backorder status and attempt to satisfy the backordered demand with orders to the next supplying level in the chain.

All of these parameters are also user-defined and can be varied to create different situations.

Level	Name	Order Cost	Lead Time Weeks	Initial Stock on Hand	Customer Wait for Backorder?
1	Retail	$500	1	100	No
2	Local Distributor	$1,000	2	200	Yes
3	National Distributor	$1,500	3	250	Yes
4	Factory	$2,000	6	300	Yes

Table 2. Data Parameters by Level.

The challenge is for individual students operating each level in the supply chain to decide what order quantity they wish to issue to the next level upstream in the supply chain each week, given the amount of orders they receive from their adjacent level downstream. The student team's collective goal is to maximize profit over the entire horizon of retail customer demand. The class instructor provides customer orders to the retail level. At the other end of the supply chain, it is assumed that the raw material supplier is always able to completely fill whatever orders they receive from the factory, delivered to the factory six weeks later.

Spreadsheet Model

The spreadsheet model was implemented in a Google Documents spreadsheet and shared with students in the class (with order quantities of zero filled in at each level). Figure 2 shows the data computed and used at each level of the supply chain for decision-making purposes. The columns of data, for each week, are as follows:

- **Orders Received from Downstream –** Order size received from the next level downstream. For level one retail, the source of this demand is customer demand from the course instructor. For other levels, the source of this demand is the "Amount of Order to Upstream" column of the next level downstream, and represents the decision of the student operating that level.

- **Orders Filled –** This amount is computed to be the smaller of the orders received from downstream that week and stock available to meet that demand (the stock level on hand from the prior week plus resupply orders received at the end of the prior week.) This amount will be the amount actually shipped to the next level downstream, which might be less than what that level actually ordered.

- **Stock Level (After Orders Filled) –** The inventory level on hand after demand orders are filled, available to be used to fill orders the following week.

- **Stock out –** The amount of the weekly demand that exceeded the available inventory (stock level carried over from the previous week plus any shipments that arrived at the end of the previous week.)

- **Amount of Stock out on Backorder –** The amount of the stock out which will be carried on backorder and satisfied with future arrivals of supply from upstream. Table 2 shows the policy codes ("Yes" or "No") indicating whether this is done or not at this level.

- **Amount of Order to Upstream –** This column contains the weekly decisions of the student operating this level of the supply chain, given the arrival of the weekly demand orders received from downstream, stock levels and backorder position, and perceived trends. Once an order quantity decision is entered into a given week, the student is not allowed to change it later.

- **Amount Actually Shipped from Upstream –** This is the amount actually shipped from the next level upstream, given their response to this level's order, as constrained by their inventory stock level on hand.

- **Amount Shipped and Not Yet Received –** The amount of the actual shipment from upstream which is in route but has not yet arrived. This amount is a function of both the amount shipped and the resupply lead time.

- **Amount Received (End of Week) –** The amount of the order actually shipped from upstream at the end of the week when it arrives. This amount of stock will be available the following week to meet new demand orders or backorders.

The data for each level shown in Figure 2 are replicated on separate sheets in the spreadsheet file and the student operating a given level may, or may not, be allowed to look at data for other levels, depending on the point at which the instructor wishes to encourage team collaboration versus isolation.

At the point in the assignment at which the instructor wishes to allow and encourage team collaboration, a set of charts (Figure 3) is provided to each team summarizing the performance of their supply chain. The charts provide the following cost data by week and supply chain level:

- The upper left chart panel shows ordering costs.
- The upper right chart panel shows inventory holding costs.
- The lower left chart panel shows backorder costs.
- The lower right chart panel shows three cumulative lines. One line is the cumulative potential profit that would be realized by satisfying all of the customer demand. Another line is the actual profit generated by whatever orders were actually filled at the retail level. The third line is the cumulative cost line, which is the total of the three other costs shown in the other panel charts: ordering, inventory holding, and backorder costs.

Student teams are encouraged to develop other charts that would be useful in their decision making. For example, since all of the charts in Figure 3 are in dollars, another useful set of charts would indicate order sizes, amount of stock outs and backlogs, etc.

Level	1
Description	Retail
Lead Time from Upstream Supply	1
Order Cost from Upstream Supply	$ 500

Supply and Demand

Week	Orders Received from Downstream	Orders Filled	Stock Level (After Orders Filled)	Stock out	Amount of Stock out on Backorder	Amount of Order to Upstream	Amount Actually Shipped from Upstream	Amount Shipped and Not Received	Amount Received (End of Week)
			100						
1	40	40	60	0	0	40	40	40	0
2	35	35	25	0	0	30	30	30	40
3	40	40	25	0	0	45	45	45	30
4	45	45	10	0	0	50	50	50	45
5	60	55	0	5	0	75	75	75	50
6	80	50	0	30	0	100	80	80	75
7	120	75	0	45	0	160	55	55	80
8	180	80	0	100	0	240	75	75	55
9	250	55	0	195	0	320	0	0	75
10	350	75	0	275	0	450	100	100	0
11	10	0	0	10	0	0	50	50	100
12	10	10	90	0	0	10	145	145	50

(Note: **Amount of Order to Upstream** is the decision to be made each week by the student operating this level.)

Figure 2. Example of Data Used for Each Level.

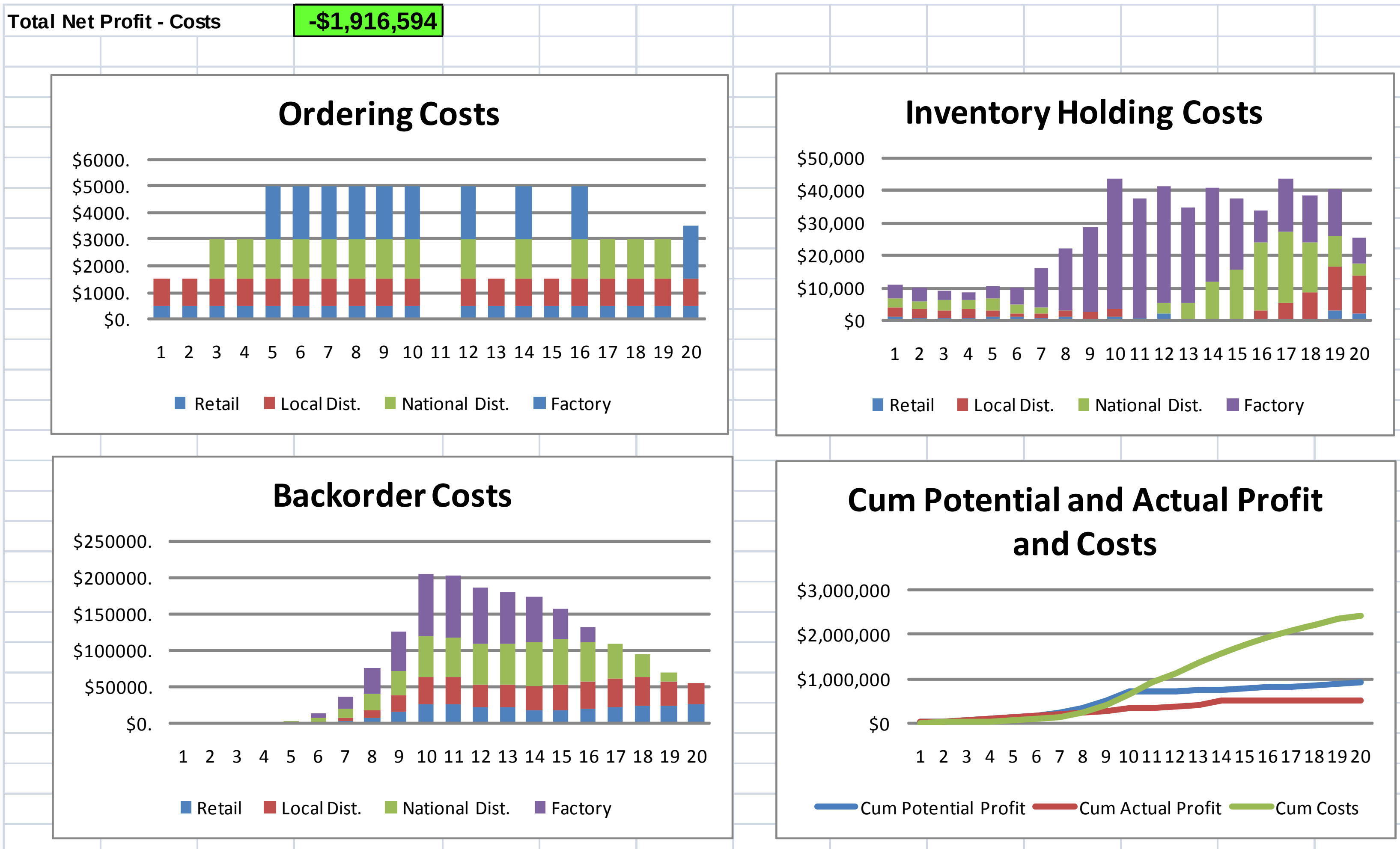

Figure 3. Example Charts from Performance Summary Dashboard.

Use of the Model in a Team Exercise

A class of 20 students was divided into 5 teams of 4 students each. Each student within a team operated one level of their team's supply chain. The exercise was conducted in two rounds. Round one required one 50 minute class period and round two required two class periods. In the first round, the customer demand was revealed by the instructor one week at a time, at which time each student in succession had to make a decision about how much to order from the next level upstream. In round one, the team members were not allowed to talk to each other at all, nor look at each other's sheets in the shared spreadsheet files. Once an ordering decision was made for a given week, then that decision could not be changed later.

In round two, the same customer demand profile was used and all weekly demands over the entire planning horizon were known from the outset. The team members were also allowed to talk to each other and look at each other's data on each worksheet in the shared file as well as the summary charts. The students were also allowed to change any order size decision for any week and not just determine the decisions sequentially in time.

Figure 4 shows the instructor-generated retail customer demand pattern over a 20 week time horizon. This pattern was selected for the purpose of creating a demand ripple effect through the supply chain with the expectation of confusion, order size variation and distortion increasing with each level of the supply chain. (Examples of this "forward buying" consumer behavior are common in business, caused either by promotional pricing or by external events such as the anticipated arrival of a hurricane.)

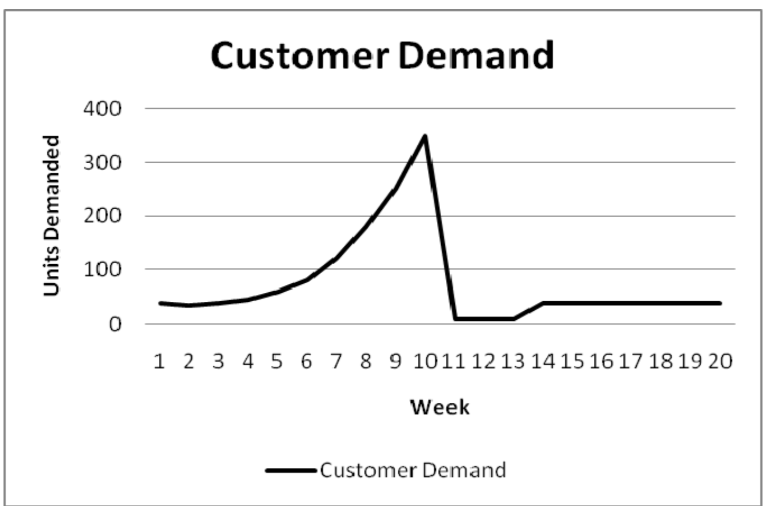

Figure 4. Customer Demand Pattern Generated by Instructor.

Figure 5 is a photograph of the class during the assignment exercise. The advantages of executing the exercise in a computer lab environment include the shared energy level within and between the teams, the ability to project any of the team's performance charts on the screen, discuss possible strategies, and emphasize teaching points. On the other hand, a mobile learning environment allowing team member separation would also have interesting pedagogical possibilities.

Figure 5. Supply Chain Management Class Using the Exercise.

Results

The expected result in the first round occurred as anticipated. There was considerable confusion and frustration as the retail customer demand oscillation pattern rippled back through the levels of the supply chain. Figure 6 shows one team's order quantities by level and illustrates the order variability amplification at higher levels in the supply chain.

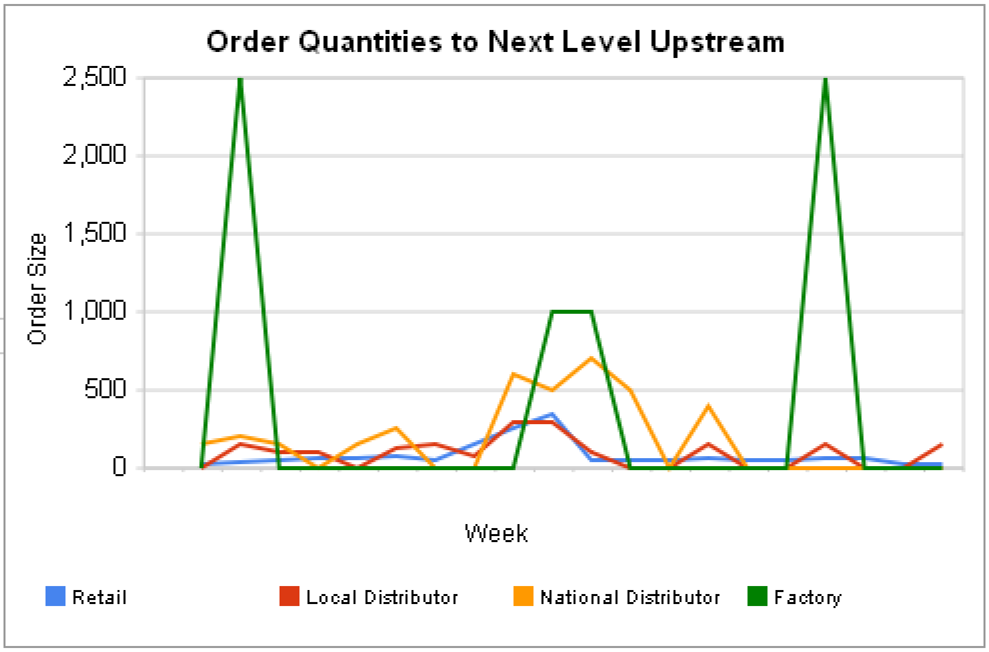

Figure 6. Snapshot from Team 1 Results After Day 1 of Exercise Illustrating Order Quantity Amplification "Bullwhip" Effect.

In round two, the complete demand forecast visibility and ability for team members to communicate led to rapidly improving financial performance as summarized in Table 3. Two of the teams achieved the optimal solution by the end of the 2nd day of round two.

	Total Net Profit (or Loss)		
Team	**Round 1**	**Round 2, Day 1**	**Round 2, Day 2**
1	-$972,215	$484,385	$518,192
2	-$32,206,619	-$861,885	$298,719
3	-$7,7759262	-$334,223	$518,192
4	-$304,635	$10,338	-$258,288
5	-$1,476,065	$79,119	$371,888

Table 3. Overall Team Results.

For this particular example problem, the determination of the optimal solution requires close coordination between levels to eliminate the backorder costs. The relatively high ordering costs, as compared with inventory holding costs, dictate issuing as few orders as possible. Beginning in week one, each level must immediately order the amount initially available in stock at the next level upstream. Given the lead times, each level must anticipate when those initial shipments will arrive at the next level downstream, and then order them on to the subsequent level downstream, and so on until all of the initial stock on hand reaches level one. The other necessary decision in week one is for Level four (the factory) to immediately order an amount of material from the raw material supplier that will cover total future retail demand not satisfied when all level's initial stock on hand is shipped down the supply chain to the retail level. (A subtle issue in this particular example problem is that it is impossible for the supply chain to respond fast enough to meet the entire customer demand spike shown in Figure 4. Therefore, the factory can avoid unnecessary expense by determining the amount of this unavoidable shortfall and not ordering that amount from the raw material supplier. Figure 7 shows the cost performance charts for the optimal solution.

From a model implementation standpoint, Google Spreadsheets was found to be very adequate to achieve the assignment learning objectives, but not as logically and graphically functional as Microsoft Excel at this point in time. Several limitations were also discovered in attempting to upload Excel files to Google Spreadsheets and vice versa. With respect to classroom execution, an issue was encountered involving very slow network internet speed on one of the class days which appeared to be a local university network issue. This is a risk in any exercise using online applications. Otherwise, the file sharing worked well and allowed the student teams to collaborate in real time and facilitated a rich team learning experience.

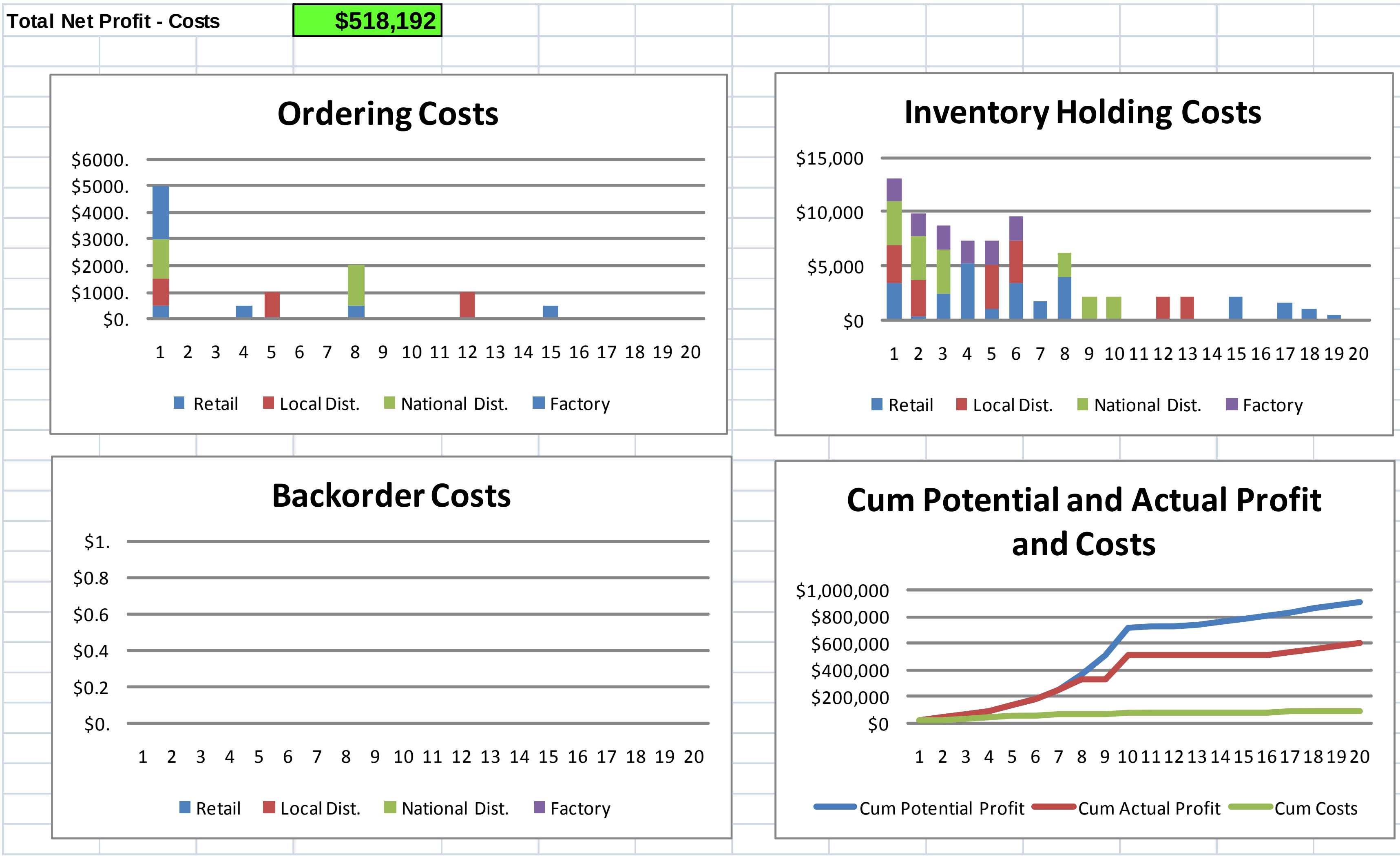

Figure 7. Performance Summary Dashboard Charts for Optimal Solution.

TOPICS FOR DISCUSSION AND ALTERNATIVE EXERCISES

The exercise provides the opportunity to discuss many inventory management topics and has many possible directions for expansion of the example problem as presented here. The following are some of these topics and possible extensions:

- Economic order quantity and single-period model theory - Although these concepts cannot be applied independently at each level of this multi-level problem, the conceptual tradeoffs between the various costs (cost of having inventory, cost of a stock out, and costs of ordering more) are still conceptually applicable at the system level and should be discussed. (If the ordering costs in this example problem were decreased relative to inventory holding costs, then economic order quantities would need to be derived for each level.)

- Capacity – The imposition of capacity constraints at any level, including the raw material supplier, adds a layer of planning complexity.

- Returns – Returns are a significant element in supply chains and fully recognized in the SCOR framework. The addition of random levels of returns back upstream through the supply chain is another possible extension.

- Uncertain supply – In the baseline example problem, raw material supply was slow but certain. The raw material supplier was able to completely fill every order from the factory, with the shipment arriving 6 weeks after the order is issued from the factory. If the raw material fill rate were a random variable, that uncertainty of supply would add another element of interest.

- Transportation time/cost tradeoffs – In the baseline problem, the lead times were known and fixed. Another valuable learning exercise would include faster, more expensive shipment options.

- End-of-horizon product obsolescence – Another possible element would be the cost of obsolescence of all product left in stock at the end of the time horizon, caused by product model changes, competition, or other factors.

- Study supply/demand policy tradeoffs involving “functional” versus “innovative” products as defined by Fisher (1997). Innovative products have very high unit profit margins, but unpredictable demands over short market life cycles. Functional products, on the other hand, exhibit very low unit profit margins, but higher and more predictable demand patterns over long product life cycles. In the context of this teaching exercise, an innovative product would be modeled without a known future customer demand forecast, a very high unit profit margin and end-of-horizon product obsolescence. Functional products would be modeled with a known (or fairly accurate) demand forecast and low unit profit margins. In both cases, the students would choose between fast and expensive transportation options versus slow and less expensive options, safety stock levels, and other decisions.

- Formulas instead of values for decisions – In this variation of the exercise, team members must develop formulas for the weekly decisions about ordering more supply from the next upstream level. After the teams have tested and submitted their proposed formulas in each level, the winning team is determined by average performance using a number of simulated demand patterns.

- Finally, a useful extension to the model is to compute an income statement and balance sheet for each level, and total financial statements for the entire supply chain extended enterprise. Such a view would clarify and emphasize issues concerning individual versus collective financial incentives of different firms in the supply chain.

CONCLUSIONS AND FUTURE DIRECTIONS

Web-hosted spreadsheet models have proved to be a flexible and powerful method for modeling complex supply chains and teaching collaborative supply chain management and interaction between levels. These online office applications also provide a context for experiencing and discussing the opportunities and issues with web-based cloud computing in the corporate environment. The next planned extensions to this research are 1) to model enterprise resource planning (ERP) systems in web-hosted spreadsheets, and 2) to shift from a desktop computer lab classroom environment to a mobile learning environment using mobile devices and spreadsheet apps suitable for mobile devices.

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