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Studying the operational efficiencies of a multi-product supply chain using excel spreadsheet model

Sameer Kumar*, John Kropp

College of Business, University of St. Thomas, Mail # TMH 343, 1000 LaSalle Avenue, Minneapolis, MN 55403-2005, USA

Abstract

This paper presents a simple Excel spreadsheets-based model with @Risk add-in software that incorporates the effects of variability in demand, forecast and lead time. The model replicates a four-stage supply chain with multiple-retailers, wholesalers, manufacturers, and suppliers to demonstrate how a multi-product supply chain will react to certain changes.

The model was created so that it could be used in either a teaching setting or in industry for making supply chain design decisions. From the teaching aspect, students can look at a supply chain and see the effects of changes without having to experience it firsthand. Professionals in industry can modify the model to make it more like their own supply chain and see what the affects are when they want to make changes in one or more attributes. Other key characteristics of a supply chain such as, bullwhip effect, total supply chain cost analysis and information sharing can also be studied using this model.

Keywords: Supply chain design; Supply chain tutorial model; Supply chain analysis; Bullwhip effect; Total supply chain cost analysis; Integrated supply chain management

1. Introduction

We begin with an overview of some of the topics reported in the professional literature that are being discussed in this paper. This is just general information so that a reader can have a reference to other opinions about the issues addressed.

1.1. Bullwhip effect

Donovan (2002/2003) gives a good overview of what the bullwhip effect is. It basically says that bullwhip effect has the negative effects of oversupply and false orders. It goes on to detail that the main causes of bullwhip are demand, promotions, sales, policies, processes, systems and suppliers. Because these things are so ingrained into our organizations it is hard to get rid of the bullwhip, but it gives us some ideas of reducing it. They are as follows: minimize cycle time, monitor actual demand, understand the demand patterns, share information with little delay, eliminate inventory replenishment methods, decrease volume transportation discounts, minimize promotions, offering your products consistently, and eliminate all cancellations of orders by understanding why they happen. Donovan provides us good insight of why bull whip occurs and how to minimize it.

1.2. Technology and software

Lacefield (2005) reviewed firms that are using technology and software to plan their supply chain. Despite the focus on distribution centers the analysis reported shows that managers are becoming more sophisticated when it comes to the supply chain coordination and synchronization. Lacefield emphasizes technology helps facilitate users in making strategic supply chain decisions based on facts instead of instinct.

1.3. Supply chain complexity

The current market trends present pressing demands on product supply chains. Time to market, customer tailor

*Corresponding author. Tel.: +1 651 962 4350; fax: +1 651 962 4710.
E-mail address: skumar@stthomas.edu (S. Kumar).

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doi:10.1016/j.technovation.2005.08.001

products and innovation are the keys to be competitive in the market place. An editorial piece that appeared in Materials Management and Distribution (Anonymous, 2003.) points out that the top companies in the supply chain are focusing on a few things and doing these quite well. Another point made is that customer service is key. It is also noted that the companies that are seeking innovation are the companies that are also doing well. In concludes that companies with supply chain focus need to think about the future and that they may have to make operational changes to remain competitive in the future.

1.4. Supplier relationship management

Amaral (2004) addresses the issue of how the growth of outsourcing has really put an emphasis on supplier relationship management. The analysis shows that companies are spending more money in their supply chain and that with these small additional problems are becoming more evident. To become better with problems, Amral suggests five rules to follow when it comes to evaluation. The first rule is that assessment of performance must be multifaceted. The second is that the process must be exception based; meaning you need to define and identify exceptions. The third rule is that performance measures must provide an overall summary and a detailed description. The fourth rule is the process must be participatory and provide the suppliers the opportunity to respond. Finally, the fifth rule is that the process must be systematic. In a nutshell, it shows that it is necessary to consider many factors when it comes to supply chain relationships and because of the increased amount of money being spent, it is imperative to do so.

1.5. Integrated supply chain management

During the past few years, supply chains—excellence, optimization and integration—have become the focus of many organizations worldwide (Davis, 1993; Andersen et al., 1997; Chen, 1999). This is because progressive firms focus on revenue growth instead of merely striving to meet annual cost reduction targets. Strengthening management of the supply chain is perceived by many firms as enhancing customer satisfaction and enabling profitable growth (Cohen, 1996; AMR, 1997; Keller, 1995; Tzafestas and Papsiotis, 1994).

Depending on why and how the supply chain concept has been applied to problem solving, it has come to signify independent evaluation and/or implementation of one or more of the following characteristics:

1. An arrangement of suppliers of products and services.
2. A network for efficient management of demand and flow of products and services.
3. A philosophy of conducting business.
4. A strategy to gain competitive advantage through coordination and synchronization of actions of its members.

This is primarily due to lack of awareness of techniques available for implementing structural components of supply chain (such as represented by characteristics 1 and 2 above) with its functional components (such as represented by characteristics 3 and 4 above).

The motivation for this study is to explore the behavior of an industry supply chain using the computer-based model and Monte Carlo simulation. The model was developed using Excel spreadsheets and @Risk add-in software tool for Monte Carlo simulation to answer a set of questions listed below.

- Q1. To increase customer service, does a firm need to have increased availability of inventory with a high fill rate and a complete order?
- Q2. Is a lifelong customer in the supply chain cheaper than changing customers every time based on price?
- Q3. Can just-in-time technique greatly increase a firm's customer relationships?
- Q4. By using higher quality materials in manufacturing, does a firm need to worry less about its service?
- Q5. Customer and supplier: can they become competitive, if yes, how and when?
- Q6. Does long-term partnership improve supply chain efficiency and effectiveness? What are the parameters of this relationship?
- Q7. How important is trust in a global supply chain, when is it useful?
- Q8. Would better forecasting (by itself) aide in demand management?
- Q9. What are the factors which would optimize high level of demand management?
- Q10. How would you minimize bullwhip effect, what would need to be controlled?
- Q11. Can a manufacturer sustain a relationship only on CRM with a minimal emphasis on SRM long term?
- Q12. How do we respond to long lead times, what can we do, how do we incorporate this in demand management, can you try different things?

These questions are important questions to look at when thinking about the dynamics of a supply chain. These questions have cost consequences and a manager would not want to make a wrong decision. That is why this model can help a manager in making improved business decisions that lead to maximizing customer service and profits by capitalizing on the value of taking an integrated approach to managing the entire supply chain as opposed to managing each component of the supply chain.

Much like the beer games, this simulation looks at different entities in a supply chain and how they deal with variability in demand and forecasts (Sterman, 1984, 1989; Li and Simchi-Levi, 2003). This model differs from them because it adds in a few different complexities discussed in the next section.

2. Background

The supply chain model presented here consists of four stages—retailer, wholesaler, manufacturer, and supplier. Each stage has multiple entities such as 7 retailers, 3 wholesalers, 2 manufacturers, and 4 suppliers. In this supply chain there are three products or product lines: A, B, and C. Each of these products is made up of two components obtained from suppliers. The components that the suppliers handle are I, V, and X. Product A is made up of one I and one V, product B is made up of one V and one X, and product C is made up of one I and one X. The four suppliers carry all of the components and they distribute them equally to both manufacturers, so their market shares are treated as equal (shown in Table 1). It may be noted, we have chosen a market share distribution percents for various entities and products in the supply chain (shown in Tables 1–4) to demonstrate a working example of the proposed Excel spreadsheet model.

Both manufacturers generate all three products. The way the market is set up right now is that manufacturers 1 and 2 have equal market share of 50% for all products (shown in Table 2). The manufacturers then sell these products to the wholesalers and two retailers.

The three wholesalers do not sell all three product lines. Wholesaler 1 sells products A and B, wholesaler 2 sells product B and C, and wholesaler 3 sells products A and C. Each wholesaler sells 45% of total market demand in each product that they carry and manufacturers make up the remaining 10% (shown in Table 3). As mentioned before, manufacturers 1 and 2 also sell certain portion of all three of their products to two retailers directly. This model treats these manufacturers as wholesalers at this stage. It was important to include this feature to make the model more complete and have more options. These manufacturers differ at this point because they do not incur the cost of goods sold (COGS) like a wholesaler would. They only get charged extra for transportation and inventory carrying costs (ICCs).

The seven retailers do not carry all the product lines. Retailer 1 carries A, retailer 2 carries A and B, retailer 3 carries A, B, and C, retailer 4 carries B and C, retailer 5 carries A and C, retailer 6 carries B, and retailer 7 carries C. The market share for each retail outlet can be seen in Table 4.

The way various product supply chains look can be seen in Figs. 1–4.

The proposed model works as a demand-driven model. When the Monte Carlo simulation is run, a number is created that is from the normal demand distribution for that product line. It then compares it to what is being forecast which also is generated from a normal distribution for forecast. This creates an order amount. This order amount is now the next entity demand. This process continues itself through the supply chain. The Excel model is set up for 1 year in terms of months. There are 12 cost worksheets, one for each of the 12 months. The Monte Carlo simulation is run for a year. Because of the variability between the forecast and the demand, we are going to experience excess inventory and stock outs. These are also carried from 1 month to the next. This creates a

Table 1
Supplier market share

Supplier	Component		
	I (%)	V (%)	X (%)
1	25	25	25
2	25	25	25
3	25	25	25
4	25	25	25

Table 2
Manufacturer market share

Manufacturer	Product		
	A (%)	B (%)	C (%)
1	50	50	50
2	50	50	50
	100	100	100

Table 3
Wholesaler market share

Wholesaler	Product		
	A (%)	B (%)	C (%)
1	45	45	
2		45	45
3	45		45
Mfr. 1	5	5	5
Mfr. 2	5	5	5
	100	100	100

Table 4
Retailer market share

Retailer	Product		
	A (%)	B (%)	C (%)
1	20		
2	10	10	
3	40	60	40
4		10	20
5	30		10
6		20	
7			30
	100	100	100

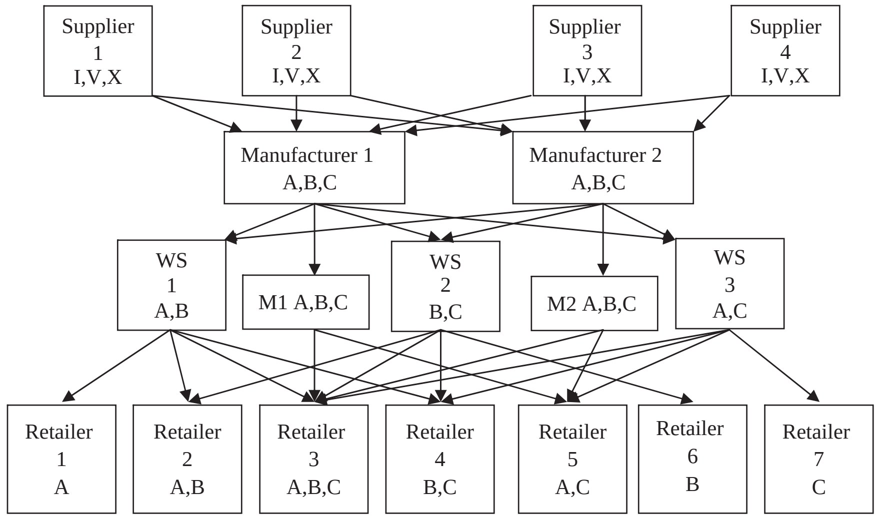

Fig. 1. Combined supply Chain for products A–C—total market structure.

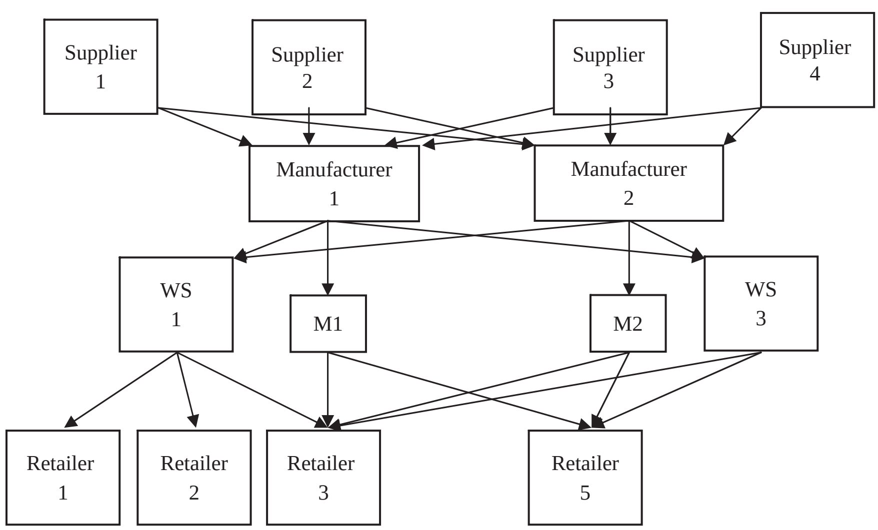

Fig. 2. Supply chain for product A.

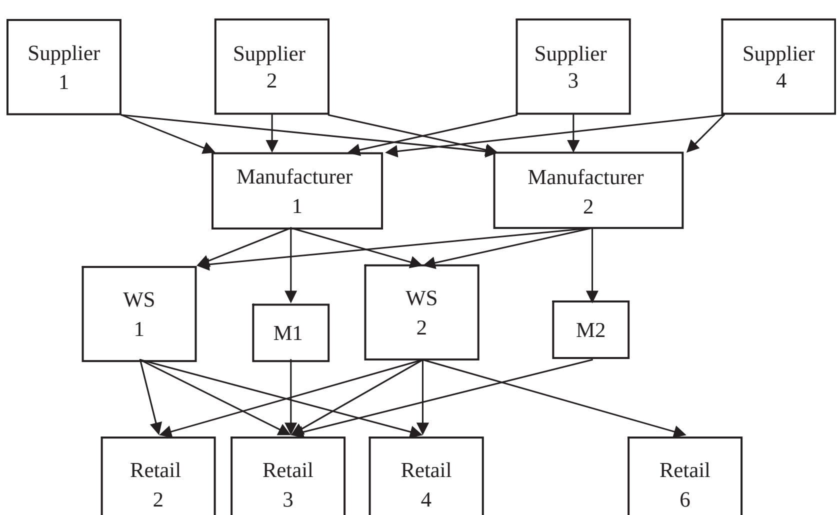

Fig. 3. Supply chain for product B.

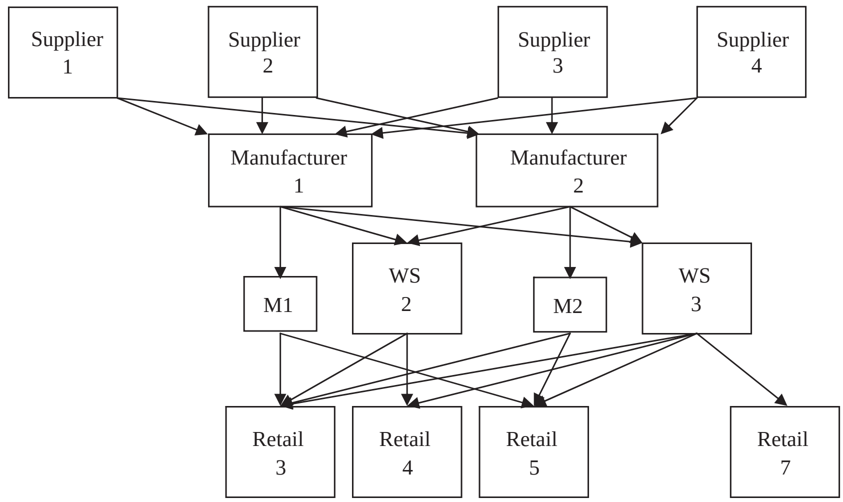

Fig. 4. Supply chain for product C.

realistic dimension to the model. The model is built on assumptions discussed in the next section.

3. Major assumptions

1. Manufacturers are the centerpiece of the supply chain and because of this, we can view them as either separate, as two supply chains, or as one composite supply chain. The reason that we separated them was that we wanted to look at the supply chain when we made changes to one entity and not the other. The manufacturer is the one that produces the product and that is why it was chosen as the centerpiece.
2. Each of the entities in the supply chain has vendor managed inventory system. This would eliminate ordering costs. We realize that in many cases, when ordering from the same entity, you would not get charged for multiple orders. This model does have the capability of calculating the number of orders per entity and one would have to associate a cost with that.
3. The demand behaves as normal distribution around the mean that was randomly chosen by the user. The forecast is also considered to be a random variable with normal distribution because we know that a forecast is an estimate of how much we expect to sell and it is never accurate. Other distributions could be used but a normal distribution is what people are most familiar with.
4. ICCs section includes multiple costs such as finance charges, insurance, product handling, inventory space, damage, and obsolescence. The reason for grouping these together was because they are all a percentage of COGS and it would not make sense to make them individual. It is much simpler to lump them together.
5. The transportation costs include delivery and early or late delivery charges. Both of these costs are a percentage of COGS. The reason that we put them together is much like the same reason that we grouped the ICCs together. Building in a lead time characteristic in the model would have been more difficult; however, managers really are more interested to know about costs. This was a good way of recognizing that lead time exists and that it is difficult to deliver on time. Since this is a random component, we use a triangular distribution to generate the percentage. It is estimated from a most likely percentage and has max and min percentages as well. @Risk then randomly chooses a number for this cost and they differ between product and business entities.
6. The manufacturers would only sell the product to a wholesaler or retailer at one price. This was to simplify the model at an early point. Since there are four suppliers and they have the opportunity to sell the components at different prices, we want to make sure that we do not have to keep track of all these costs later downstream in the supply chain. This price was taken as an average of the cost to manufacturer and the markup for both the wholesaler and retailer.
7. Retailers cannot suffer a stock out. It is assumed that a retailer can take an order for a product and supply it at a later date when the supply chain catches up with demand. The reason for this assumption is that we would have had to build in a forward product moving feature creating a different level of complexity. This could be added in at a later date to make the supply chain more realistic.
8. Market share is assumed constant in the simulation. We realize that market share would fluctuate in the real world and that if there are stock outs then we would have certain activities to alleviate the problem. If we were to change the market share each time, then we would have to retool many of the formulas that have been entered. Most notable would be either the manufacturer's market share or the retailer's market share.

9. Change in price and inventory quantities will not change the dynamics of the simulation. Expanding on the above point, bullwhip effect is being shown in the simulation and there are ways to alleviate the problems or make them worse. This simulation only shows that the problem exists. One could build some of the ways to take care of bullwhip effect but it would add complexity to the model. For the scope of this project, it was not considered.
10. Each time one runs the Monte Carlo simulation, it will start out with zero inventory. This assumption can change but one will have to manually enter in the amount of inventories for each entity. This could be tedious and time consuming.

4. Actual workbook

The model is linked through 28 worksheets in Excel. There are two worksheets that are primarily factual data and drive the simulation. The other 26 worksheets give representation of what is going on in the supply chain and link 1 month to the next. A more in-depth description about them is given below.

The market structure worksheet contains the way the supply chain is set up. It tells the market share and demand in units to the separate entities. If this was a human, it would be called the heart and the brains because without it, the model could not run. One can change the different market shares on this worksheet and see how it would affect the supply chain. This is also where the total demand and forecasts are found. These numbers also can be manipulated for experimental purposes. There are few different sections of this worksheet. Below are their representations with a brief description of what they are. We start with Table 5 that shows how the market share is broken up in this supply chain. These numbers can be modified and changed to see what would happen to costs and other attributes in other worksheets.

Table 6 shows how the demand and forecasts will be broken up by each entity. It works by being driven by total demand and the market share table we just saw. The @Risk simulation creates an output for normal demand distribution for each product. Then this number is put through the Monte Carlo simulation that goes through many iterations Excel is set for. When we do this, the spreadsheet reads this number and cross refer it with the market share data set that we just saw. For example, total demand for product line A is 1500, because of this Retailer 1 is expected to sell 300 units ($=1500*20\%$). The wholesalers work a little differently because they calculate the number of components needed to complete the different product lines.

For example, component I is used in product lines A and C. It takes the market share percentage from that data set and then uses that to calculate the total market share that I will need for both these product lines. For example, 625 units of I for supplier 1 ($=1500$ of $A*25\% + 1000$ units of $C*25\%$). The forecast and demand sets are separate; they are both shown here because they work the same way.

Table 5
Market share for retailers, wholesalers, manufacturers and suppliers

Retailer	Product		
	A (%)	B (%)	C (%)
1	20		
2	10	10	
3	40	60	40
4		10	20
5	30		10
6		20	
7			30
	100	100	100
Wholesaler			
1	45	45	
2		45	45
3	45		45
Mfr. 1	5	5	5
Mfr. 2	5	5	5
	100	100	100
Manufacturer			
1	50	50	50
2	50	50	50
	100	100	100
	Component		
Supplier	I, V (%)	V, X (%)	I, X (%)
1	25	25	25
2	25	25	25
3	25	25	25
4	25	25	25

This worksheet also has two more data sets that it uses to run the model. The first data set may be seen in Table 7.

This set (Table 7) is used to break down who is supplying the product to what entity and at what percentage that they are doing it. For example, Product C is being sold by retailer 3 and there are four entities supplying retailer 3. Wholesaler 2 supplies 88 percent to retailer 3, wholesaler 3 supplies 4%, manufacturer 1 supplies 4%, and manufacturer 2 supplies 4%. If we were to change the market shares of the retailers, then this table would have to be recalculated. Table 8 is the last data set in this worksheet.

Table 8 shows the proportion of a component used in each product. This is important to have because when the demand and forecasts are variable; this amount is going to be a variable. It is crucial in calculating the costs later.

The cost structure worksheet is the other worksheet that is factual and can be modified. It gives the basic cost structure of the three product lines and it follows them through the supply chain. Each entity has the ability to

Table 6
Demand and forecasts for each entity by products and components

	Total demand				Forecast demand		
	A	B	C		A	B	C
@Risk	1500	2000	1000	@Risk	1500	2000	1000
Retailer				Retailer			
1	300	0	0	1	300	0	0
2	150	200	0	2	150	200	0
3	600	1200	400	3	600	1200	400
4	0	200	200	4	0	200	200
5	450	0	100	5	450	0	100
6	0	400	0	6	0	400	0
7	0	0	300	7	0	0	300
	1500	2000	1000		1500	2000	1000
Wholesaler				Wholesaler			
1	675	900	0	1	675	900	0
2	0	900	450	2	0	900	450
3	675	0	450	3	675	0	450
Mfr. 1	75	100	50	Mfr. 1	75	100	50
Mfr. 2	75	100	50	Mfr. 2	75	100	50
	1500	2000	1000		1500	2000	1000
Manufacturer				Manufacturer			
1	750	1000	500	1	750	1000	500
2	750	1000	500	2	750	1000	500
	1500	2000	1000		1500	2000	1000
Supplier	I	V	X	Supplier	I	V	X
1	625	875	750	1	625	875	750
2	625	875	750	2	625	875	750
3	625	875	750	3	625	875	750
4	625	875	750	4	625	875	750
	2500	3500	3000		2500	3500	3000

Table 7
Percent breakdown of products supplied to various retailers by various wholesalers and manufacturers

Product A	WS 1 (%)	WS 3 (%)	Mfr. 1 (%)	Mfr. 2 (%)	Total (%)
Retailer 1	100.0				100
Retailer 2	100.0				100
Retailer 3	37.5	50.0	6.3	6.3	100
Retailer 5		83.4	8.3	8.3	100
Product B	**WS 1 (%)**	**WS 2 (%)**	**Mfr. 1 (%)**	**Mfr. 2 (%)**	**Total (%)**
Retailer 2	50	50			100
Retailer 3	58.3	25.0	8.3	8.3	100
Retailer 4	50	50			100
Retailer 6		100			100
Product C	**WS 2 (%)**	**WS 3 (%)**	**Mfr. 1 (%)**	**Mfr. 2 (%)**	**Total (%)**
Retailer 3	88.0	4.0	4.0	4.0	100
Retailer 4	50	50			100
Retailer 5		33.6	33.6	33.6	101
Retailer 7		100			100

Table 8
Proportion of each component in various products

Product	Component		
	I (%)	V (%)	X (%)
A	60	43	
B		57	67
C	40		33

Table 9
Basic cost structure used by the four suppliers to make components I, V and X

	Supplier 1	Supplier 2	Supplier 3	Supplier 4
I				
Raw material/unit	$2.0	$2.0	$2.0	$2.0
Labor/unit	$3.0	$3.0	$3.0	$3.0
Total var cost	$5.0	$5.0	$5.0	$5.0
Mark up	50%	50%	50%	50%
Cost to Mfr.	$7.50	$7.50	$7.50	$7.50
V				
Raw material/unit	$1.0	$1.0	$1.0	$1.0
Labor/unit	$5.0	$5.0	$5.0	$5.0
Total var cost	$6.0	$6.0	$6.0	$6.0
Mark up	75%	75%	75%	75%
Cost to Mfr.	$10.50	$10.50	$10.50	$10.50
X				
Raw material/unit	$3.0	$3.0	$3.0	$3.0
Labor/unit	$1.0	$1.0	$1.0	$1.0
Total var cost	$4.0	$4.0	$4.0	$4.0
Mark up	40%	40%	40%	40%
Cost to Mfr.	$5.60	$5.60	$5.60	$5.60

change their mark-ups and product costs. This worksheet also contains the ICCs and transportation costs. These two costs are a percentage of costs of good sold. They also can be modified to make it more realistic to the industry that we are interested in. There are five main sections to this worksheet and they are highlighted in Table 9.

Table 9 gives the basic cost structure used by the suppliers. There are two variable costs: raw materials and labor costs. They then add a markup to these costs. Each component is and can be different, as well as the supplier for each component. These are variables that can be easily changed and manipulated for study.

Table 10 works like the supplier table with a few exceptions. It takes the cost of the components to make up the product from each of the different suppliers. Then the manufacturer adds their markup for either the retailer or the wholesaler. It is then averaged out. The reason that it is averaged out is because we would expect that the product would be sold at the same price to either the retailer or wholesaler even if it costs more to make. Also, another reason that it is averaged out is because after this stage it would become very complex to track costs from the supplier to manufacturer to wholesaler to retailer. There would be over a hundred combinations.

The reason that it is split into two tables is because the different manufacturers may have different labor costs or they might want different markups. This creates a lot of flexibility when one is playing with the model and trying to solve problems.

Table 11, like the ones above, does basically the same thing. It uses the cost from the manufacturer and adds markup. These are also separate because different wholesalers might have different wholesaling strategies and this allows the flexibility to manipulate some of the numbers.

Table 12 shows the percentage of COGS that are going to be charged to ICCs. These numbers are picked and may or may not be realistic. A user would be able to more realistically assign numbers that represent the industry that they are in.

Transportation costs (Table 13) are also taken as a part of COGS. The main difference between this section and the ICCs section is that we have made them random. Again using @Risk, we have assigned a triangular distribution for transportation costs (as a percent of COGS) for each of the entities. When we run the simulation we get output values for these distributions and these are run with the numbers from the simulation worksheets. The reason that these percents are random is because of the early and late delivery charges. In a perfect world we would have lead time but in this model we are using cost as the main driver.

The simulation worksheet is the first representation worksheet. This worksheet calculates how much product needs to be ordered and what the inventory or stock outs are going to be. It is color coded by the product, so it is easier to follow. The only thing that one can modify on this page is the order quantity. This will affect the number of orders that the entity will generate during that one run in the simulation. So we can try and test a lean and JIT system if we wanted. The manufacturing portion is shown in Table 14.

The forecast and demand are linked from the market structure worksheet and then we calculate the orders by using the forecast minus the beginning inventory. Ending inventory is calculated by subtracting the forecast and demand and adding back in beginning inventory. Stock outs occur when there is a negative onhand inventory. If this is the case, excel uses an if/then scenario and records the number of stock outs. Once again, there are 12 of these worksheets and each represents one month.

The costs worksheet calculates all the costs for the supply chains and entities. It is broken into three sections. It is broken into product lines because we want to keep track of all three separate product lines and what they do to separate entities. It is also broken into costs by the different manufactures. We see the manufacturers as the centerpiece of the supply chain and because of this we want to have two separate supply chains to keep track of the costs. There is also a total supply chain cost for each of the product lines. This is helpful to know because it shows

Table 10
Basic cost structure used by the two manufacturers

	Mfr. 1					Mfr. 2				
A	Supplier 1	Supplier 2	Supplier 3	Supplier 4		Supplier 1	Supplier 2	Supplier 3	Supplier 4	
Raw material/unit	$18.00	$18.00	$18.00	$18.00		$18.00	$18.00	$18.00	$18.00	
Labor/unit	$10.00	$10.00	$10.00	$10.00		$10.00	$10.00	$10.00	$10.00	
Total var cost	$28.00	$28.00	$28.00	$28.00		$28.00	$28.00	$28.00	$28.00	
Mark up WS	75%	75%	75%	75%	Average	75%	75%	75%	75%	Average
Cost to WS	$49.00	$49.00	$49.00	$49.00	$49.00	$49.00	$49.00	$49.00	$49.00	$49.00
Mark up retail	100%	100%	100%	100%		100%	100%	100%	100%	
Cost to retail	$56.00	$56.00	$56.00	$56.00	$56.00	$56.00	$56.00	$56.00	$56.00	$56.00
B										
Raw material/unit	$16.10	$16.10	$16.10	$16.10		$16.10	$16.10	$16.10	$16.10	
Labor/unit	$12.50	$12.50	$12.50	$12.50		$12.50	$12.50	$12.50	$12.50	
Total var cost	$28.60	$28.60	$28.60	$28.60		$28.60	$28.60	$28.60	$28.60	
Mark up WS	75%	75%	75%	75%	Average	75%	75%	75%	75%	
Cost to WS	$50.05	$50.05	$50.05	$50.05	$50.05	$50.05	$50.05	$50.05	$50.05	$50.05
Mark up retail	100%	100%	100%	100%		100%	100%	100%	100%	
Cost to retail	$57.20	$57.20	$57.20	$57.20	$57.20	$57.20	$57.20	$57.20	$57.20	$57.20
C										
Raw material/unit	$13.10	$13.10	$13.10	$13.10		$13.10	$13.10	$13.10	$13.10	
Labor/unit	$15.00	$15.00	$15.00	$15.00		$15.00	$15.00	$15.00	$15.00	
Total var cost	$28.10	$28.10	$28.10	$28.10		$28.10	$28.10	$28.10	$28.10	
Mark up WS	75%	75%	75%	75%	Average	75%	75%	75%	75%	
Cost to WS	$49.18	$49.18	$49.18	$49.18	$49.18	$49.18	$49.18	$49.18	$49.18	$49.18
Mark up retail	100%	100%	100%	100%		100%	100%	100%	100%	
Cost to retail	$56.20	$56.20	$56.20	$56.20	$56.20	$56.20	$56.20	$56.20	$56.20	$56.20

Table 11
Basic cost structure used by the wholesalers

	Mfr. 1	Mfr. 2
Wholesaler 1		
Product A	$49.00	$49.00
Mark up	2%	2%
Cost to retailer	$49.98	$49.98
Product B	$50.05	$50.05
Mark up	2%	2%
Cost to retailer	$51.05	$51.05
Wholesaler 2		
Product B	$50.05	$50.05
Mark up	2%	2%
Cost to retailer	$51.05	$51.05
Product C	$49.18	$49.18
Mark up	2%	2%
Cost to retailer	$50.16	$50.16
Wholesaler 3		
Product A	$49.00	$49.00
Mark up	2%	2%
Cost to retailer	$49.98	$49.98
Product C	$49.18	$49.18
Mark up	2%	2%
Cost to retailer	$50.16	$50.16

the entire cost for the supply chain and it can be compared to the individual supply chains very quickly. Product Line A may be seen below (Tables 15–17).

As one can see, this worksheet (shown in Tables 15–17) is quite complex to look at but in reality it just measures the cost in supply chains. COGS is measured by the amount ordered each time one runs the model multiplied by the cost of that good. Then ICC and transportation cost are percentages of that COGS. Stock outs are the number of stock outs from the simulation worksheet multiplied by the amount that one would have obtained for that unit. Variable labor and raw materials are calculated like COGS but these two costs need to be represented to make the model more accurate. Fixed property plant and equipment (PPE) are numbers that can be changed. It also was added to make the model more realistic and the numbers may or may not be accurate. Total cost is all the costs that have been accounted for. It is the sum of COGS, ICC, transportation, stock outs, variable labor and raw materials, and PPE. The last section of total cost between the supply chain one and two is obtained by just adding up the amount in the first two sets.

The final worksheet is the product movement worksheet. This gives a visual representation of where the product is moving and to what entity. This worksheet is a simple version of what the simulation worksheet shows. It is helpful when one wants to quickly track the product movement in the entire supply chain. An example of this worksheet is shown below (Fig. 5).

These cells refer the simulation worksheet. The reason that the suppliers look like they are supplying too much

Table 12
Inventory carrying costs for supply chains 1 and 2 as a percent of cost of goods sold

Supplier	Supply chain 1				Supply chain 2		
	A (%)	B (%)	C (%)	Supplier	A (%)	B (%)	C (%)
1	8	8	8	1	8	8	8
2	8	8	8	2	8	8	8
3	8	8	8	3	8	8	8
4	8	8	8	4	8	8	8
Manufacturer				Manufacturer			
1	10	10	10	1	10	10	10
2	10	10	10	2	10	10	10
Wholesaler				Wholesaler			
1	12	12	12	1	12	12	12
2	12	12	12	2	12	12	12
3	12	12	12	3	12	12	12
M1	11	11	11	M1	11	11	11
M2	11	11	11	M2	11	11	11
Retailer				Retailer			
1	15			1	15		
2	15	15		2	15	15	
3	15	15	15	3	15	15	15
4		15	15	4		15	15
5	15		15	5	15		15
6		15		6		15	
7			15	7			15

Table 13
Transportations costs as a percent of cost of goods sold

	A (%)	B (%)	C (%)
Supplier			
1	4	4	4
2	4	4	4
3	4	4	4
4	4	4	4
Manufacturer			
1	7	7	7
2	7	7	7
Wholesaler			
1	15	15	15
2	15	15	15
3	15	15	15
M1	15	15	15
M2	15	15	15
Retailer			
1	20		
2	20	20	
3	20	20	20
4		20	20
5	20		20
6		20	
7			20

Table 14
Manufacturers' forecast, demand, order and inventory data

	Product A	Product B	Product C
Manufacturer 1			
Forecast	750	1000	500
Demand	750	1000	500
Order amount	750	1000	500
Begin inventory	0	0	0
End inventory	0	0	0
Stock outs	0	0	0
Order quantity	100	100	100
# of orders	8	10	5
Manufacturer 2			
Forecast	750	1000	500
Demand	750	1000	500
Order amount	750	1000	500
Begin inventory	0	0	0
End inventory	0	0	0
Stock outs	0	0	0
Order quantity	100	100	100
# of orders	8	10	5

product is because they are supplying two components for one product. This provides a quick visual and makes the model easier to understand.

5. How @Risk works with Excel to run the Monte Carlo simulation

In this section, we will take a more in depth look at how @Risk helps drive this Excel simulation and to what benefit this is. @Risk is a Monte Carlo simulation software and in this capacity is being used to generate numbers and track the results.

When one runs @Risk it first looks at the inputs; in this case, demands, forecasts, and transportation costs. It then runs the simulation once with the random numbers that it has picked and comes up with the outputs. In this model, the costs of each month by product and by supply chain are the outputs. It then will rerun the simulation as many times as one tells to reiterate it. By running the simulation many times, we will get a range of results. @Risk tracks these results and creates a distribution. This is helpful because one can see the peaks and the extremes at what the costs would be in different situations. Also, it would give a good mean value of what to expect of a cost.

Another nice feature of @Risk is that one can easily change the ranges of the distributions and the types of distribution for random input variables. By being able to easily change the range of the distributions, one can create examples for different industries. Also, an industry may have a different distribution other than a normal one. One can change the distribution without changing the model but with changing the outcome. @Risk is a powerful tool and has added great value to this model and simulation.

Table 15
Breakout of costs for supply chain 1

A	Retail	COGS	Inventory CC	Transportation	Stockout			Total cost
	1	$7,497	$1,125	$1,499				$162,496
	2	$3,749	$562	$750				
	3	$15,220	$2,283	$3,044				
	4		$-	$-				
	5	$11,470	$1,721	$2,294				
	6		$-	$-				
	7		$-	$-				
	Wholesaler	**COGS**	**Inventory CC**	**Transportation**	**Stockout**			
	1	$16,538	$1,985	$2,481	$-			
	2		$-	$-				
	3	$16,538	$1,985	$2,481	$7			
	Mfr. 1		$2,310	$3,150	$-			
	Manufacturer		**Inventory CC**	**Transportation**	**Stockout**	**Var labor**	**Var raw**	**Fixed PPE**
	1		$2,100	$1,470	$-	$7,500	$13,500	$10,000
	Supplier		**Inventory CC**	**Transportation**	**Stockout**	**Var labor**	**Var raw**	**Fixed PPE**
	1		$165	$83	$-	$1,500	$563	$5,000
	2		$165	$83	$-	$1,500	$563	$5,000
	3		$165	$83	$-	$1,500	$563	$5,000
	4		$165	$83	$-	$1,500	$563	$5,000

Table 16
Breakout of costs for supply chain 2

A	Retail	COGS	Inventory CC	Transportation	Stockout			Total cost
	1	$7,497	$1,125	$1,499				$162,496
	2	$3,749	$562	$750				
	3	$15,220	$2,283	$3,044				
	4		$-	$-				
	5	$11,470	$1,721	$2,294				
	6		$-	$-				
	7		$-	$-				
	Wholesaler	**COGS**	**Inventory CC**	**Transportation**	**Stockout**			
	1	$16,538	$1,985	$2,481	$-			
	2		$-	$-				
	3	$16,538	$1,985	$2,481	$7			
	Manuf. 2		$2,310	$3,150	$-			
	Manufacturer		**Inventory CC**	**Transportation**	**Stockout**	**Var labor**	**Var raw**	**Fixed PPE**
	2		$2,100	$1,470	$-	$7,500	$13,500	$10,000
	Supplier		**Inventory CC**	**Transportation**	**Stockout**	**Var labor**	**Var raw**	**Fixed PPE**
	1		$165	$83	$-	$1,500	$563	$5,000
	2		$165	$83	$-	$1,500	$563	$5,000
	3		$165	$83	$-	$1,500	$563	$5,000
	4		$165	$83	$-	$1,500	$563	$5,000

6. Application: a practical example

In this example, we are going to say that manufacturer 1 has come up with a new way of producing their products. This new way of producing is more labor intensive and more costly, but it is going to reduce the ICC from the manufacturer to the retailer. This should prove that even though they are paying more for a product, they will save

Table 17
Combined breakout of costs for supply chain 1 and 2

A	Retail	COGS	Inventory CC	Transportation	Stockout			Total cost
	1	$14,994	$2,249	$2,999	$-			$324,992
	2	$7,497	$1,125	$1,499	$-			
	3	$30,440	$4,566	$6,088	$-			
	4	$-	$-	$-	$-			
	5	$22,941	$3,441	$4,588	$-			
	6	$-	$-	$-	$-			
	7	$-	$-	$-	$-			
	Wholesaler	COGS	Inventory CC	Transportation	Stockout			
	1	$33,075	$3,969	$4,961	$-			
	2	$-	$-	$-	$-			
	3	$33,075	$3,969	$4,961	$15			
	Manuf. 1	$-	$2,310	$3,150	$-			
	Manuf. 2	$-	$2,310	$3,150	$-			
	Manufacturer		Inventory CC	Transportation	Stockout	Var labor	Var raw	Fixed PPE
	1 & 2		$4,200	$2,940	$-	$15,000	$27,000	$20,000
	Supplier		Inventory CC	Transportation	Stockout	Var labor	Var raw	Fixed PPE
	1		$330	$165	$-	$3,000	$1,125	$10,000
	2		$330	$165	$-	$3,000	$1,125	$10,000
	3		$330	$165	$-	$3,000	$1,125	$10,000
	4		$330	$165	$-	$3,000	$1,125	$10,000

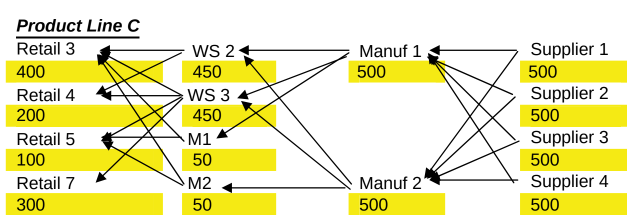

Fig. 5. Illustration of product movement in the supply chain for product C.

in the long run because of the quality and thus a reduction in ICCs. This simulation run will also show the effects of bullwhip and what that can be done to the supply chain costs. To make this happen, the simulation is going to be run one time for 5000 iterations. @Risk will record all the important data such as the min, max and mean for demand, forecast, costs for both supply chains, and the total aggregate cost for the composite supply chain.

These are the only changes that were made. Everything else was held constant for this sample run. We changed labor and ICCs for manufacturer 1 as shown in Table 18.

To reiterate what we thought would happen was that the total cost from supply chain 1 and manufacturer 1's three products would overall be less than supply chain 2 and manufacturer 2's products. We found the following (Table 19).

This provides a great example of why we would do this sort of modeling and simulation. Our intuition told us that if we could reduce ICC by increasing our labor cost, that overall we would provide more value to the supply chain.

Table 18
Showing changes in labor and inventory carrying costs (ICC) for manufacturer 1

Manufacturer 1	Old cost	New cost	Old (%)	New (%)
Product A	$10	$12		
Product B	$12.50	$15		
Product C	$15	$17		
ICC for Mfr.			8	5
ICC for WS			10	7
ICC for Retailer			15	12

Table 19
Total supply chain costs by products for the two supply chains

Product	Supply chain 1	Supply chain 2	Total cost
A	$2,849,835	$2,742,422	$5,592,256
B	$3,851,100	$3,655,158	$7,506,258
C	$1,960,353	$1,868,808	$3,829,161

As it turns out, we did not provide more value but took away from it. Manufacturer 1 wanted to gain more market share by delivering a total lower cost to the supply chain. If this was the real world and they had done this, more than likely, then they would have lost market share.

To get a visual representation of what @Risk provides, here are a few graphs and charts (Figs. 6 and 7) with a brief explanation.

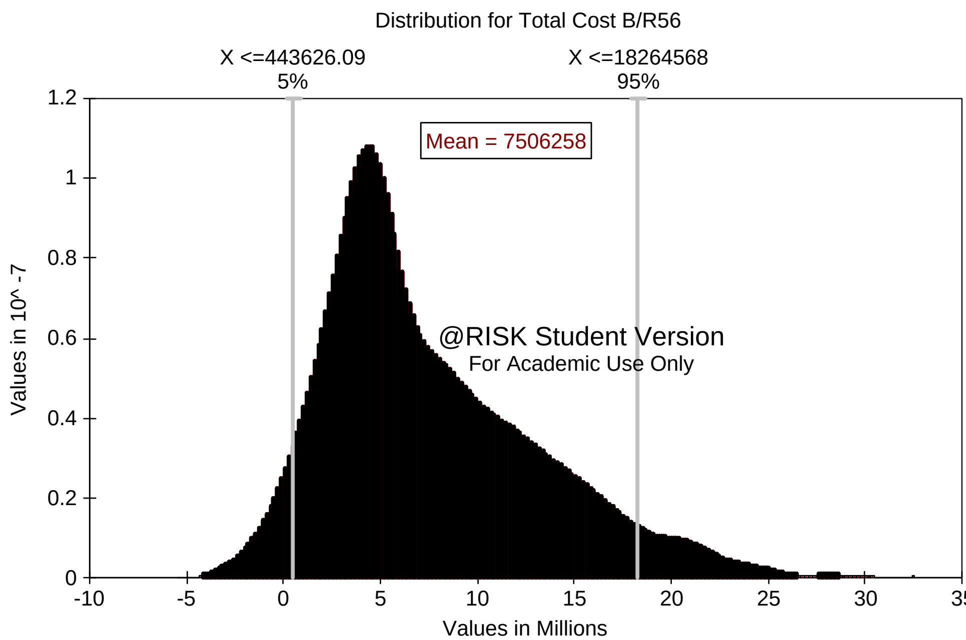

Fig. 6. Total cost distribution for 12 months for product B.

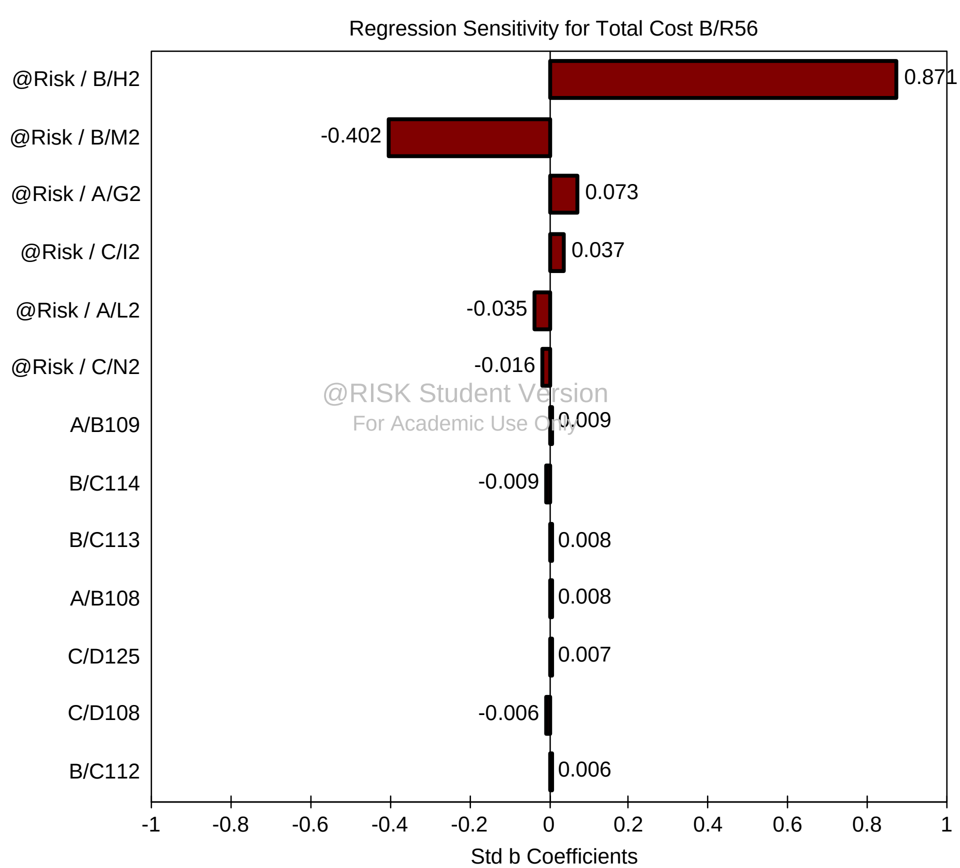

Fig. 7. Regression sensitivity of total cost for product B.

Fig. 6 shows the total cost distribution for the 12 months for both supply chains for product B. This shows us that for the most part it is a normal distribution but it is skewed slightly in the favor of smaller costs. It does show that in an extreme case, costs may go above 25 million.

The graph (Fig. 7) shows the biggest factor in determining the cost of product B that was seen in the previous graph. It states that the cell @Risk B/H2 is the main driver for this simulation. Cell B/H2 is the demand for product B. Conversely, the forecast was a negative factor in the cost but was still quite high in affecting the cost.

7. Conclusions, implications, and recommendations

This section is to revisit the beginning and answer the questions that were first posed, as well as have a brief discussion on the value of this model and models in general. Finally, pose some recommendations that could be made to further improve this model and the research that could be done with it.

The first question asks if a firm needs to have high inventory availability and complete orders to increase customer service. This model could be used to look at this from a point of how many stock outs occur given a time period. The way we prove this is that when stockout costs are low, and complete orders are high, we would believe that we have increased the customer service.

The second question asks if a life long customer in the supply chain is cheaper than acquiring new ones. This model could answer this question through changes in market share distribution and the addition of new products in different entities. The additional costs of doing these things could show that having a customer for a long time can give significant price breaks to a firm. Also, new products and new customers could drive up the entire supply chain costs.

The third question asks if just-in-time techniques can improve firm's relationships. This can be shown by adding a cost for orders and then gradually moving order quantity towards one. This combined with lowering stockouts should be able to show that customer service would go up but costs also would go up. A person who wanted to ask this question would have to find the tradeoff between cost and service.

The fourth question asks if a firm uses higher quality materials in manufacturing its product, it will have to worry less about service. This example was tried in the above section, only it was with labor cost. One could raise its materials cost and figure out if your increase in quality of materials will offset the increasing costs of materials with lower inventory carrying costs (ICCs).

The fifth question asks if a customer and supplier can be in competition. This model has this built into it. The manufacturer and wholesaler are in direct competition with two retailers. Both of them could play around with different ways to try and gain more market share with this model by changing different variables such as costs of goods sold (COGS) or ICCs.

The sixth question asks if a long-term partner can increase efficiency and effectiveness in the supply chain. This question is harder to answer because all entities are treated equal in the supply chain. The way that one can show this is by having some entities having better forecasts, and, therefore lower costs. We would assume that the longer the relationship, the better it is and the more information sharing that would take place. This could result in increased efficiencies, effectiveness, and decreased costs.

The seventh question asks if trust is important in a supply chain and when is it useful. This is a hard question to quantify because trust is not a real quantitative attribute. One could show this by building in some switching of entities and partners and make this random. This could show the impact of one entity that does not know when the other is going to break the partnership and discover that what the extra costs that they incur. This also could be a question of product reliability and an increase of ICCs. One could build some random distribution here, those with high trust have a small distribution, and those with little trust have a large distribution with a high degree of variability.

The eighth question asks if better forecasting by itself would aide in demand management. The model is primarily based on this question and the answer tends to be no. The key to this answer would have to be that to get better forecasting one needs to have a high degree of information sharing between entities. Better forecasting helps aide in demand management but other factors also need to be considered.

The ninth question asks what factors would help with demand management. This model can help us with this question but it cannot directly answer it for us. One can look at the costs that are involved with demand management and see where the costs are minimized. One may have to build certain things into the model to answer direct questions about certain other factors.

Question 10 asks what could be done to minimize the bull whip effect. Again, this model cannot directly answer the question but one can change different variables to try and see what works the best. For example, one could test better forecasting and see if they decreases your inventory and stock outs. Or one could try building in some lead time to see if it can offset some of the demand management issues. This model does a good job of showing bull whip effect but it has trouble trying to resolve it.

Question 11 asks if an entity can do well with only looking at the customer relationship and neglecting the supplier relationship. This could be shown through some better information sharing coming from the front and then not continuing going to the back of the supply chain. This could be done with better forecasts until a certain point and then increase the randomness of the next stage. This could show that if we do not have a solid relationship throughout the supply chain, then we cannot fulfill orders as well.

The last question (Q12) asks about how we respond to long lead times. This question can be studied by changing the transportation cost distribution and the cost involved with that. We could say that we can have a tight distribution with little variability but we have a higher mean percentage of COGS. Then, on the other hand, we could have a wide distribution with a great deal of variability but with a lower mean percentage. If one tested it this way, one could see whether the costs would go down or up and see what kind of relationship we would want with our supplier.

The final conclusion is that this model and models in general have many applications that are less costly than really making the wrong mistake. This model has its flaws and this paper shows that it certainly cannot give us a specific right answer. It can give us an estimation of what might go on in the real world and how we would deal with that problem.

The main implication to point out is that this model can be used as a tool. It can be used in two settings; either an industry setting where top level managers can use it to make large decisions or it can be used in an academic level where teachers can use it to show some of the intricacies of a supply chain. To expand on this point, it provides a decision making framework to whoever is using it. This person can make their assumptions and write them down and then provide support to the results that they get. This model will never be able to replace logic or intuition but it certainly can add to it.

This model is a backward thinking model. To improve this model, we could build in a forward thinking part with forecasts. This would aide in seeing where the product is moving. An addition to this model could be an ARENA simulation and we could actually see where the product is moving in the different months. This model has generalized many costs and made many assumptions. It could be made better if the costs were broken up into their own column and given their own distribution. This would aide in real world management because we know that nothing ever is a sure thing. Overall, the model could be made more robust. At large, it looks like a quite simplistic model. It would be nice to see it has more complexities to relate more with the real world.

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Sameer Kumar is currently a Professor and Qwest Endowed Chair in Global Communications and Technology Management in the College of Business at the University of St. Thomas. Major areas of research interests include optimization concepts applied to various aspects of global supply chain management, information systems, technology management, product and process innovation, and capital investment justifications.

John Kropp has worked in product marketing area in industry after finishing his Bachelor of Business Administration in Marketing from the University of Wisconsin-Eau Claire in 2001. He completed his MBA from the University of St. Thomas in 2005.