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The Poker Chip Game: A Multi-product, Multi-customer, Multi-echelon, Stochastic Supply Chain Network Useful for Teaching the Impacts of Pull versus Push Inventory Policies on Link and Chain Performance

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Abstract

Supply chain management is a topic that many practitioners and students generally find difficult to understand (Boudette, 2005). The authors present a supply chain game that they have found to be an effective tool to increase student interest in and comprehension of supply chain management. The supply chain game literature is briefly reviewed. The poker chip game is discussed with respect to the well-known Beer Game. The poker chip game is a multi-product, multi-customer, multi-echelon, stochastic supply chain game used to teach the problems of traditional push models (economic order quantity/reorder point and Min-Max inventory models) and the elements of the new pull models (Just inTime and Theory of Constraints).

1. Introduction

The consulting firm of Bain and Company (2002) reports that 85% of senior executives surveyed say that improving supply chain performance is a top priority for their firm. However, nearly 50% reported having only basic information or (worse) little or no information on their supply chain while only 7% reported having complete information. It is little wonder then that many companies still attempt to manage their supply chains using such traditional inventory ordering methods as Economic Order Quantity/Reorder Point or Min/Max systems in an attempt to minimize the individual firm's supply chain costs instead of thinking of the supply chain as a system. With respect to systems thinking, Senge (1990) describes two types of complexity-detail complexity and dynamic complexity. Detail complexity is where many variables, definitions, and lists of items are used to describe a system. Since we generally present supply chain concepts as detail complexity, students find the subject boring and difficult to understand. Supply chain structure (objectives, measures, policies, and procedures) is therefore difficult to explain to students who have not worked in a production/distribution environment. In contrast, dynamic complexity describes systems where cause and effect are subtle and where the effects over time of interventions are not obvious. It is difficult to explain the dynamic complexities caused by the delays and interactions in a complex system such as a supply chain system structure. Systems researchers therefore developed and refined the beer game as a teaching aid in explaining dynamic complexities of complex systems. The purpose of this paper is to describe the use of an in-class exercise to illustrate the impact (dynamic complexity) of using traditional push and newer pull production/distribution models in a supply chain from a systems perspective. We examine a multi-product, multi-customer, multi-echelon, stochastic supply chain

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system using the poker chip game. This game is fun to play (and quite realistic) and Socratically teaches some very interesting lessons. The objectives of playing the poker chip game are to illustrate:

1. The impact of each link in a supply chain managing by traditional inventory models (reorder point/ economic order quantity or Min-Max) on other links and on the production/ distribution system.
2. The type of goals, strategies, policies, procedures, and measures required to make a supply chain effective.

The paper is organized as follows. First, we provide a brief review of supply chain games and a more detailed review of systems thinking and the Beer Game. Second, we discuss the Poker Chip game within the context of the course where it is used and introduce the game, the play, and then critique the first round of the poker chip game. Third, we briefly discuss various views of improving supply chain systems, introduce the second game, the play, and then critique the second round of the poker chip game. Fourth, we discuss the effectiveness of the poker chip game as a teaching tool for understanding and managing complex systems.

2. Brief Review of Supply Chain Games and Discussion of Systems Thinking and the Beer Game

In a literature review of two library databases (Academic Source Primer and Engineering Village) for the terms supply chain (22,784 and 7,824 cites, respectively), supply chain management (6,818 and 4,707 cites, respectively), supply chain game (17 and 153, respectively) and supply chain management game (2 and 110, respectively), only a couple of supply chain games were identified. [Excluding game theory cites. Leng and Parlar (2005) reviewed over 130 articles on the use of game theory in supply chains. These game theory articles relate to agency theory, price contracts and spot markets, transfer pricing, etc. For example, a series of research articles (See: Arunachalam, R., and N. M. Sadeh (2005), Wellman, M. P., J. Estelle, S. Singh, Y. Vorobeychik, C. Kiekintveld, V. Soni (2005), and Zhang, D., and K. Zhao (2004)) are written on trading agent competition supply chain management (TAC-SCM).]

Of the supply chain game literature, the citations primarily fall into research and education categories with the majority being research. The MIT Beer Game dominated the literature (over a dozen research cites) in both categories. Other games where a description is provided include the Wood Supply Game (WSG with 2 research cites), and the LEAP Supply Chain game (1 research cite). Other games (ITL and LEGO games) are mentioned briefly in the literature but no descriptions are provided. The WSG and the LEAP games are briefly reviewed then a detailed discussion and critique is provided of the Beer Game as it is the most noted in both the research and education literature.

The WSG was developed by Fjeld (2001) and Haartveit and Fjeld (2002) and is described in a chapter by Moyaux, Chaib-Draa, and D'Amours in Klusch et al (Eds) 2004. The WSG, a board game designed for teaching supply chain dynamics on the wood industry, is based on the Beer Game. The major difference is that WSG has a divergent product structure (a V-structure with two distribution systems (lumber and paper) compared to the Beer Game I-structure which has one) and consists of two flows. One product flow is: a Forest, a Sawmill, a Lumber Wholesaler, a Lumber Retailer and the Lumber Customer. A second serial flow is: a Forest, a Sawmill (the same mill as above), a Paper Wholesaler, a Paper Retailer, and to the Paper Customer. The delays and shipping times are similar to the Beer Game as are ordering and backorder costs. The divergent point in the product flow is introduced to bring more relevance to the supply chain game. Each position is played similar to the Beer Game except the Sawmill receives orders from both the flows, the Lumber Wholesaler and the Paper Wholesaler. These two products come from the same raw materials ordered from the Forest. This board game has created research interest (Moyaux, Chaib-Draa, and D'Amours, 2003; 2004) in the bullwhip effect of this supply chain structure.

Holweg and Bicheno (2002) describe the 'Lean Leap Logistics Game' which was developed primarily to model the British automobile steel industry in an attempt to foster awareness of the bigger picture and collaboration among the links in a production and supply chain. The LEAP game links includes the customer (the vehicle manufacturer), dispatch, final assembly, press shop, blanking operations, service center/slitting and steel mill. Two products are produced,

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one with steady demand and one with variable demand. Playing the game led to insights into scheduler behavior and decision making, prioritizing improvement activities and into supply chain 'Bullwhip' effect. Gimenez, Diaz, and Lorenzo (2004) describe SILOG, a logistic simulator modeling the complexities of global supply chain. The SILOG physical network is similar to Michigan State University LOGA and the University of Minnesota Logistics Simulation I games. SILOG demonstrates the modules of an enterprise resource planning (ERP) system.

In addition to Sterman (1989) classic work on order behavior on the Beer Game, several researchers have used the Beer Game as a basis for conducting research on supply chains. Kimbrough, Wu, and Zhong (2001) and Kimbrough, Zhong, and Wu (2002) model the MIT Beer Game as an electronic supply chain managed by artificial agents to determine whether the agents do better than humans. The primary use of the Beer Game has been to demonstrate the 'Bullwhip Effect' (the growth in order variability along a supply chain). Hieber and Hartel (2003) demonstrate the effects of supply chain optimization strategies and the possible impacts of new strategies in their simulation research. Mason-Jones and Towill (1997) examine the impact of the Burbidge (bullwhip) effect of reducing the order processing time between links in the Beer Game. Raghavan, Srinivasa, Shreshtha, and Rajeev (2004) develop web-enabled versions of the Beer Game for on-line playing by single or multiple players. Steckel, Gupta, and Banerji (2004) construct a simulated supply chain experiment of the Beer Game to examine how changes in order and delivery cycles, availability of shared point-of-sale (POS) information, and the pattern of customer demand affect supply chain efficiency. Riddalls and Bennett (2002, 2003) study the Beer Game using the Smith predictor control system to study system stability.

The beer game was originally developed at the Sloan School of Management, Massachusetts Institute of Technology in the early 1960's and has been used for over four decades to teach systems thinking and system dynamics. Jay Forrester (1958) first discussed a number of the problems of a production/distribution system in his classic article, "Industrial Dynamics: A major breakthrough for decision makers" in the Harvard Business Review. Forrester recommends the use of three types of information to simulate the characteristics of the production/distribution system: organizational structure (the order flows and goods flows), time delays in decisions and actions, and policies on purchasing orders and inventories. Forrester further recommends simulating complex systems to understand system dynamics. The beer game simulates a supply chain using these information types. The beer game network is illustrated in Figure 1.

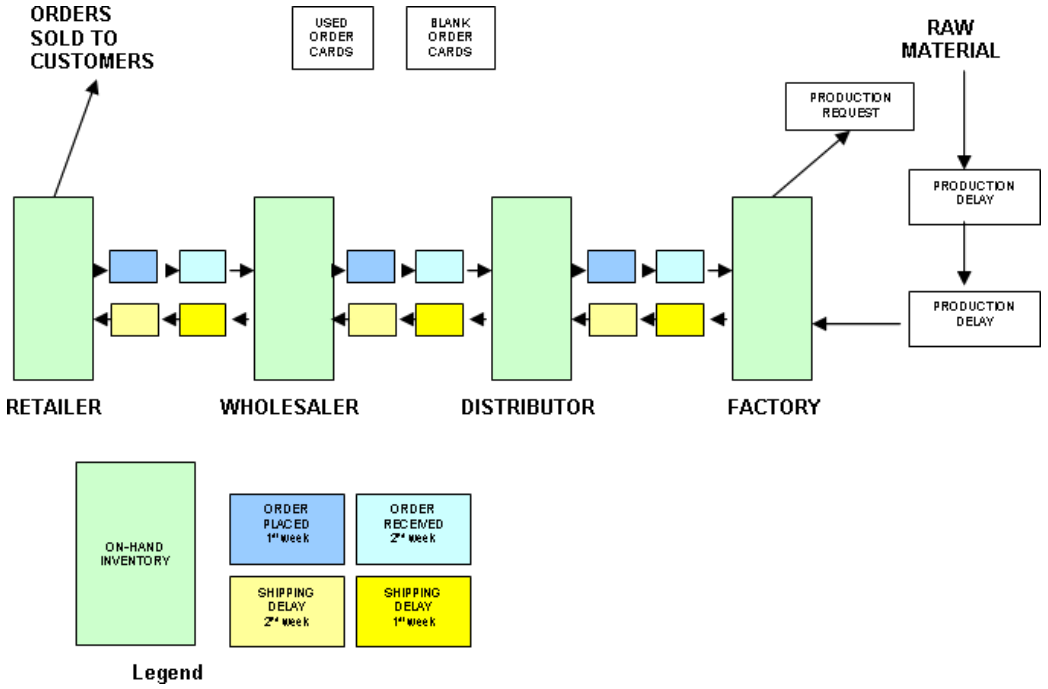


Figure 1: Conceptual Layout of the Beer Game.

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Within the Beer Game framework, Sterman (1989) studied participant behavior and concludes (p. 328) that the complexity of the system "renders calculation of the optimal behavior intractable." Senge (1990, chapter 3) provides three lessons learned from the beer game: 1, structure influences behavior; 2, structure in human systems is subtle; and 3, leverage often comes from new ways of thinking. Senge describes several variations to the beer game in Chapter 3 notes. A causal loop diagram is provided in Figure 2 to illustrate the logic of ordering in the beer game. It is read showing an increase or decrease in each entity. The effect has the same direction as the cause if the sign at the tip of the arrow is a plus (+). The effect has the opposite direction as the cause if the sign at the tip of the arrow is a minus (-). For example, if my customer's incoming orders increase then my inventory decreases which causes my beer shipments to the customer to decrease. As my inventory decreases, my orders placed increases which depletes my supplier's inventory or increases his backlog. He ships my beer after some delay and the beer arrives in my inventory to increase my balance. The causal loop diagram shows the interacting parts of the system. The beer game has been played thousands of times over the past 40 years with basically the same results-an unstable system.

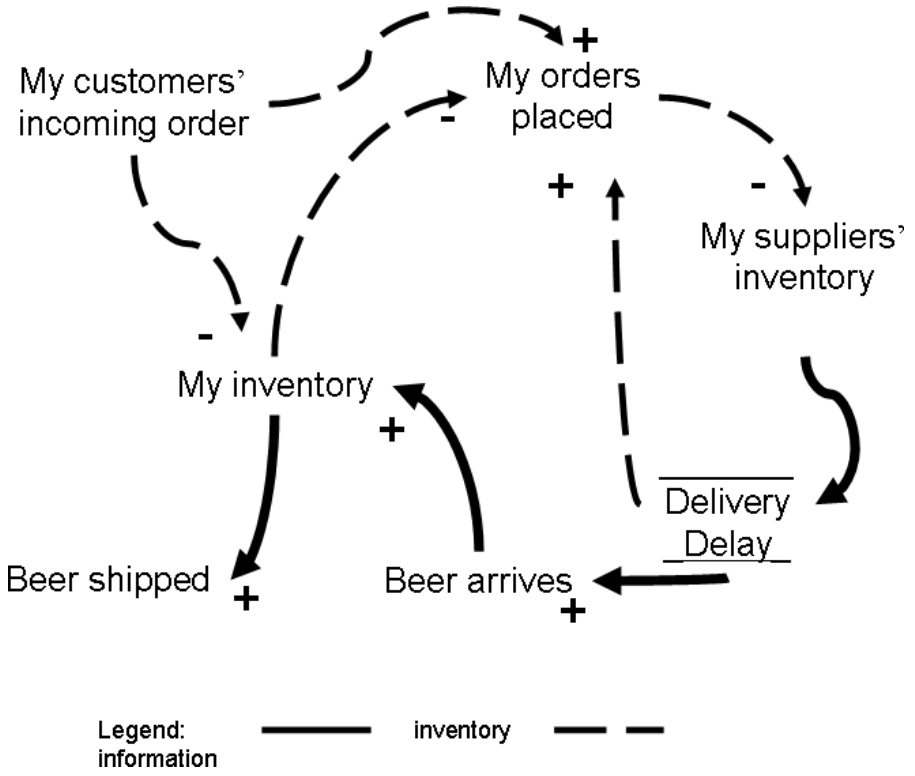


Figure 2: Causal loop diagram for my (any) position of beer game. Modified from Senge (1990, p. 49).

The beer game is an exceptional game to teach systems thinking concepts. One major lesson is that the sum of the local optima is not equal to the global optimum. Each system position tries to minimize its costs and in doing so creates chaos throughout the system. In a second round to the traditional play of the Beer Game, Cox (1999) drives this point home by letting the beer game players work as a team (instead of as individuals) and play the second game where they establish the team objective, measures, and policies and procedures for the system and each link. The team is given only the following information: Lover's beer has a weekly demand of say 10 units, which is highly variable (they do not know the variability which is generally a low of 4 to a high of 16 units per week). Generally, teams change the goal to making money as a chain, change the measure to sales and stockouts at the end of the chain, and use a kanban or a drum-buffer-rope/strategic buffering production/distribution system. Performance is improved significantly. Generally, no stockouts occur at the retailer with a stable amount of inventory in the system.

The criticism of most students after playing both rounds of the beer game is that the game was fun but unrealistic. A company usually has more than one product, more than one customer, uses traditional inventory models (where the link has little discretion in

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ordering) and demand is stochastic. These different system characteristics are believed by the student to reduce or eliminate the improved results shown in the second round of the beer game.

The Beer Game dominant advantage is its simplicity; this same advantage proves to cause several major disadvantages. It has eliminated most of the supply chain characteristics found in reality and the literature. Disadvantages include:

1. The Beer Game uses only one product where most supply chains have many products.
2. The Beer Game instructs the participants to determine what and when to order. Most links in a supply chain use traditional inventory models found in the literature to determine order quantity and timing.
3. The Beer Game is multi-echelon but has only one of each echelon-an I- distribution structure. Most supply chains are more a V- or matrix structure.
4. The Beer Game has deterministic demand with 4 units demanded per week for 5 weeks then 8 units per week afterwards. Most supply chains have stochastic demand.

The other supply chain games have similar disadvantages. For example, the Wood Supply Game (based on the Beer Game) has similar disadvantages: it has only two products with similar demand as the Beer Game; it also instructs the participant to subjectively determine ordering and stocking policies; it has two products with only one divergent point in the network (an improvement over the Beer Game); it has deterministic demand as does the Beer Game. The LEAP Game is primarily a production supply chain with flows from one manufacturer to another. Its network structure is more an A-production structure than a V-distribution structure.

The poker chip game differs from previous games in several ways. It was designed to eliminate these students' criticisms of the Beer Game by creating a more realistic production/distribution system. In both the Wood Supply Game and the LEAP Game, the developers constructed games that featured characteristics of their specific environment (the wood industry and the automotive steel industry). The poker chip game was designed to provide a generic supply chain network to illustrate how traditional inventory policies, measures, and procedures (system structure) create many of today's supply chain problems (smooth demand at the consumer link leading to very lumpy demand at the manufacturer link for multiple products). It is a three-product multi-customer, multi-retailer (six retailers), multi-regional warehouse (two region warehouses), central warehouse and manufacturer (multi-echelon) game with dice being used to create stochastic weekly product demands at the retailer level. Different inventory policies could be used with this framework. For the versions presented here, we chose to use a traditional push inventory system (min-max or reorder point/economic order quantity) for the first round and a newer pull inventory system (just-in-time or theory of constraints) for the second round.

3. The Poker Chip Game-Round 1

3.1. Course Background

The poker chip game is usually played in the last segment of an undergraduate or MBA introductory operations management course. The course is divided into four basic segments. Segment one is an introduction to operations management (including systems thinking), the theory of constraints, the just-in-time (lean), and the total quality management (6s) philosophies. Segment two includes strategy, performance measurement, and planning and control systems. Segment three includes the tools of Industrial Engineering, Theory of Constraints, Just-in-time, Total Quality Management, traditional capacity and materials planning and control, and traditional inventory management. Segment four includes applications in lines, projects, and supply chain systems. In this last segment, gedanken experiments and educational games are usually played to illustrate many of the concepts presented in the course.

In the first class session on finished good inventories and supply chain, the students learn traditional inventory definitions (pull vs. push inventory systems, strategic buffering, kanban, milk runs, min-max, reorder point/economic order quantities, etc.), inventory models, model assumptions, and calculations. They learn to compute inventory order quantities, order points, and safety stocks and to use time-phased order point forms. An exercise based on the given data in Table 1 is assigned to the students where they compute the economic order quantities, reorder points, and

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safety stocks for given levels of service for three products (red, white, and blue chips) for three levels of demand (retailer, region warehouse, and central warehouse).

Table 1: Pertinent data for the poker chip game.

Given:	Echelon		
Retailer	Region Warehouse	Central Warehouse	
Ordering cost	$25	$25	$25
Annual carrying cost	40%	40%	40%
Red and Blue annual demand	175	525	1050
Red and Blue unit cost	$51.50	$51.50	$51.50
White annual demand	350	1050	2100
White unit cost	$25.75	$25.75	$25.75
Calculated:			
Red and Blue EOQ	21 units	36 units	51 units
Red and Blue ROP	17 units	51 units	102 units
White EOQ	42 units	73 units	103 units
White ROP	35 units	105 units	210 units

In the second session, the students play the beer game in two different sets of simulations. In the first set, the game is played as described by Sternam (1989) and Senge (1990), except a time-phased order point form is used to record inventory transactions. A discussion follows based on the game results. The core problems are identified using the Current Reality Tree.

In the second set, the students are given ten minutes to design a supply chain goal, strategy, tactics, procedures and measures. They then play the game. Interestingly most teams invent the JIT solution of using kanbans between chain links or using the TOC solution of drum-buffer-rope/strategic buffering assuming the consumer is the constraint, the buffer is located in retailing and the rope links to either finished goods inventory in manufacturing or to raw materials release in manufacturing. The students gain a good understanding of the value of systems thinking and what dynamic complexity really means.

The Poker Chip Game is then played in sessions three and four. In the third session, the students' solutions to the ROP/EOQ and safety stocks are reviewed. This solution provides the basis for the ROP/EOQs used for the retailers, the region warehouses and the central warehouse for the three products and are shown in Table 1. A theoretical customer service level of 100% (zero stockouts) is computed and used for the poker chip game. After playing the game for several courses and having students complain about not having enough safety stock to prevent stockouts, the authors determined that since the dice are discrete distributions a theoretical calculation of 100% customer service could easily be computed. By using the 100% customer service (0 stockouts) safety stock calculated for each echelon in the chain, the students feel that the results should be excellent. Of course, stockouts still occur at the region and central warehouses.

3.2. Poker Chip Game Background

The purposes of the Poker Chip Distribution Game are: 1) to demonstrate the detrimental impact of using traditional single-item, single-firm inventory theory (e.g. min-max or EOQ/ROP) in a multi-item, multi-echelon production/ distribution system (this is round 1); and 2) to have students derive a logically sound production/distribution system for a multi-item, multi-echelon production/ distribution environment using theory of constraints (TOC) and just-in-time (JIT). The concepts of strategic buffering and mixed model scheduling provide the foundation for developing the new inventory management system (this is round 2).

The structure of the supply chain used in this game is as shown in Figure 3. There are six retailers, two region warehouses, one central warehouse, and one factory producing three products - red, blue, and white chips. Each of the two region warehouses services three retailers, and is, in turn, serviced by the central warehouse. The demand for the products varies at the retail level. This variation is accomplished by a toss of a six-sided die for the red and blue products and the toss of two six-sided dice for the white product. Hence we know that demand will range from 1-6 for the red and blue products (a uniform distribution averaging 3.5 units per week each) and 2-12 for the white product (approximately a normal curve averaging 7 units per week). There is a one-week delay between order

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placement by a downstream firm and order receipt by the upstream firm. Additionally, there is a one-week transportation delay between order shipping at the upstream firm and order receipt at the downstream firm.

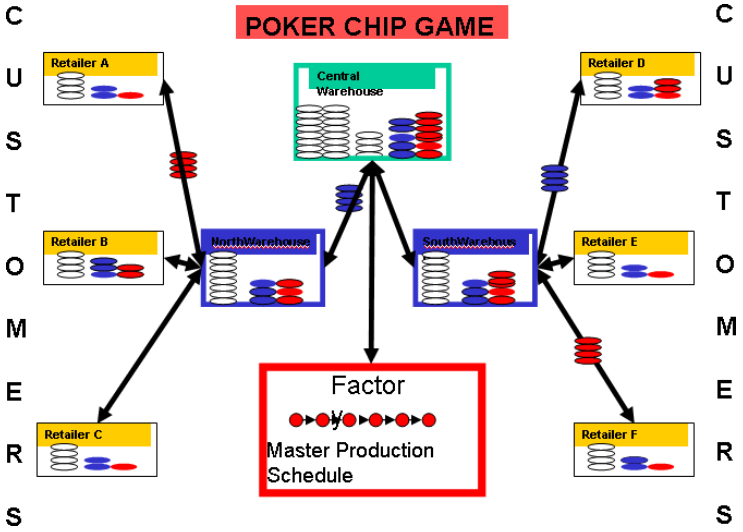


Figure 3: Conceptual layout of the poker chip game.

3.3. Round 1 Description

Given unit costs, ordering costs, carrying cost percentage, average annual demand, and lead times, the students calculate the EOQ and ROP for each of the three products at each echelon of the supply chain. These data are summarized in Table 1. Each retailer, region warehouse, and central warehouse location is seeded with varying amounts of inventory (not the maximum) to assure that all orders in an echelon are not placed simultaneously. For instance, one retailer on each side might be given the maximum amount of red, 2/3 of the maximum amount of blue, and 1/2 the maximum amount of white whereas another retailer would be given the maximum amount of blue and the third given the maximum amount of white. The objective in setting item inventories at each location is to spread the orders out over time with each retailer ordering one product about every two weeks, each region warehouse ordering one product about every week, etc.

3.3.1. Round 1 Play

The worksheet provided in Figure 4 is a time-phased order point (TPOP) form. TPOP (Blackstone and Cox, 2005, p. 116) is defined as "... an approach that uses time periods, thus allowing for lumpy withdrawals instead of average demand. When used in distribution environments, the planned order releases are input to the master schedule dependent demands." The factory planner is given a worksheet with the first column showing the products (red, blue, and white chips) and the remaining columns showing the weekly time periods similar to the TPOP forms. This worksheet shows the workload submitted to the plant by week.

RETAILER A	Week	1	2	3	4	5
Item=Red	Beginning Inventory	33	29	29	26	25
Leadtime=2 wks	+ Inv Rcvd Fm Reg Whse	0	0	0	0	
EOQ=21	= Current Inventory	33	29	29	26	
ROP=17	- Sales (Dice Roll)	4	5	3	1	
MIN=	= Ending Inventory	29	24	26	25	
MAX=	+ Outstanding Orders	0	0	0	0	
	= Total Inventory Balance	29	24	26	25	
	Order Plcd to Reg Whse	0	0	0	0	
	Order To Be Rcvd	0	0	0	0	
Item=Blue	Beginning Inventory	24	19	17	11	28
Leadtime=2 wks	+ Inv Rcvd Fm Reg Whse	0	0	0	21	
EOQ=21	= Current Inventory	24	19	17	32	
ROP=17	- Sales (Dice Roll)	5	2	6	4	
MIN=	= Ending Inventory	19	17	11	28	
MAX=	+ Outstanding Orders	0	0	21	0	
	= Total Inventory Balance	19	17	32	28	
	Order Plcd to Reg Whse	0	21	0	0	
	Order To Be Rcvd	0	0	0	21	
Item=White	Beginning Inventory	44	34	22	58	46
Leadtime=2 wks	+ Inv Rcvd Fm Reg Whse	0	0	42	0	
EOQ=42	= Current Inventory	44	34	64	58	
ROP=35	- Sales (Dice Roll)	10	8	6	12	
MIN=	= Ending Inventory	34	22	58	46	
MAX=	+ Outstanding Orders	0	42	0	0	
	= Total Inventory Balance	34	66	58	46	
	Order Plcd to Reg Whse	42	0	0	0	
	Order To Be Rcvd	0		42	0	

Figure 4: Typical TPOP form showing five weeks of game play for Retailer A.

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This TPOP worksheet is provided for each of the six retailers, each region warehouse, and the central warehouse. The factory planner worksheet is provided to the factory student. Ten students are randomly assigned (we usually just let them choose a chair) to play the various positions in the game. The students record the appropriate ROP/EOQ (or Min-Max) data from Table 1 to the TPOP form and establish the beginning inventory for each of the three products as described above.

For the retailer, the lead time is 2 wks, the EOQ is 21 and the ROP is 17 for red and blue and 2 wks, 42, and 36 for white. The beginning inventories were entered as 33, 24, and 44 at the beginning of week 1 (this retailer A should have this number of chips at her location). A student or the teacher should call cadence for the players-Week 1 receive your incoming inventory, roll your dice, record and ship the units sold, record your inventory balance and place any order (for the EOQ) for items at or below the reorder points. Note the student manages both the physical flows of items and the paperwork of purchasing items and recording inventory transactions.

In week 1, the retailer has 33 units of red beginning inventory, no inventory has arrived from the region warehouse therefore current inventory is 33. Similar calculations are performed for the blue and white products. The retailer A then rolls the dice with sales of 4 units for red, 5 units for blue, and 10 units for white. These values are entered as sales in week 1 for these respective products and subtracted from the current inventory balance to determine the ending inventory for week 1. These quantities are removed from the retailer inventories. The ending inventories for each product are then compared to the ROPs for that product (17, 17, and 35, respectively). If the ending inventory is at or below the ROP then the economic order quantity is ordered (if Min-Max is used then the inventory quantity to bring the inventory to the Max level is ordered) and the amount placed on the Order plcd to Reg Whse in week 1, the Outstanding Orders line in week 2 and the Order to be Rcvd in week 3. These lines are provided on the worksheet to prevent double ordering of products when the reorder point is reached. For our example in Figure 4, neither red nor blue trigger an order but white does. Recall the beginning inventory for white was 44, no orders were received from the region warehouse, the current balance was then 44, sales for the week were 10, generating an ending inventory of 34. No outstanding orders were present therefore the total inventory balance was 34. The total inventory balance is below the ROP of 35 therefore an order for the EOQ of 42 is placed. This amount is entered in week 1 orders placed to region warehouse, week 2 outstanding orders, and week 3 orders received. The outstanding order column insures that a new order is not placed in week 2. The total inventory balance is compared to the ROP when an order is outstanding. The 42 units entered on Orders to be Rcvd in week 3 reminds the retailer that an order should arrive for 42 units therefore when the physical inventories arrive the 42 unit entry (please count the chips) should be received and entered on the Inv. Recvd Frm Reg Whse. The reader should continue across the rows for the three products to ensure she understands how the inventory is managed.

3.3.2. Round 1 Debriefing

The game is usually played for 13 weeks (after about 7 or 8 weeks the students usually understand the problem). It is critically important that the instructor (or a student at the table) call cadence to ensure that everyone is working on the same week. At the end of game play several measures are collected and discussed. Daniel and Rajendran (2004) chose to use total supply chain costs (holding and shortage costs at all installations in the supply chain) as their primary measure. Keeping this in mind the measures used in this game are: Total revenues from sales (to the end-consumer); Average chain inventory investment; total chain carrying costs; total chain ordering costs; number of stock-outs at the retail level; and, inventory turnover of the chain. Team data has to be extrapolated to 26 weeks. Table 2 summarizes the results a typical 26-week game for both the EOQ/ROP and the Min-Max games (traditional push systems).

Table 2: Summary of the results of a typical 26-week game.

Measure	Round 1 (EOQ)	Round 1 (Min-Max)
Retail Sales	$109,231.50	$109,231.50
Average total inventory investment (entire chain)	$59,056.63	$57,371.00
Total carrying costs (entire chain)	$5,733.65	$5570.00
Total ordering costs (entire chain)	$1,875.00	$800.00
Total costs (entire chain)	$66,665.29	$63,741.00
Retail stock-outs	0	0
Total costs as a percent of sales	61.03%	58.35%
Inventory turnover (Sales/Average Inventory)	1.85	1.90

When debriefing the students, it is often found that while no retailer stocked out, stock-outs occasionally occurred at the region and central warehouses. The

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retailers occasionally complain about the service that they are getting from the region warehouses-orders are shipped short (if rationing occurs) or shipped late (if a first-come, first-served priority scheme is used). The region warehouses complain about stocking-out at their level due to poor service from the central warehouse and about the retailers ordering huge quantities and that these orders seem to hit them infrequently (on average once every six weeks for each product). The central warehouse complains that it experiences stock-outs due to poor service from the factory and that the region warehouses seem to order infrequently and in large quantities (several weeks of demand for each product). The factory complains that the central warehouse orders are large and infrequent causing difficulty in scheduling production. In other words, the bullwhip effect is alive and well. [See Lee, H., Padmanabhan, V., and Whang, S. (1997, 2004), Chandra and Gabis (2005) for a discussion of the bullwhip effect.]

The inter-relationships of these problems are graphically presented in Figure 5 as a current reality tree (CRT). [See Goldratt (1994, chapters 12-16), among others, for a full explanation of this system mapping tool.] The CRT is read simply as an if-then statement-if the base of the arrow, then the tip of the arrow. For example, if 100 Link(s) uses EOQ/ROP model then 104 In EOQ/ROP and Min-Max models, links order infrequently. If 101 Demand for each item at the retailer is variable but steady, then 102 The ROP for each retailer/item is reached in a random order. If 104 In EOQ/ROP and Min-Max models, links order infrequently then 115 Sometimes region warehouses receive few or no orders from retailers for a while. If 101 Demand for each item at the retailer is variable but steady then 117 Sometimes 2 or more retailers reach their EOQ/ROP for the same item simultaneously. If 117 Sometimes 2 or more retailers reach their EOQ/ROP for the same item simultaneously then 116 Sometimes region warehouses receive large orders from several retailers simultaneously.

When one encounters a straight line or ellipse across two arrows in a CRT, it is read as "and"-if the base of one arrow, and the base of the second arrow, then the tips of the arrows. For example, if 104 In EOQ/ROP and Min-Max models, links order infrequently and 102 The ROP for each retailer/item is reached in a random order then 115 Region warehouses receive few or no orders from retailers for a while. If 103 Usually the longer a link waits to place an order, the larger the order must be and 104 In EOQ/ROP and Min-Max models, links order infrequently then 105 Often links must place orders for several weeks of inventory at a time. If 105 Often links must place orders for several weeks of inventory at a time and 117 Sometimes two or more retailers reach their ROP for the same product simultaneously then 116 Sometimes region warehouses receive large orders from several retailers simultaneously. If 100 Link(s) uses EOQ/ROP and 115 Sometimes region warehouses receive few or no orders from retailers for a while and 116 Sometimes region warehouses receive large orders from several retailers simultaneously then 114 The region warehouses receive infrequent but large orders (much greater than actual customer demand) from the retailers (lumpy demand). Notice at the retailer level, the demand is steady but due to lot-sizing (to save setup and carrying costs) the region warehouse faces large and infrequent orders (lumpy demand). The remaining causal linkages are read in a similar manner. Note at the top of the CRT-if 125 Inventory cost rise then (after a delay) 128 EOQs rise. Also, if 123 Links increase their safety stocks in the face of increased uncertainty then (after a delay) 124 ROPs (Mins) increase. Both 124 and 128 independently cause 104 In EOQ/ROP and Min-Max models, links order infrequently. We see from the CRT that the use of EOQ/ROP (or Min-Max) at each link in the supply chain causes infrequent but larger and larger orders to be used throughout the supply chain. This causes chaos in leveling the capacity load of the master schedule and increased expediting to get emergency orders completed and shipped to customers. These actions increase costs and lead time uncertainty. We have a vicious cycle leading to further and further degradation of the supply chain. This diagram is used to show students that the symptomatic problems (stockouts, excess inventory, overtime, layoffs, etc.) they encountered are the result of one system core problem or cause-100 Link(s) uses EOQ/ROP. All of the symptomatic problems encountered (above) can be traced to this cause.

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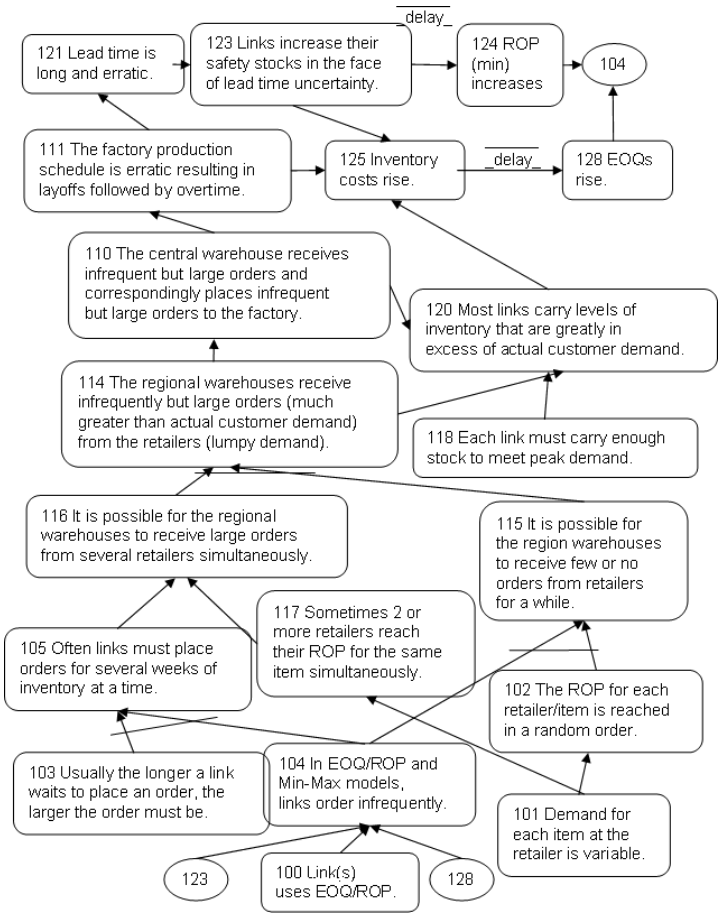


Figure 5: CRT of the problems encountered in Round 1 of the poker chip game.

4. The Poker Chip Game-Round 2

4.1. Designing an Effective Supply Chain System

Numerous researchers have pointed to different problems (measures, information sharing, poor planning, etc.) within a supply chain as being the cause of poor performance; other researchers have offered different recommendations (new measures, supply chain software, vendor managed inventory, etc.) for fixing supply chains. For example, Gunasekaran, *et al.* (2004) call for the design of a set of measures to evaluate supply chain performance observing that the role of such measures "in the success of organizations cannot be overstated." Chan and Qi (2003) echo this sentiment. Robson (2004) suggests that a "single, unified measurement approach" is required to improve SCM performance. The calls for supply chain measures, particularly a unified approach, require that organizations within the supply chain share a considerable amount of information. Fu and Piplani (2004) found that shared information in a two-echelon supply chain leads to better chain performance in terms of stabilizing inventory and increasing service level compared with not sharing information. Lockamy and McCormack (2004) examine the Supply Chain Council's Supply-Chain Operations Reference (SCOR) model and found that sharing information is required, in varying degrees, to realize the benefits of its use. Fiala (2005) found that sharing information, particularly that of actual customer demand, has a mitigating impact on the bullwhip effect[(1)]. Kulp, *et. al* (2004) made a similar observation, noting that collaborative planning is "directly and positively related to manufacturer margins." Senge (1990, p. 104) warns "Beware the symptomatic solution. Solutions that address only the symptoms of a prob-

(1) Sharing customer demand does little to improve supply chain performance when the links in the chain use their own lotsizing calculations and various links offer discounts for volume purchases. For example, super market chains have collected daily sales by bar code scanners for years with little improvement in bottom line results. It is far better to persuade the links to pass consumer demand and lotsizing rules through the system. The better rule is to "Report demand daily and order frequently".

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lem, not fundamental causes, tend to have short-term benefits at best. In the long term, the problem resurfaces and there is increased pressure for symptomatic response."

What most researchers do not recognize is that a systems approach is needed to study and analyze supply chains. Goldratt takes a systems approach where most researchers take a fragmented approach to identifying symptomatic problems and fragmented solutions. In Insights into Distribution and Supply Chains, Goldratt (2003) uses the Current Reality Tree to causally link symptomatic problems within a distribution system to the core problem and conflict. He further provides a holistic solution with a detailed description of how to perform the calculations for each part of the solution and further predicts the benefits of these actions and their synergistic impact on the other links in the supply chain. Briefly his supply chain solution includes:

1. Establish the plant (central) warehouse[(2)].
2. At each place and for each product establish the inventory target according to the formula based on maximum demand during time to replenish.
3. Move to "Order daily-Replenish periodically".
4. Monitor the inventory levels according to the buffer zones.
5. Re-examine policies of make-to-stock versus make-to-order.
6. Establish measures for the system.
7. Establish measures for the links in the chain.

While it is beyond the scope required for presenting this supply chain game, Goldratt (2003) provides a detailed causal analysis of the symptomatic problems and core problem(s) of supply chains, a detailed discussion of the logic of and how to perform each step in the solution list above, and a framework for an implementation plan for these processes.

A Just-in-Time supply chain also provides a systems perspective by using kanbans to replace items sold at retailers, the demand is linked back as a mixed model through the links back to the factory master schedule. These two solutions represent system approaches to managing complex systems. Just-in-time was developed by trial and error over several decades while Theory of Constraints was developed by the thinking process logic tools.

4.2. Round 2 Description

Changing the physical structure of the system in the poker chip game is not permitted (region warehouses and/or the central warehouse can not be eliminated). Changing the lead times is not allowed. Sharing information is allowed but the one week lead time for information processing is still enforced. Lead time between submitting orders among the links is still one week with transportation time between pairs of consecutive links being one week. Students are allowed to change their policies and procedures for ordering and stocking inventory. Some students want to order weekly instead of every two weeks. Others maintain ordering every two weeks but want to synchronize orders from retailers to smooth the work load across the supply chain. Others implement a simple kanban system while others implement a buffer system at retailers and pull replenishment from a centralized plant warehouse using region warehouses primarily as transshipment points. We have provided one proposed solution to the game.

4.2.1. Round 2 Play

In round two of the poker chip game, order transmission and shipping delays remain constant at one week each. However, ordering policies are changed. Retailers are to place a single order for all products (Red, Blue, and White) every two weeks. Care must be taken to stagger the orders from individual retailers. This is accomplished by having North retailers (A, B, and C) order every odd week and South retailers D, E, and F order every even week (Figure 4). The region warehouses are to place an order every two weeks for all products. Orders to the central warehouse are staggered by having the north region warehouse order in even weeks and the south region warehouse order in odd weeks. [This is opposite of the retailers to account for the one week delay in the transmission of retail orders to the region warehouse.] The central ware-

(2) Recognize that in most companies where a central warehouse is used, little inventory is warehoused, the inventory is shipped to region warehouses and the plant manager's income statement treats the transfer as a sale by the plant. Orders from region warehouses disrupt the master schedule frequently.

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house places weekly orders for all products to the factory. Thus configured, the central warehouse and factory receive weekly orders.

4.2.2. Round 2 Debriefing

The students are familiar with the foundations of two pull production/distribution systems (versus push systems used in Round 1). They have studied the Just-in-time philosophy and the tools of Just-in-time (mixed model scheduling, kanbans, etc.). Some students design and implement a JIT pull system linking customer demand through the retailer, to region warehouses, to central warehouse to the plant master schedule. This approach links demand to production and provides a level schedule with the one week delays for order transmission between links.

The students have also studied the TOC thinking tools (to identify system problems, system solutions and implementation plans), the five focusing steps and performance measures, drum-buffer-rope scheduling, and buffer management systems. While not capable of developing the full TOC supply chain solution from this introductory background, as a team they can devise very good solutions and identify how to manage and improve the system using buffer management.

We conducted a simple computer simulation to provide a comparison of the results of the traditional EOQ/ROP system, the Min-Max system, the Just-in-time system and the Theory of Constraints production/distribution system. Both pull systems outperform the traditional push systems. The results of both the JIT and JIT/TOC systems are commendable (table 3). The investment in inventory is down; inventory turnover is up; total costs are reduced; and, the bullwhip effect is gone.

When the students were asked about playing the poker chip game in Round 2 versus Round 1, the students no longer have complaints about the level of service received from their suppliers, and the suppliers no longer complain about massive orders. In reviewing the Current Reality Tree in Figure 5, what has been accomplished is the elimination of the entity, 100 Link(s) use ROP/EOQ from each link (retailers, region warehouses, and central warehouse) in the supply chain with using either the kanban or drum-buffer-rope distribution system. This action destroys the causal logic of the CRT given in Figure 5. The bullwhip effect is not present in either the JIT or JIT/TOC systems. The systems still provide 100% service to the consumer (final customer), and do so with less inventory and a more uniform factory master production schedule (Figure 6).

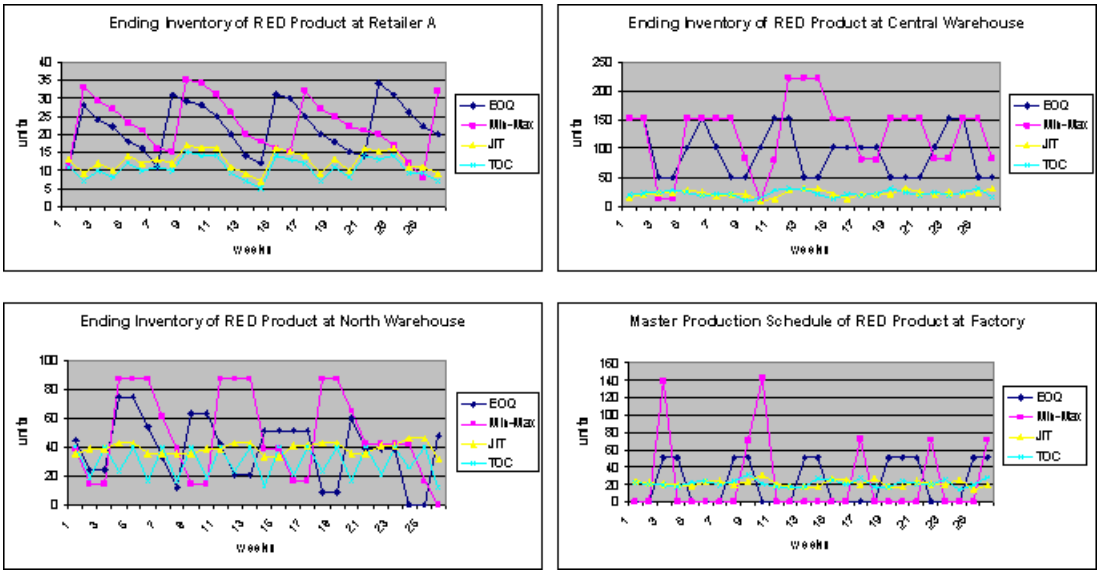


Figure 6: Comparison of inventory levels in the various echelons of the supply chain under different SC management systems.

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5. Summary and Discussion

Games are an excellent methodology for students to understand the dynamic complexity of a system. [Four recent articles (Billington, 2004; Cox and Walker, 2004; Cox and Walker, 2005; Walker, 2004) have used a similar, game-based approach to teach students the basic concepts of production planning and control systems and project management.] Too often teachers lecture and try to explain the dynamics of how a complex system works or teachers provide a series of definitions, lists, etc., to describe a system.

While the beer game is a proven teaching tool to illustrate the problems of complex systems-the structure caused wild swings in both customer orders and inventories across the links of the supply chain. The delays between links, the lack of critical information, the local conflicting goals, costs, and measures, etc. cause actions that harm the individual and system performance. Playing the beer game as a team, with a common goal and system policies, procedures, and measures, results in improved system performance. However, in teaching supply chain management, the beer game still has several shortcomings as previously noted. The beer game network is a simplified I-structure (one product, one customer, one retailer, one wholesaler, one distributor, and one factory). Both the WSG and the LEAP game were designed to model specific structures or networks.

To overcome the shortcomings of these games, we designed the poker chip game using a traditional distribution network (V-shape with one manufacturer, a centralized warehouse, regional warehouses, several retailers and customers) and a multi-product, multi-echelon production/distribution system with multiple customers in a stochastic demand environment. It examines different concepts from the beer game. The poker chip game has proven effective in our classes in demonstrating the problems faced by the links in the supply chain when using Min-Max or EOQ/ROP ordering policies at each location. Coordinating the supply chain through the use of JIT ordering and, further, though the use of TOC concepts greatly reduces the supply chain costs, inventory levels, and the bullwhip effect.

The students have expressed such comments as: "Wow, I never realized how complicated this stuff is - the game really brought home the concepts"; "There were poker chips everywhere the first time we played and we never seemed to have the right product ... things went a lot better the second time"; and, "The second round seemed to be common sense - why isn't everyone doing this?"

One 13-week round of the game takes about one hour to complete. Accordingly, the instructor must allow sufficient class time to play both rounds. By having a break between rounds, the students have the opportunity to reflect on the problems they faced and often can suggest improvements that parallel or duplicate the JIT or JIT/TOC solutions. Table 3 summarizes the lessons learned from playing the poker chip game and Appendix A provides the time-phased forms and examples of the order cards used at each location.

Table 3: Summary of the results of a typical 26-week game.

Measure	Round 2 (JIT)	Round 2 (JIT/TOC)
Retail Sales	$109,231.50	$109,231.50
Average total inventory investment (entire chain)	$33,619.60	$27,077.12
Total carrying costs (entire chain)	$3,264.04	$2,628.85
Total ordering costs (entire chain)	$1950.00	$1950.00
Total costs (entire chain)	$38,833.63	$31,655.96
Retail stock-outs	0	0
Total costs as a percent of sales	35.55%	28.98%
Inventory turnover (Sales/Average Inventory)	3.25	

Table 4: Managing the links versus managing the chain.

The Links-Game 1	A Chain- Game 2
Links are optimized independently according to the goals of the links.	The chain is optimized as a whole according to the goals of the chain.
Problems are attacked by independent links.	Links perceive each other as partners.
Some links benefit, some don't.	The links benefit.
Links view each other as "the problem".	Attacking problems becomes "us against the problem" v. "us against each other".
The links suffer in the long run.	Each link benefits in the long run.
The chain suffers in the long run.	The chain benefits in the long run.

While the several parameters (customer weekly demand, order lead time, shipping lead time, order size, ordering and holding costs, demand per week, safety stock and service levels) of the Poker Chip Game can be changed to suit the needs of the instructor and audience, some disadvantages of the current Poker Chip Game include:

1. It doesn't explicitly show the impact that traditional inventory policies used within a distribution system have on the production capacity of a manufacturer. It only provides a set of production orders placed on manufacturing for each game only.
2. It doesn't consider link and chain profit improvement caused by superior customer service. This

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could be included with the development of selling prices and expenses at each link in the chain.

3. It doesn't include imbalances in demand in a supply chain (retailer A having twice the demand of retailer B). The game was designed as a fairly symmetrical game to be quickly explained to participants.
4. It doesn't consider seasonality, promotions, or new product introduction on stocking in a supply chain. Generally 10-12 weekly periods for each round are the maximum that can be played. One might change the weekly periods to months but this would include changing several other parameters also.
5. It doesn't consider quality problems, transshipment, and stockouts.

Some of these disadvantages can be overcome by developing other versions of the game but most disadvantages are very difficult to address given the time restrictions in playing the game. For example, to address seasonality, enough periods must be played to encounter the high and the low periods of the cycle. Playing this number of periods would be quite time consuming. A computerized version of the game might be used to address some of the nuances of a realistic environment once the game is played manually. Also, playing additional rounds of the game to introduce promotions, new product introduction, defects, transshipment and stockouts in a manual game may not be worth the payoff versus a computerized version of the game to illustrate these points.

In addition to the previous disadvantages of the game, some disadvantages of actually playing the poker chip game are:

1. The initial investment in poker chips-for one game table requires over 1000 poker chips. One game is suited for ten players maximum.
2. It takes approximately 30 minutes to physically set up the game prior to class (dice, TPOP forms, order cards, pencils, seeding inventories at each location, etc.)
3. It takes approximately 30 minutes to pack up the game after class.
4. Numerous insights can be gained by relating content from several chapters in a course to the poker chip game are possible. Advanced preparation and rehearsal is required to cover the points and remain within the designated class time.

Even with these disadvantages, comments on student course evaluations at the end of the term far outweigh these items.

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