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A Distributed Retail Beer Game for Decision Support System

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Abstract

A beer game is a simulation tool for the study of Supply Chain Management (SCM) issues used by the students of MIT. It has been augmented over the time to make it industry ready for decision making and risk management. Apart from smooth information and material flow among the distributed partners excess inventory is still an issue to control. In this paper, an attempt is made to improvise the Beer Game model to a Petri Net model for risk analysis and decision making. A successful simulation of the Petri Net model on efficient redistribution of stock towards inventory management is presented in this paper. The paper also establishes that the analysis is done in polynomial time.

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Keywords: SCM; Beer Game; Inventory; Petri Net;

1. Introduction

The MIT Beer distribution game is a four stage role-play SCM simulation tool [P. Spagnoletti, E. D'Atri, A. D'Atri, 2009]. Factory produces beer and delivers to retailers through wholesaler and distributor without any communication and collaboration among them. Beer game was used to study the SCM behaviors. Single SCM simulation game was improved to multiple games to operate in parallel. The chain that finishes the game at a least cost wins the game. The objective is decision making and risk management without compromising the cost of the inventory. Operating issues like choice of supplier, over stock, delay in delivery, and shrink in market demand are considered by the retailer only on the basis of the order from the first customer. The retailer then sets up a policy to trim down accumulation echelon [Martinez M. T, Fouletier P, Park K. H, 2001]. Issues like high safety stock, inadequate capacity utilization, and inappropriate demand forecasting leads to high value and over inventory at the retailers point. This is known as Bullwhip effect [Hau Lee, V. Padmanabhan, Seungjin Whang, 1997].

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The formalism of the Beer Game proposed in this paper opens up a scope of formal analysis for decision making. The proposed revised model is capable of accessing demand and processing of supply orders in a location independent manner from order to delivery to avoid Bullwhip effect. It has been established that the time complexity of the model to process a SCM order is polynomial. In section two, a brief literature review on the Beer game and Bullwhip effect is presented. In section three, the Beer Game functionality has been explained using an UML diagram. This is followed by a Petri Net (PN) model of the Beer Game to look up the variation in demand. This PN model may be revised dynamically depending on the changes in the operating issues. The revised PN model in section 4, attempts to control the piled stock of the role players with the help of planning servers. In section five, the PN model is revisited using a composite Boolean logic to verify the NP completeness of the proposed model. The paper ends with concluding notes in section six.

2. State of the Literature Survey

The MIT Beer game simulation tool is used to study various situations in a controlled laboratory environment over behavioural hypothesis, bounded rationality, experiential learning, and systems learning [Diana Yan Wu, Elena Katok, 2006] for SCM. The order unevenness and its effects are studied to formulate the strategies of stock holding. The Beer game functions without information sharing and collaboration [Kai Riemer, 2008]. Author wants to share information and collaborate among the chain partners to make the chain live and agile to fill the gap of inventory overstocking. Seasonal data is analyzed in smoothing production data in a retail chain. However, demand variability dominates the smoothing efforts [Cachon, Randall, and Schmidt, 2007]. The magnitude of the Bullwhip effect increases depending on speed of information flow, time for ordering flow of material, and product aggregation [Frank Chen, Zip Drezner, Jennifer K. Ryan, 2000]. The results of the study show that the bullwhip effects are found reducing but not eliminated in a centralized demand environment. In order to control the Bullwhip effect in manufacturing an H control mechanism is proposed [H F Guo, J W Xu, 2008]. Two different inventories are maintained, the product inventory is retained with the manufacturer and virtual inventory with the customer. The author claims the production fluctuation and inventory fluctuation of the system can be smoothed and the bull-whip effect will be guarded. A two-tier Supply Chain model is proposed for negotiation between retailer and manufacturer to carry out sales forecast and delivery planning of products [Yan, Xiu-Tian, Jiang, et. al. 2008]. Mixed integer programming (MIP) technique is used to solve the problem. A test problem is discussed with illustration to formulate the strategy. The operational success of the retail network depends on collaboration but suffers from Bullwhip effect. Poor ordering mechanism sometimes enlarge the demand variance for upstream suppliers which leads to inefficiencies in the entire chain [Roman Schmidt, 2009]. The performance of a supply chain may be improved by aggregating order data through information sharing strategies. Time and again it prompts that the trouble initiates through fundamental thinking than organisations and policy. Our aim is to remove the causes for blocking and introduce efficient SCM operation.

3. Beer Game

The MIT beer game is played on a board or on computer, which portrays the production and distribution of beer. The players at each position are free to make decisions. The goal is to maximize profits subject to customer demand and no backlog. Each brewery consists of four sectors: retailer, wholesaler, distributor and factory. One player manages one sector. Cards are used to represent customer demand. In each week, customers place demand order (OP) for beer to the retailer, shipment is done with shipping delay (SD) and inventory is adjusted. The retailer in turn orders beer from the wholesaler, who ships the beer requested out of the wholesaler's inventory with SD. The process repeats in tandem till it reaches the end player at the factory. In case, the stock is not available at any stage, OP needs to be placed to the next player in the supply-chain. This is considered as a backlog [BL]. In a backlog situation, the OP can be met only after supply of beer is received from the next level. This involves some additional cost. At any stage, the stock position may be assessed for each team by using a cost function: e.g., (Cost = Total Inventory x \$0.50 + Total Backlog x \$1). Here, it is assumed that \$0.50 is the carrying cost of inventory and \$1 is the backlog cost, both expressed per case per week. The average team costs are calculated using the cost function and hence to determine the winner. In fig. 1, the Beer Game functionality has been explained using an UML diagram.

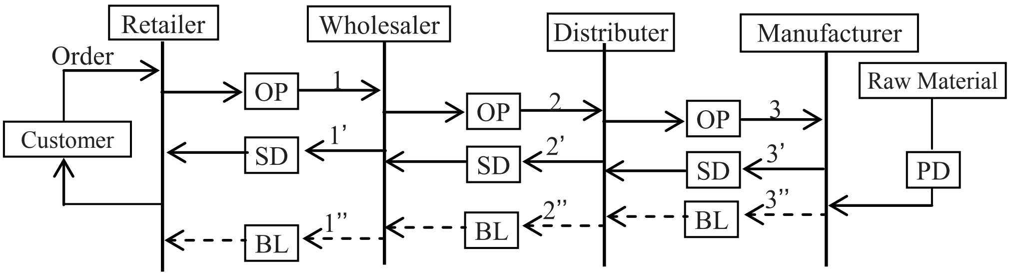

Fig.1. Beer Game Supply Chain UML Diagram

The MIT beer game model needs a rule-set for its deployment in the context of SCM. This has been listed below using the terminologies described above.

If (Inventory) $\geq$ OP, then
SD $\leftarrow$ OP; Inventory $\leftarrow$ Inventory – OP; Backlog $\leftarrow$ 0;
Elseif (Inventory) < OP, then
SD $\leftarrow$ Inventory; Inventory $\leftarrow$ 0; Backlog $\leftarrow$ OP - SD;
Endif.

Case-I: OP = 5, Inventory = 8, SD = 5, Backlog = 0.
Code set will produce SD = 5, Inventory = 8 - 5 = 3 and Backlog = 0.

Case-II: OP = 10, Inventory = 6, Backlog=0.
Code set will produce SD = 6, Inventory = 0 and Backlog = 10 - 6=4.

This backlog (BL) would be replenished when stocks are available from the next player towards the factory. This would reset the Inventory and Backlog values before the next cycle begins.

4. Petri Net Model

A PN is a directed bipartite graph with two types of nodes, places and transitions. PN are formed from finite sets of places, transitions, and Arrows connecting either places to transitions or transitions to places. An ordinary PN structure is a 4 tuples represented as $N = (P, T, D^-, D^+)$, where P is the set of places, T the set of transitions. D^- and D^+ are the input and the output matrices, $D^- = (P \times T) \neq 0$, $D^+ = (T \times P) \neq 0$, $D = [D^+ - D^-]$. The system dynamics are characterized by concurrency, synchronization, mutual exclusion, and conflict, which are typical features of distributed environments. A Generalized stochastic PN (GSPN) holds both immediate and deterministic transition times [M. Ajmone Marsan, 1994].

4.1. Petri Net Model of the Beer Game

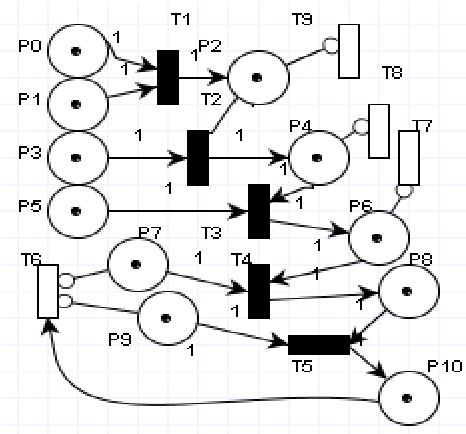

Fig. 2. Beer Game Petri Net Model

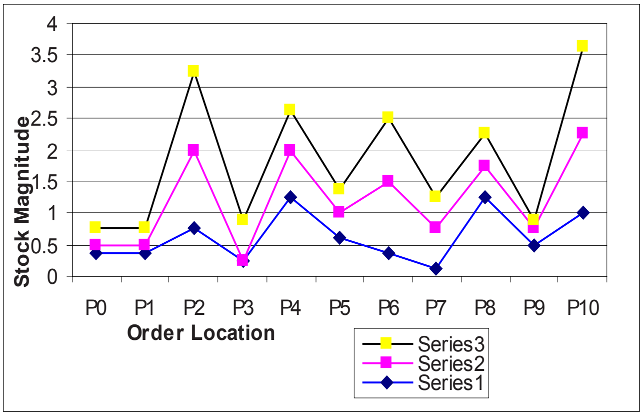

Fig. 3. Beer Game Stock Distribution Chart

Table 1 describes the place holders of fig. 2. Transitions {T1-T5} are immediate transitions. {T6-T9} are timed transitions with unit weights. PN state space analysis results shows the net is bounded, and safe. PIPE2 tool is used to study the performance of the model [Bonet, P., Llado, C. M., Puijaner, R, 2007]. The simulation results are in fig. 3 and table 2. Three different parametric sets have been used in the PIPE2 simulation for the proposed model. These are for firing=100, replication=5; firing=1000, replication=10; and firing=2000, replication=50. This shows that raw material supplier at P0 is holding some stock. Manufacturer (P2), Distributor (P4), Wholesaler (P6), Retailer (P8) Retailer order (P7), and Retailer (P8) are holding huge stock at each stage to cater the customer uneven demand at (P10), which will create backlog in customer demand and such unevenness is the demand variability exists in the game.

Table 1. List of Places, Weights and Transitions of GSPN

Loc.	Function	Trns.	Wt.	Descriptions
P0	Raw mat. Supplier	T1	1	Immediate TT
P1	Manufacturer Plan	T2	1	Immediate TT
P2	Manufacturer Stock	T3	1	Immediate TT
P3	Distributor Order	T4	1	Immediate TT
P4	Distributor Stock	T5	1	Immediate TT
P5	Wholesaler Order	T6	1	Timed TT
P6	Wholesaler Stock	T7	1	Timed TT
P7	Retailer Order	T8	1	Timed TT
P8	Retailer Stock	T9	1	Timed TT
P9	Customer Order			
P10	Customer supply			

Table 2. Petri Net Simulation Results

Loc.	Average Token (100/5)	Average Token (1000/50)	Average Token (2000/100)
P0	0.375	0.125	0.25
P1	0.375	0.125	0.25
P2	0.75	1.25	1.25
P3	0.25	0.5	0.625
P4	1.25	0.75	0.625
P5	0.625	0.375	0.375
P6	0.375	1.125	1
P7	0.125	0.625	0.5
P8	1.25	0.5	0.5
P9	0.5	0.25	0.125
P10	1	1.25	1.375

5. Revised Petri Net Model of the Beer Game

Overstock at Retailer, Wholesaler, Distributor, and at Manufacturer points can be controlled by introducing location independent Parallel Product Plan Servers at P16, P17, and P18 of fig. 4. After process inception all subsequent orders should route through the planned servers. This will exterminate communication and collaboration among the chain partners. Process delays will exist but over stock will be eliminated. PN classification results show the net is Extended Free Choice Simple Net. State space analysis shows the net is bounded and safe. Assuming the reachability, we have conducted a simulation using 3 sets of parameters same as table 2 and presented in table 3. The simulation result is presented in fig. 5. The raw material supplier (P0) is idle and the manufacturer (P1) is holding minimum stock at P2. Distributor is at (P3) having order but holding minimum stock at (P4). The similar situation is for Wholesaler and retailer at P6 and P8 respectively.

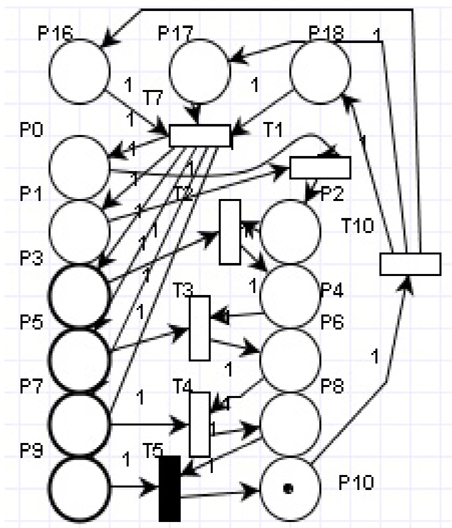

Fig. 4. Revised Petri Net Model of Beer

Table 3. Petri Net Simulation Results

Loc	Avg. Token (100/5)	Avg. Token (1000/50)	Avg. Token (2000/100)
P0	0.15842	0.14386	0.14343
P1	0.15842	0.14386	0.14343
P2	0.13861	0.14286	0.14293
P3	0.29703	0.28671	0.28636
P4	0.13861	0.14286	0.14293
P5	0.43564	0.42957	0.42929
P6	0.13861	0.14286	0.14293
P7	0.57426	0.57243	0.57221
P8	0.13861	0.14286	0.14243
P9	0.71287	0.71528	0.71464
P10	0.13861	0.14186	0.14243

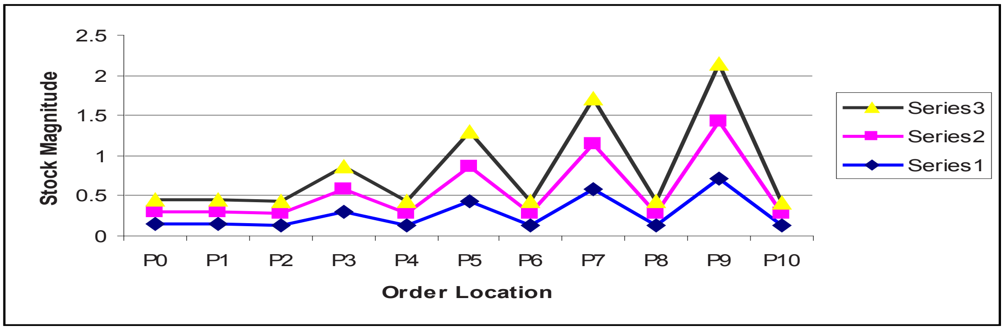

Fig. 5. Revised Beer Game Stock Distribution Chart

Customer order at (P9) is high and the corresponding customer order supply at P10 is enabled. So the system caters higher demand situation without blocking stock and so as the cost of inventory is reduced and the Bullwhip effect is eliminated.

6. NP Completeness of the Revised Net Model

Model checking ensures how the number of states in a system grows with the system components and the corresponding complexity with satisfiability (SAT) problem. A problem is said to be NP if its solution comes from a finite set of possibilities and it takes polynomial time to verify the correctness of a candidate solution. The formula for the circuit in the fig. 6 is representing the Beer game with satisfying assignments for P10 are {P0=1, P1=1, P3=1, P5=1, P7=1 and P9=1}.

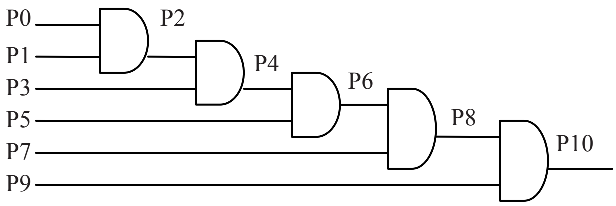

Fig. 6: Circuit satisfiability for Beer Game ordering

The Boolean expression of the game is represented as Q.

$$Q = (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (P6 \wedge P7)) \wedge (P6 \leftrightarrow (P5 \wedge P4)) \wedge (P4 \leftrightarrow (P2 \wedge P3)) \wedge (P2 \leftrightarrow (P0 \wedge P1))$$

$$= (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (P6 \wedge P7)) \wedge (P6 \leftrightarrow (P5 \wedge P4)) \wedge (P4 \leftrightarrow (P2 \wedge P3) \wedge (P2 \leftrightarrow (1 \wedge 1))$$

$$= (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (P6 \wedge P7)) \wedge (P6 \leftrightarrow (P5 \wedge P4)) \wedge (P4 \leftrightarrow (P2 \wedge P3)) \wedge (P2 \leftrightarrow 1) \qquad [P2=1]$$

$$= (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (P6 \wedge P7)) \wedge (P6 \leftrightarrow (P5 \wedge P4)) \wedge (P4 \leftrightarrow (1 \wedge 1)) \qquad [P4=1]$$

$$= (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (P6 \wedge P7)) \wedge (P6 \leftrightarrow (1 \wedge 1)) \qquad [P6=1]$$

$$= (P10 \leftrightarrow (P9 \wedge P8)) \wedge (P8 \leftrightarrow (1 \wedge 1)) = 1 \qquad [P8=1, P10=1]$$

Now Q is a satisfiable Boolean formula SAT [Edmund Clarke, Armin Biere, 2001]. The Truth table for Q can be expressed for six different inputs as combination of (26) =64 alternatives. The above Boolean combinatorial circuit is representing the retail order supply Beer Game. It is composed of AND gates. The size of the Boolean expression is the number of Boolean combinational elements plus the number of wires in the circuit. The wires transmit bits of data carrying a value zero or one until they reach to a gate or terminate. An encoding can be devised to map any given circuit Q to a binary string <Q>, whose length is polynomial in the size of the circuit itself. We can therefore define Circuit-SAT= {(Q): Q is a satisfiable Boolean combinational circuit}. From the theory of polynomial-time algorithms we say that the circuit satisfiability problem is NP complete and the worst case running time complexity on input size n is O(nk) for some constant k [Thomas H. Corman, 2003]. The Beer game has input size n=6 and K= 9 and the time complexity is O (69) =10077696. If we further consider the parallel planned distributed retail servers for subsequent orders then each process will be NP complete. Thus it may be concluded the model is NP complete and solvable in polynomial time.

7. Conclusion

A Petri Net based model for the MIT Beer Game has been proposed in this paper. The proposed PN model improves the decision making process using Beer Game tool. A successful simulation of the proposed model demonstrates this improvement in section 5. Accordingly, the revised proposition of placing global servers helps to decide on releasing redundant stocks held with the players. This significantly contributes to achieve the objective of de-bottlenecking the corresponding blocked stocks and thereby reducing the risk of overstocking. In future, the model may be used more extensively to collect the primary qualitative data and access the effectiveness in diverse scenario for different retail marketing chains. This opens up the scope for formal analysis and efficient handling of the Supply Chain Management issues using Beer Game. It includes an in depth study of SCM in terms of reachability, safeness, boundedness, liveness, concurrency control, and dead lock instances. The paper also establishes that the analysis using the proposed model is done in polynomial time.

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