Modeling the Bullwhip Effect in a Multi-Stage Multi-Tier Retail Network by Generalized Stochastic Petri Nets

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Abstract— **Bullwhip effect (BWE) refers to the accumulation of stock flowing up and down along the supply chain management (SCM). It reduces the operating efficiency of the chain and blocks the operating resources. Some of the common causes of BWE are demand order variations, long lead times, competence defects between supply chain links, lack of communication among links in the chain, etc. There have been efforts to overcome these issues. However, very little work has been reported based on formal representation and analysis of resource flow in the supply chain system. In this work, a novel framework is proposed using Generalized Stochastic Petri-net (GSPN) model towards handling this issue in a distributed scenario. The analysis on the stochastic nets allows identifying the bottlenecks in the supply chain echelons along with customer relationship management (CRM). This has been used to rebuild infrastructure with the end-objective of reducing the BWE.**

Keywords: SCM, BWE, BWE-Index, GSPN, Retail Network, CRM

I. INTRODUCTION

Bullwhip effect (BWE) [37] is one of the trickiest evils for supply management systems. Sustainability for small and medium size enterprises becomes an issue when BWE is moderately high. Prompt delivery of product is more and more a key issue that provides competitive advantage of collaborative process [22]. Business challenges have increased along with the globalization with a view to adopt the changes and advance. A single stage, single tier chain with single customer is the simplest form of SCM, where there is no BWE, e.g., when a government. is a buyer of an item from a single supplier and no other roll players are involved in the process, or in case of a bend market where only manufacturer and buyer exists. However, we are getting to global collaborative retail chains like food retail, health and beauty products, clothing, durable goods, etc, where the success of the chain primarily depends on customer satisfaction, and the different actors play their sole in different, distributed, geographical contexts, e.g., a South African garment manufacturing company may have retailers in America or Europe; orders issued from Europe, raw material is purchased in Korea, the material is dyed in Taiwan, and finished garments is assembled in Thailand.

The main aim of this work is to investigate the reasons of BWE at every stage of Supply Chain (SC) and measure it. Some of the common observations of BWE are communication gap, information twisting, and gaming for destabilizing the chain among the SC partners [20]. This leads to disproportionate inventory, fund blockage, loss of revenue and inept customer service [2]. Prompt decision making, demand order processing and monitoring of delivery logistics, a large distributed multi dimensional real time data repository is necessary [10]. The existing works on BWE points out qualitative aspects, and suggested measures to reduce BWE based on such qualitative analysis. The first quantitative measure of BWE was attempted using BWE index [11]. The present work provides experimental evidence by a significant simulation of the impact of stochastic Petri Nets enhanced with data mart controlling the entire Supply Chain operations in order to reduce the BWE.

Section 2 presents a brief literature survey on related scientific contributions. Section 3 introduces multi stage multi tier retail chain for demand analysis; Subsection 3.1 provides the GSPN model of the retail chain. Section 4 presents a revised GSPN model of the Retail Network. Section 5 describes some warehouse applications. The paper ends with concluding remarks in section 6.

II. LITERATURE SURVEY

A good number of works published in leading journals in last 15 years dealing with BWE are briefly reviewed and analyzed in this section. BWE can be seen as a random measure of performance of a SCM over some specific period of time. SCM performance is measured as a ratio of demand against delivery. If the ratio is greater than unity, the performance is considered to be negative [11], i.e., BWE prevails. The four broad classes of BWE studies Behavioral, Analytical, Industrial, and Dynamic approaches are presented herein.

Behavioral: Uneven customer demand is identified and capacity adjustment to do keeping inventory level unchanged is studied in [5]. Demand forecasting and order lead times are identified as root causes of BWE [6]. US census bureau data is used to observe dependency on the order variance ratio, and demand distortion of BWE [7]. Seasonal BWE is discussed and three forecasting levels are

used to monitor lead time to control BWE [8]. When seasonal variation is larger than demand uncertainty then demand to order variance ratio becomes insignificant for measuring BWE [12]. Rationing, Gaming, and Order Batching are the causes and VMI is used to control the BWE [16]. Amplified demand, data incompleteness and data aggregation are the primary causes of BWE discussed in [19]. Four operational aspects of BWE are demand forecast updating, order batching, price fluctuation, rationing and shortage due to gaming are identified [20]. Five basic functions of SC; plan, source, make, deliver and return are mapped to SCOR model and measure SC performance to monitor BWE [23]. A class room model with four echelon is used to explain the BWE, no formalism suggested [38].

Analytical: Logistic cost minimization techniques are discussed to control the BWE [1]. Transfer function plot is used to monitor the BWE on replenishment rules [15]. A nonlinear optimization model is proposed to reduce BWE by using a four stage echelon system on demand distortion, misperception of feedback, price variation, batch ordering, and strategic decisions. [21]. BWE is measured using the statistical technique ANOVA over information enrichment percentage, time to adjust inventory; time to adjust work in progress; production delay; and sales exponential smoothing {25}. Time delays are major causes of BWE at every stage of SCM. A mixed integer model is used to measure and monitor the BWE [34]. BWE propagation is measured using Fourier Transform [42].

Industrial: Surveyed thirty fast moving consumer goods (FMCG) to emphasize quantitative presence of BWE in SCM. In [18], as many as eleven key design guidelines are suggested to optimize SC. BWE studied over perishable products, customer demand, retailers and wholesalers order cycle varies, and delay in delivery at various touch points occurs. By adjusting the order cycle and delivery delay time the model can be optimized to stabilize the convergence function [45].

Dynamic: BWE at packaging business is studied. A stochastic demand reduction SC model suggested and confirms shorter the lead time, lesser will be the BWE [30]. IT enabled Service Oriented Architecture (SOA) proposes performance measurement (PM) matrices to evaluate SC performance and corresponding BWE effects over multiple channels [32]. An ERP framework is recommended for understanding all types of enterprise applications that maintain the SC and its corresponding BWE at each echelon [39]. A four stage tree structured SC model and a software simulation is designed and suggested the causes of reverse BWE [47].

In a single or a multi echelon SC one culminating point is that either from the behavioral side or from analytical viewpoint or industry specific models or it is IT enabled software driven systems there are some issues in common for occurring the BWE. However, not much holistic approach to control the BWE in a dynamic, multi-aspect decentralized, stochastic and non-linear environment is yet to be explored. It requires efficient modeling using

appropriate tool suitable for distributed environment to embed stochastic behavior of demands in the model itself.

In this work, a high-level net model is proposed analyzed and used for demand driven SC to substantially control the BWE, if not eliminated. We choose Petri Net for modeling due to its strong mathematical formalism. A short review on Petri net and its high level extensions are presented in subsection 2.1.

2.1 HIGH LEVEL REVIEW ON NET MODELS

Petri Nets are directed bipartite graphical notations for modeling of discrete dynamic systems developed by Carl Adam Petri. It is often used as a meta-modeling tool to study and analyze the complexity among the large number of collaborative devices, business processes, distributed communications, and various process simulations. It provides two models: Structural and Behavioral [29].

A Structural Model is a directed graph representing the static part of the system. There are two kinds of nodes, places and transitions, represented by circles and rectangles. Places represent state variables and transitions represent transformers. The net is said to be ordinary when all arc weights are equal to one, i.e. each occurrence of adjacent transitions consumes one token from input to output place. Behavioral Models captures the dynamics of the system behavior using evolution rules for the marking. Markings are represented by tokens. The token at a place is its state value. The values change in adjacent states with the occurrence of transitions. Modeling of some service with simultaneous arrival of tokens to a queue ordinary net can't model such situations: concurrency is not handled.

Extension of ordinary Petri net is therefore needed, where a transition is enabled when its pre-conditions hold but not post-conditions. However, the boundedness is ensured with a maximum token capacity at each place. Similarly, the ordinary net or the elementary net can't model the time dependent system flows or workflows or delayed time transition flows or uncertainties in transitions. In order to model real time systems, various time extensions are proposed through Petri Nets. Time Petri Net model (TPN) is a powerful formalism and conciliation between modeling power and verification complexity. The timed nets are classified as timed place Petri Nets (TPPN) and timed transition Petri Nets (TTPN) depending on whether the timing bounds annotate places or transitions. TPN are useful for performance evaluation and can be implemented using stochastic or constant timing [3]. The stochastic timing is useful to model events where time is important and all the enabled transitions in the model are equally likely to occur. Constant timed Petri Nets are useful to model time dependent events where transitions occur after some predetermined time [43].

Another dimension in high-level net modeling is Color. The Colored Petri Nets (CPN) associate attributes with the individual token. It is commonly used in network protocol simulation and of course, mathematically well-founded. CPN provides a fitting formalism for the description, construction and analysis of distributed and concurrent

systems [27]. Good models depend on data quality, tools and clear thinking. The non-definitive nature of the large retail networks is perfectly suitable for modeling such systems using the Generalized Stochastic Petri Nets (GSPN). The GSPN supports a unique combination of graphical as well as mathematical formalism to model a dynamic system. Rich mathematical foundations permit in-depth analysis of work-flow nets [13].

A generalized SPN (GSPN) supports both immediate and timed transitions. A GSPN with initial markings can be described uniquely by a 6-tuple: GSPN (P, T, I, O, M, λ), where, (P, T, I, O, M) is a marked PN. A marked Petri Net is a 5-tuple composed of Places; P and Transitions; T. The sets P and T are mutually exclusive. I is the Input function, where the value I (p, t) is the number of directed arcs from the place p to the transition t. O is the output function, where the value O(t, p) is the number of arcs from the transition t to the place p. M is the Initial marking of places, where the value M(p) is the number of tokens that are located in the place p. λ = (λ1, λ2, λ3, … , λn) are marking dependent firing rates associated with transitions. Firing delay is an elapse time associated with every transition.
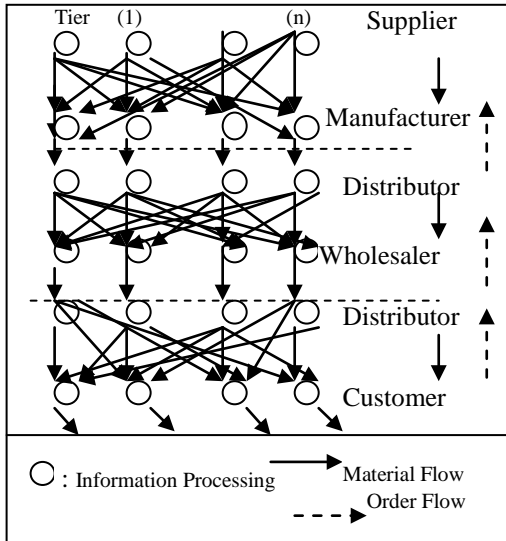

Fig. 1 Multi Stage Multi Tier SC

This delay is a random variable with negative exponential probability density function. For any marking dependent transition ti with associated firing rate λi, can be expressed as λi(mi) and the average firing delay of transition ti in marking mi is [λi (mi)]-1[9].

III. MULTI STAGE MULTI TIER RETAIL CHAIN

There are some frequently used SCM models like SCOR [23]. Epicor a SOA based SCM software, AMT is a SCM ERP application (http://www.softwareadvice.com) may be referred for FlexRFP, which is a web based ERP application.

Figure 1 is the proposed schematic of a multi echelon and multi tier system to deal with multiple products, multiple suppliers in a location independent manner. Managing the inventory in a stochastic natured multi echelon model is a complex process consisting of a set of virtually linked upstream and downstream flows of products, services,

finances and information meeting customer's demand.

The supply-chain echelon of our proposed model is composed of customer, retailer, wholesaler, distributor, manufacturer, and supplier. The multiple tiers and its sequence are horizontally presented from left to right at each echelon. Multi stage is presented vertically. Top down flow indicates material flow and bottom up direction represents information flow, e.g., the Beer game is a four Stage model [38], [28]. However, not much discussion is found in the existing literature on multi-tier issues within one supply chain.

This paper aims to model the schematic of figure 1using a GSPN model and reduce or eliminate Bullwhip effect by analyzing the proposed model. The proposed model is simulated using PIPE 2.5 simulation tool.

3.1. GSPN MODEL OF THE RETAIL CHAIN

Let us now model the multi stage multi tier SC using high level net. The GSPN model as shown in figure 2 symbolizes P0, P1, P2 as suppliers, P3, P4, P5 as manufacturers, P6, P7, P8, P9 as distributors, P10, P11, P12, P13, P14 as wholesalers, P15, P16, P17, P18 as Retailers and P19, P20, P21 as customers in tires. {T0 to T18} are the corresponding timed transitions with rate=1.

The net is designed with a constrain that material flow will be to any of the role players in the succeeding layer and information flow will be to its preceding layer only. There is no restriction of tokens at any of the places. The process is initiated with inhibitor arcs from the initial suppliers P0, P1, P2. The PIPE 2.5 tool, used for the GSPN simulation classifies that the proposed is an extended simple type ordinary net as all arc weights are unity.
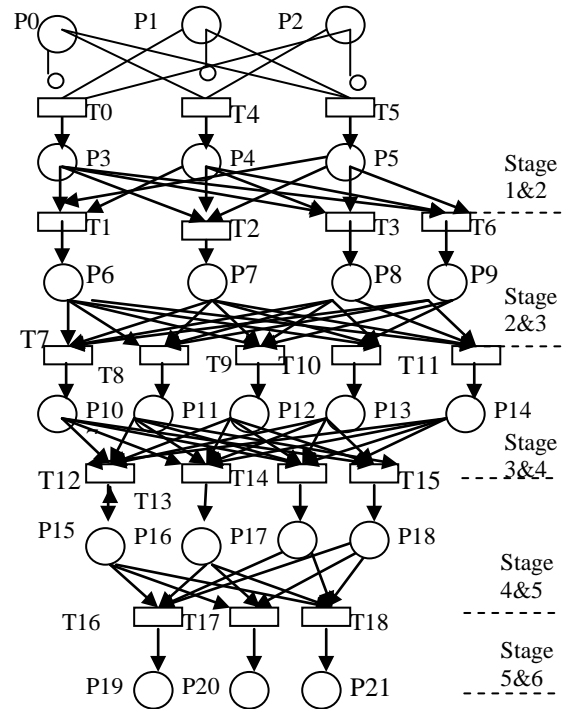

Fig 2: GSPN Model of the Retail Network

The state space analysis pronounces that the GSPN model is not safe. Besides as all the places in the net are not directly connected to each other, so it is not strongly connected. Also there is no live markings and no nonzero safe marking for the proposed model.

Table 1: Token Accumulation after Random Trials

LOC	OB1	OB2	OB3	OB4	Total
P0	6.93	16.83	84.16	94.06	201.98
P1	7.92	17.82	89.11	99.01	213.86
P2	8.91	10.89	54.46	56.44	130.69
Supplier	**23.76**	**45.54**	**227.72**	**249.51**	**546.54**
P3	9.90	12.87	77.23	80.20	80.20
P4	0	5.94	29.70	35.64	35.64
P5	0	7.92	39.60	47.52	47.52
Manufacturer	**9.90**	**26.73**	**146.54**	**163.37**	**346.54**
P6	5.94	9.90	49.50	53.47	53.47
P7	5.94	3.96	19.80	17.82	17.82
P8	1.98	2.97	14.85	15.84	15.84
P9	4.95	6.93	34.65	36.63	36.63
Distributer	**18.81**	**23.76**	**118.81**	**123.76**	**285.15**
P10	4.95	4.95	24.75	24.75	59.41
P11	4.95	4.95	24.75	24.75	59.41
P12	0	1.98	9.90	11.88	23.76
P13	0	1.98	9.90	11.88	23.76
P14	4.95	4.95	9.90	9.90	29.70
Wholesaler	**14.85**	**18.81**	**79.21**	**83.17**	**196.04**
P15	9.90	6.91	19.80	16.81	53.43
P16	3.95	4.94	13.86	14.85	37.60
P17	0	1.98	5.94	7.92	15.84
P18	0	1.98	7.92	9.90	19.80
Retailer	**13.85**	**15.81**	**47.52**	**49.49**	**126.67**
P19	4.95	4.95	4.95	4.95	19.80
P20	4.95	4.95	4.95	4.95	19.80
P21	4.95	3.96	3.96	2.97	15.84
Customer	**14.85**	**13.86**	**13.86**	**12.87**	**55.45**

The GSPN model in figure 2 is not bounded and there can be deadlocks. This is because the number of tokens at any place is a positive integer and each transition gets an output place in the immediate succeeding layer [6], [40].
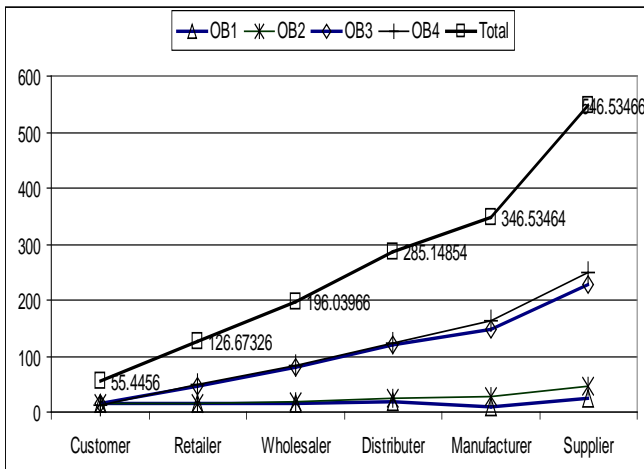

Fig. 3: Simulated Stock Status at different SC Partners

A random number of continuous observations were performed on the GSPN model of figure 2 over four stages OB1 to OB4. These are recorded in Table 1. Figure 3 clearly shows that as the operation progresses, the performance of the system becomes non-linear.

Further, the Bullwhip effect indexes are measured between the pair of communicating role players in the supply chain like distributor and wholesaler, wholesaler and retailer, and retailer and customer. The corresponding bar graphs are presented in figure 4(a) thru 4(c).
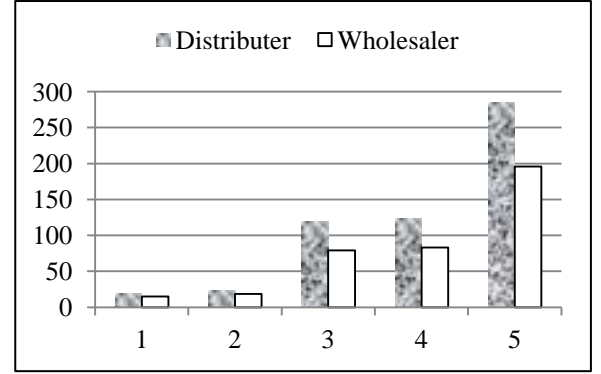

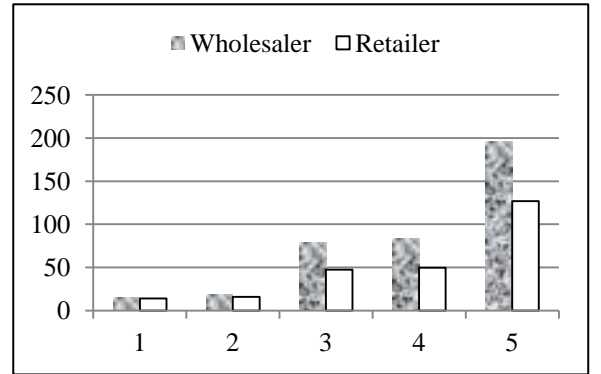Fig. 4a BWE between distributor and wholesaler

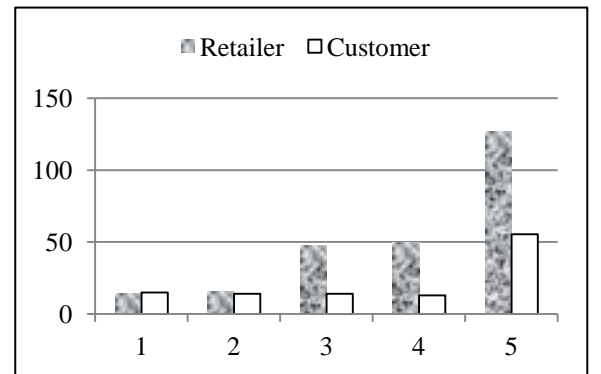Fig. 4b: BWE between Wholesaler and Retailer

Fig. 4c: BWE between Retailer and Customer

The fact that the BWE index is greater than 1 shows the presence of BWE in the system. Our objective is to model the system in such a way that the BWE should be minimum without affecting the customer's interest. Hence the model demands some major revisions. The revised model is presented in section IV.

IV. THE REVISED GSPN MODEL

T: Time; I: Item; L: Location; S: Supplier

Tier I: Supplier, Manufacturer

Tier II: Distributor, Wholesaler

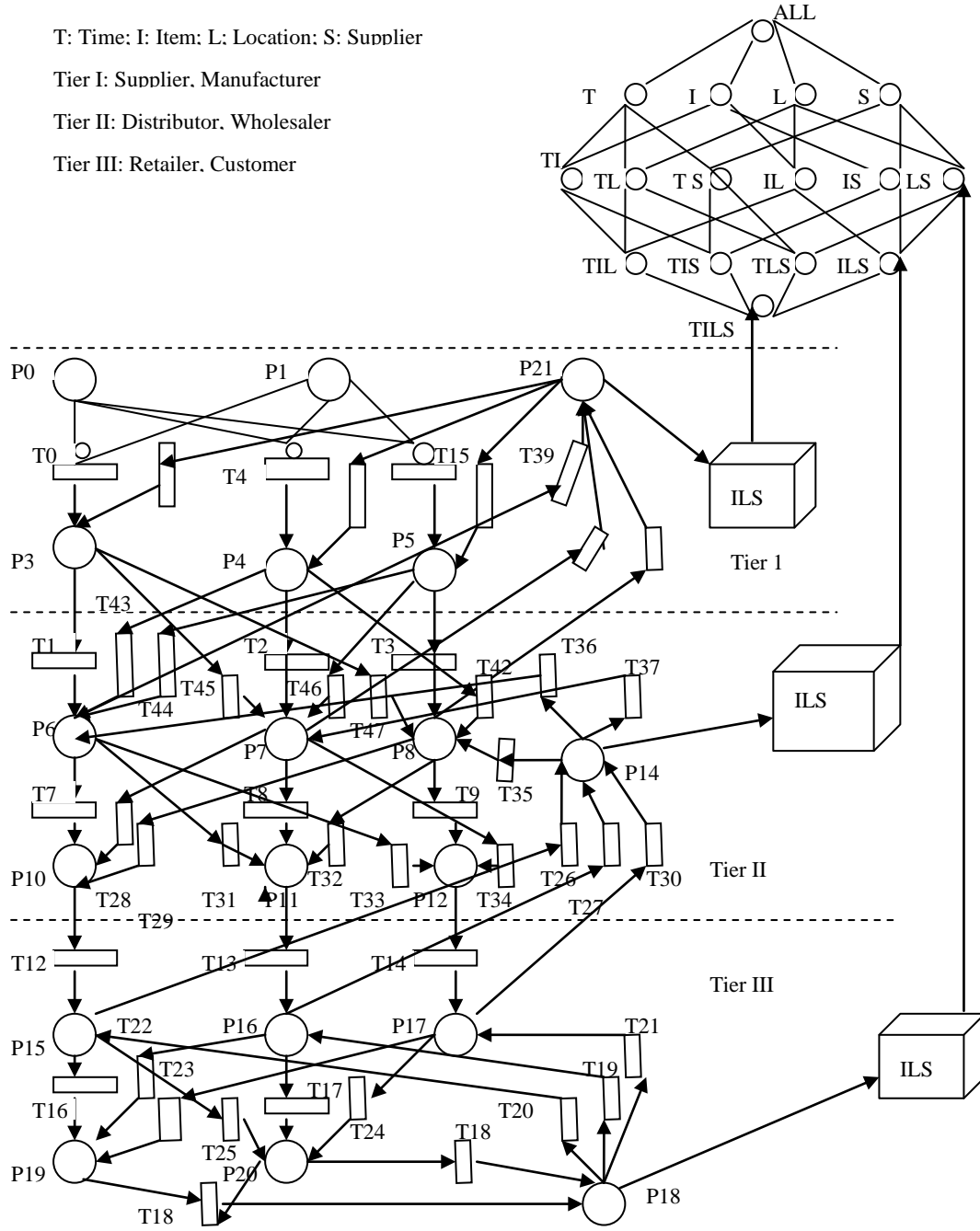Tier III: Retailer, Customer

Fig. 5: Revised GSPN model of Retail Network

In this section we introduce an enhanced GSPN model for Retail Network. Its main objective is to remove the non linearity from the SCM process and control the BWE. In order to revise the process, tier wise separate data marts are planned to cater the retailing need of the particular tier. These data marts finally encompass an enterprise warehouse to check for the global retailing needs.

Data marts are subjective and time variant to the respective tiers provides up-to-date requirement need of the immediate succeeding tier and also update the enterprise warehouse for global monitoring and controlling the BWE. With this view we introduce three data marts each at layer 1,

layer 2 and at layer3.The success of the retail chains depends on customer relationship and managing the issue the presence of data marts and the corresponding warehouse is inevitable.

With this view the revised model of figure 5 holds two suppliers, three manufacturers, distributors, retailers, and two customers separated over three tires. Each tier holds one data mart with the demand information over the concept hierarchy of item, location, and supplier. The data mart at tier 3 is linked with the server at location P18 dealing with customer and retailer, tier 2 data mart is linked with the server at P19 dealing with distributor and wholesaler, tier 1

data mart is linked with the server at P21 dealing with manufacturer and supplier, and finally the operational data marts of tier I to tier III builds the enterprise warehouse with the concept hierarchy time, item, location, and supplier.

Table 2: Token Accumulation in revised model

LOC	OB1	OB2	Total
P0	21.78218	49.50495	71.28713
P1	38.61386	63.36634	101.9802
Supplier	**60.396**	**112.871**	**173.267**
P3	43.56436	65.34653	108.9109
P4	33.66337	53.46535	87.12872
P5	28.71287	72.27723	100.9901
Manufacturer	**105.941**	**191.089**	**297.03**
P6	29.70297	49.50495	79.20792
P7	31.68317	51.48515	83.16832
P8	26.73267	46.53465	73.26732
Distributor	**88.1188**	**147.525**	**235.644**
P10	28.71287	48.51485	77.22772
P11	35.64356	55.44554	91.0891
P12	25.74257	45.54455	71.28712
Wholesaler	**90.099**	**149.505**	**239.604**
P15	21.78218	41.58416	63.36634
P16	39.60396	59.40594	99.0099
P17	27.72277	47.52475	75.24752
Retailer	**89.1089**	**148.515**	**237.624**
P19	47.52475	67.32673	114.8515
P20	41.58416	61.38614	102.9703
Customer	**89.1089**	**128.713**	**217.822**

The tire wise servers and corresponding data marts are used for communication, material flow and the business intelligence applications. In order to control the entire SC operations and customer relationship management (CRM), some retail chain demands a centralized source of information for effective operation of the chain and the warehouse so built will serve that purpose.

The warehouse server can be placed and maintained in the cloud for efficient distributed application. The properties of the net in figure 5 remains same as that of figure 2 analyzed by the tool [6], [40]. A random number of continuous observations were performed on the high level net of figure 5 over two stages OB1 and OB2 and the data is recorded in table 2.

It clearly shows that with the progresses in operation the non linearity of figure 3 is substantially reduced in figure 6. Further we have measured the BWE index between the pair of communicating role players and presented the results in figure 7(a) – 7(c). The bullwhip effect between distributor and wholesaler as well as between Wholesaler and Retailer are eliminated.

These are demonstrated in figure (7a) and in figure (7b) respectively. However, the BWE between the retailer and customer is reduced but could not be completely eliminated as shown in figure (7c). Table 2 reflects that BWE index between other pairs of operators like supplier-manufacturer-distributor or wholesaler-distributor, in most of the cases are less than unity.
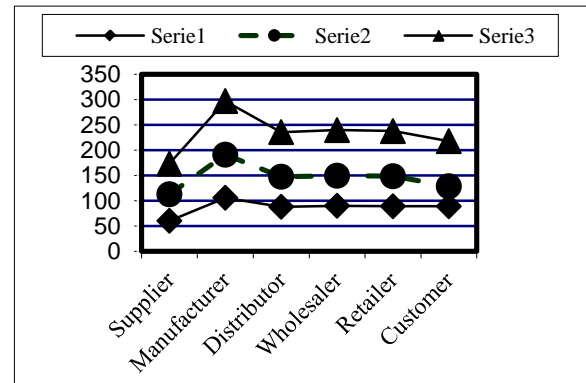

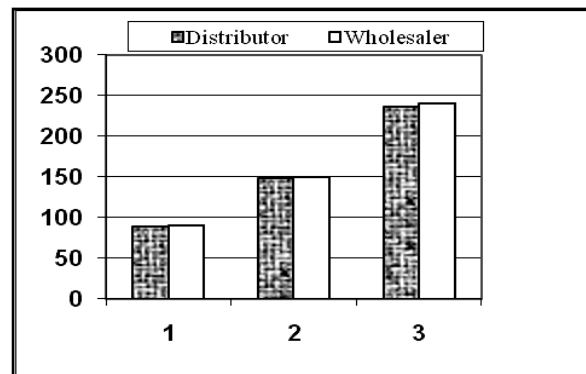Fig. 6: Token Accumulation for the Revised Model

Fig. 7a: Revised BWE for Distributor and Wholesaler
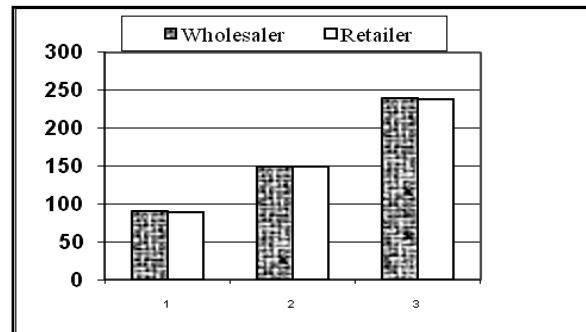

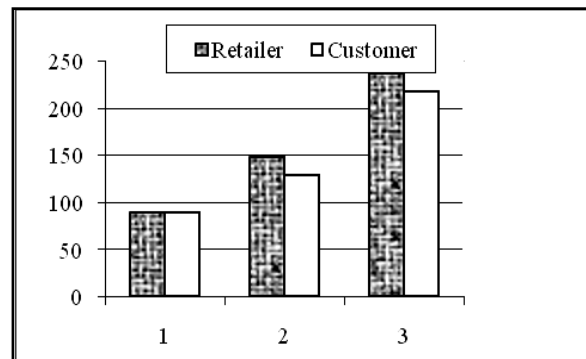Fig. 7b: Revised BWE for Wholesaler and Retailer

Fig. 7c: Revised BWE for Retailer and Customer

The empirical observations were random and the outcomes are tabulated to reflect the facts that BWE has been reduced due to the inclusion of the data mart in the form of a server to share the information and material flow. However, some existence of BWE may be needed on a player to player basis as a part of CRM strategies. In section V, we discuss some of the derived advantages of the warehouse.

V. WAREHOUSE APPLICATIONS

CRM is the key to success of the retailing business. Some of the CRM queries that can be generated from the multi dimensional data cube are:

- Which distribution channels contribute the greatest revenue and gross margin?
- Which customers are most profitable based upon gross margin and revenue?
- How many unique customers are purchasing this year compared to last year?

The first query generates the total amount sold and the second query checks for the location in which maximum sales has taken place. There could be many such queries can be generated by adding customer as one of the dimension of the warehouse, which will be an added overhead to the warehouse. Instead, local data marts can be used to generate more interesting queries for efficient CRM operations. The objective of the lattice of figure 5 is to carry out online analytical processing (OLAP) of the multi echelon SC. The local OLAP operations can be performed from the data marts of the respective tiers. The data warehouse model can be used to find the most valuable customer through Recent access, Frequency, and Monetary value (RFM) for CRM activities defined as a strategy to enable the organization proactive and profitable. It helps the organizations to have right focus and allocate sufficient resources to where is needed [14]. The star schema of the model for query processing is presented in figure 8.

Time Dimension   Location Dimension

Time-Key		Location-Key
Date		Loc-Email
	Time-Key	Loc-Phone
	Location-Key	Loc-Pin
	Supplier-Key	
	Item-Key	
	Unit-Ordered	
	Unit-Delivered	
	Unit-Billed	

Supplier Dimension   Item Dimension

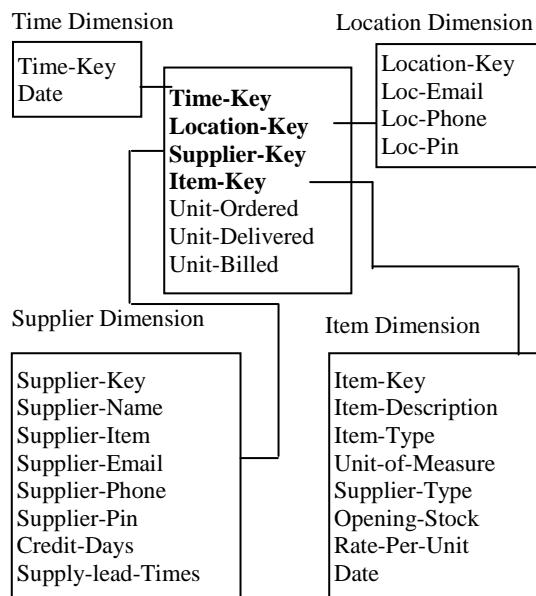| Supplier-Key | | Item-Key |
Supplier-Name		Item-Description
Supplier-Item		Item-Type
Supplier-Email		Unit-of-Measure
Supplier-Phone		Supplier-Type
Supplier-Pin		Opening-Stock
Credit-Days		Rate-Per-Unit
Supply-lead-Times		Date

Fig 8: Star schema of the Lattice of figure 5

VI CONCLUSION

Autonomous forecasting by the Supply Chain players invites BWE. Information visibility and stage wise centralized repositories reduce the BWE. The proposed model is capable of handling demand driven real time activities among the SCM partners. Operational soundness can be pioneered with the augmentation of multi dimensional data cubes and a central warehouse, such components helps in real time CRM applications. Initially a multi echelon, multi-tier retail network has been proposed in section 3 and after a set of simulation run, it is observed that inventory is getting piled along the SC partners, which provokes risks of uncertainty of demand and supply and obsolescence of product. In figure 5, the revised GSPN model is proposed with a demand driven procurement strategy along with stage wise data marts and a central warehouse to avoid the effect of demand variability and real time CRM application.

The proposed virtual multi-tier retail network is collaborative, data intensive and distributed. The large repository will support real time demand analysis, market forecast and strategic decision making. From the operational view point there are only a few global large size retailers who may be interested in maintaining the integrated chain but for the sake of scalability of the proposed model stage wise data marts are also employed for medium and small size retailers. It will not be out of place to mention that ERP based SCM chains can handle transactions and control BWE but beyond transaction management is CRM as SCM starts with the customer and ends with the customer and our proposed model is capable of handling real time CRM operations.

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