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# Designing a Dynamic Buyer-Supplier Coordination Model in Electronic Markets Using Stochastic Petri Nets

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## ABSTRACT

*Functional relationship between supplier and buyer in an open market place leads to investigate the role of both quantifiable and non-quantifiable parameters in coordination mechanism with the aim of achieving higher performance in supply chain activities. Here, we develop a supply chain model and a new agent to analyze and simulate the players' behavior in the network. A cooperative game theory framework is utilized between buyer and supplier in order to increase the supply chain performance. The study is supported by presenting SC Net Optimizer as a tool for implementing the proposed coordination mechanism and evaluates the performance of the chain by simulation using stochastic Petri nets (SPNs). The model provides a more realistic optimization process by taking into consideration the dynamic information flow in an uncertainty environment.*

*Keywords:* *agent; e-SCM; Game theory; SPNs; supply chain coordination*

## INTRODUCTION

Globalization of market competition, reducing gap between products in terms of quality and performance are compelling the researchers to rethink about ways to manage business operations more efficiently and effectively (Sarmah, Acharya, & Goy, 2006). Electronic market has added a new dimension to the investigation of the business relationship. Electronic markets are defined as a network information system that serves as enabling infrastructure for buyers and sellers to exchange information, transact, and perform other related activities (Lancastre & Lages, 2006). The benefits of e-environments motivate the researchers to align and coordinate the business processes and activities of the net members dynamically as well as to improve the overall performance of supply chain strategies.

A supply chain can be viewed as a network with the entities possibly owned by owners in geographically diverse locations. Supply chain management (SCM) benefits from a variety of concepts that were developed in several different disciplines as marketing, information systems, economics, system dynamics, logistics, operational management, and operations research. In the literature, supply chains are usually described as multi-echelon inventory systems. However, most existing models can only describe a restricted class of supply chains with simplifications (Chen, Lionel, Chu, & Labadi, 2005). For instance, most multi-echelon inventory models don't explicitly take account of transportation operations and capacity constraints in supply chain by simply assuming a constant lead time between any two adjacent stocking locations (Tayur, Ganeshan, & Magazine, 1998). These models lack flexibility and generality in describing real-life supply chains. The coordination, however, is quite difficult because of the inherent complexity and uncertainty of the supply chains.

Here, we view the supply chain as a discrete event dynamic system (DEDS) and the research is geared towards providing the mathematical model that can describe material, information, and financial flows of a decentralized supply chain in an integrated way. This provides a tool, which can help industrial practitioners to model, evaluate performance, and optimize operational policies of their supply chains. In the next section, we provide a brief literature review about coordination mechanism.

The rest of this article is organized as follows: In background, the literature on coordination mechanism in both centralized and decentralized supply chain, game theory, agent, and simulation-based approaches in supply chain is reviewed. In the next section, system architecture, detailed mechanisms of the model and supply network strategy are presented. The scenario statement of small supply network section describes the details of implementing the simulation and develops the scenario design. Moreover, some discussions are provided for performance criteria of supply chain. Finally, the conclusions and some guidelines for future research are presented.

## BACKGROUND

### Coordination Mechanism

Several strategies such as credit option, buy/back return policies, quantity flexibility, and commitment of purchase quantity are used to align the business process and activities of diverse members of supply chains in terms of cost, response time, timely supply, and customer service (Sarmah et al., 2006). They particularly investigate SC coordination models that have used quantity discount as a coordination tool under deterministic environment, which has received much attention in production/operation management.

Supply chain coordination is concerned with the development and implementation of such strategies. There is no universal coordination strategy that will be efficient and effective for all supply chains as the performance of coordination strategy in SC characteristics is dependent. Totally, if the coordination is weak or does not exist at all, a conflict of objectives appears among different participants, who try to maximize personal profits. Besides, all the relevant information for some reason can be unreachable to chain participants, or the information can get deformed in non-linear activities of some parts of chain leading to irregular comprehension. All these lead to the bullwhip effect resulting from information disorder within a supply chain. Different chain phases have different calculations of demand quantity, and thus the longer the chain between the retailer and wholesaler the bigger the demand variation.

The advent of new information systems and technologies (IS and IT) such as electronic data interchange (EDI), Internet, intranet, and extranet, in particular, and inter-organizational communication and coordination mechanisms cast unprecedented opportunities for the integration of supply chains (Mahdavi et al., 2007). Thus, dynamic and timely information flow in an uncertain environment play important roles in coordination mechanisms. The interested reader may refer to Pant, Sethi, and Bhandari (2003) to have better understanding of creation and implementation of e-supply chain systems. The authors draw on research in the areas such as Web-based information systems and inter-organizational information systems. Averbakh and Xue (2007) also pointed to supply chain scheduling problems in off-line environment and proposed online environment, with unknown future.

An interesting development in the field of e-SCM is exploiting the benefits offered by coordination mechanism on functional relationship between buyer and supplier. The buyers in an electronic market are faced with supplier selection. Moreover, the presence of multiple suppliers will require the buyer to set-up a competitive mechanism for capacity allocation among the selected suppliers (Hazra & Mahadevan, 2006). In this case, a collaborative strategy that can allocate the benefits of coordination among the supply chain members should be applied to align the objectives of coordination. Such a system is regarded as a decentralized supply chain system.

Three dimensions are introduced by Li and Wang (2007) on which the operational activities of a supply chain can be coordinated in order to maximize system profits. First, order quantities that optimize individual performance are often not able to optimize system performance. There is a vast literature on discount policies that suppliers can use to entice buyers to increase their order quantities so as to improve profits (Wang, 2005). Second, orders can be synchronized to reduce system inventory. If the buyers are coordinated to place orders at the same point in time, the supplier may adopt a lot-for-lot policy and carry no inventory. If the buyers aren't coordinated on the timing of their orders, the supplier inventory replenishment cost is double of that under the lot-for-lot policy (Wang, Chay, & Wu, 2006). Finally, accurate, timely, and easily accessible information can improve decisions. In the context of SCM, a supplier is able to match inventory supply better with demand when information is available on the buyers' inventory status. Although, the benefits of information depends on how it is used.

In the next section, we review the concept of centralized and decentralized supply chains as well as the role of supply chain coordination.

## Centralized / Decentralized Supply Chain

A centralized supply chain system is viewed as an entity that aims to optimize system performance. Various production/inventory policies have been developed to optimize the performance of a centralized supply chain system. There are two main categories in centralized supply nets: (1) deterministic systems, and (2) stochastic systems.

The objective of a deterministic system is to develop a production/inventory policy to minimize system cost. It is typically assumed that demand occurs at a buyer/retailer side continuously at a constant rate. Early studies have focused on the existence and development of optimal policies. However, such policies are usually difficult to implement. A comprehensive review of such models can be seen in Li et al. (2007).

In reality, a stochastic model that specifies demand as a stochastic process is often more accurate than its deterministic counterpart (Zheng, 1992). However, a barrier to the application of a stochastic model is that the optimal policy does not have a simple structure. This implies that appropriate coordination mechanisms are especially necessary (Li et al., 2007). Moreover, information sharing contributes another dimension to coordination when demand is stochastic. A decentralized supply chain differs from a centralized system in that members act independently to optimize their individual performance. Although more and more firms have realized that collaboration with their supply chain partners can significantly improve their profits, the centralization of inventory and production decisions for a decentralized SC is often unrealistic (Li et al., 2007). Therefore, the challenge is to devise coordination mechanisms that are not only able to coordinate the activities but also to align the objectives of independent supply chain members (Chen, Drezner, Ryan, & Simchi-Levi, 2000).

Cheung and Lee (2002) discuss the value of sharing information about the retailers' inventory positions, which could be used to coordinate shipments from the supplier to enjoy economies of scale in shipments, and for eventual unloading of the shipments to retailers to rebalance their stocking positions. In view of previous studies, for a decentralized supply chain system with members belonging to different firms a coordination mechanism should include at least three components: (i) an operational plan to coordinate the decisions and activities of supply chain members, (ii) a structure to share information among the members, and (iii) an incentive scheme to allocate the benefits of coordination so as to entice the cooperation of all members (Li et al., 2007).

Here, we introduce the concept of dynamic information flow in a decentralized supply chain. An agent is designed to analyze and simulate the players' behaviors in an SC network. A cooperative game theory framework is also utilized between the actors in order to increase the supply chain performance.

## Game Theory

Traditional research in operation management focused on providing tools in order to analyze the corresponding problems. The tools relied largely upon dynamic programming and other optimization techniques. In the past several years, SCM has evolved to recognize that a business process consisting of several decentralized firms and operational decisions of these different entities impact one another's profit and thus the profit of the whole SC (Nagarajan

& Sosˇic´, 2008). In a decentralized supply chain where the members belong to two different firms, the method of bargaining and negotiation solution, which is dynamic in nature may result in a better coordination in SC as compared to the static coordination solution in a centralized supply chain. To effectively model and analyze decision-making in such multi-person situation where the outcome depends on the choice made by every party, game theory is a natural choice (Nagarajan et al., 2008). More comprehensive literature review on game theory for supply chain agents can be found in Nagarajan et al. (2008).

There is a broad division of game theory into two approaches: (1) cooperative, and (2) non-cooperative. In a non-cooperative game, the intention of the players is to maximize their individual gain, while in a cooperative game both buyer/seller would consider maximizing the system profit.

Different types of game models have different solution concepts. The bargaining game in a cooperative game theory addresses the problems in which a group of two or more agents are faced with a set of feasible outcomes, any one of which will be the result if it is specified by a unanimous agreement of all participants. In the event that no unanimous agreement is reached, a given disagreement outcome is the result.

In the Stackelberge game, the player who holds a more powerful position is called the leader and the other player who reacts to the leader's decision is called the follower and the solution obtained to this game is the Stackelberg solution (Sarmah et al., 2006). When two players negotiate, it is reasonable to expect that the player with the higher bargaining power receives a larger share of the pie than his weaker counterpart

Our model of supply chain is composed of three main players: (1) supplier/seller, (2) buyer/customer, and (3) control/optimization service agent. The word supplier/seller is used to represent the upstream member in the supply chain who sells the items to the buyers. An agent facilitates the communication between customers and suppliers and allows us to design, simulate, and analyze our collaborative strategies.

## Agent-Based Supply Chain Management

In general, global optimization is a central issue for system modeling approaches. The main interest of managers is to ensure that the overall cost is reduced and operations among various systems are integrated through coordination (Fazel Zarandi et al., 2007). In a decentralized supply chain, where the members belong to two different firms, the method of bargaining and negotiating solution, which is dynamic in nature, may result in a better coordination in SC as compared to the static coordination solution in a centralized supply chain. To effectively model and analyze decision-making in such a multi-person situation, where the outcome depends on the choice made by every party, dynamic information sharing is a natural choice. Lately, Internet-based technologies such as Web services have been emerging. However, despite the merits of these technologies, there exist some limitations in flexibility and dynamic coordination of distributed participants in supply chains. The agent-based systems are alternative technologies for SCM because of certain features such as distribution, collaboration, autonomy, and intelligence (Fox, Barbucean, & Teigen, 2000). According to Wooldridge (2002) and García-Sánchez et al. (2005), agents make the second-generation e-commerce systems possible, in which many aspects of a customer's buying behavior is automated. A comprehensive review of agent-based approaches in supply chain can be found in Parunak (1999).

### Simulation and Petri Nets in Supply Chain Management

Supply chain experts have also taken various complementary perspectives when investigating coordination and information sharing within a supply chain. One useful tool for evaluating the performance and achieving more visibility of complex systems is simulation-based approach. Simulation-based approaches allow dynamic modeling of firm behaviors with varying degrees of constraints and policies as well as show the visibility and efficiency of various strategies and stochastic events. Since contemporary manufacturing enterprises are more strongly coupled in terms of material, information and service flows, there exists a strong urge for process oriented approach to address the issues of integrated modeling and analysis. Petri nets are a powerful tool for modeling and analysis of discrete event systems such as manufacturing systems (Wang, 1998). Since from a high level of abstraction supply chains are also discrete event systems, it is possible to develop a Petri net for modeling and analysis of supply chains (Chen et al., 2005). The advantages of Petri nets have been identified and comparisons have been made with other models by several researchers (Li & Zhou, 2004; Lin, Shan, Liu, Qu, & Ren, 2005), etc. For more details on PN, readers are referred to Jensen (1997).

Although the literature of Petri nets is comprehensive, very little work applied Petri nets to modeling of supply chains. Supply chains are modeled by use of colored Petri nets, where each supply chain entity is modeled by a block with action, resource and control as a subnet of a colored Petri net model (Chen et al., 2005). Supply chains are also modeled using generalized stochastic Petri nets (GSPNs) (Viswanadhm & Raghavan, 2000). PNs have well-developed formalisms and semantics that can model systems with interacting concurrent components. In any net, there are two basic elements: Nodes and links. A PN has two types of nodes: Places and transitions. Places are used to represent resources such as storage spaces or states of processes. Transitions are used to indicate actions or operations. A PN employs directed arcs to connect from places to transitions or vice versa. The dynamic feature of a PN is achieved by tokens, which can represent customer requests. An arbitrary distribution of tokens on the places is called a marking. Each marking corresponds to a state of the modeled system. The execution of the PN is regulated by the number and distributions of tokens and changes the system state.

A Stochastic Petri Net (SPN) consists of (1) a finite set of places, P, (2) a finite set of transitions, T, and (3) input and output arcs connecting places to transitions. However, the transition times must either be deterministic or follow exponential distributions (Lee, Huang, Liu, & Xu, 2006). Since the interval time of requests and inventory replenishments have mostly exponential distributions, we run the simulation through a SPN. In the next section, we introduce a coordination mechanism among buyers and sellers in an e-market. The proposed solution approach combines operation research methodologies and what-if simulation approaches in an agent-based system.

## THE PROPOSED COORDINATION MODEL AND SIMULATION ALGORITHM

Assume that suppliers are located in different nations with a vast network of clearing and forward agents. The integration of these geographically separated supplier locations and the fulfillment of demands of different customer centers are a big challenge. Indeed, consider a family of products that a buyer would like to procure from an electronic market for which there are some pre-qualified suppliers available to supply as per specification. The information for a rough-cut capacity planning will be carried out at different supplier locations based on actual shift time, total actual time available during the planning period, and the average break-down by supplier-agent interaction. We assume the inventory system of supplier with periodic review (*s, S)* policy where the inventory replenishment decisions are based on position. The agent mediates the interaction between buyers and suppliers in an electronic marketplace. It computes the optimum quantities of transactional commodities for both buyer and seller by considering the whole SC profit under game theory framework. It also evaluates the performance of the current system in terms of inventory level and service level for buyers.

### Transaction Agent for Control and Optimization

In agent-based supply chain management section, we described the roles of agents in coordination and information sharing in supply networks. This section presents the functionality of the transaction agent (TA) as well as its architecture in our model. It plays the most important role in our proposed supply chain system as it handles all computational processes used to coordinate and evaluate the network.

### Agent Architecture

The major components and functions of an agent are as follows:

a. Offered prices of buyers, quantitative and qualitative attributes related to customers' evaluation (Table 1).
b. Desired prices of suppliers based on capacity and inventory carrying cost, quantitative and qualitative attributes related to suppliers' perception (Table 1).
c. Preprocessing and building customer profiles and computing the optimum solution with no cooperation in SC net.
d. Preprocessing and building supplier is profile and computing the optimum solution in order to satisfy relevant demand and capacity.
e. Preprocessing, building and applying the model in a cooperative game theory framework.

The overall architecture of agent is presented in Figure 1. The proposed model, after a contact made by the agent, using simulation module and coordination mechanism, determines the optimum quantities of transactional commodities for both buyers and sellers in market with the aim of minimizing the total system cost as well as evaluating the performance of current status. The simulation module increases the clarity of market status and allows both buyers and sellers to evaluate and adopt their strategies in the uncertain environment. The agent then delivers the message back to buyers and sellers. In the next section, we will illustrate the ways of acquiring of rich and accurate profiles in

*Table 1. Quantitative and qualitative attributes corresponding to buyer and seller*

| | Buyer | Seller |
|---|---|---|
| **Quantitative Attribute** | Lead Time, Transportation Cost, … | Sales Volume, Capacity, Product Life Cycle,… |
| **Qualitative Attribute** | Service Level, Aesthetics, Management,… | Customer Satisfaction, Technological Standard, Geographical Benefit,… |

an electronic supply chain system. Managers are required neither to understand the entire coordination mechanism supported by the agent, nor to identify the demand function.

## Analytical Modeling

Here, we discuss the analytical approach used in this article. First, we state the overall procedures and strategy. Then, these procedures are applied to the SC problem. The notations to be used in the proposed model are presented next.

**Notations:**

$b_i$: The $i^{th}$ number of customers/buyers for $i = 1,2,…,m$.

$s_j$: The $j^{th}$ number of suppliers/sellers for $j = 1,2,…,k$.

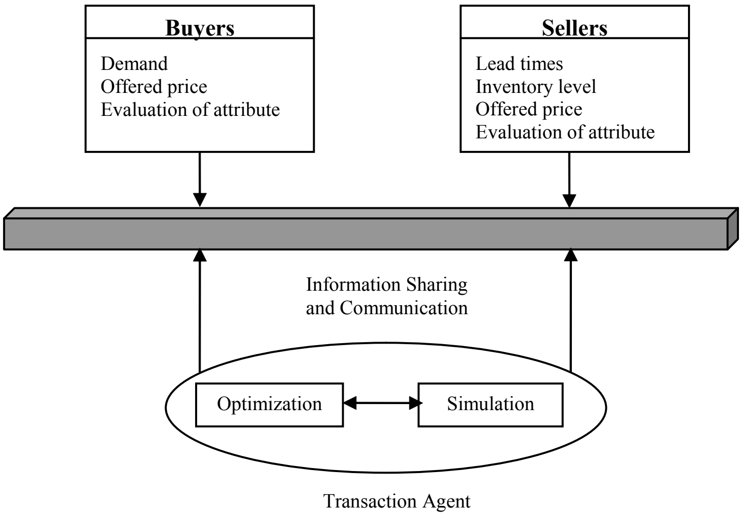
$k_d$: The key attributes of the $d^{th}$ aspect of customers' perception for $d = 1,2,…,n$.

$c^d_{ij}$: The preference value of $i^{th}$ customer on $j^{th}$ supplier for key attribute $d$.

$s^d_{ij}$: The preference value of $j^{th}$ supplier on $i^{th}$ customer for key attribute $d$.

$BP^i_{dr}$:The relative preference of key attri-

*Figure 1. Agent's architecture*



bute $d$ with respect to key attribute $r$ for the $i^{th}$ buyer.

$SP^j_{dr}$: The relative preference of key attribute $d$ with respect to key attribute $r$ for the $j^{th}$ supplier.

$a_{ij}$ : The final priority of $i^{th}$ buyer with respect to $j^{th}$ seller.

$\beta_{ij}$: The final priority of $j^{th}$ seller with respect to $i^{th}$ buyer.

$p^b_{ij}$: The offered price of $i^{th}$ buyer for $j^{th}$ seller.

$p^s_{ij}$: The offered price of $j^{th}$ seller for $i^{th}$ buyer.

$X_{ij}$: The decision variable giving the quantity of commodities which $i^{th}$ buyer buys from $j^{th}$ seller (or equivalently, $j^{th}$ seller sells to $i^{th}$ buyer).

**Buyer's Profile**

The agent receives all the necessary information about the quantitative and qualitative attributes related to each product from $m$ customers electronically. Then the agent decides on $n$ key attributes for all aspects of customers' perceptions. Then, a vector of comprehensive key attribute is created as $CK = \{k_1, k_2, \ldots, k_n\}$. For each key attribute $d$, the agent also designs a customer-key attributes incidence matrix as

$$CKIM^d = \left[ C^d_{ij} \right],$$

where $C^d_{ij}$ represents the preference value of $i^{th}$ customer for $j^{th}$ supplier ( $i = 1,2,\ldots,m$ and $j = 1,2,\ldots,k$) corresponding to key attribute $d$. The scale of preferences is categorized in Figure 2.

To normalize the preferences, we divide each component of the $CKIM^d$ in to the sum of its corresponding column. Each value within the normalized matrix indicates the relative weight a customer associates with a supplier on a special key attribute of a product. We can also calculate the weight of each attribute as a priority of corresponding key attribute for each buyer's view using the following formula:

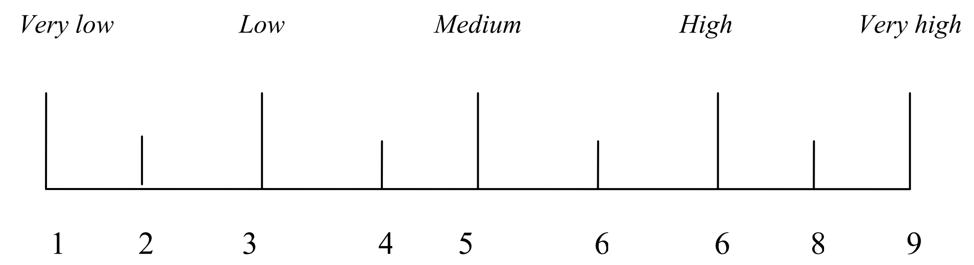
$$W^i = \left[ v^i_d \right]_{n \times 1}, \quad i = 1,\ldots,m, \qquad (1)$$

where,

$$v^i_d = \left( \sum_{r=1}^{n} \left( \frac{BP^i_{dr}}{\sum_{l=1}^{n} BP^i_{lr}} \right) / n \right), \; d = 1,\ldots n. \qquad (2)$$

Note that $v^i_d$ according to (2) represents the normalized weight of key attribute $d$ using the mean of the corresponding relative preferences. With these weights, we can calculate the average weight of $CKIM^d$ matrixes to obtain the buyer profile matrix as below:

*Figure 2. The scale for preferences*



$$MCKIM = \begin{bmatrix} a_{11} & . & . & a_{1k} \\ a_{21} & . & . & a_{2k} \\ . & . & . & . \\ . & . & . & . \\ a_{m1} & . & . & a_{mk} \end{bmatrix}$$

where,

$$a_{ij} = \sum_{d=1}^{n} C_{ij}^{d} W_{d}^{i}.$$

We observe that the value calculated for $a_{ij}$ as above represents the final priority level of $i^{th}$ customer on $j^{th}$ supplier.

It is evident that, based on the association between the elements of the final priority matrix *(MCKIM)* and cost elements, the lower the weight corresponding to a buyer associated with a supplier, the higher the costs will be. Hence, we modify the elements of MCKIM as:

$$\left(MCKIM\right)' = \left[a'_{ij}\right]_{m\times k}$$

so that $a'_{ij} = 1 - a_{ij}$ for all entities of the corresponding matrix. This modification produces a matrix with each component representing the non-desirability of buying from a supplier for an individual buyer.

The agent also constitutes the buyer's price matrix separately as follows:

$$P^{b} = \begin{bmatrix} p_{11}^{b} & . & . & p_{1k}^{b} \\ . & . & . & . \\ . & . & . & . \\ p_{m1}^{b} & . & . & p_{mk}^{b} \end{bmatrix}$$

The prices should be adjusted ultimately to reflect non-quantifiable factors. Thus, in order to obtain the interaction between price and relevant attributes matrices, independent multiplication as a relative matching method can be applied as follows:

$$PA^{b} = [T^{b}_{ij}]$$

where,

$$T_{ij}^{b} = p_{ij}^{b} \times a'_{ij} \qquad \begin{matrix} \forall i = 1,\ldots,m \\ \forall j = 1,\ldots,k. \end{matrix} \tag{3}$$

Therefore, the $PA^{b}$ matrix introduces the buyers' priorities of matching between prices and attributes in an electronic supply chain environment.

Finally, we can use this matrix in the following model to obtain optimal solution for buyers with no cooperation within the SC network:

$$Min\ P^{b}\ (X) = \sum_{i}\sum_{j}(T_{ij}^{b} \times X_{ij}) \tag{4}$$

*s. t.*
*demand and supply are satisfied*

where, $X_{ij}$ is decided to be the quantity of commodity the $i^{th}$ buyer buys from the $j^{th}$ supplier.

**Supplier's Profile**

The agent forwards all the information related to each product in the buyer's profile to all suppliers electronically. Then agent obtains the value of each supplier on key attributes of customers. After obtaining all the information from the supplier's side, a supplier-key attribute incidence matrix is created. The agent the designs the supplier-key attribute incidence matrix as

$SKIM^d = [S^d_{ij}]$, where each $S^d_{ij}$ represents the preference value of the $j^{th}$ supplier on the $i^{th}$ buyer $(j = 1,2,\ldots,k$ and $i = 1,2,\ldots,m)$ corresponding to key attribute $d$. This value indicates the priority level of suppliers on buyers to satisfy the specific attribute of customers.

To normalize the preferences, we divide each component of the $SKIM^d$ in to the sum of its corresponding column. Each value within the normalized indicates the relative weight a customer associates with a supplier on a special key attribute of a product. We can also calculate the weight of each attribute as a priority of corresponding key attribute for each supplier's view using the following formula:

$$W^j = \left[ v_d^j \right]_{n\times 1}, \quad j = 1,\ldots k \qquad (5)$$

*where*

$$v_d^j = \left(\sum_{r=1}^{n} \left(\frac{SP_{dr}^j}{\sum_{l=1}^{n} SP_{lr}^j}\right)/n\right), \quad d=1,\ldots,n \qquad (6)$$

Note that $v^j_d$ according to (6) represents the normalized weight of key attribute $d$ using the mean of its corresponding relative preferences. With these weights we can calculate the weight mean of $SKIM^d$ matrix to obtain the supplier profile matrix as below:

$$MSKIM = \begin{bmatrix} \beta_{11} & . & . & \beta_{1k} \\ \beta_{21} & . & . & \beta_{2k} \\ . & . & . & . \\ . & . & . & . \\ \beta_{m1} & . & . & \beta_{mk} \end{bmatrix}$$

where,

$$\beta_{ij} = \sum_{d=1}^{n} S_{ij}^d W_d^j.$$

We observe that the value calculated for $\beta_{ij}$ as above.

It is evident that, based on the association between the elements of final priority matrix and price elements, the higher the weight corresponding to a supplier associated with a buyer, the higher the revenues will be. Hence, we modify the elements of $MSKIM$ as:

$$(MSKIM)' = \left[ \beta'_{ij} \right]_{m\times k}$$

with $\beta'_{ij} = 1+\beta_{ij}$ for all entities of the corresponding matrix. The agent also constitutes the offered price matrix of $j^{\text{th}}$ seller to $i^{\text{th}}$ buyer as follows:

$$P^s = \begin{bmatrix} p_{11}^s & . & . & p_{1k}^s \\ . & . & . & . \\ . & . & . & . \\ p_{m1}^s & . & . & p_{mk}^s \end{bmatrix}$$

The adjusted prices of suppliers can then be calculated as:

$$PA^s = [T^S_{ij}]$$

where,

$$T_{ij}^S = p_{ij}^s \times \beta'_{ij} \qquad \begin{matrix} \forall i = 1,\ldots,m \\ \forall j = 1,\ldots,k. \end{matrix} \qquad (7)$$

The $PA^s$ matrix introduces the priorities of matching between prices and attributes in an electronic supply chain environment. Using this matrix in the following model, the optimal solution for suppliers with no cooperation within the SC network will be obtained.

$$Max\ P^S(X) = \sum_i \sum_j (T_{ij}^S \times X_{ij}) \quad (8)$$

*s.t.*
*demand and supply are satisfied*

where, $X_{ij}$ is decided to be the quantity of commodity the $j^{th}$ supplier sells to the $i^{th}$ buyer.

### Supply Chain Optimal Solution

In a non-cooperative game, the individual players independently, the intention of each player is to maximize his individual gain. On the other hand, in a cooperative game both buyer and supplier would consider maximizing the system profit subject to each buyer's total annual cost at cooperation being at least equal to the one at non-cooperation. This is due to the reality that the optimal solutions with no cooperation are ideal ones. Thus, in order to make the transaction practical, a compromised combined weighted objective should be optimized. Thus, the objective function for this cooperative game from the general model can be written as:

$$Max\ Z = -\lambda * P^b(X) + (1-\lambda) * P^s(X)$$

*s.t.*

$P^b(X) \geq p*(b)$

$P^s(X) \leq p*(s)$

*and*
*demand and supply are satisfied,*

where *p*(b)* and *p*(s)* represent the optimal values of the buyer and supplier objective functions before cooperation, respectively.

The value of $\lambda$ is set to varies between 0 and 1, depending upon the bargaining power of the suppliers and the buyers. Solving this linear model, the optimal values of transactional commodities for both buyers and sellers in the market will be obtained minimize the total system cost while coordinating among players.

In the next section, the simulation approach interacting with the coordinated optimization process will be described. We intend to show that Petri nets can serve as a simulation tool for studying the bullwhip effect and especially for experimenting on how different replenishment strategies would affect the parameters of certain players and of the entire supply chain.

## Simulation and Performance Evaluation

As described in transaction agent for control and optimization, the agent after the optimization process evaluates the performance of the network by simulation using SPN and sends the results to buyers and suppliers according to their access levels. The input data for simulation would be based on historical data in buyers and suppliers profiles. Here, the profiles are constructed through random numbers generation. The following section describes the simulation algorithm of trading strategy in the network.

### Supply Chain Strategy

In the computational simulation of trading strategy between suppliers and buyers, the simulation algorithm has four main stages: *initialization, identification, adaptation, and updating*. Briefly, initialization starts with opening the market structure and gives the initial valuations of the agent. In the identification stage, each player then infers a model representing how the system is behaving and identifies the partner that will most probably be offered for trading in the next round (i.e., each player selects which plants are likely to be traded). In adaptation, each player computes the set of partners he or she will attempt to buy and sell given the inferred model (i.e., the set of partners most likely to be traded) in order to simplify the coordination problem. Then, at least two of the players trade a plant. Finally, in the updating stage the algorithm updates the state of the model (i.e., it recalculates the capacities owned by each player) and the respective cost structures.

In what follows, we apply our proposed methodology to a small network with two suppliers. Then, *SC Net Optimizer* as a simulation and analysis tool is presented. It supports the data acquisition in supply chain and reports the optimal solution in SC as well as evaluates the performance of the currents status of the market in terms of inventory levels for suppliers and service levels.

## SCENARIO STATEMENT OF SMALL SUPPLY NETWORK

Consider a scenario in which the sellers sell a product (electronic connector). The manufacturer needs three raw materials to produce the connector: Flat, rod, and screw. At the manufacturer's site, rods of aluminum are cut into shafts with a given length, flat is bored and ground. Each finished product is then produced by assembling a shaft, a flat and two screws. The product will be packaged in seller site and delivered to customers (Chen et al., 2005).

Figure 3 shows the Petri net model of the SC. The interpretation of the places and the transitions in the model are given by Table 2 and Table 3, respectively, where the D(T) in Table 2 denotes the mean firing delay (in days) of transition T. In the model, there are three types of flows: Material flow, information flow and financial flow. The material flow is represented by timed transitions $t_1$ and $t_2$ (inventory replenishments of suppliers), $t_3$ (delivery preparation) and their associated places and arcs. The information flow is represented by immediate transitions $t_4$, $t_6$, $t_7$, $t_9$, $t_{11}$, $t_{12}$, and their associated places and arcs. The financial flow is represented by timed transition $t_{10}$ and its associated places and arcs. For the sake of simplicity, we assume that supply net is composed of two different suppliers. We also consider the inventory system of suppliers with the periodic review (*s, S)* policy in which *S* refers to the desired maximum level of inventory and *s* is the maximum inventory in reorder point. That is, the order will be released if the on hand inventory is equal or less than *s*. The inventory carrying cost for each part of the family is deterministic for suppliers and is based on historical data.

We have chosen Java platform to design the application of the simulator called *SC Net Optimizer*. The data storage is done by MYSQL and through a control-filter that rejects faulty measurements. It is assumed that the firing time of buyer's demand follows an exponential distribution with mean value 0.0355 where it can be obtained from historical data. The demands will be filled if there is a sufficient on-hand inventory. Otherwise, the demand will be removed. The inventory policy parameters of two suppliers are taken as ($S_1$=5000, $s_1$=2000) and ($S_2$=5500, $s_2$=2300) arbitrarily. For financial flow, buyers pay to suppliers within a given time period after receiving the finished products. The preference values in buyer and seller profiles are generated randomly in terms of an introduced comparison scale. We run the model under this strategy that buyer has more bargaining power than supplier by taking $\lambda$=0.6 in SC model. Figures 4 and 5 illustrate the layout of related knowledge definition for buyer/supplier profiles and optimal solution.

Due to stochastic nature of the model, multiple replication of simulation over a long time horizon should be performed to obtain a reliable estimation of the performance indices. For the industrial case, the number of replications is taken to be N=25 and the simulation horizon is taken to be $T=T_0+10T_0$ time units with $T_0$=200 (Chen et al., 2005). In this study, we have shown the model with 10 successive iterations for a single period. The final result of simulation for SC optimal solution and remainder stocks diagram for each supplier are given in Figure 6.

## DISCUSSIONS

The buyer company enters its demand and selects the desired comprehensive attributes in order to prioritize the suppliers (Figure 4). Then, the buyer is asked to enter the suggested price for each seller. The agent forwards this information to the seller profile and sellers enter their supplies and own preference values for corresponding attributes (Figure 5). The optimal solutions or weight values can be observed by selecting the menu or hitting the related buttons for both buyers and sellers.

As shown in Figure 4, the optimal solution for buyer 1 in the network, for instance, is to deal with both sellers whereas this is in conflict with sellers' optimal solution. These locally optimal solutions can lead to disturbing to the stability of the network since there is no cooperation among the entities. Thus, a coordination mechanism is required to facilitate the transactional relationship and also build a structure to share the information such that the benefits are allocated to all member of the network. Comparing the reported outcomes of the

*Figure 3. Stochastic petri net model for supply chain*

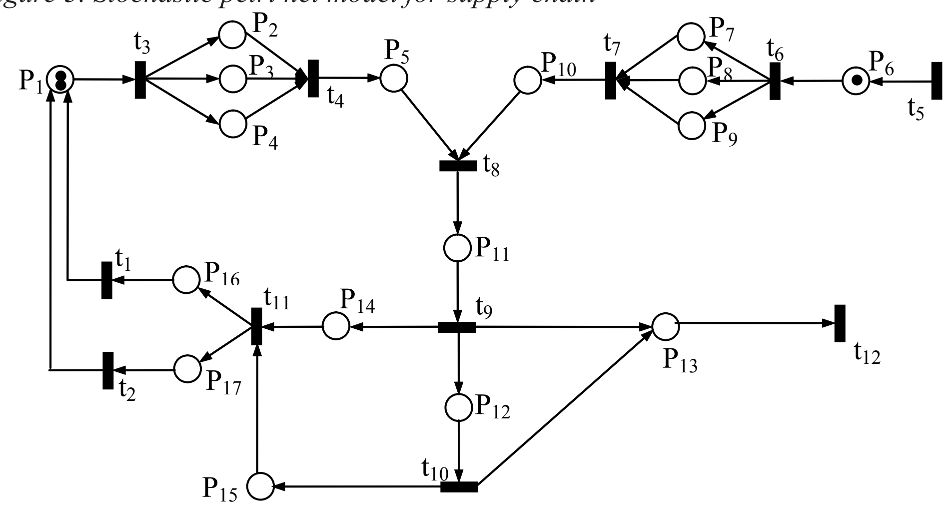


*Table 2. Interpretation of transistions*

| T | Description | D(T) |
|---|---|---|
| t1 | Inventory replenishment of seller 1 | 5 |
| t2 | Inventory replenishment of seller 2 | 2 |
| t3 | Start of delivery preparation | - |
| t4 | Seller profile | - |
| t5 | Demand | 0.0355 |
| t6 | Start of order placement | - |
| t7 | Buyer profile | - |
| t8 | Loading of solutions on input buffer | - |
| t9 | Start of loading information flow | - |
| t10 | Payment from buyer to seller | 1 |
| t11 | Loading sales information for seller | - |
| t12 | Loading sales information for buyer | - |

*Table 3. Interpretation of places*

| | |
|---|---|
| P1 | Record of available inventory of stocks |
| P2 | Record of offered price (seller) |
| P3 | Record of quantitative attributes (seller) |
| P4 | Record of qualitative attributes (seller) |
| P5 | Minimization of corresponding model |
| P6 | Pending customer orders |
| P7 | Record of offered price (buyer) |
| P8 | Record of quantitative attributes (buyer) |
| P9 | Record of qualitative attributes (buyer) |
| P10 | Minimization of corresponding model |
| P11 | Minimization of cooperative model |
| P12 | Final stocks order in delivering preparation |
| P13 | Updated buyers profile in SC network |
| P14 | Updated sellers profile in SC network |
| P15 | Record of financial flows |
| P16 | Record of remainder stocks (seller 1) |
| P17 | Record of remainder stocks (seller 2) |

suggested coordination mechanism (Figure 6) with the individual optimal solutions, clarifies the role of real-time information flow and negotiation results in the profit of the whole supply network. The remaining stock diagrams in SC profile provide opportunities for the suppliers to evaluate their strategies for inventory management.

*Figure 4. User interface for buyer profile in the sc net optimizer*

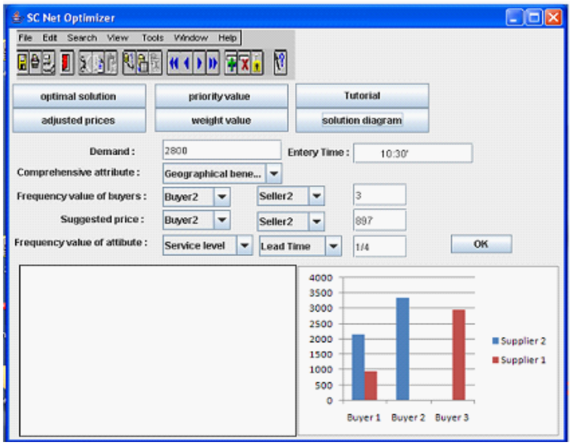



*Figure 5. User interface for seller profile in the sc net optimizer*

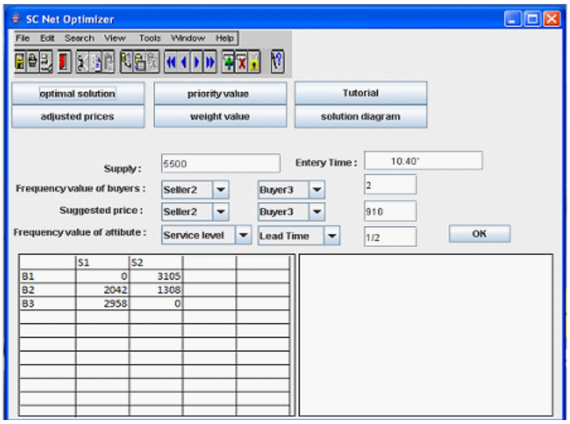
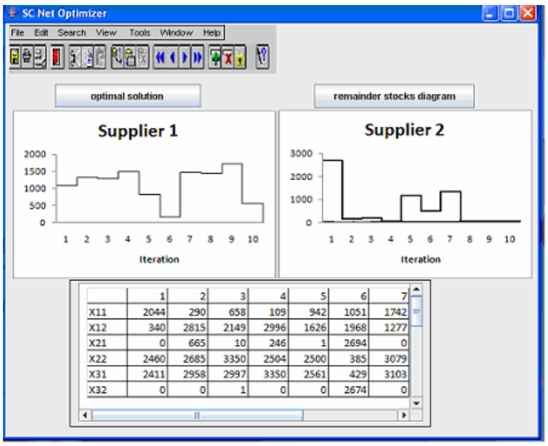



*Figure 6. The SC optimal solution*



Overall, we have shown through the use of a small network that the present approach is a useful tool to solve and evaluate SC network problems. This optimization is centered on the negotiation among buyers and sellers. Clearly, the optimal values of the SC profile will depend on the price matrix in buyer and seller profiles. These are controllable parameters that one encounters in the decision making process while negotiating in a supply chain.

Inventory systems form another important component of supply chains and inventory management plays a key role in SCM. Inventory management addresses two fundamental issues: When a stock should replenish its inventory and how much should be ordered for each replenishment. The performance criteria of the supply chain can include average inventory level and also the service level for each stock, where the service level is defined as the probability that the customer's orders are filled on time. The first criterion is easy to obtain since it corresponds to the average number of tokens in the discrete place representing the stock. For the evaluation of service level, we need to know the total time that the discrete place has no token while the place representing customer orders is not empty in each simulation. Our SC net simulator provides the graphical results for average inventory level and also the visibility of orders for determining inventory policy.

The point estimation of each performance index and the standard error of estimation obtained by the simulation can be calculated. Given the point estimation and the standard error, a confidence interval for each performance index can be calculated for any given level of confidence under the condition of the independence of replications (Chen et al., 2005). A 100(1-$\alpha$)% confidence interval for performance index $\theta$, based on t-distribution, is given as

$$\bar{\theta} - t_{\alpha/2,N-1} S/\sqrt{N} \leq \theta \leq \bar{\theta} + t_{\alpha/2,N-1} S/\sqrt{N}$$

where $\bar{\theta}$ and $S$ are the point estimation and the standard error of the estimation of $\theta$, respectively, $N$ is the number of independent replications, and $t_{\alpha/2,N\text{-}1}$ is the 100(1–$\alpha$/2) percentage point of a t-distribution with $N$-$1$ degrees of freedom.

## CONCLUSION

The advent of Internet-based marketplaces motivate the researchers to investigate the conceptual buyer/supplier coordination models to save the system costs and ultimately improve the performance of the supply chain. A coordination mechanism for decentralized supply chain whereby members are separate economic entities has to include a collaborative strategy to optimize system performance and provide an incentive scheme to distribute the benefits of coordination so as to entice cooperation. Moreover, the coordination of a supply chain also requires that accurate and timely information about members' operational decisions and activities be shared among all in order to reduce uncertainties.

We developed an agent-based framework to facilitate collaboration and information sharing in the environment with high supply and demand uncertainties. Due to the complexities of supply chain systems, we have introduced the concept of dynamic supply chain information flow. An agent is designed to analyze and simulate the players' behaviors in the SC network. Coordination is made to control inventory at different echelons and minimize the total cost of the SC by sharing information. Consequently, optimization can be achieved more effectively and the bullwhip effect is reduced. The basic information is considered in the form of a customer-key attribute incidence matrix to obtain a real-time customer profile. The supplier profile is designed to analyze the possibility of interaction between two main actors in SC, suppliers and buyers. The interaction between the suggested price and comprehensive attributes in each profile is computationally derived to produce a more realistic model. In order to improve the SC performance, these profiles are applied under a cooperative game theory framework to give rise to the SC optimal solutions.

Finally, we defined a scenario to run the proposed model. The study was supported by presenting *SC Net Optimizer* as a tool for implementing the proposed coordination mechanism and evaluating the performance of the chain by simulation using stochastic Petri nets (SPNs). This approach presents a great potential to resolve several problems in real-world SC systems such as evaluation of inventory policies while the parameters are stochastic in nature. The use of our model for an extensive empirical analysis on Web pages as well as extension of the supply chain coordination model and sensitivity analysis performance are interesting areas of further research. Moreover, the interval time of demand was assumed to have an exponential distribution. This assumption could be relaxed to consider any general distribution for further research.

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