17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

A Performance Assessment Framework for Supply Chain Networks

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Abstract

In multi-echelon decentralized supply chains, distribution logistics (inclusive of both material and information flows) play a leading part in helping a supply chain gain advantage over competitors. The uncertain consumer demand and non-optimal operation of distribution nodes are some of the major problems that a supply chain must contend with. A distribution node in the network generally belongs to different companies thereby encouraging the decentralized management of nodes. Decentralized management may worsen the overall performance of the supply chain system and in turn affect the supply chain cost and customer satisfaction. Our work is focused on developing an assessment framework to examine and enhance the performance of an existing supply chain. Data from an existing network is used to determine the bottlenecks or poorly performing nodes. With the knowledge of supply chain architecture, time-series data analysis techniques are employed in this effort. Simulation based optimization are extensively employed to enrich the performance of the inferior nodes close to achievable benchmark standards by minimizing the supply chain cost. The concepts presented will be complemented by realistic simulation examples.

Keywords: performance metrics, supply chain, management, diagnosis, optimization.

1. Introduction

A well-coordinated supply chain is characterized by a harmonious balance between inbound logistics, production scheduling and product distribution. The distribution logistics were handled by various researches to improve the system behaviour with enhanced performance. Lee, et al [1] developed a support model for HP Company to describe the benefit of partly-shared information flow over fully centralized and decentralized system to manage better material flow across the organizational barrier. The sources for the bullwhip in a multi-echelon system were identified and quantified by Chen, et al [2]. Hybrid dynamic simulation tools were developed to analyze the impact of several heuristic decision-making policies on the dynamic behaviour of a supply chain system. In addition, the control of a multi-product multi-echelon system using model predictive control (MPC) strategy was investigated by Perea-Lopez, et al [3]. They conclude that centralized control of the overall network provides better performance than decentralized management of individual nodes in the supply chain network. Although the centralized management provides better benefits than decentralized management, decentralized management is unavoidable in the real world where the agents of the distribution network belong to different companies and prefer to focus only on their individual performances. A simulation-based optimization strategy using genetic algorithm was proposed by Mele, et al [4] to overcome the difficulties of large-scale mixed integer nonlinear problem (MINLP) for centralized control of the overall network. The effort of the above method is restricted to order-upto-policy and lacking bullwhip constraint. The performance of the decentralized management can be improved by reorganizing the operational goal of all the nodes to dampen the bullwhip effect. This may be done by a supervisory authority (e.g. a third party consultant for the supply chain). Through this work, efforts are taken to address the issues to achieve profitable decentralized network.

2. Problem Statement, background

In this section, the supply chain studied by Perea-Lopez, et al [3] will be used to illustrate the ideas. The distribution network (shown in figure 1) consists of ten retailers (R1 to R10), four distribution centers (DC1 to DC4) and manages nine different products with warehouse (W)-manufacturing facility (P) for each product. We seek to enhance the performance of this multi-product multi-echelon distribution network by analyzing the network data followed by multiple optimization steps. This demand driven system is fully decentralized in which all distribution nodes belong to different companies. The internal strategy of the distribution nodes differs depending on whether the inventory level is maintained at a constant target value or made responsive to the uncertain demand (see Table 1). The well-balanced relation between flow entities of the distribution node is described using information and material balance relations on a discrete-time basis by Lin, et al [5].

Table 1: Internal Strategies of the network

Distributor Node	Internal Strategy	Replenishment Policy
R1, R2, R3	Responsive	PI
R4,R5	Non-Responsive	PI
R6, R7, R8	Non-Responsive	Order-upto-policy
R9,R10	Responsive	Order-upto-policy
DC1	Responsive	PI
DC2	Responsive	Order-upto-policy
DC3	Responsive	SOP1
DC4	Responsive	SOP2

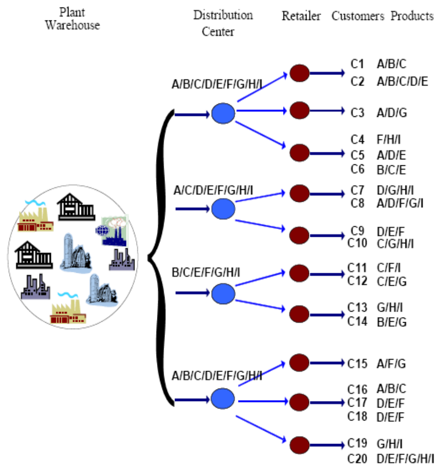

Figure 1: Distribution Network

Replenishment Policies: In real situations, Order-upto-policy is used as the replenishment strategy to manage inventory position in the distribution system. The bullwhip effect (BW), which causes huge build-up in excess inventory and back order followed by stock outs, is inevitable for a system practicing this policy. BW is quantified as the ratio of variance in outgoing order to the supplier to the incoming order from the downstream nodes. Other replenishment policies include the Proportional–Integral policy (PI), Smoothing ordering policy (SOP1) and the Smoothing Order Policy 2 (SOP2). *Choosing right replenishment rule with appropriate parameters in relation to the demand pattern and business goal is a challenging task for the overall network.*

Performance Indicators and Performance Index of the Distribution node and network: *The ideal system is one which utilizes minimum resources to produce maximum output with reliable responsiveness.* For a distribution network, the resource indicators represent the supply chain costs like excess inventory cost and back order cost. The output indicators represent the outcome of the distribution node like customer satisfaction and probability (or number) of stock outs. The performance index of the distribution unit is represented as the weighted combination of excess inventory and back order along with the bullwhip constraint. *Minimizing the performance index is the ultimate goal to minimize the supply chain cost.* In the optimization process, the weights assigned to the excess inventory and back order depends on their relative importance to the business goals. The above definition for performance can be extended to the overall network performance index by summing up the individual performances.

3. Methodology

The proposed performance assessment framework for a decentralized distribution network is based on a portfolio aspect of performance measures following an order of importance relevant to the type of supply chain system. It starts with identifying the performance indicators reflecting the supply chain strategic goals. Inventory, downstream orders and product replenishment are used to estimate the performance metrics (excess inventory, back order and bullwhip) of the existing system. The performance assessment framework is implemented in stages to attain the enhanced performance. The proposed framework starts by troubleshooting the inefficient (aggressive, weak and conflict) nodes that causes performance deterioration in the network. The aggressive node is the one which optimizes the performance locally without considering the adverse BW effects caused to the network by demand distortion. The weak node is the one with poor performance and service level due to inappropriate replenishment rule and the non-optimum parameters. The nodes that are not capable of restricting the BW effect due to inappropriate replenishment rule structure are referred as conflicting nodes. At first, replenishment parameters of aggressive nodes are retuned to dampen the bullwhip effect. In the second stage, replenishment parameters of the weak nodes (having higher back order and excess inventory) are retuned to enhance its performance. Finally, the conflicting nodes are optimized by changing replenishment rule and modifying the internal strategy to be responsive to the demand faced. In all improvement stages, BW is considered as a dominant constraint to facilitate equal advantage to all the nodes of the network. The ultimate performance obtained from this framework is closer to the performance benchmark. Our performance benchmark is the optimum performance obtained using the similar type of replenishment rule (proportional-integral policy, SOP1 or SOP2) in all the nodes of the network while respecting the bullwhip constraint.

3.1. Case studies

Market Demand: The distribution network is subjected to two patterns of market demand to analyze the performance assessment and enhancement framework. The first type represents a steady demand pattern (i.e. stationary stochastic demand) and the second type representing non-stationary demand. In either case, the demand pattern is generated by a zero mean, unit variance white noise sequence $\xi(t)$ passing through suitable filters.

3.2. Results & Discussions

The information available about the distribution network for performance enhancement are the description of the product demands from the customer, connectivity between the customers, retailers, distribution centers, and production plants as well as the internal strategies practiced by the distribution nodes. The time-series data of inventory at-hand (I_H), demand faced (U_S), demand satisfied (Y_{ij}), order placed (U_P) and order satisfied (Y_{pi}) are available from all the nodes in the network. The identified inefficient distribution nodes have to be rectified for performance enhancement using the potential opportunities like the responsive inventory target, the replenishment rule structure and its parameters. System identification approaches are used to extract the lead time information from time-series data obtained from the distribution system. For example, when the suppliers are capable of satisfying all downstream orders, the lead time can be obtained from the autocorrelation between order placed (U_S) and material received from the supplier (Y_{ij}).

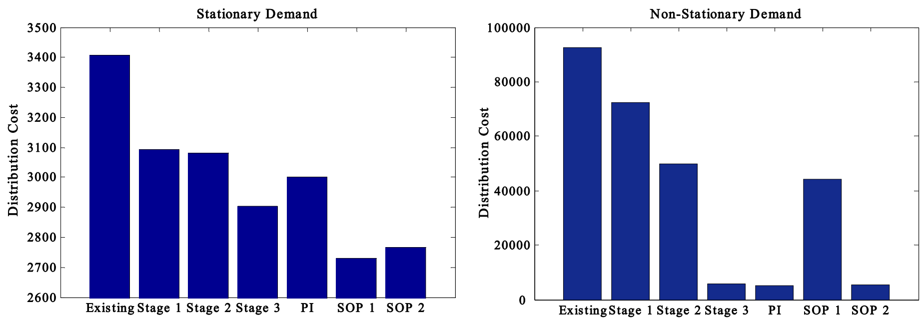

Figure 2: Distribution Cost of decentralized network

Case Study (1) Stationary Demand:

The result obtained from the proposed enhancement procedure compares very well with the performance obtained with the benchmark performance. This performance assessment framework is utilized to address different levels of benefits under various implementation conditions. The performance improvement obtained at different assessment stages and the optimized performance attained using identical replenishment policies in all nodes are shown in Figure 2. With reference to the performance benchmark, the performance is improved from the initial 80.14% to 88.33% by dampening the aggressive effects of the nodes (R1-R3, DC1, DC3 & DC4) in the first stage. In the second stage, by retuning the R4 and R5 nodes, the performance is slightly improved to 88.65%. Significant improvement upto 94% is attained in the final stage by modifying the internal strategies of the conflicting nodes (R6-R10 and DC2). Among the replenishment rules, SOP1 provides the best performance.

Case Study (2) - Non-Stationary Demand:

The performance improvement obtained during the assessment stages and the optimized performance attained using the various heuristic rules are shown in Figure 2. With respect to the achievable performance benchmark, the overall network performance is improved from 5.7% to 7.3% by dampening the aggressive effects of the nodes (R1-R5, DC1 & DC3) in the first stage. In the second stage, performance is improved to 10.56% by retuning the weak node (DC4). The final stage of improvement (89.47% of benchmark performance) is attained by modifying the internal strategy of the conflicting nodes (R6-R10 & DC2). In this case, PI strategy provides the best performance. As described Lin, et al [5], PI, SOP1 and SOP2 control strategies result in higher back order than excess inventory in the retailer nodes while the opposite happens in the distribution nodes.

4. Conclusions

Performance improvement of a decentralized distribution system through a metrics based staged approach is considered here. In decentralized network, heavy interaction and inappropriate co-ordination between the nodes results in disparate benefits to the components of the distribution system. Through the proposed performance assessment framework, various issues affecting the overall network performance are addressed. Using a realistic supply chain example, we have demonstrated the workability of our strategy under two different demand trends. The proposed approach results in a better supply chain system under two different demand trends.

References

1. H. L. Lee and C. Billington, Operations Research., 41 (1993) 835.
2. F. Chen, Z. Drezner, J. K. Ryan and D. Simchi-Levi, Management Science., 46 (2000) 436.
3. E. Perea-Lopez, B. E. Ydstie and I. E. Grossmann, Computers and Chemical Engineering., 27 (2003) 1201.
4. F. D. Mele, G. Guillen, A. Espuna and L. Puigjaner, Ind. Eng. Chem. Res., 45 (2006) 3133.
5. P. H. Lin, S. S. Jang and D. S. H. Wong, Ind. Eng. Chem. Res., 44 (2005) 9120.