Paper ID: IE-21

Performance Evaluation of a Supply Chain Network Distinctly by Some New Flexibility Indexes with the Real-World Applicability: A Case Study

Md. Al-Mamun* and Md. Tajmiruzzaman
Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh
**E-mail: mamunrazruet09ipe@gmail.com*

Abstract

Supply chain management, analysis, and improvement are becoming increasingly important. To develop and improve a supply chain network, the evaluation of its quantitative performance is a prerequisite that has to be consistent with the real-world situations. In this paper, we propose flexibility measures: demand flexibility, lead time flexibility, and product type flexibility as new indices to evaluate the quantitative performance of a specific type of supply chain network. To describe these measures some assumptions are made. Finally, numerical analysis is adopted to illustrate the performance of the supply chain by means of flexibility indexes distinctly in favor of searching an optimal supply chain network with respect to industrial case.

Keywords: Supply Chain Network, Flexibility Index, Performance Evaluation, Industrial Case.

1. Introduction

A supply chain network (SCN) is an integration of facilities, supplies, customer, information, communication, transportation, manufacturing, distribution, purchasing, and method of controlling inventory etc. In recent years, the importance of designing an optimal supply chain network is becoming necessary because of competitive business due to globalized market. Nevertheless, designing an optimal supply chain is a difficult and critical task because supply chain network design covers a wide range of areas including multiple layers, members, periods, products, and inventory decision [1]. Designing obviously includes the task of performance evaluation. Three types of performance measures are: resource measures (generally cost), output measures (generally customer responsiveness), and flexibility (how well the system reacts to uncertainty) measures [2]. Among these three we present the flexibility measure. The measurements of flexibility that are existent are: volume flexibility, delivery flexibility, mix flexibility, new product flexibility [2]. But in this paper we propose three new measurements of flexibility these are: demand flexibility, product type flexibility, and lead time flexibility to evaluate supply chain performance in favor of designing an optimal supply chain network. Firstly the formulation of these flexibility measurements is done and secondly the numerical analysis is adopted by taking the necessary data from two case companies named 1) Lafarge Surma Bangladesh Lt, and 2) Bangladesh Master Pack Limited.

2. Literature Review

The literature on the quantitative performance evaluation considering the real-world situation of the system is limited. Tinggui Chen et al. [1] present a new method for evaluating the performance of a supply chain network. The main index is cost factors, which include four categories: production costs, disruption costs, co-ordination costs, and vulnerability costs. Benita M. Beamon [2] presents an overview and evaluation of the performance measures used in supply chain models and also presents a framework for the selection of performance measurement systems for manufacturing supply chains. He presents four flexibility indices to evaluate the performance of a supply chain. Zuo-Jun Max Shen [3] presents a profit-maximizing supply chain design model in which a company has flexibility in determining which customers to serve. The company may lose a customer to competition if the price it charges is too high. Benita M. Beamon [4] presents a focused review of literature in multi-stage supply chain modeling and defines a research agenda for future research in this area. He also presents that, for years, researchers and practitioners have primarily investigated the various processes within manufacturing supply chains individually. Recently, however, there has been increasing attention placed on the performance, design, and analysis of the supply chain as a whole. This attention is largely a result of the rising costs of manufacturing, the shrinking resources of manufacturing bases, shortened product life cycles, the leveling of the playing field within manufacturing, and the globalization of market economies. Jayaraman and Pirkul [5] had considered total cost of supply chain as an objective function in their studies. However, there are no design tasks that are single objective problems. The design, planning, scheduling projects are usually involving trade-offs among different incompatible goals. Recently, multi objective optimization of SCNs has been considered by different researchers in literature. Altiparmak et al. [6] Leaving aside the procurement function (purchasing of raw materials), the SC network becomes a multi-echelon production/distribution system. Santoso et al. [7] the design of SC networks is a difficult task because of the intrinsic complexity of the major subsystems of these networks and the many interactions among these subsystems, as well as external factors such as the considerable uncertainty in product demands. Tsiakys et al. [8] in the past, this complexity has forced much of the research in this area to focus on individual components of supply chain networks. Recently, however, attention has increasingly been placed on the performance, design, and analysis of the supply chain as a whole. In the last decades, several optimization procedures have been developed to solve NP-hard problems. In the last decades, several optimization procedures have been developed to solve these problems. Recently, Amiri [9] presented a heuristic method based on the Lagrange relaxation technique to minimize the total cost of a two stages, un-capacitated SCN distribution network. Ilkka Sillanpää [14] presents an empirical study of measuring supply chain performance. The purpose of this paper is to create a supply chain measurement framework for manufacturing industry. The key elements for the measurement framework were defined as time, profitability, order book analysis and managerial analysis. The measurement framework is tested by measuring case SC performance. Suggestions for future research are multiple case studies in different manufacturing industry areas and positivistic-based SC performance research. The remaining of this paper is organized as follows. Section 3 describes the illustration of supply chain network and formulation of different measurements of flexibility. In section 4, numerical analyses are adopted with respect to industrial cases. The conclusion and future work are shown in section 5. Section 6 represents references.

3. The Method for Evaluating Supply Chain Network Performance

3.1 Illustration of a Supply Chain Network

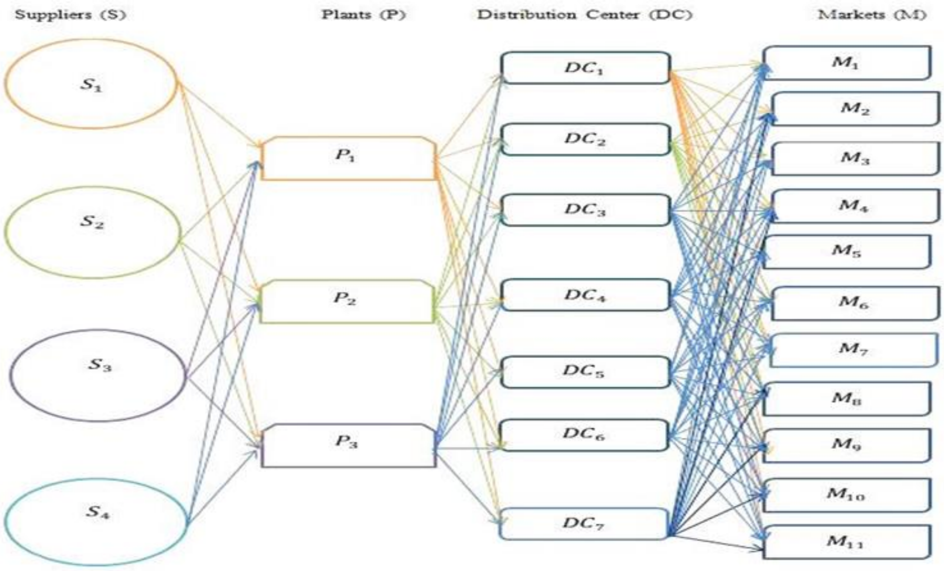

Fig. 1. Existing supply chain network of Lafarge Surma Bangladesh Lt

The topological structure of a supply chain is shown in figure 1. We all know that, purchasing, distribution, planning, marketing, and manufacturing organizations along the supply chain operated independently. But every organization has its own objective so these are often conflicting [1]. Therefore, an optimal, stable, and efficient supply chain is always necessary. Illustration of a supply chain is shown in figure 1. In figure 1, we can see that if we want to deliver a product directly from plant to the market then a direct connection between the plants to the market is needed. Furthermore, as depicted in figure 1, there, distribution centers, and transportations in the supply chain network.

3.2 Supply Chain Performance Evaluation

3.2.1 Demand flexibility (F_D)

The generalization of demand flexibility is to measure of the range of demand of product that will be demanded by customer at a certain time period. For any manufacturing system demand fluctuation incurs generally cost to the business. Demand could be greater or less than the volume that the manufacturer produces. But we consider here that the market demand is always equal to the volume that is transferred to the market stage from the manufacturing stage through the supply chain. For the establishment of supply chain demand flexibility measure we are interested in how much the market demand can be met considering the range of product that are produced profitably by the manufacturer. Here we also assume that the production of product is approximately equal to the demand. So that inventory does not affect the profit of the manufacturer when the demand is in a profitable range.

Demand flexibility measure, F_D measures the proportion of demand that can be met by the existing supply chain. Let us consider that demand volume (D) is a random variable of an approximate normal distribution. Again consider that the maximum and minimum market demand is D_{max} and D_{min} respectively. If the demand volume data are available then we can consider mean demand and demand variance as $\bar{D}$ and S_D^2, respectively, where

$$\bar{D} = \frac{\sum_{t=1}^{T} d_t}{T} \quad (1)$$

And

$$S_D^2 = \frac{\sum_{t=1}^{T} (d_t - \bar{d})^2}{T-1} \quad (2)$$

Where $d_t$the demand during time period t and T is the number of periods we assume.

Demand flexibility can be written as

$$F_D = P\left(\frac{D_{min} - \bar{D}}{S_D} \leq D \leq \frac{D_{max} - \bar{D}}{S_D}\right) \quad (3)$$

Or

$$F_D = \Phi\left(\frac{D_{max} - \bar{D}}{S_D}\right) - \Phi\left(\frac{D_{min} - \bar{D}}{S_D}\right) \quad (4)$$

Where $0 < F_D < 1$, and F_D represents the long-run proportion of demand which can be met by the supply chain. The demand flexibility above represents the performance of supply chain the manufacturer uses.

3.2.2 Lead Time Flexibility (F_L)

The scope of delivering a product considering extended lead time and reduced lead time are important in supply chain management. This ability facilitates supply chain to accurate orders and special orders etc. Lead time flexibility can be expressed as the percentage of lead time that can be either extended or reduced. Although reduction of lead time is at most a rare case in the real world situation, it might be considered as a favorable case for the manufacturer. If there are p= 1, 2, 3, ….., P products in the system then the total lead time that is deviated from the actual lead time can be given by the quantity

$$\sum_{p=1}^{P} \{(T_p^d + L_p^n + L_p^e - t^*) - (T_p^d + L_d^n - t^*)\}$$ for the case of extension of lead time

And

$$\sum_{p=1}^{P} \{(T_p^d + L_p^n + L_p^r - t^*) - (T_p^d + L_d^n - t^*)\}$$ for the case of reduction of lead time

Where,

t^*= time when order is placed, T_p^d= exact delivery time of product, L_p^n= normal lead time, L_p^e= extended lead time, L_p^r= reduced lead time.

The lead time flexibility can be expressed in percentage form as

$$F_L = \frac{\sum_{p=1}^{P} \{(T_p^d + L_p^n + L_p^e - t^*) - (T_p^d + L_d^n - t^*)\}}{\sum_{p=1}^{P} (T_p^d + L_p^n + L_p^e - t^*)} \times 100\% \text{ (for the extension of lead time)} \quad (5)$$

This simplifies to

$$F_L = \frac{\sum_{p=1}^{P}\{(T_p^d + L_p^n + L_p^s) - (T_p^d + L_d^n)\}}{\sum_{p=1}^{P}(T_p^d + L_p^n + L_p^s - t^*)} \times 100\% \tag{6}$$

$$F_L = \frac{\sum_{p=1}^{P}\{(T_p^d + L_p^n + L_p^r - t^*) - (T_p^d + L_d^n - t^*)\}}{\sum_{p=1}^{P}(T_p^d + L_p^n + L_p^r - t^*)} \times 100\% \text{ (for the reduction of lead time)} \tag{7}$$

This simplifies to

$$F_L = \frac{\sum_{p=1}^{P}\{(T_p^d + L_p^n + L_p^r) - (T_p^d + L_d^n)\}}{\sum_{p=1}^{P}(T_p^d + L_p^n + L_p^r - t^*)} \times 100\% \tag{8}$$

3.2.3 Product Type Flexibility (F_{pt})

Conceptually the product type flexibility is same as the process and job flexibility of a system. This can be expressed as the percentage of number of additional products type that can be produced at a certain time period. Additional products mean the extra products that have to be produced with the initial or existing product type. Here assumption should be made that an additional product will take the same labor and time as the previous product one. Let P_j^i is the initial number of product type, P_k^a isthe additional number of product type, and there are j= 1, 2, 3,.…., J types of initial product and k= 1, 2, 3,…., K types of additional product. Then the product type flexibility can be calculated as

$$F_{pt} = \frac{(\sum_{j=1}^{J} P_j^i + \sum_{k=1}^{K} P_k^a) - \sum_{j=1}^{J} P_j^i}{\sum_{j=1}^{J} P_j^i + \sum_{k=1}^{K} P_k^a} \tag{9}$$

This simplifies to

$$F_{pt} = \frac{\sum_{k=1}^{K} P_k^a}{\sum_{j=1}^{J} P_j^i + \sum_{k=1}^{K} P_k^a} \tag{10}$$

4. Numerical Analysis

4.1 Demand flexibility (F_D)

We collect some data from Cement Company named Laferge Surma Bangladesh Lt in where Market wise Demand Volume in Metric ton is like as in table 1. The manufacturer supplies product using its supply chain at eleven markets:

Table 1. Market wise Demand Volume in Metric ton *(Source: Lafarge Surma Bangladesh Lt)*

Market	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}
Demand	4100	3600	3300	2800	3600	3100	3500	3300	3400	3400	3700

So, for this system

$$\bar{D} = \frac{\sum_{t=1}^{T} d_t}{T} \cong 3436.36 \tag{11}$$

And

$$S_D = \sqrt[+]{S_D^2} = \sqrt[+]{\frac{\sum_{t=1}^{T}(d_t - \bar{d})^2}{T-1}} \cong 335.48 \tag{12}$$

The system has the maximum and minimum profitable demand is 4100 and 2800 metric ton respectively per unit time period so the demand flexibility can be determined by:

$$\begin{aligned} F_D &= \Phi\left(\frac{4100-3436.36}{335.48}\right) - \Phi\left(\frac{2800-3436.36}{335.48}\right) \\ &\Phi(1.98) - \Phi(-1.90) \\ &0.9474 \end{aligned} \tag{13}$$

4.2 Lead Time Flexibility (F_L)

Laferge Surma Bangladesh Lt is able to deliver its product approximately within two days after ordering by its customer that means lead time is two days. The company has single type of product so p=1. Letting the ordering dates by the customer are: 1, 8, 15, and 22 in a certain month (ordering dates are the first day of consecutive weeks of a certain month) and both the extension and reduction of lead time is one day then we can show these data at a glance as in table 2.

Table 2. Ordering time, delivery time, and lead time *(Source: Lafarge Surma Bangladesh Lt)*

Ordering time	Time to deliver T_p^d	Normal Lead time L_p^n (day)	Extended lead time L_p^e (day)	Reduced lead time L_p^r (day)
1	3	2	1	1
8	10	2	1	1
15	17	2	1	1
22	24	2	1	1

So the lead time flexibility is

$$F_L = \frac{\sum_{p=1}^{P}\{(T_p^d + L_p^n + L_p^e - t^*) - (T_p^d + L_d^n - t^*)\}}{\sum_{p=1}^{P}(T_p^d + L_p^n + L_p^e - t^*)} \times 100\% \text{ (when lead time extended)} \quad (14)$$

$$= 20\%$$

And

$$F_L = \frac{\sum_{p=1}^{P}\{(T_p^d + L_p^n + L_p^r - t^*) - (T_p^d + L_d^n - t^*)\}}{\sum_{p=1}^{P}(T_p^d + L_p^n + L_p^r - t^*)} \times 100\% \text{ (when lead time reduced)} \quad (15)$$

$$= 20\%$$

4.3 Product Type Flexibility (F_{pt})

Bangladesh Master Pack Lt Produces five types of Bag: FIBC, WPP Bag, Jumbo Bag, Bulk container, and Builder Bag initially but now wants to produce other tree types of Bag so if it has a supply chain like figure 1 then that supply chain will have a performance.

Table 3. Initial and additional number of product and product type *(Source: Bangladesh Master Pack Limited)*

Initial number of product type P_j^i					Additional number of product type P_j^a		
FIBC	WPP bag	Jumbo bag	Bulk container	Builder bag	P_1	P_2	P_3
350	300	200	350	300	250	350	400

So, we get

$$F_{pt} = \frac{\sum_{k=1}^{K} P_k^a}{\sum_{j=1}^{J} P_j^i + \sum_{k=1}^{K} P_k^a} \cong 0.4 \quad (16)$$

So the product type flexibility of supply chain of Bangladesh Master Pack Limited is approximately 40% when the approximate number of monthly production of FIBC, WPP Bag, Jumbo Bag, Bulk container, and Builder Bag are: 350, 300, 200, 350, 300 respectively with the additional number of products P_1= 250, P_2= 350, P_3= 400.

5. Conclusion

In this paper, we present some new measures for evaluating the performance of a supply chain network. The main index is flexibility measures, which includes some categories among these, we propose three categories: demand flexibility, lead time flexibility, and product type flexibility. Additionally, to describe these flexibility indices some assumptions are made. Finally, numerical analysis is adopted to illustrate its efficiency and effectiveness in searching for an optimal scheme in supply chain network design.

The future work may be focus on the following two aspects: (1) how to find out other flexibility indices need further study; (2) other influence factors such as customer satisfactory may also affect the decision making of a supply chain network design. As a result, how to quantify these indices is another direction that may be explored in future.

6. References

[1] Tinggui Chen, Xiaoqing Gong, "Performance evaluation of a supply chain network", *Procedia Computer Science*, Vol. 17, pp. 1003-1009, 2013.

[2] Benita M. Beamon, "Measuring supply chain performance", *International Journal of Operations & Production Management*, Vol. 19, No. 3, pp. 275-292, 1999.

[3] Zuo-Jun Max Shen, "A profit-maximizing supply chain network design model with demand choice flexibility", *Operations Research Letters*, Vol. 34, pp. 673- 682, 2006.

[4] Benita M. Beamon, "Supply chain design and analysis: models and methods", *International Journal of Production Economics*, Vol. 55, No. 3, pp. 281-294, 1998.

[5] Jayaraman, V., And Prkul, H., "Planning and coordination of production and distribution facilities for multiple commodities", *European Journal of Operational Research*, Vol. 133, pp. 394-408, 2001.

[6] Altiparmak, F., Gen, M., Lin, L., and Karaogla., I., "A steady-state genetic algorithm for multi-product supply chain network design", *Computers and Industrial Engineering*, Vol. 56, No. 2, pp. 521-537, 2009.

[7] T. Santoso, S. Ahmed, M. Geotchalskx, A. Shapiro, "A stochastic programming approach for supply chain network design under uncertainty", *European Journal of Operational Research*, Vol. 167, pp. 96-115, 2005.

[8] P. Tsiakys, L. G. Papageorgiou , "Optimal production allocation and distribution supply chain networks", *International Journal of Production Economics*, Vol. 111, pp. 468-483, 2008.

[9] A. Amiri, "Designing a distribution network in a supply chain system: Formulation and efficient solution procedure", *European Journal of Operational Research*, Vol. 171, No. 2, pp. 567-576, 2006.

[10] Deniel Kitaw et al., "Supply chain network design-opportunities for cost reduction as applied to east Africa bottling share company in Ethiopia", *Journal of EEA*, Vol. 28, pp. 67- 82, 2011.

[11] Suhong, Li., Nathan, B., Nathan, T.S., and Rao, S., "The impact of supply chain management practices on competitive advantage and organizational performance", *The International Journal of Management Science, Omega,* vol. 34, pp. 107-124, 2006.

[12] Peter, T. and Aleš, G., "Measurement of supply chain integration benefits", *Interdisciplinary Journal of Information, Knowledge, and Management,* vol. 1, 2006.

[13] Handfield, R.B. and Nichols, E.L., "Introduction to supply chain management", *Prentice-Hall*, 2006.

[14] Ilkka Sillanpää, "Empirical study of measuring supply chain performance", *Benchmarking: An International Journal*, Vol. 22 No. 2, pp. 290- 308, 2015.

[15] Shaw, S. Grant, D.B. and Mangan, J., "Develo[ping environmental supply chain performance measures", *Benchmarking*, Vol. 17, No. 3, pp. 290- 339, 2010.

[16] Bhagwat, R. and Sharma, M.K., An application of the integrated AHP-PGP model for performance measurement of supply chain management", *Production Planning and Control*, Vol. 20, No. 8, pp. 678-690, 2009.

[17] Bigliardi, B. and Bottani, E. "Performance measurement in the food supply chain: a balanced scorecard approach", *Facilities*, Vol. 28, Nos. 5-6, pp. 249-260, 2010.

[18] Caridi, M., Crippa, L., Perego, A., Sianesi, A. and Tumino, A., "Measuring visibility to improve supply chain performance: a quantative approach", *Benchmarking*, Vol. 17, No. 4, 593-615, 2010,

[19] Chia, A., Goh, M. and Hum, S.-H., "Performance measurement in supply chain entities: balanced scorecard perspective", *Benchmarking*, Vol. 16, No. 5, pp. 605-620, 2009.

[20] Lin, L.-. and Li, T.-., "An integrated framework for supply chain performance measurement using six-sigma metrics", *Software Quality Journal*, Vol. 18, No. 3, pp. 387-406, 2010.

[21] Olsen, E.O., Zhou, H., Lee, D.M.S., Ng, Y., Chong, C.C. and Padunchwit, P., Performance measurement system and relationship with performance results: a case study analysis of a continuous improvement approach to PMS design", *International Journal of Productivity and Performance Management*, Vol. 56, No. 7, pp. 559-582, 2007.

[22] Ramanathan, U., Gunasekaran, A. and Subramanian, N., Supply chain collaboration performance metrics: a conceptual Framework", *Benchmarking*, Vol. 18, No. 6, pp. 856-872, 2011.

[23] Thakkar, J., Kandar, A. and Deshmukh, S.G., Supply chain performance measurement framework for small and medium scale enterprises", *Benchmarking*, Vol. 16, No. 5, pp. 702-723, 2009.