A Simulation-based Optimization Approach to Facility-Allocation under Demand Uncertainty and Enforced Level of Service

Joyjit Bhowmick
Trade Services (Pvt.) Ltd.
Dhaka, Bangladesh
joyjittspl@gmail.com

Abstract

Deciding on the number and configuration of distribution centers (DC) is one of the most impactful decisions that create a pathway for competitiveness and responsiveness. In this research, the allocation of distribution center problem is studied under demand uncertainty. The purposes of this study were to specify the optimal number and allocation of distribution centers out of candidate ones. This paper proposes a three-step model with probabilistically distributed demand where the coefficient of variation is the measure of risk along with the enforced level of service metrics that are focused on responsiveness which aligns with real-world problems and the considered company, working as a backward linkage of the fast fashion industry. To consider uncertainty, a set of scenarios for customer demands is created based on the Monte Carlo simulation. The best network structure is identified by optimizing each scenario and detecting which configuration has been observed the highest amount of times. Furthermore, the uncertainty of demands creates variations of the optimized total cost which is imposed on the logistical system. Notably, this research has been done in one of the oldest textile yarn distribution firms in Bangladesh.

Keywords
Simulation-based Optimization, Demand Uncertainty, Network Design, and Integer Linear Programming.

1. Introduction

A supply chain consists of a set of tiers ranging from suppliers, manufacturers, distributors, retailers, and customers. Within these tiers, there is are flows of physical goods, financial transactions and movement of information with the objective of fulfilling the requirement of a customer (CTL.SCOx Spring 2017). In a supply chain, the flow of products reaching up to the customers goes across multiple stages and each stage may include some facilities (Sabri & Beamon, 2000). Supply chain design is the most cardinal and impactful decision that will influence the entire supply chain and due to the increase of competitiveness in markets, it has been obtaining much importance recently (Simchi-Levi & Kaminsky 2004; Thomas & Griffin 1996). It has become involuntary for firms to maintain customer service levels while they are obliged to reduce costs as much as possible and maintain profit margins at the same time. Distribution network design is considered as the primary key for making profits because it directly affects both the cost of supply chains as well as the satisfaction of the customers (Chopra 2003). As there is a significant amount of investment involved, the allocated facilities are expected to sustain their expected activities for a long period of time. Therefore, it is mandatory to design a well-performing supply chain network with some parameter variation across time to compete with the tight standards of the market (Santosa 2003).

Supply chain design includes tactical decisions such as determining the number, location, and capacity of facilities in each stage of the supply chain. The location of facilities and the allocation of demands to them have been a prominent area for research. In fact, the configuration stability of a supply chain network is highly desirable since substantial investments are usually involved with this type of decision (Izadi & Kimiagari 2014). In this paper, the goal is to obtain a distribution network configuration that can cope with the future demand variations and achieve robustness in the network design taking into consideration the responsiveness or level of service (LOS) provided. In this case study, actual data are used from a company that is one of the oldest textile yarn distribution firms in Bangladesh. Operating in the country which is one of the leaders for exporting readymade garments and mostly operating in the fast fashion industry which requires great responsiveness across the whole supply chain, it is mandatory that the network design is capable of handling demand fluctuations with minimized costs.

Although deterministic models are computationally inexpensive and require comparatively less data, the fluctuating demands cannot be captured by these models. In this paper, the robustness of the solution is maintained by taking into consideration the stochasticity of demands across all the customer zones. The solution is reached in three stages. First, an Integer Linear Program (ILP) is developed to minimize the total cost that includes transportation cost, goods handling cost, fixed facility cost and cost of goods to obtain the optimized configuration of distribution centers among the potential ones. In this ILP model, the demand values are deterministic. After that, to incorporate uncertainty, demand scenarios are created using the Monte Carlo Simulation technique to represent the stochasticity which is in-line with practical application. Finally, a very simple and easy to use algorithm is formulated to combine simulation and optimization where each of the scenarios is deterministically optimized to obtain a probabilistic result of the optimized configuration.

2. Problem Statement

The problem that is considered in this paper is deciding on the distribution center configuration, the number of distribution centers allocation out of the selected candidate ones, for one of the oldest textile yarn distribution companies in Bangladesh. Textile and Garments industry in Bangladesh is by far the most challenging and most foreign currency earning industry in Bangladesh. Being cost-competitive as well as fast-responsive is the target of all the companies involved in this industry. The yarn distribution companies act as a connector between the yarn manufacturers and fabric maker or garment producers.

It has become one of the most challenging issues for such distribution companies to be as responsive as possible as well as cost-competitive. Even delivering yarns to customer one-hour age can create a lot of impact on the total supply chain. This is because the country mostly operates in the fast fashion industry which requires extremely short lead time. As most of the garment manufacturing company in Bangladesh do not have own units that can manufacture and supply yarn, it is imperative for them to secure yarns as fast as possible to meet the tight deadlines of the end customer. Therefore, in this problem, the level of service that the yarn distributor can provide has been taken into account with great importance.

The customers of the considered companies are firms with a fabric manufacturing unit only as well as vertically set up companies that ship out finished garment products. Moreover, the range of customers includes yarn retailers as well as re-distributors. The distribution firm has two major suppliers that are considered in this problem with more than a hundred customers.

There is no confusion that this optimization problem requires a very large amount of data. Therefore, data aggregation is the first crucial step that should be done. The most effective approach which is used for this purpose is grouping all the customers in each region into one cluster. Then, all customers located in each cluster are replaced by a single demand point in the center of the cluster. Data aggregation would create a pathway for inexpensive computation and an efficient approach to this problem even if there is suitable technology available to capture this amount of data. The consequence of data aggregation would be reduced data variability and forecasting with aggregated data has significantly more precision compared with non-aggregated data (Simchi-Levi & Kaminsky 2004). With this method, the range of over a hundred customers has been clubbed into eleven customer zones shown in figure 1.

The considered company approximately handles more than two hundred types of products. Due to the relatively large number of products, these are integrated into one product. Furthermore, how much weight each customer demands require, is significant to the company more than any other parameter. So, the required monthly weights of each customer are calculated, and it is used as the measure of customer demands. Therefore, this problem is considered as a single product and multi-level supply chain design problem (Sousa et al. 2011).

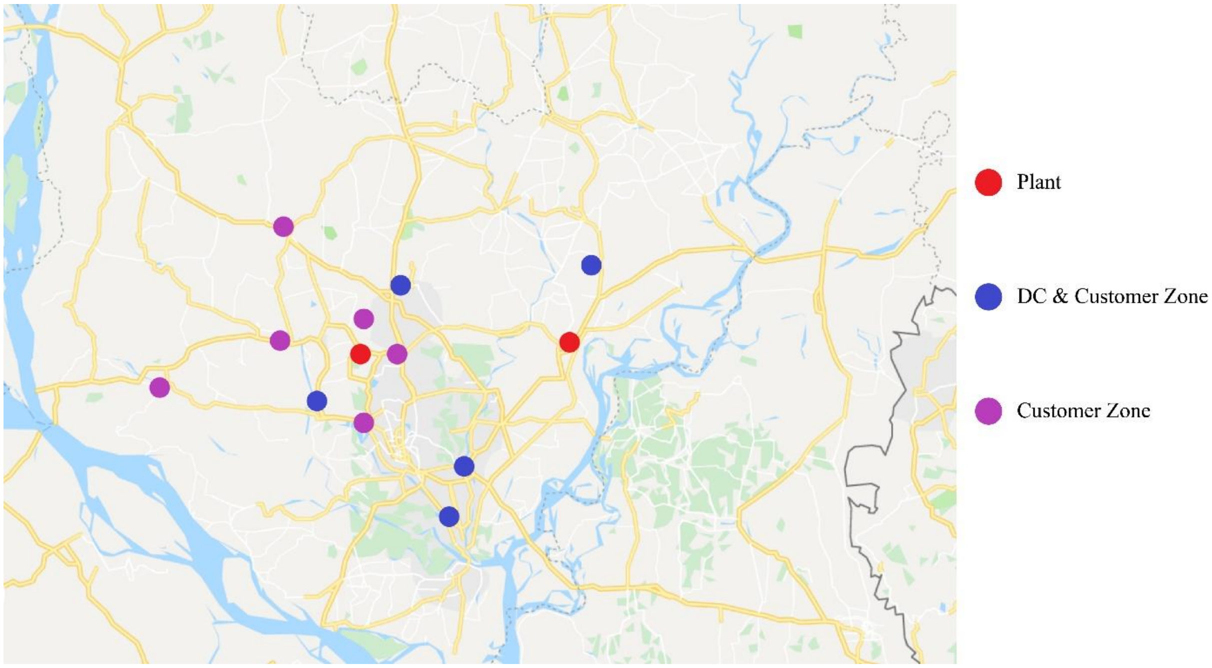

Figure 1: Plants, Distribution Centers & Customer Zone locations

3. Model Description

The problem that is considered in this paper is deciding on the distribution center configuration for one of the oldest textile yarn distribution company in Bangladesh. Textile and Garments industry in Bangladesh is by far the most challenging and most foreign currency earning industry in Bangladesh. Being cost-competitive as well as fast-responsive is the target of all the companies involved in this industry. The yarn distribution companies act as a connector between the yarn manufacturers and fabric maker or garment producers. The assumptions on which this proposed model is based on are –

- The algorithm is structured as a transportation model where the DCs do not have any variable holding cost and all the goods transported to the DC are also transported out of DC.
- The company intends to operate on a monthly fixed cost and unit wise variable cost for transportation to & from DCs. Therefore, the holding cost is not taken into consideration in this paper.
- Transportation cost is linear with different unit costs for inbound and outbound.
- The capacities of potential distribution centers are known.
- The number of customers and their demands are known.
- There is no capacity limit on the network arcs so that any amount could be transported
- The fixed cost of DC is calculated on a monthly basis with the assumption that with time there will not be any changes.

Under these assumptions, we propose a three-step model formulation that includes building a deterministic model having level of service (LOS) constraints, creating scenarios with co-efficient of variation of demand by Monte Carlo Simulation technique and modeling the final simulation based optimization algorithm to combine the previous two steps. These three steps are described below -

3.1 Facility Allocation Integer Linear Programming Model

Linear Programming (LP) has become the most popular of approaches falling within mathematical techniques of optimization and have been continuously being applied to improve supply chain performance. This technique has been widely used to allocate limited resources among competing demands in an optimal way. Finding the optimal allocation of facilities or distribution centers by evaluating shipping costs between alternatives of facilities along with supply and demand sources is one of the areas to use this method (Chase et al. 2014).

Integer Linear Programming (ILP) refers to the LP technique where all the decision variables are set as integers. The first step of the model formulation is the deterministic ILP model described in this section. The proposed ILP model in this paper will have the following notations-

Plants i
Distribution Centers j
Customer Zones k

S_i = Available supply at plant i (Kg) $\forall i \in S$
D_k = Demand by customer k (Kg) $\forall k \in D$
c_i = Average total cost of goods at plant i ($/Kg)
c_{ij} = Cost to transport to DC j from plant i ($/Kg/Km)
x_{ij} = Amount of Kg transported from plant i to DC j
c_{jk} = Cost to transport from DC j to customer k ($/Kg/Km)
x_{jk} = Amount of Kg transported from DC j to Customer Region k
f_j = Fixed cost for opening DC j ($)
h_j = Goods handling cost in DC j ($/Kg)
P_{MIN} = Minimum number of DCs required to open
P_{MAX} = Maximum number of DCs allowed to open
M = A really big number
dij = Distance from Plant i to DC j (km) $\forall i,j$
dj_k = Distance to Customer k from DC j (km) $\forall j,k$
Y_j = Binary decision variable for opening DC j
a_{jk} = 1 if customer k to DC j within 30 KM, 0 otherwise $\forall j,k$
MAD = Max allowable average distance DCs to Customers
MPI= Min allowable demand within specific kilometers of a DC, in this problem 30 KM

$$\text{Minimize } Z = (\textstyle\sum_i\sum_j x_{ij}\, d_{ij})\, c_{ij} + (\sum_j\sum_k x_{jk}\, d_{jk})\, c_{jk} + \sum_j f_j\, Y_j + \sum_i x_{ij}\, c_i + \sum_j\sum_k h_j x_{jk} \quad (1)$$

The objective function (1) takes into consideration four kinds of costs – the total cost of transportation of goods represented by - $(\sum_i\sum_j x_{ij}\, d_{ij})\, c_{ij} + (\sum_j\sum_k x_{jk}\, d_{jk})\, c_{jk}$, the total fixed cost of opening a distribution center represented by $\sum_j f_j\, Y_j$, the total cost of goods sourced presented by $\sum_i x_{ij}\, c_i$ and total handling cost of goods at the opened distribution centers represented by $\sum_j\sum_k h_j x_{jk}$.

The objection function is subject to the following constraints:

$$\textstyle\sum_i x_{ij} \le S_i \qquad \forall i \in S \quad (2)$$
$$\textstyle\sum_k x_{jk} \ge D_k \qquad \forall k \in D \quad (3)$$

These are the supply and demand constraints which ensure that the flow of goods from the plants is less than or equal to supply and the flow of goods to the customer is greater than or equal to the demand. Consequently, the result of these two operating constraints is that the total supply of goods from the plant is equal to the total delivered goods to the customer areas.

$$x_{ij} - MY_j \le 0 \quad (4)$$

This constraint (4) acts as a linking constraint between the two types of decision variables. Implementing this secures that flow of goods through a DC only happens when that particular DC is open.

$$\sum_j x_{ij} - \sum_j x_{jk} = 0 \quad (5)$$

This is the conservation of flow constraint (5). It makes sure that the goods that go to a DC must also be delivered within the considered timeline, in this case in a month.

$$\sum_j Y_j \leq P_{MAX} \quad (6)$$
$$\sum_j Y_j \geq P_{MIN} \quad (7)$$

These two constraints ensure that the minimum and the maximum number of DCs opened remain within the specified range.

$$x_{ij} \geq 0 \qquad \forall i,j \quad (8)$$
$$x_{jk} \geq 0 \qquad \forall j,k \quad (9)$$
$$Y_j = \{0,1\} \qquad \forall j \quad (10)$$

The constraints (8) & (9) represent that the flow of goods will be integer amounts and constraint (10) reflects the open and not-open decision variables for the DCs.

$$\sum_{jk} (d_{jk} x_{jk} / \sum_{jk} D_k) \leq MAD \quad (11)$$
$$\sum_{jk} (a_{jk} x_{jk} / \sum_{jk} D_k) \geq MPI \quad (12)$$

The constraint (11) takes the demand-weighted average distance and ensures that it is less than or equal to some critical level of maximum average distance (*MAD*) which can also be considered as the maximum allowed average weighted distance. As a result, the model will make sure that the average customer is not at a great distance.

The previous constraint (11) considers only the average, which means that we do not know how much of our demand has an LOS below a certain threshold. The constraint (12) ensures that at least a specified percentage of the demand is less than a specified distance from a DC. The binary variable a_{ij} then denotes whether or not a certain flow is shorter (a_{ij} =1) than a specified distance or not (a_{ij} =0). That is, the constraint ensures that not a great number of customers are far away and enables the optimal result to make a specified number of customers within a specified distance from the considered distribution center (CTL.SC2x Summer 2018). Here, 30 KM is set as the specified distance and the notation *MPI* refers to the minimum percentage of customers within 30 KM.

3.2 Adding Uncertainty

Several parameters of a Supply Chain Network Design (SCND) problem, such as costs, demand, and supply, have inherent uncertainty. Moreover, supply chain networks can be affected by major man-made or natural disruptions such as floods, terrorist attacks, earthquakes, and economic crises. However, these kinds of disruptions usually have a low likelihood of occurrence, but their impacts on the supply chain network are prominent. The objective of SCND under uncertainty is to achieve a configuration so that it can perform well under any possible realization of uncertain parameters. But, this measure of performing well for different SC networks under uncertain environments could be quite different according to the viewpoints of decision-makers (Kannan et al. 2017).

The previously described Integer Linear Programming (ILP) model is formulated deterministically that is able to minimize the total cost of distribution which includes manufacturing cost, goods handing cost, transportation cost and fixed costs of opening a distribution center. However, building the model with deterministic values does not hold real-world variations. In reality, the demand always fluctuates and to build a robust model we definitely need to address the unpredictability of demand. Therefore, incorporating demand uncertainty for each of the eleven customer zones in the model would make it more robust.

Simulation technique has been used in a variety of contexts including modeling system uncertainty. There are several methods of simulation modeling that include system dynamics, Monte Carlo Simulation, discrete time simulation and agent-based simulations (CTL.SCOx Spring 2017).

From the historical data of the past 5 years of the considered company, it is found that the demands in each of the customer zones closely follow a normal distribution. Moreover, the average coefficient of variation (CV) of these eleven zones is approximately 0.3 with each customer zone having known mean demand and variance.

Based on the available data, we have randomly created 1000 different demand scenarios for each of the customer zones with the help of the Monte Carlo Simulation technique. The following (figure:2) represents the total demand of eleven customer zones for each scenario which showcases the randomness of the total demand.

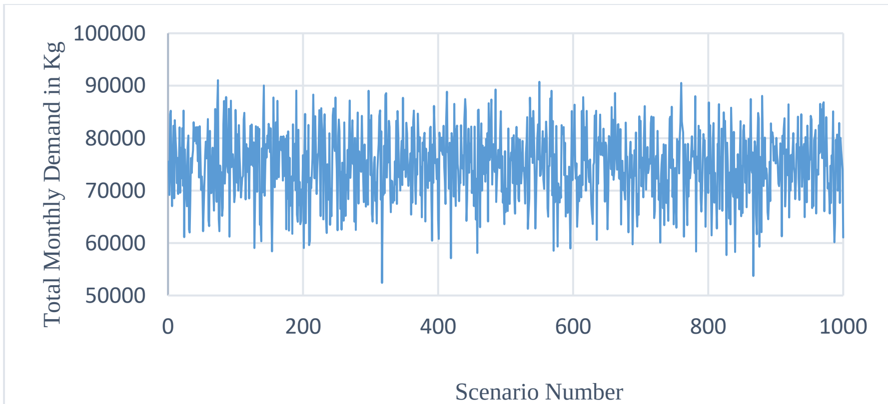

Figure 2: Generated total demand per scenario through Monte Carlo Simulation

3.3 The Simulation-based Optimization Algorithm

The final step of the model is created with the help of a comprehensible algorithm that optimizes each of the generated scenarios separately with a Simplex Linear Program solver and records the result. The first step of this algorithm is to select a demand scenario and setting the ILP constraints according to that scenario. After that, the model optimizes the objective function by Simplex LP solver with the given constraints and parameters. Next, the optimal decision variable for that particular demand scenario is stored along with other costing blocks. Then the algorithm resets the solver parameters and selects the next demand scenario.

It is an easy to use and very simple algorithm that has been enabled to take into consideration the uncertainty of demand. The following is the flow chart that represents the ideology for the algorithm –

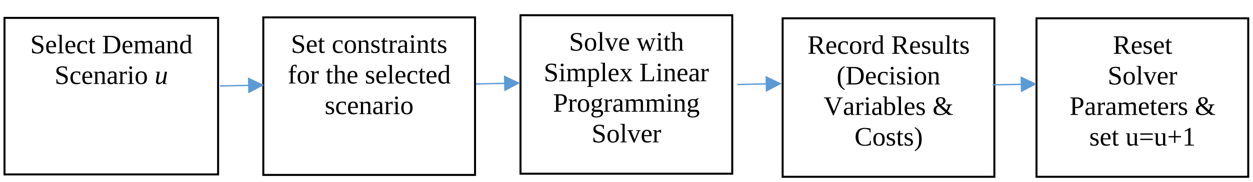

Figure 3: The flow for the proposed simulation-based optimization algorithm

The algorithm will run until a specified number of *u*. In this problem, we run the algorithm for a thousand runs to obtain a probabilistic value of an optimal configuration of distribution centers from the candidate ones. The above algorithm is developed in VBA with the use of the Simplex LP solver for the optimization of each of the scenarios.

4. Results & Analysis

Figure 4 demonstrates the Histogram of the optimal number of distribution centers based on the 1000 scenarios of customer demands. In each scenario, the best number of distribution centers is found through minimizing the total cost which includes manufacturing cost, transportation costs, and goods handling cost. Using the proposed simulation-based optimization algorithm, the results of the optimized configuration is recorded.

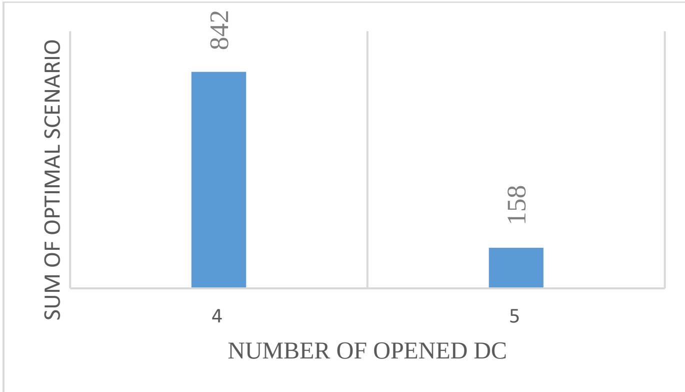

Figure 4: Frequency histogram of the optimized configuration

Only two types of configurations appeared optimal in our analysis. This figure: 3 illustrates that the logistical structures with only 4 & 5 distribution centers gain the most optimized frequencies among all the structures. Table 1 suggests that all the other distribution centers except Narayanganj one were opened in every scenario of our simulation run of 1000 scenarios. The distribution center Narayanganj only appeared in optimal result for 15.8% of the time. Therefore, from figure 3 & table 1, it is evident that a distribution network of 4 distribution centers excluding only Narayanganj one would be providing the optimal cost structure for the company with a probability of 84.2% which is based on 1000 random scenarios of the proposed algorithm.

Table 1: Percentage of optimal appearances of candidate distribution centers

Candidate DC	Percentage of Optimal Appearance
Narayanganj	15.80%
Gazipur	100.00%
Tarabo	100.00%
Shibpur	100.00%
Savar	100.00%

Further comparison into the total cost and the costs in different sectors (Table 2) also represents that the configuration of 4 distribution centers incurs a lesser average cost in each sector of the supply chain. Furthermore, goods handling cost in these distribution centers are the second-highest cost centers after sourcing costs which include the cost of material, processing, packaging, and other services cost up to the loading of the packaged goods.

Table 2: Average cost comparison of different DC configuration

Number of Opened DC	4	5
Average of TOTAL COST	249,048.17	291,842.12
Average of DC fixed cost	1,630.00	2,030.00
Average of OB Transport	35,430.98	42,416.04
Average of IB Transport	32,847.11	40,835.17
Average of Sourcing Costs	102,678.06	117,337.83
Average of Handling	76,462.03	89,223.09

5. Conclusion

In this paper, a facility allocation model has been formulated in order to identify the optimal allocation of distribution centers out of candidate centers. The objective function was modeled to minimize the total cost that includes inbound transportation cost, outbound transportation cost, goods handling cost, fixed cost of opening a distribution center and sourcing cost of the goods. The model is formulated as a three-echelon supply chain model with demand uncertainty with two plants or goods sourcing points, five candidate distribution centers, and eleven aggregated customer zones.

To represent the uncertainty of demands, scenarios have been generated using the Monte Carlo Simulation technique with the coefficient of variation. In the developed model it has been made sure that the average customer is not at a great distance as well as not a great number of customers is far away to impose the required level of service in the optimal outcome. The result gives us a probabilistic output that shows us that it would be optimal to open four distribution centers without the one that had the lowest optimal appearance with a probability of 84.2%.

The uncertainty of demand that is taken into consideration in this study is generated because of the existing fierce bullwhip effect throughout the whole supply chain. Although the generated demand is the most visible and impactful area where unpredictability is present, other components of uncertainty can also be considered as an extension of this study. Furthermore, other additional elements of the level of service like the condition of the delivered product, after-sales service and strict time windows for delivering the products can also be taken into account for future studies. Moreover, the objective of this model was to minimize the incurred cost for the considered element and multi-objective models might also be explored as an improvement of model formulation.

References

Chase R.B., Shankar R., Jacobs F.R. & Aquilano N.J. 2014, *Operations & Supply Management*, 12th edition, pp 44-45

Chopra S. 2003 *Designing the distribution network in a supply chain.* Transp Res Part E 39:123–140

Izadi, A. & Kimiagari, A.M. J Ind Eng Int 2014, 10: 50. https://doi.org/10.1007/s40092-014-0050-1

Kannan G., Mohammad F. & Esmaeil K., Supply chain network design under uncertainty: A comprehensive review and future research directions, *European Journal of Operational Research*, vol. 263, issue 1, pp. 108-141, 2017

Sabri E.H. & Beamon B.M. 2000, *A multi-objective approach to simultaneous strategic and operational planning in supply chain*. Omega 28(5): 581–598

Santosa T. 2003, *A comprehensive model and efficient solution algorithm for the design of global supply chains under uncertainty*. Dissertation in Georgia Institute of Technology, pp 22–44

Simchi-Levi D. & Kaminsky P. 2004, *Managing the supply chain: the definitive guide for the business professional*. Irwin McGraw- Hill, Boston

Sousa R.T., Liu S., Papageorgiou L.G. & Shaha N. 2011, *Global supply chain planning for pharmaceuticals*. Chem Eng Res Des 89:2396–2409

Spring 2017 – MIT Center for Transportation & Logistics (CTL), SC0x – *Supply Chain Analytics Key Concepts* – MITx MicroMasters in Supply Chain Management, V1 pp 3-58

Summer 2018 - MIT Center for Transportation & Logistics (CTL), SC2x - *Supply Chain Design Key Concepts* – MITx MicroMasters in Supply Chain Management pp 14-15

Thomas D.J. & Griffin P.M. 1996, *Coordinated supply chain management*. Eur J Oper Res 94:1–115

Biography

Joyjit Bhowmick is currently working as a Sourcing Responsible of the knit supply chain for H&M Bangladesh. Prior to this he has worked as a part-time analyst for an early stage e-commerce startup in Bangladesh with the responsibility of designing the distribution network. He has also worked in one of the oldest textile yarn distribution companies in Bangladesh, Trade Services (Pvt.) Ltd., and focused on the optimization of the supply chain network. Academically, he has the MicroMasters credential in Supply Chain Management from Massachusetts Institute of Technology. He has completed his under graduation in Industrial & Production Engineering from Bangladesh University of Engineering & Technology.