Mathematical Model Formation for Optimizing Transportation Cost for a Multi-Echelon Downstream Supply Chain

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Abstract

This research develops a mathematical model for a multi-echelon downstream supply chain. Due to the complicated structure of multi-echelon supply chain management, a specific number of factors have been considered to determine the optimum transportation cost. The mathematical model presented in this study gives an optimum way to determine the transportation cost for a multi-echelon downstream supply chain. The proposed model is applicable for single product manufacturing industries. This research aims to optimize the total transportation cost during the shipment. A Mixed Integer Programming (MIP) model is utilized to find out the optimum solution. GAMS (Generic Algebraic Modeling System) algorithm is applied to execute the model in GAMS software. Two different solvers in GAMS like CPLEX and XPRESS are demonstrated on a downstream supply chain for a cement manufacturing industry. At the end of the study, the industry's optimum transportation cost is estimated using the formulated model. The generic assumptions and comparison of the two solvers are demonstrated in this research.

Keywords

Mathematical Modeling, Linear Programming, Generic Algebraic Modeling System (GAMS), Downstream Supply Chain

1.Introduction:

Supply Chain refers to the system of fulfilling the customer demands. It includes all the stages that are directly or indirectly connected to the fulfillment of customer demands. It consists of the stages among manufacturers, suppliers, transporters, warehouses, retailers, and customers (Chopra and Meindl. 2003). So, the Supply chain is concerned with the flow of material from the suppliers to the end-users. As a result, the management of the supply chain is crucial for any organization (Mentzer et al. 2001). A typical structure of the supply chain is presented in Figure 1.

The objective of managing a supply chain is to synchronize the requirements of the customers with the flow of raw materials from the suppliers in order to make a balance between all the conflicting goals like the highest level of customer service with the lowest level of inventory management and unit cost (Stevens 1989).In recent years, young researchers and practitioners are overly concerned with the analysis of individual stages of a supply chain to make it more efficient by minimizing the total supply chain cost (Beamon 1998).

The entire supply chain of an organization can be divided into some sub-chains like supplier supply chain, in house supply chain and retailer supply chain. Each portion of the sub-chains plays a vital role in controlling the total supply chain cost. Every stage of the supply chain network is closely related and interdependent to each other. As well as all the stages work together to manage, control, and improve the overall flow of materials and information from the supplier to the end-users of the product or service (Christopher 2016).

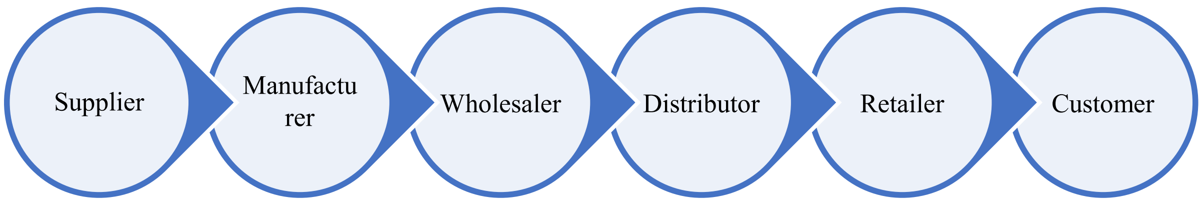

Figure 1: Supply Chain Structure (Chopra and Meindl. 2003)

However, Supply chain management is an integrative approach consisting of all the stages involved directly or indirectly in fulfilling customer demand. The function of it involves manufacturers, suppliers, transporters, warehouses, retailers, and customers themselves. The purpose of supply chain management is to satisfy customer requirements as efficiently as possible. It aims to optimize the entire processes to cope with the supply chain efficiency with the customer responsiveness. Minimizing customer response time, however, can increase the costs to skyrocket. As a result, maximizing chain efficiency is equally crucial for the organization. To make an effective supply chain, it is necessary to ensure that the product is delivered as quickly as possible within the least transportation cost and the proper quality.

The most reputed companies obtain an effective supply chain by utilizing complicated logistics tools such as computer algorithms and company databases. Computer algorithms help to choose optimal routes for product shipping, and company database allows the distant employees to pool order information and coordinate their efforts in real-time. An adequate supply chain management always tries to minimize the total supply chain cost by eliminating unnecessary steps from the stages of the supply chain.

An adequate supply chain works to increase negotiating power with suppliers or retailers, which helps the organization reduce the material requirement and cost. That is why most of the top companies have the department, working for the proper supply chain management, which directly or indirectly helps the companies to gain substantial cost advantages (Mack and Houston 2018).

2. Literature Review

Multi echelon supply chain involves multiple stages in the supply chain; each stage may have various parties, and products are supplied from one stage to another. The stages in the supply chain either represent the physical activities or items in the BOM or processing activities. Stages to the left are upstream, and right is downstream. A simple structure of the Multi echelon Supply Chain is illustrated in Figure 2.

Thousands of research work has been done in a multi-echelon supply chain, as its structure and characteristics are very complex in real life. Laigang et al. performed a multi-echelon supply chain simulation using metamodel. Metamodels are the kind of simulation model that simplifies a system's input-output relationship with the help of mathematical expression. It provides a rational way to study the behavior of a complex system. This paper describes the application of metamodel simulation in solving a multi-echelon supply chain problem as well as makes statistical analysis of the parameters (Song et al. 2008). Prasad et al. presented an application of a genetic algorithm for inventory optimization problem for a supply chain employing multiple products to minimize the excess and shortage of stocks. Inventory management is always being a critical concern for supply chain management. This research presents a clear description of multi-product inventory optimization in a multi-echelon supply chain using the Genetic Algorithm approach (Prasad et al. 2017). Thousands of mathematical models have been developed yet based on a variety of constraints for different industries. This section will describe different research work on mathematical model formulation work in the supply chain. The section will also highlight the purpose of varying optimization model work and give an overview of their nature and characteristics.

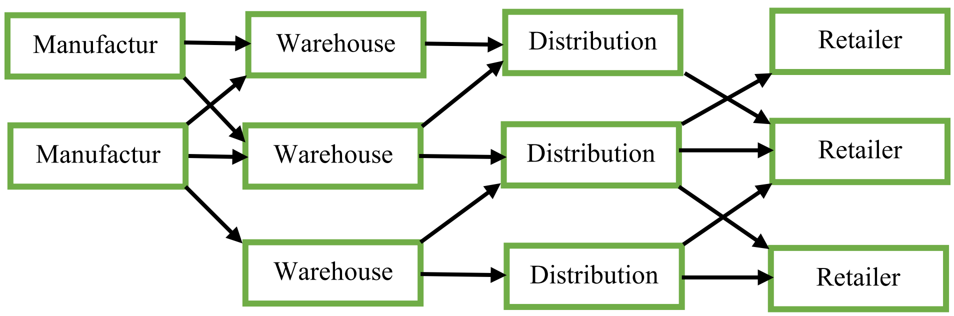

Figure 2: Simple Structure of Multi echelon Supply Chain

Yan et al. propose a strategic production-distribution model for supply chain design considering bills of materials (Yan et al. 2003). They show the relationships among the leading entities of a supply chain such as suppliers, producers, and distribution centers are formulated as logical constraints in a mixed integer programming (MIP) model. In this way, they state BOM's role in supplier selection as a strategic design of a supply chain. Their aim is to illustrate the formulation's effectiveness and convenience by introducing the logic constraints into the model.

Jang et al. consider a two-stage multi-echelon problem where they provide an optimization model to minimize the total cost of transported items from susceptible plants to warehouses and from warehouses to distribution centers (DCs) (Djafar et al. 2015). The proposed supply network management system consists of a supply network design optimization module, planning module for production and distribution operations from raw material suppliers to customers, model management module, and data management module.

From Amiri, a clear perception of the distribution network design problem in a supply chain system can be gathered (Amiri 2006). The paper describes the location of the production plants and distribution warehouses. Also, it determines the best strategy for distributing the product from the plants to the warehouses and from the warehouses to the customers. Here the priority is to select the optimum numbers, locations, and capacities of plants and warehouses to open so that all demand of the customer is satisfied at a minimum total cost in the distribution network.

According to Nagurney et al., an equilibrium model of a competitive supply chain network is a general way to handle many decision-makers and their independent behaviors (Zhang and Liu 2015). An equilibrium structure provides a standard benchmark with which the existing product shipments and prices are often compared. The model works as a basement in the development and evaluation of dynamic supply chain network models.

Kannan et al. show an optimization model on a closed-loop supply chain system (Kannan et al. 2010). They use the genetic algorithm approach to develop a multi-echelon, multi-period, multi-product closed-loop supply chain network model for product returns, and the decisions are made based on the material procurement, production, distribution, recycling, and disposal.

Ferreira developed a supply chain distribution model for a single product, intending to minimize transportation costs, handling materials, duties and tariffs, production, and fixed infrastructure (Ferreira 2009). The distribution network is a combination of manufacturing facilities, warehouses, distribution centers, and customer zones. The combination of manufacturing facilities, warehouses, and distribution centers is determined here to find out the optimum solution.

A different model formulation in the field of a supply chain is investigated through the discussion on the literature review. In a multi-echelon downstream supply chain, optimizing cost is an important consideration. A different mathematical model is already developed based on the characteristics of a multi-echelon downstream supply chain. Besides why mathematical models are formulated in various fields of the supply chain is also mentioned in the previous study.

Through the discussion on the literature review, a different model formulation in the field of the supply chain is discovered. In a multi-echelon downstream supply chain, optimizing cost is an important consideration. A different mathematical model is already developed based on the characteristics of a multi-echelon downstream supply chain. Nevertheless, there is no model for direct shipment from different stages, ignoring one or more stages between them. Besides, in the previous discussion, some study in distance calculation is shown, which is not necessary at all. So, these types of discussions are entirely ignored in the present model.

3.Mathematical Model Formulation

3.1. Problem Analysis

The model is suitable for a company having multiple suppliers, warehouses, distribution centers, and retailers. Figure 3 gives a clear reflection of the supply chain structure for which the model is formulated. For the model formulation cost of shipment from manufacturer to warehouses, warehouses to distribution centers, distribution centers to retailers are considered. This model is also suitable for direct shipment from warehouses to retailers. The aim of this model formulation is to minimize the transportation cost and find out the optimum quantity that is needed to ship from different supply chain points.

3.2 . Assumptions

The various assumptions involved in this paper are described below.

- Only Single-product condition is considered.
- Single time period considered.
- Multi staged supply chain system is considered that is from manufacturers to warehouses, warehouses to DCs, DCs to retailers and warehouses to retailers.
- The transportation cost per product from the supplier to the manufacturing plant is included in fixed cost like truck hiring cost and variable cost which depends on the distance between supply chain points.
- The daily demand of the retailer zone is deterministic, shortage is not allowed.
- The transportation cost per unit product from each plant to all warehouse, from each warehouse to all the DCs, from each DC to all retailer zones, from the warehouse to the retailer zones remains fixed for all the periods.

3.3. Indices

- a = Manufacturer index (a= 1,2, 3, … A)
- i =Warehouse index (j = 1,2,3, …… I)
- j = distribution centers (DCs) index (k = 1,2,3, …… J)
- k =Retailer index (r = 1,2,3, ……K)

3.4. Decision Variable

- Q_{ai}= Quantity shipped from manufacturer a to warehouses i
- Q_{ij}= Quantity shipped from warehouse i to distribution centers j
- Q_{jk}= Quantity shipped from distribution centers j to retailer k
- Q_{ik} =Quantity shipped from warehouse i to retailer k

3.5 . Binary Variable

- $v_i = \begin{cases} 1, \text{if the warehouse is open} \\ 0, \text{otherwise} \end{cases}$
- $v_j = \begin{cases} 1, \text{if the distribution centers is open} \\ 0, \text{otherwise} \end{cases}$

3.6 . Parameter

- m_a = Total output of the manufacturer a
- n_k =Demand of retailer k
- f_i =Maximum capacity of warehouse i for

- f_j = Maximum capacity of distribution centers j for
- c_{ai} =Unit transportation cost from manufacturer a to warehouse i
- c_{ij} =Unit transportation cost from warehouse i to distribution centers j
- c_{jk} =Unit transportation cost from distribution centers j to retailer k
- c_{ik} =Unit transportation cost from warehouse i to retailer k

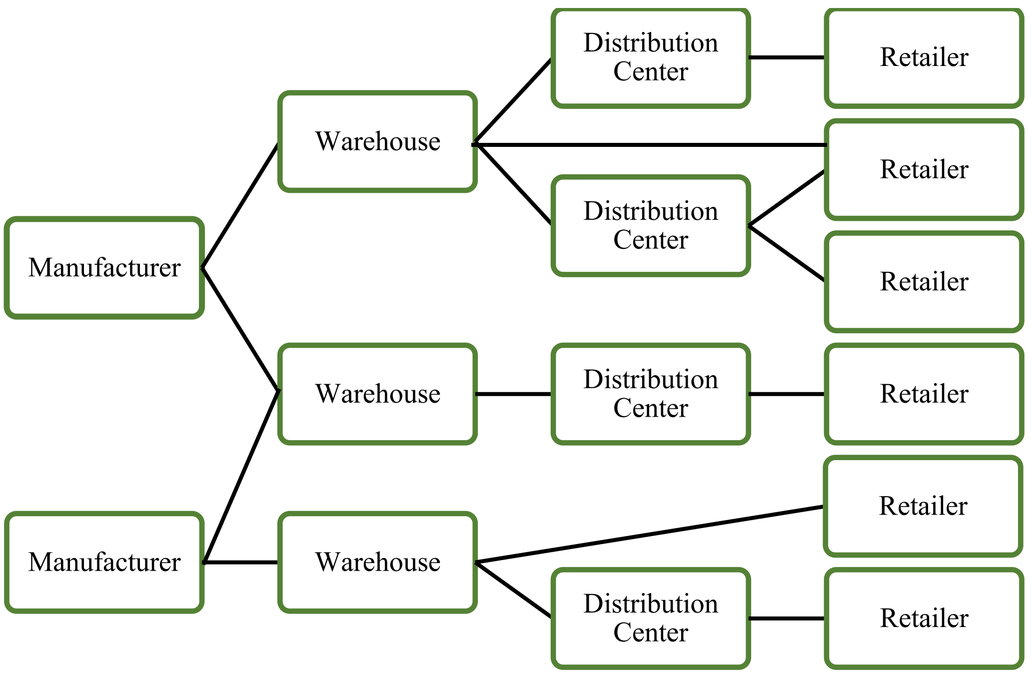

Figure 3:General Supply Chain Structure for the Model Formulation

3.7 . Objective Function

$$Minimize\ Total\ Cost = \sum_{a=1}^{A}\sum_{i=1}^{I} c_{ai}Q_{ai} + \sum_{i=1}^{I}\sum_{j=1}^{J} c_{ij}\, Q_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} c_{jk}\, Q_{jk} + \sum_{i=1}^{I}\sum_{k=1}^{K} c_{ik}\, Q_{ik}$$

The Model minimizes the total transportation cost of the transported material from the manufacturer to the warehouses, warehouses to the distribution centers (DCs), distribution centers (DCs) to retailer and warehouses to the retailers.

In objective function,
$\sum_{a=1}^{A}\sum_{i=1}^{I} \boldsymbol{c_{ai}Q_{ai}}$ denotes the transportation cost from manufacturer a to warehouses i.
$\sum_{i=1}^{I}\sum_{j=1}^{J} \boldsymbol{c_{ij}\, Q_{ij}}$ denotes the transportation cost from warehouse i to distribution centers (DCs) j.
$\sum_{j=1}^{J}\sum_{k=1}^{K} \boldsymbol{c_{jk}\, Q_{jk}}$ denotes the transportation cost from distribution centers (DCs) j to retailer k.
$\sum_{i=1}^{I}\sum_{k=1}^{K} \boldsymbol{c_{ik}\, Q_{ik}}$ denotes the transportation cost from warehouse i to retailer k.

3.8 . Constraints

The constraint (1) restricts the amount shipped from the warehouses to the distribution centers (DCs) and the retailers. The amount shipped from the warehouses to the distribution centers (DCs) and the warehouses to the retailer depends on the output of the manufacturer for a certain period. The warehouse cannot ship to the distribution centers (DCs) and retailers more than the output of the manufacturer.

$$\sum_{j=1}^{J} Q_{ij} + \sum_{k=1}^{K} Q_{ik} \leq \sum_{a=1}^{A} m_a \quad \forall i --- (1)$$

The constraint (2) represents the shipment barrier to the retailer. The demand of the retailer always needs to be fulfilled. That is why the amount shipped to the retailer from both the distribution centers (DCs) and warehouses are greater than or equal to the demand of the retailers.

$$\sum_{i=1}^{I} Q_{ik} + \sum_{j=1}^{J} Q_{jk} \geq n_k \quad \forall k --- (2)$$

The constraint (3) restricts the supply from the manufacturer to the warehouse i based on the capacity of the warehouse i. The amount shipped to the warehouse i should be less than or equal to the capacity of the warehouse i if that warehouse is open. If the warehouse i is closed, no material can be shipped to the warehouse i form the manufacturer.

$$\sum_{a=1}^{A} Q_{ai} \leq f_i v_i \quad \forall i --- (3)$$

The constraint (4) restricts the supply from the warehouse i to the distribution center j based on the capacity of the distribution center j . The amount shipped to the distribution center j should be lower than or equal to the capacity of the distribution center j if that distribution center j is open. If the distribution center j is closed, no material can be shipped to the distribution center j form the warehouse i.

$$\sum_{i=1}^{I} Q_{ij} \leq f_j v_j \quad \forall j --- (4)$$

The constrint (5) restricts on the amount to be shipped from distribution centers (DCs) j to the retailer k. The amount shipped to retailer k from the distribution center j has to be less than or equal to the amount shipped from warehouse i to the distribution centers (DCs) j.

$$\sum_{i=1}^{I} Q_{ij} \geq \sum_{k=1}^{K} Q_{jk} \quad \forall j --- (5)$$

The constriant (6) represnts that the total amount to be shipped form warehouse i to both the distribution center j and retailer k has to be less than or eqaul to the amount to be shipped form manufacturer to the warehouse i.

$$\sum_{a=1}^{A} Q_{ai} \geq \sum_{j=1}^{J} Q_{ij} + \sum_{k=1}^{K} Q_{ik} \quad \forall i --- (6)$$

The Constraints (7) and (8) represents the binary characteristics of the variable. The value of $v_i$and v_j have to be 1 or 0 based on the condition of the warehouse i and distribution center j. If the warehouse i is open then v_i is 1 ,otherwise 0. In the same way, if the distribution center (DC) j is open then v_j is 1 ,otherwise 0.

$$v_i € \{0,1\} --- (7)$$

$$v_j € \{0,1\} --- (8)$$

The Constraint (9) illustrates the non-negetive bindings of the variables.

$$Q_{ij}, Q_{jk}, Q_{ik}, Q_{ai} \geq 0 \qquad \forall a, i, j, k --- (9)$$

The formulated model is solved using GAMS algorithm with the help of two different solvers which are CPLEX and XPRESS.

4. Case Study

4.1. Company Problem Statement

For this study, a cement industry was chosen. In Bangladesh it has two plants one of which is in Meghnaghat and another is in Mongla. The capacity of the plant in Meghnaghat is much higher and covers most of the market demand in Bangladesh.

Comparatively, capacity of the Mongla plant is quite lower. The main duty of Mongla plant is to serve the customer demand of the Khulna division along with Barisal, Faridpur regions.

The supply chain management system of the company is satisfactorily well organized. The entire supply chain system can be divided into two areas such as upstream supply chain and downstream supply chain. Depending upon the forecast, a specific amount of cement is produced in the plant. After that the cement is transferred from the plant to the warehouses, warehouses to the distribution centers (DCs) and distribution centers (DCs) to the retailers.

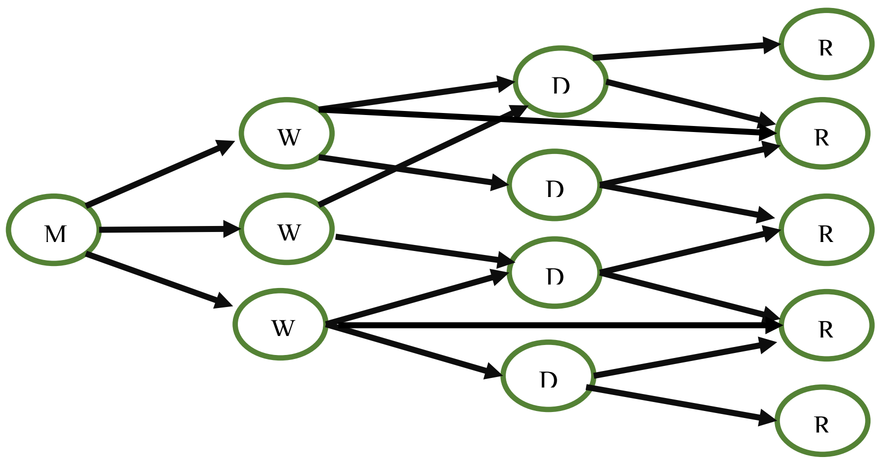

Figure 4: Retail Supply Chain Network of the Studied Factory

But when the demand of the retailers is quite higher, cements are directly shipped to the retailers from the warehouses. The total transportation cost involves the unit transportation cost from plant to the warehouses, warehouse to the distribution centers (DCs), distribution centers (DCs) to the retailers and warehouse to the retailers. The Figure 4 shows the retail supply chain network of the following plant. And after all of those this company have to bear a large transportation cost which need to be reduced.

4.3. Related Data Analysis

The daily production capacity of the Mongla plant is 720 ton. The plant has three warehouses. The capacity of the warehouses is mentioned in Table 1.

Table 1: Capacity of the warehouses i

Warehouse	Capacity of the Warehouse (Tons)
Mongla 1	1400
Mongla 2	1600
Mongla 3	1200

The unit transportation cost required to ship from manufacturer to the warehouses is illustrated in Table 2.

Table 2: Unit Transportation cost from manufacturers a to warehouses i (BDT)

Warehouse	Shipment cost per Ton (BDT)
Mongla 1	60
Mongla 2	60
Mongla 3	60

The capacity of the distribution centers is shown in Table 3.

Table 3: Capacity of the distribution centers j

Distribution Center	Capacity (Tons)
Khulna	1500
Jhenaidah	1200
Barisal	1000
Faridpur	1000

The unit transportation cost is 7.8 BDT to ship 1 ton of cement per kilometer. The unit transportation cost to ship cement to ship cement from warehouses to distribution centers (DCs) is in Table 4.

Table 4: Unit Transportation cost from warehouses i to distribution centers j (BDT)

	To	Khulna	Jhenaidah	Barisal	Faridpur
From					
Mongla 1		413	1084	936	1162
Mongla 2		413	1084	936	1162
Mongla 3		413	1084	936	1162

As discussed before after shipped to distribution centers the cements are delivered to each retailer zones. It is found that Mongla plant is actively supplying their cement from 4 distribution centers (DCs) to each of the retailer zones which can be divided in 19 regions. The demand of each retailer zone for a specific time period (here it is for 4 days) is shown in Table 5

Table 5: Demand of Each Retailer Zone

Retailer Zone	Demand (Tons)	Retailer Zone	Demand (Tons)
Khulna	200	Rajbari	90
Shatkhira	100	Narail	100
Bagerhat	110	Gopalganj	150
Jessore	120	Barisal	150
Jhenaidah	100	Pirojpur	100
Magura	150	Jhalokathi	100
Kustia	140	Bhola	120
Chuadanga	130	Potuakhali	150
Meherpur	100	Borguna	100
Faridpur	140		

The unit transportation cost to ship cement from distribution centers (DC) to the retailer zones are given in Table 6.

Table 6: Unit Transportation cost from distribution centers to retailers (BDT)

	To	**Khulna**	**Shatkhira**	**Bagerhat**	**Jessore**	**Jhenaidah**	**Magura**
From							
Khulna		200	897	335	456	819	652
Jhenaidah		795	1271	1107	388	100	278
Barisal		1131	1911	554	1474	1567	1404
Faridpur		1162	1451	1151	555	415	252
	To	**Kustia**	**Chuadanga**	**Meherpur**	**Faridpur**	**Rajbari**	**Narail**
From							
Khulna		1193	1068	1263	920	1146	494
Jhenaidah		334	327	493	415	635	629
Barisal		1684	1888	2075	1154	1248	1084
Faridpur		748	736	928	100	234	616
	To	**Gopalganj**	**Barisal**	**Pirojpur**	**Jhalokathi**	**Bhola**	**Potuakhali**
From							
Khulna		560	1131	518	767	1747	1599
Jhenaidah		1061	1568	1443	1622	2449	2293
Barisal		601	100	399	288	881	730
Faridpur		732	1154	1115	1131	1856	1708

According to the logistics system of the studied cement industry when the demand of the retailer is good enough at a specific time, company ships the cement directly to the 19 retailer zones from the warehouses. The unit transportation costs from warehouses to the retailer zones are represented in in Table 7.

Table 7: Unit Transportation cost from warehouses i to the retailers (BDT)

	To	**Khulna**	**Shatkhira**	**Bagerhat**	**Jessore**	**Jhenaidah**	**Magura**
From							
Mongla 1		413	1193	332	819	1084	1014
Mongla 2		413	1193	332	819	1084	1014
Mongla 3		413	1193	332	819	1084	1014
	To	**Kustia**	**Chuadanga**	**Meherpur**	**Faridpur**	**Rajbari**	**Narail**
From							
Mongla 1		1536	1427	1622	1162	1567	850
Mongla 2		1536	1427	1622	1162	1567	850
Mongla 3		1536	1427	1622	1162	1567	850
	To	**Gopalganj**	**Barisal**	**Pirojpur**	**Jhalokathi**	**Bhola**	**Potuakhali**
From							
Mongla 1		622	1193	536	720	1170	1614
Mongla 2		622	1193	536	720	1170	1614
Mongla 3		622	1193	536	720	1170	1614

5. Result and Discussion

The research was about to determine the optimum quantity to be shipped from one point to another within the supply chain network. Due to this, a model is formulated to optimize the total cost of downstream supply chain by fulfilling retailers demand properly. The developed model is prepared by GAMS (General Algebraic Modeling System) algorithm using GAMS software. To solve the model two solvers are used, one is CPLEX and another one is XPRESS. The number of differences is observed in the solutions.

5.1. Output Analysis of solver CPLEX

CPLEX is a GAMS solver that allows the operators to combine the high-level modeling capabilities of GAMS with the power of CPLEX optimizers. CPLEX optimizers or solvers are designed to optimize large, complex problems in short time and with least operator intervention. Access is provided (subject to proper licensing) to CPLEX solution algorithms for linear, quadratically constrained and mixed integer programming problems. While numerous solving options are available, CPLEX can automatically calculate and set most options at the best values for any specific problems. For all these reasons, the model is initially solved by CPLEX which gives the optimum solution of the model.

The solver solves the problem initially and sets the value of all decision variables in an optimum level. The optimum quantities to be shipped from manufacturer to the warehouses are illustrated in Table 8. CPLEX suggest that the warehouse no 3, named as Mongla 3, can be closed to reduce the cost. As the rest two warehouses can successfully fulfill all the market demand, warehouse 3 (Mongla 3) can be closed without any problem.

The quantity which has to be shipped from warehouses to the distribution centers set by the solver CPLEX which are noted in Table 9. It is found that the solver said to close the distribution center in Khulna because it is very closer to Mongla. As Khulna is very nearby to Mongla, the solver suggests sending the cement directly from warehouse to the retailer zones in Khulna.

Table 8: Quantity Shipped from manufacturer to warehouses (by CPLEX)

	Mongla 1	**Mongla 2**
Manufacturer	1400	950

Table 9: Quantity Shipped from warehouses to distribution centers (by CPLEX)

	Jhenaidah	**Barisal**	**Faridpur**
Mongla 2	370	150	90

Here, warehouse Mongla 2 only ship to the distribution centers (DCs)of Barisal and Faridpur the amount that is necessary only to cover the demand of the retailer zones of that area. CPLEX recommends shipping 370 Tons of cement from Mongla 2 to Jhenaidah to cover the demand of the retailer zones of that area and nearby.

It is noticed that the amount which is shipped to distribution center (DC) Jhenaidah can fulfill the demand of 3 retailer zones like Kustia, Chuadanga and Meherpur. The amount, which is sent from Jhenaidah to Khustia, Chudanga and Meherpur are illustrated in Table 10.

Table 10: Quantity Shipped from distribution centers (DC) to retailer zones (by CPLEX)

	Barisal	**Kustia**	**Chuadanga**	**Meherpur**	**Rajbari**
Jhenaidah		140	130	100	
Barisal	150				
Faridpur					90

Another variable in the model is the amount to be shipped directly from the warehouse to the retailer zones. Here CPLEX shows that it is effective to conduct most of the shipment directly from the warehouses to the retailer zones.

According to CPLEX, the third warehouse should be closed. As shipment from warehouse Mongla 1 and Mongla 2 is enough to fulfill the demand of current demand. It should be mentioned that only Faridpur requires shipment from both Mongla 1 and Mongla 2. The output of GAMS for this portion is given in Table 11.

Table 11: Quantity Shipped from warehouses to retailer zones (by CPLEX)

	Khulna	**Jhenaidah**	**Faridpur**	**Shatkhira**	**Bagerhat**	**Jessore**
Mongla 1			100	100	110	120
Mongla 2	200	100	40			
	Magura	**Narail**	**Gopalganj**	**Pirojpur**	**Jhalokathi**	**Bhola**
Mongla 1	150	100	150	100	100	120
	Potuakhali	**Borguna**				
Mongla 1	150	100				

CPLEX shows that the optimum total transportation cost in the retailer supply chain is about 2521870 BDT and the output of CPLEX is represented in Figure 5. CPLEX also says that 2521870 BDT is the best solution for the formulated model.

```
Proven optimal solution.

MIP Solution:      2521870.000000    (36 iterations, 0 nodes)
Final Solve:       2521870.000000    (40 iterations)

Best possible:     2521870.000000
Absolute gap:             0.000000
Relative gap:             0.000000
```

Figure 5:Minimized Total Cost (by CPLEX)

5.2 . Output Analysis of solver XPRESS

GAMS/XPRESS which is also referred to as XPRESS is a versatile, high-performance optimization system. This system integrates a powerful simplex-based Linear Programming solver, a Mixed Integer Programming module with cut generation for integer programming problems and a barrier module implementing a state-of-the-art interior point algorithm for very large Linear Programming problems.

XPRESS solves the problem in an organized way with the help of GAMS algorithm and sets the value of all decision variables in an optimum level. It suggests keeping open all the warehouses. The amount which must be shipped from manufacturer to the warehouses according to this solver is represented in Table 12.

Table 12: Quantity Shipped from manufacturer to warehouses (by XPRESS)

	Mongla 1	**Mongla 2**	**Mongla 3**
Manufacturer	910	380	1060

The quantity which has to be shipped from warehouses to the distribution centers by solver XPRESS is noted in Table 13. According to solver XPRESS distribution center (DC) in Khulna should be closed as Khulna zone is very closer to Mongla. The solver suggests sending the cement directly from warehouse to the retailer zones in Khulna.

Table 13: Quantity Shipped from warehouses to distribution centers (by XPRESS)

	Jhenaidah	**Barisal**	**Faridpur**
Mongla 1	370		90
Mongla 3		150	

Here, it is seen that the solver suggests sending the cement to the distribution centers (DCs)only from first and third warehouses. Third warehouse denoted as Mongla 3 supplies cement only to distribution centers (DC) of Barisal.

Very vital outcome of this research is that the company should supply cements the distribution center (DC) of Barisal and Faridpur just to cover the demand of the retailer zones of that area. CPLEX recommends shipping 370 Tons of cement from Mongla 1 to Jhenaidah to cover the demand of the retailer zones of that area and nearby.

It is observed that the amount shipped to Jhenaidah, can cover the demands of 3 retailer zones that are Kustia, Chuadanga and Meherpur. The amounts which are sent from Jhenaidah to Khustia, Chudanga and Meherpur are illustrated in Table 14.

Table 14: Quantity Shipped from distribution centers (DC) to retailer zones (by XPRESS)

	Barisal	**Kustia**	**Chuadanga**	**Meherpur**	**Rajbari**
Jhenaidah		140	130	100	
Barisal	150				
Faridpur					90

Another decision variable in the model is the amount to be shipped directly from warehouses to the retailer zones. Here CPLEX shows that it is effective to conduct most of the shipment directly from warehouse to each retailer zones.

According to XPRESS no warehouse is closed. It should be mentioned that most of the retailer zones are covered by the shipment from third warehouse. The output of XPRESS for this portion is given in Table 15.

After the shipment, the XPRESS shows that the optimum transportation cost in the retailer supply chain is about 2521870 BDT and the output of XPRESS is represented in Figure 6. XPRESS also shows that 2521870 BDT is the best solution of the formulated model.

```
Final objective                        : 2.521870000000000e+06
  Max primal violation      (abs / rel) :       0.0 /       0.0
  Max dual violation        (abs / rel) :       0.0 /       0.0
  Max complementarity viol. (abs / rel) :       0.0 /       0.0
All values within tolerances

fixed LP solved successfully, objective = 2521870.

Integer solution proven optimal.

MIP solution  :    2521870.000000
Best possible :    2521870.000000
Absolute gap  :          0.000000     optca :          0.000000
Relative gap  :          0.000000     optcr :          0.100000

--- Restarting execution
```

Figure 6:Minimized Total Cost (by XPRESS)

Table 15: Quantity Shipped from warehouses to retailer zones (by XPRESS)

	Khulna	**Jhenaidah**	**Faridpur**	**Shatkhira**	**Bagerhat**	**Jessore**
Mongla 1	200					
Mongla 2					110	120
Mongla 3		100	140	100		
	Magura	**Narail**	**Gopalganj**	**Pirojpur**	**Jhalokathi**	**Bhola**
Mongla 1		100	150			

Mongla 2	150					
Mongla 3				100	100	120
	Potuakhali	**Borguna**				
Mongla 3	150	100				

5.3 . Comparison Between the Result of CPLEX And XPRESS Solver

Same mathematical model was solved by using two different solvers which are CPLEX and XPRESS where in both cases GAMS (General Algebraic Modeling System) algorithm is used. There are a lot of similarities with the results of these solvers along with numbers of dissimilarities. All of those are listed as follows:

- As the solved model is same for both solvers, the value of the objective functions is remained same which was 2521870 BDT.
- The main difference is in the number of the warehouses that the company should open. CPLEX solver suggests opening first and second warehouse where XPRESS recommends keeping all the warehouses open.
- As all the warehouses need to be opened by solver XPRESS, a fixed cost of operating warehouses has to be paid by the industry. On the contrary, CPLEX suggests using the next warehouses as if prior warehouses are fulfilled according to their capacity. That is why CPLEX solver may help to reduce the operating cost along with minimizing the total transportation cost within the downstream supply chain.
- Both solvers can work on the same platform of GAMS software without any further installation.

6. Conclusion

In the modern world, industries are very much concerned with every single portion of the entire supply chain system. As the industries are moving towards a sustainable logistics and transportation era, the study will reveal critical information on the application of computational modeling approaches to solve real-world problems. The research work provides a holistic approach to a proper network design that is tightly aligned to the overall supply chain model and corporate strategies to ensure success in today's demanding markets. After all, an excellent network design confirms higher profitability, fewer business risks along with proper management of growth. Mainly the research paper proposes a model to find out the optimum number to be shipped from one point to another of a supply chain network. To verify that model, a data set of renowned cement industry is used. To solve the model GAMS algorithm is used. The problem is solved by two different solvers which are CPLEX and XPRESS. The solvers provide an optimum result of the model, which is the desired task of the paper.

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