Performance analysis of inventory models, distribution and transportation networks in forward supply chain: a theoretical approach

Palvisha Ishtiaq and Syed Mehmood Hassan

Industrial and Manufacturing Engineering Department,
NED University of Engineering and Technology,
P.O. Box 75270,
Karachi, Pakistan
Email: palvisha.zaib@gmail.com
Email: syed.m.hasan@hotmail.co.uk

Sharfuddin Ahmed Khan*

Industrial Engineering and Engineering Management Department,
University of Sharjah,
P.O. Box 27272, Sharjah, UAE
Email: skhan@sharjah.ac.ae
*Corresponding author

Abstract: In the past decade, multiple researchers have focussed on various techniques and models of finished goods inventory, distribution and transportation. This paper emphasises the role of these processes in forward supply chain, according to their requirements and needs as they may occur, to expedite the process. This research is based on a qualitative approach. The study strives to find out and deduce the different segments of forward supply chain and the inter-relation between them. This paper gives a precise description of the usage of tools and techniques that may be most appropriate for the specific combination of multiple situations of forward supply chain of particular firm. As handling finished goods inventory is the initial step of forward supply chain processes and it is the most significant and extravagant factor in an industry as it amounts to 50% of the total capital investment. Then comes the distribution; another driver, which is the main component of contributing to a company’s effectiveness and finally while transportation plays an integral part from the beginning to the end of a supply chain. This research paper is implied to the forward supply chain processes for which finished goods inventory and outbound logistics have been considered. The paper furnishes some realistic suggestions for the inventory, distribution and transportation managers regarding the selection of a feasible model as per their system requirements.

Keywords: distribution network; forward supply chain; inventory management; supply chain management; transportation network.

1 Introduction

Supply chain is a hybrid approach that rotates around and involves the management of incoming raw material to an organisation, manufacturing of finished goods from the raw material (internal processes) and the dispatch of the finished goods to the customer. Term ‘supply chain’ is not limited to a single organisation. It connects the suppliers to manufacturers, manufacturers to distributors, distributors to retailers and retailers to end users; ensuring the fulfilment of consumers supply and demand.

The involvement of different industries and corporations for the exchange of information regarding production potentialities, product availabilities and market wavering is the basic thought behind supply chain management (SCM).

Supply chain significance can be realised by the fact that it is the key factor in meeting the demand of globalisation. SCM system is diverted towards the revenue generation and enhancement of customer value. Normally, SCM emphasises on demand fulfilment, while marketing focuses on demand creation. Hence, the goal of SCM is to formulate the effective and efficient system that can meet marketing strategies.
1.1 Forward supply chain

Forward supply chain is regarded as the system used to deliver the final product to the end user. It comprises of a huge amount of knowledge pertaining to suppliers, dealers, end customers, information system, distribution and transportation of product, etc. Today, the aim of forward supply chain is to increase the accessibility to particular customer needs, while attaining efficiency through standardisation, specialisation and centralisation. The most effective forward supply chain delivers product as sprint and cheaply as possible while maintaining the desired quality level. It can be split into three major sections as shown in Figure 1.

Figure 1  Forward supply chain

1.1.1 Inventory management

One of the most expensive and major belongings of many firm is its ‘Inventory’, which represents about half of the total finance revenue stream. It may be kept as a raw material, work in process (WIP) or a final product. Finished goods inventories are meant to supply a source of good for dispatch to buyer. They are planned to shield against quality matters, differences in machine production rates, scheduling problems, irregularities in lead time demand, labour issues and other production characteristics.

Goods inventory control is crucial for industries in order to survive in a competitive environment. Reducing inventory levels is not always a good choice because sometimes it leads to customer dissatisfaction when stock-outs occur. Thus, industries must ensure a balance between high and low inventory levels. There are several inventory control techniques including different models in which an industry may engage, as shown in Figure 2.
1.1.2 Distribution network

Distribution network is supposed to provide a key that an organisation can use to unlock the competitive advantage. Supply chain cost and customer value both are directly affected by distribution, hence it is said to be a key driver leading to a great degree of profitability to the firm. Designing the best distribution network, one that will increase the flexibility and customer service and decrease capital investment, operating cost and risk, can be quite a challenging task. Many of the supply chain goals ranging from high responsiveness to low cost to have greater efficiency can be accomplished by an appropriate distribution network. Following are the measures that influenced distribution network design:

a. **Response time** (the interval when a buyer receives a shipment and place order).

b. **Product variety** (the amount of non-identical products/configurations that buyer desires from the supply network).

c. **Product availability** (the possibility of having a product inventory when a buyer demand arrives).

d. **Customer experience** (includes that without difficulty the customer can receive and place order).

f. **Order visibility** (ability of the buyer to trace their request from order to delivery).

1.1.3 Transportation network

Transportation is one of the major supply chain’s factors because production and consumption of products occur rarely at a same place. Hence, an appropriate transportation network is one of the secrets of successful supply chain.

The performance of supply chain is affected by the design of transportation network by the formation of substructure within which decisions concerning to routing and scheduling are taken. A good-design transportation network permits the achievement of
Performance analysis of inventory models

desired responsiveness at a low cost. A combined view of distribution and transportation network is shown below in Figure 3.

Figure 3  Distribution and transportation network design (see online version for colours)

1.2  Our contribution

Our contribution of this research paper in supply chain literature can be summarised as follows:

a  This paper emphasises the role of these processes in forward supply chain, according to their requirements and needs as they may occur, to expedite the process.

b  The study strives to find out and deduce the different segments of forward supply chain and the inter-relation between them.

c  This paper gives a precise description of the usage of tools and techniques that are most appropriate for forward supply chain.

d  The paper furnishes some realistic suggestions for the inventory, distribution and transportation managers regarding the selection of a feasible model as per their system requirements.

Reminder of the paper is organised as follows. In Section 2, the literature review of inventory models, distribution and transportation model is discussed. Then in Section 3, calculations and model implementation of forward supply chain is discussed. Finally, conclusion and future research directions are offered in Section 4.
2 Literature review

As a result of globalisation, companies nowadays are facing greater challenges in increasing product variety and amount of customer-adapted products as well as shortening product life cycle (Christopher et al., 2004). It indicates that market has become more turbulent and fragmented. Now the need of time is to deliver products responsively to customers while retaining the cost efficiency. This research has been carried out to combine all models and formulas, utilisation of which proved to be fruitful for any organisation in terms of profit.

Forward supply chain embraces all the steps of distributing and transporting a material right from finished goods inventory to the end user. As supply chain’s motive is to integrate the supplier with all intermediaries working to satisfy the end user with their products, many research projects have been carried out till now with creation of different innovative mathematical models, tables and formulas to solve inventory, distribution and transportation issues of product.

In May 2013, research has been carried out on the coordination contracts within forward and reverse supply chain. The purpose of the research work was to present different types of contracts classification and to define the importance of coordination among all organisations involved in delivering the finished product to the consumer, through contracts. (Savaskan et al., 2013)

In 2016, a research was carried out having a motive to find out the impacts of carbon emissions-sensitive demand on decision regarding the forward supply chain design. In this, design of forward supply chain was examined on the basis that input components were procured from external suppliers and then finished products are manufactured by those components to come up with the demand of customers. The demand was considered to be sensitive to carbon emissions per unit and it was assumed that on decreasing per unit carbon emission demand will be increased. Mathematical models were designed first and then confirmed from one of the textile industries. To obtain optimality, it was deduced that for such kind of product production and consumption area must be located near to each other. However, it was decided that if the customer is willing to pay more amount of product then the carbon emissions per unit might be reduced. (Imen et al., 2016)

Further in May 2016, a research project was done on operational planning of forward and reverse logistic activities on multi-echelon supply chain networks. In this paper, distribution problems of chemical and food industries is highlighted along with recovery of recyclable material. A mathematical model was presented in this which is used for the vehicle (small and large both) that took the dispatched material from plant to desired location and collect the recyclables at lowest network level. Further, the results were computed based on real case study. (Rudolf et al., 2016)

In July 2016, a closed-loop supply chain system was designed that it is the integration of forward and backward supply chain. Demand uncertainty along with returned products was highlighted in the research work. The paper has a motive to maximise profit by two things; integration of both supply chains and waste management. The method presented was also verified from a real case study of tire industry (Ali et al., 2016)

In September 2016, a mathematical framework was designed for flow planning. The model has been designed so that manufacturers and merchandisers can work together to integrate their forward and after sales supply chains. Demand was considered to be volatile. The focus of the paper was also towards the product warranty packages as order
becomes more reliable and unwavering in warranty-sensitive markets (Shabnam et al., 2016).

Researchers are continuously publishing their work on multiple aspects of forward supply chain, which is still in continuation process. As it is said, so that almost all quality improvements come via simplification of design, manufacturing, layout, processes and procedures.

3 Calculations and models implementation

3.1 Inventory control techniques

Inventory control system and planning strategies vary from organisation to organisation. Most commonly used techniques are described below.

3.1.1 ABC analysis

One of the important factors in controlling and managing inventory is ‘inventory ABC analysis’. It is a very efficacious tool for classification and control of inventories. It is the system of categorisation, having similarities with Pareto analysis. It categorises the inventory into three classes as per control scheme.

Most important products are ‘A’, ‘B’ items are significant and ‘C’ items are slightly significant. Hence firm should put maximum control on items which are outstandingly important as compared to other two classes.

3.1.2 Ratio analysis (inventory turnover ratios)

The process of establishing and elucidating various tools is ‘ratio analysis’. Hence, it is one of the robust tools in financial analysis. Inventory turnover ratios include:

a turnover ratios of raw material inventory
b turnover ratios of WIP inventory
c turnover ratios of finished goods inventory

Inventory turnover ratios are helpful in analysing inventory management and are regarded as the measures of company performance. They indicate whether the investment in inventory lies within proper limits or not. Low inventory turn indicates excess inventory, therefore poor sales. High inventory turn is considered to be better and indicates strong sales. A very high inventory turn indicates loss of sales due to shortage in inventory (Rambabu et al., 2014).

\[
\text{Inventory turn} = \frac{\text{Cost of goods sold}}{\text{Average inventory value}}
\]

\[
\text{Raw material inventory turn} = \frac{\text{Raw material consumed}}{\text{Average raw material}}
\]
Work in process inventory turn = \( \frac{\text{cost of goods manufactured}}{\text{Average stock of work in process}} \)

Finished goods inventory turn = \( \frac{\text{cost of goods sold}}{\text{Average goods}} \)

*Implementation of model:* Here, the researcher has considered the research work of the well-known electronics industry of Rambabu et al. (2014), which is one of the technological progressive industries in India, with business interest in power electronics, industrial and automotive batteries, sheet metal products, fasteners and food processing. As in any organisation, the investment in inventory accounts for the most significant working capital, so it needs to be controlled by optimum raw material utilisation or by reducing cost. This industry, being an auto-ancillary, was facing a tough competition in market.

In order to minimise the investment on inventory management, a research was carried out for verification of the proper usage of inventory controlling techniques as per requirements. Data were collected from annual report, schedules, store ledgers, budgets and purchase orders, and comparative analysis was done for ABC technique and turnover ratios on yearly basis. The outcomes and recommendations are given below:

a. Inventory turnover ratio was 6.61 times in the year 2009. Then it decreased 3.69 times in 2010, and then it increased 4.44 times in the year 2011 and then 4.71 times in 2012.

b. The finished goods turnover ratio increased 34.70 times in the year 2011–2012, compared to the year 2008–2009, 32.08 times, which indicates strong sales of AREL.

c. The percentage of value of ‘A’ class items in 2012, i.e. 74.79%, where eventually increased, as compared to the year 2009, i.e. 72.16%, this indicates that the ‘A’ class items receives the most concentration of AREL.

d. The consumption value of ‘C’ class items decreased from 2009 to 2012, i.e. 9.63 to 7.77.

e. By properly following the inventory management techniques, profit of company can be increased.

f. Just-in-time (JIT) technique can be applied to improve sales and reduced cost.

### 3.2 Inventory control models

#### 3.2.1 Single-period inventory model

This type of inventory model is especially used when one time purchase of an item is made, for example, perishable products. This model helps to identify the required amount of product quantity which has to be ordered. Since the product loses its quality in a limited interval of time so special consideration is required about the order quantity in order to avoid over/under stocking.
It is the critical thought to maintain balance of cost according to demand without facing lost.

Calculations: Assuming sales are normally distributed, then,

1. Probability of the product will not be sold is given as:

\[ P = \frac{C_o}{C_o + C} \]

where

- \( C_o \) = overestimated demand of per unit cost
- \( C_u \) = underestimated demand of per unit cost

2. Demand distribution can also be found by finding the Z-score (using a table or by using the NORMSINV function in Excel).

3. Here, safety stock is calculated to face over/understocking. Safety stock can be calculated as:

\[ \text{Safety Stock} = \text{ROUND} \left( Z \text{-score} \times \sigma \right) \]

Here, \( \sigma \) = the standard deviation of units sold over the planning horizon.

4. Total order can be calculated as:

\[ \text{Total order} = \mu + \text{safety stock} \]

Here, \( \mu \) = the average number of units sold over the planning horizon.

Implementation of model: Following are the few well-known examples on which single-period model is implemented.

- a. T-shirts of football match
- b. Newsperson (how much paper that has to be required for sold)
- c. Ordering of fashion items
- d. Flowers sales two multi-period inventory models

3.2.2 Economic order quantity model or fixed order quantity model

This model examines the tradeoff between storage cost and ordering cost in choosing the quantity to use in refill inventories. It is a continuous examination inventory system in which fixed quantity is requested in each schedule as inventory level comes to a particular reorder point.

This model is used for calculating suitable reorder point and an optimal reorder quantity so that inventory can be replenished without shortages. It is based on the following assumptions:

- a. Demand is known and constant
- b. Constant lead time (duration in which order is placed and receipt)
- c. Price per unit product is constant
Calculations: The formula for total cost is (Heizer et al., 2011):

\[
\text{Total annual cost} = \text{Annual purchase cost} + \text{Annual holding cost} + \text{Annual ordering cost}
\]

\[
\text{Total annual cost} = (D \times C) + \left( D \times \frac{C_o}{Q} \right) + \left( Q \times \frac{C_h}{2} \right)
\]

where

- \( D \) = annual demand
- \( C \) = cost per unit
- \( Q \) = quantity to be ordered
- \( C_o \) = ordering cost
- \( R \) = reorder point
- \( C_h \) = annual holding cost per unit of average inventory (often holding cost is taken as a percentage of the cost of the item, such as \( H = iC \), where \( i \) is the percent carrying cost)

\[
\text{Reorder point} = d \times L
\]

where

- \( d \) = average daily demand
- \( L \) = lead time

Optimal order quantity at which cost is minimized:

\[
(Q_o) = \frac{\sqrt{2DC_h}}{C_o}
\]

Implementation of model: Let us consider the case study of a well-known multinational beverage industry, working in Nigeria, evolved as a tool of optimising resources in a manufacturing industry. In terms of sales, company’s performance was highly appreciated and products are widely acceptable.

Following a previous trend, the company was maintaining the bulk inventory of raw material due to which a huge amount of investment was committed on raw material. Finding out the optimal inventory was essential for the company. To address the issue, research was started. Five-year data were collected through interviews of labours, previous records of annual reports and literature review of inventory management. Data analysis was done by using three different existing tools of inventory management optimisation that are simple variance method, economic order quantity (EOQ) inventory model and chi-square method of distribution.

It was observed that the company was not using EOQ model continuously for order placement, due to which in 3 out of 5 years under study, a big difference was encountered in the expected and observed value of each product. Due to the mismanagement, the company had made excessive investment on inventory.
So the recommendation made was the continuous use of EOQ model for order placement as it was found to be the best interest of manufacturing industries, for maintaining an optimal level of materials in warehouse that leads to reduction of excessive inventory cost (Adeyemi et al., 2010).

3.2.3 Fixed interval model (periodic system)

It is the model in which time between orders of replenishment stock is fixed may be weekly, monthly, etc. This inventory model is ‘time-triggered’. It stocks larger inventory in order to protect against stock-out during review period. Depending on usage rates, the order quantity varies from period to period. Fixed interval model is desirable in situations where buyers want to combine orders to save cost or, routine visits of vendors to customers and take orders for their whole line of products.

Calculations: The safety stock that must be reordered is given as (Jacobs et al., 2013):

\[
\text{Safety stock} = z \sigma_{T+L}
\]

The quantity to order is given as:

\[
Q = d(T + L) + z \sigma_{T+L} - I
\]

where

- \(Q\) = quantity to be ordered
- \(T\) = days between review
- \(L\) = lead time (in days)
- \(d\) = average daily demand (forecast)
- \(z\) = number of standard deviations for a specified service probability
- \(\sigma_{T+L}\) = standard deviation of demand over the lead time and review period
- \(I\) = current inventory level (includes items on order)

In this model, the values of \(L, T, d\) can be any time quantity like week, years or days so long as the consistency is maintained throughout the equation. Here, the assumption is that demand is uniformly distributed. The average demand \(d\) can be revised and forecast for each review period, or if appropriate, yearly average may be used.

Implementation of model: Let us consider a case study Changes in performance under various lengths of review periods in a periodic review inventory control system with lost sales.

Demand is one of the factors that adversely affect the determination of replenishment order. This case study examined the effects of revising length of review period in varying demand pattern, while using fixed interval inventory model. In order to achieve better performance, application of appropriate stock strategy at any point of distribution process is necessary. While using fixed interval inventory model, two parameters should be controlled that are interval between inventories review and at each analysis period and how much the inventories may be elevated.

For selecting a suitable interval for analysis period in a periodic system, a simulation method under different period’s length was used. Five levels of average demand, eight
levels of period length and four levels of standard deviation are determined. It was assumed that the functions of demand are uniformly distributed and their mean and standard deviation are deterministic. Products are classified on the basis of their standard deviation and mean value. Total 640 simulations were carried out. Review period was also considered to be longer than supply lead time, and complete shipment was assumed to be dispatched at the same time (Sezen et al., 2006).

The formula obtained for order up to level is given as:

\[ S = \mu \cdot R + k \cdot \sigma \]

where

- \( R \) = length of review period
- \( \mu \) = mean demand per unit time
- \( \sigma \) = standard deviation of demand
- \( k \) = safety factor in order to obtain service up to 95%

It was deduced from the study that as the length of review period decreases, average inventory also decreases. Also the risk of long-lasting stock-outs increases when a review period is longer for highly fluctuating demand. Shorter review periods are suggested for such scenarios. Also it was suggested that fast-moving items should have shorter review period and slow-moving items should have longer review period as it is less risky. Also, for one time-unit length, higher safety stocks should be kept by an organisation in order to remain safe from long-lasting shortages.

3.2.4 Economic production quantity

To minimise the total cost that is the inventory holding cost and setup costs for the machines, the quantity of product should be manufactured in a single batch. This optimal quantity of product is calculated by using economic production quantity (EPQ) inventory model.

In this case, firms are producing one product at a time at the production rate \( p \) or receiving shipment over uniform period time. As material is not received instantaneously, for this production capacity of firm must be greater than the demand. Assumption for this model is approximately same as EOQ model. Order cost is replaced by setup cost.

**Calculations:** The formula for total cost is (Heizer et al., 2011):

\[
\text{Total cost} = \text{Total setup cost} + \text{Total carrying cost} + \text{Total production cost}
\]

\[
\text{Total cost} = \left( \frac{D}{Q} \times C_s \right) + \left\{ Q \left( \frac{1 - \frac{d}{2p}}{2} \right) \times C_h \right\} + P \times D
\]

Optimal order/production quantity, at which cost will be minimum, can be calculated as:

\[
\text{Optimal order / production quantity (Q)} = \sqrt{\frac{2DC_s}{C_h \left( 1 - \frac{d}{p} \right)}}
\]
where
\( P = \) daily production rate  
\( d = \) daily demand  
\( Q = \) optimum order/production quantity  
\( C_h = \) holding cost  
\( C_s = \) setup cost  
\( D = \) demand rate

For multiple products made on the same plant or machines:

a. Compute Production Order Quantity (POQ), cycle time and run time for each product.
b. Find a common cycle time for all products.
c. Recalculate run time and cycle time, so the common cycle time is a multiple of each product’s cycle time.
d. Fit production runs into largest cycle time.

*Implementation of model:* The research revealed a modified EPQ model based on stochastic demand, for single item, with the objective to maximise the profit by optimal production quantity. In this model, inventory positions along with demand are combined with shortage, production, holding costs and sales price in order to yield profit. Sales price and inventory restock interval are uniformly fixed. Usually two problems are faced in achieving objective that is determining product EPQ and optimum profit when demand is uncertain. However, at the start of each interval, there is a need to decide either to produce new unit or utilise available inventory. When demand is less than or equals to, on-hand inventory production is cancelled.

The demand is classified as favourable \((F)\) or unfavourable \((U)\). In two-interval planning, the optimal EPQ found for each interval is given by:

1. When demand is favourable,  
   \[
   Z = \begin{cases} 
   1 & \text{if } v_F^i > v_F^0 \\
   0 & \text{if } v_F^i \leq v_F^0 
   \end{cases}
   \]
   \[
   g_F(z) = \begin{cases} 
   v_F^i & \text{if } Z = 1 \\
   v_F^i & \text{if } Z = 0 
   \end{cases}
   \]

   and  
   \[
   E_F^z = \begin{cases} 
   (D_F^i - I_F^i) + (D_U - I_U) & \text{if } z = 1 \\
   0 & \text{if } z = 0
   \end{cases}
   \]

2. When demand is unfavourable,  
   \[
   Z = \begin{cases} 
   1 & \text{if } v_U^i > v_U^0 \\
   0 & \text{if } v_U^i \leq v_U^0 
   \end{cases}
   \]
   \[
   g_U(z) = \begin{cases} 
   v_U^i & \text{if } Z = 1 \\
   v_U^i & \text{if } Z = 0 
   \end{cases}
   \]
and 

\[
E^z_y = \begin{cases} 
(D_{UF}^1 - I_{UF}^1) + (D_{UV}^1 - I_{UV}^1) & \text{if } z = 1 \\
0 & \text{if } z = 0 
\end{cases}
\]

where ‘\(Z\)’ is the production lot sizing policy, ‘\(D^z_y\)’ is quantity demanded, ‘\(\nu^z_y\)’ is expected profits and ‘\(E^z_y\)’ is EPQ.

The mathematical model defined above was then adopted by a manufacturer of mattresses in Uganda. In this, demand of mattresses varies on monthly basis. The motive of this company was to avoid the under and or overproduction depending on demand situation.

Keeping in mind the purpose, a sample of 60 clients was taken. Model was implemented as an EPQ over a 2-week period. Results are calculated for both favourable and unfavourable demands. The outcome of this complete process was achievement of optimal production quantity and increased profit (Mubiru et al., 2015).

3.2.5 Just-in-time

Just-in-time is the philosophy introduced by the Japanese that helps the firm to reduce their inventory and only to make products according to their need. According to this philosophy, inventories (i.e. WIP, finish good or raw material) are considered as liabilities rather than assets.

JIT aims at the elimination of wastes for refinement of productivity and product quality. It is accomplished by repeated deliveries of goods in small lot sizes. Small lot sizes lower inventory, scrap and inspection costs and increase flexibility and product quality.

It is essential for service industries also to implement JIT to compete effectively in the market by providing high-quality service at a competitive cost. JIT implementation can help service industries to enhance their efforts and activities that results in a progressive position in the competitive marketplace.

\textit{Implementation of model}: Let us consider the case, namely “Benefits Derived from JIT by European Manufacturing Companies”. This is the research carried out to find the JIT implementation in Europe-based industries and advantages obtained by adopting this model.

Keeping in mind the purpose, two separate enquiries were carried out that included the distribution of a postal questioner among 600 industries in Europe and an arrangement of a number of case studies session followed by interviews of respondents of the companies that were sent questionnaires. Out of 600, 93 questionnaires were received back, of which 66 were completely filled. Collected data were then converted in the form of tables.

It was observed at the end of research that companies following JIT had reduced their inventory levels and space, buffer stocks and WIP. For example, one of the companies had reduced its inventory levels from 130 to 50 m, which means a huge amount of cost saving and efficient production. It was also deduced that lead times and setup times of mostly companies decreased drastically. For example, one of the companies reduced its lead time from 40 days to 1 day and setup time from 8 to 2 h.
Hence, a result-based suggestion was provided at the end of the research that adoption of JIT depending upon the environment and surroundings is beneficial for the survival of companies which are holding a huge amount of inventories (Kazazi et al., 1994).

### 3.3 Performance characteristics of discussed inventory model

Based on the above-mentioned discussion and analysis of different inventory models, we are now able to summarise the performance characteristics of inventory models. Table 1 below shows the characteristics of different inventory models.

**Table 1  Performance characteristics of inventory models (see online version for colours)**

<table>
<thead>
<tr>
<th>Demand</th>
<th>Order-based classification</th>
<th>Average inventory</th>
<th>Storage capacity</th>
<th>Cost</th>
<th>Production design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed order size</td>
<td>Fixed order interval</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>EOQ</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>EPQ</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Fixed time period model</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Single-interval model</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Just in time</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

*Key: ‘✓’ shows that particular option is suitable for mentioned condition.*

### 3.4 Distribution network design

There are six different distribution network designs that are supposed to provide appropriate solution of any organisation’s problems.

a. manufacturer storage with direct shipping
b. manufacturer storage with direct shipping and in-transit merge
c. distributor storage with package carrier delivery
d. distributor storage with last mile delivery
e. manufacturer/distributor storage with customer pickup
f. retail storage with customer pickup

#### 3.4.1 Manufacturer with direct shipping

In this type of distribution network, demand is generated through retailer, and the product is directly shipped to the end customer by the manufacturer. Manufacturers are informed
of product demand by the retailer, while customer received the product by the manufacturer directly.

Since the manufacturer directly shipped the product to the end customer, it is simply called drop-shipping. Due to use of this method, manufacturer does not need to bear high level of inventory. In this type of distribution, retailers are responsible to convey the online information from the customer to the manufacture so that high level of variety can get the customers.

Supply chain helps out to save the fixed cost as all inventories are located at centralised warehouse due to which handling cost is reduced. Due to average distance of outbound shipment, transportation cost is significantly increased. This model is convenient for high value items of low demand and huge variety, for which buyers are ready for late delivery and accept partial deliveries. This model is perfect for direct sellers that are able to build-to-order. Figure 4 is the perfect illustration of the model.

**Figure 4** Manufacturer storage with direct shipping (see online version for colours)

*Source:* Chopra, Meindl and Kalra, 2001

*Implementation of model:* The model was implemented by different online retailers and companies. ABC online retailer adopted drop-shipping model for delivery of its slow-moving products to the end user by storing little amount of inventory. ABC online retailer stated that because of using this model, end user response time lies between 4 and 16 days including order processing and ground transportation (Chopra et al., 2001).

3.4.2 Manufacturer storage with in-transit merges

In in-transit merge, customer gets a single delivery by combining pieces of order from different locations. The remarkable benefit of in-transit merge is the aggregation of inventories and delay of customisation. Additional effort during the merging is its drawback. Reduced transportation cost and improved customer experience is the main benefit of this model over drop-shipping. Its coordination and implementation become more and more difficult as the sources increases. It is best for four to five sourcing locations, where every customer orders multiple products from different locations. In-transit merge require advance information infrastructure for this higher investment will be needed. Manufacturer, retailer and carrier must be in coordination. Initially, it is difficult to set because it requires integration. Returnability is similar to drop-shipping; it is difficult and expensive to implement reverse supply chain with drop shipment. Figure 5 is the pictorial representation of the model.
Performance analysis of inventory models

Figure 5  In-transit merge network (see online version for colours)

Source: Chopra, Mcindl and Kalra, 2001

Implementation of model: The model presented above was implemented by different companies. In 1984, Michael Dell founded ABC Company. Computer technology company ABC had a business of selling, supporting and repairing of computer and computer-related products. It realises the importance of supply chain for success in current business world and takes competitive advantage in market. It uses direct shipping model which was different from its competitors. According to this model, PC was selling directly to customer, without using retailer. ABC was able to acquire huge profit and competitive advantage due to efficient supply chain. It hold just 6-day inventory and follow JIT (Chopra et al., 2001).

3.4.3 Distributor storage with carrier delivery

In this model, the inventory is hold by retailers or distributors in transitional warehouses and the goods are delivering to customers from the transitional location through package carriers. This model is utilised for high demand. Inventory is much less at the distributor’s end as compared to retail network. The model is further explained by Figure 6.

Figure 6  Distributor storage with carrier delivery (see online version for colours)

Source: Chopra, Mcindl and Kalra, 2001

Since economic mode of transportation (i.e. truckload) is used, it lowers the transportation cost. The truck carries load to the intermediate warehouse which is close to the customers due to which, the response time is better. Distributor storage transports the
outbound orders to the customers in the bundled form in a single shipment rather than in multiple shipments (as done by manufacturer storage model), which further decreases transportation cost. Due to high facility cost, distributor storage is not suitable for extremely slow-moving items. The information infrastructure of distributor storage model is less complex. The distributor warehouse acts as a buffer between the customer and the manufacturer. It requires real-time visibility between customers and the warehouse, while real-time visibility between the customer and manufacturer is not required. Distributor storage model is more convenient for customers because of its responsiveness and single shipment delivery. However, it provides low variety than manufacturer storage but can provide more variety than retail stores.

*Implementation of model:* This model has been used in combination with drop-shipping by many industrial distributors. XYZ an online store was launched in 1994. IT Blue-rays, DVD’s, video downloads/streaming, CDs, software, MP3 downloads/streaming, electronics, video games, furniture, apparel, food, toys and jewellers, etc. It stocks slow-to-fast-moving items with more slow-moving items. The company grew up astonishingly till now, overcoming all the hardships. Initially, it had two fulfilment centres in New York and gradually expanded itself in all over the USA, European countries and now Asian country (India) also. It currently operates 148 distribution centres around the world (including sortation centres, fulfilment centres, returns centres, redistribution centres, etc.). XYZ follows both push system as well as pull system. XYZ.com collects the order from the customer and forwards this order to the affiliated supplier who ships the order to the customer. Thus the company became the leading online company which delivers the product through package carriers (Chopra et al., 2001).

### 3.4.4 Distributor storage with last-mile delivery

In this model, the distributor or retailer delivers the product to the customer’s home. It is more applicable in automotive spare parts delivery as it is too expensive to hold spare parts in inventory. It requires distributor’s warehouse much more close to the customer. It requires the highest levels of inventory due to lowest level of aggregation. It is preferable for fast-moving items.

Though this model consumes highest transportation cost, specifically while delivering to individuals because of uneconomic transportation mode. However, delivery cost is justifiable as customer is willing to get bulky products at home. The model is further explained by Figure 7.

**Figure 7** Distributor storage with last-mile delivery (see online version for colours)

![Figure 7](see online version for colours)

*Source:* Chopra, Mcindl and Kalra, 2001
Implementation of model: The model was implemented by many companies. The 123 company tried to deliver the order same day, while online grocers take a 1 day time in order delivery. It used the existing grocery store and labour to provide home delivery. Grocery store is used for both purposes that are replenishment centre for grocery store and fulfilment centre of online orders. This idea proved to be helpful in lowering the cost of services while improving utilisation of facility (Chopra et al., 2001).

3.4.5 Manufacturer/distributor storage with customer pickup

In this distribution technique, inventory is stored by distributor or manufacturer in his warehouse. Customers place their orders on phone or online and then travelled to specified pickup points to collect their orders. Depending upon need, orders are shipped from warehouse to selected pickup points. In this truckload and less-than-truckload carriers are used to transport order to pickup points. If new pickup sites are required to build then facilities cost will increase. Good coordination among the storage location, the pickup point and the retailer. Due to this, information cost will increase.

The benefit of this network is that it saves the delivery cost and enlarges the set of products sold. The drawback in this is the increase in handling cost and complexity at pickup locations. This network is most suitable when existing retail locations are used as pickup sites. The information and product flow are shown in Figure 8.

![Figure 8](image_url)

Implementation of model: ABC Company stores fast-moving products at pickup locations, i.e. retail outlets; whereas slow-moving products are stored at manufacturer warehouse. In the case of XYZ Company, the industry’s supply chain is based on efficiency and effectiveness. It has a distribution centre where product is received from the manufacturer on daily basis, is cross-docked and delivered to its retail outlets. The use of this distribution model has improved the utilisation of present logistical assets (Chopra et al., 2001).
3.4.6 Retail storage with customer pickup

This approach holds the inventory at retail store. Customers place order on phone or online, or walks in the store to buy desired products. Inventory cost significantly increases for fast to very fast-moving items, due to the absence of aggregation. The benefit of such type of system is that the delivery cost significantly decreases with an increase in responsiveness. The drawback of system is the increase in inventory and facility cost. Such distribution network is the most suitable for fast-moving products or for the responsive products delivery.

Implementation of model: In the case of ABC Company, customers order online or via phone, and receive their orders from its retail outlets. Another example is ABC supermarket, which is one of the largest grocery markets in Pakistan in which customers walk in and buy their desired items. It stores a huge amount of inventory in its retail store (supermarket) hence offering a great benefit to customers and saving a huge amount of cost. In Table 2, different distribution networks are compared with each other and ranked along different measures of performance.

<table>
<thead>
<tr>
<th>Performance characteristics of distribution network design (see online version for colours)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost factors</strong></td>
</tr>
<tr>
<td><strong>1. Manufacturer storage with direct shipping</strong></td>
</tr>
<tr>
<td>Inventory</td>
</tr>
<tr>
<td>Transportation</td>
</tr>
<tr>
<td>Facilities and handling</td>
</tr>
<tr>
<td>Information</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

| **2. Manufacturer storage with direct shipping and in-transit merge** | | | |
| **Inventory** | Similar to drop-shipping | Response time | Similar to drop-shipping; may be marginally high |


Table 2  Performance characteristics of distribution network design (see online version for colours) (continued)

<table>
<thead>
<tr>
<th>Performance characteristics of distribution network designs</th>
<th>Cost factors</th>
<th>Performance</th>
<th>Service factors</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Somewhat lower cost as compared to drop-shipping</td>
<td>Product variety</td>
<td>Similar to drop-shipping</td>
<td></td>
</tr>
<tr>
<td>Facilities and handling</td>
<td>Higher than drop-shipping</td>
<td>Customer experience</td>
<td>Better than drop-shipping</td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td>Higher investment as compared to drop-shipping</td>
<td>Product availability</td>
<td>Similar to drop-shipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time to market</td>
<td>Similar to drop-shipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Order visibility</td>
<td>Similar to drop-shipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Returnability</td>
<td>Similar to drop-shipping</td>
<td></td>
</tr>
</tbody>
</table>

3. Distributor storage with carrier delivery

| Inventory                      | Higher than manufacturer storage | Response time | Faster than manufacturer storage |
| Transportation                 | Lower than manufacturer storage  | Product variety | Lower than manufacturer storage |
| Facilities and handling        | Somewhat higher as compared to manufacturer storage | Customer experience | Better as compared to manufacturer storage |
| Information                    | Simpler infrastructure as compared to previous one | Product availability | Availability requires higher cost |
|                                                               |                                                           | Time to market | More time as compared to manufacturer storage |
|                                                               |                                                           | Order visibility | Easy as compared to manufacturer storage |
|                                                               |                                                           | Returnability | Easy as compared to manufacturer storage |

4. Distributor storage with last-mile delivery

| Inventory                      | Higher than previous one | Response time | Very quick. Same day delivery is possible |
| Transportation                 | Highest among all options | Product variety | Less than distributor storage with package carrier |
| Facilities and handling        | Higher than manufacturer storage | Customer experience | Very good |
Table 2  Performance characteristics of distribution network design (see online version for colours) (continued)

<table>
<thead>
<tr>
<th>Cost factors</th>
<th>Performance</th>
<th>Service factors</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>Similar to previous one</td>
<td>Product availability</td>
<td>More expensive as compared to all options except retail stores</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time to market</td>
<td>Slightly higher than previous one</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Order visibility</td>
<td>Easily implementable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Returnability</td>
<td>Easily implementable</td>
</tr>
</tbody>
</table>

5. Manufacturer/distributor storage with customer pickup

| Inventory                    | Depending on location, can match any other option | Response time | Same to package carrier delivery or distributor storage |
| Transportation               | Lower than use of package carrier               | Product variety | Same as others |
| Facilities and handling      | Handling cost increases at pickup site. Lower facility cost if existing facilities are used | Customer experience | Lower than other options because of lack home delivery |
| Information                  | Significant investment in information infrastructure | Product availability | Same as others |
|                              |                                            | Time to market | Similar to manufacturer storage option |
|                              |                                            | Order visibility | Difficult but necessary |
|                              |                                            | Returnability | Easier |

6. Retail storage with customer pickup

| Inventory                    | Higher than all other options                | Response time | Same day (immediate) pickup |
| Transportation               | Lower as compared to others                  | Product variety | Lowest among all options |
| Facilities and handling      | Highest among all options                    | Customer experience | Depends upon customers’ view |
| Information                  | Some interest in framework is needed for online and phone orders | Product availability | More expensive than others |
|                              |                                            | Time to market | Fastest time to market as compared to others |
|                              |                                            | Order visibility | Difficult, but necessary |
|                              |                                            | Returnability | Easiest among all options |
3.4.7 Selection of distribution network design

In distribution network design, network requirements as well as product characteristics both should be considered. The companies which are in their ideal condition use only one network. Combination of delivery networks is perfectly suitable for most of the industries. Table 3 is presented below which identifies networks which are not suitable for the mentioned different conditions, depending on the product. Table 4 determines that which model is suitable for different market conditions. Figure 9 shows the ranking of these distribution networks in terms of efficiency and responsiveness.

Table 3 Comparative performance of distribution network design (see online version for colours)

| Source: Chopra, Meindl and Kalra, 2001 |
| Key: ‘✓’ shows that particular option is not suitable. |

<table>
<thead>
<tr>
<th>Demand of the product</th>
<th>Product value</th>
<th>Product sources</th>
<th>Customer effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Very low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Suitability of distribution networks in different conditions (see online version for colours)
Table 4  Suitability of distribution networks in different conditions (see online version for colours) (continued)

<table>
<thead>
<tr>
<th>Demand of the product</th>
<th>Product value</th>
<th>Product sources</th>
<th>Customer effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Distributor storage with carrier delivery</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Distributor storage with last-mile delivery</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Manufacturer/distributor storage with customer pickup</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Retail storage with customer pickup</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Key: ‘✓’ shows that particular option is suitable for mentioned condition.

3.5 Transportation network design

There are five different transportation network designs that are supposed to provide feasible solution to any organisation’s problems.

a. direct shipment network to single destination
b. direct shipping with milk runs
c. all shipment via intermediate distribution centre with storage
d. all Shipment via intermediate transit point with cross-docking
e. shipping via DC using milk runs

3.5.1 Direct shipment network to single destination

In this transportation network, buyer receives all shipments directly from suppliers. Each shipment route is specified while the mode and quantity of shipment is decided by supply
Performance analysis of inventory models

chain manager. The significant advantage of this network is the simplicity of operations, eradication of intermediate warehouse and easiness of the coordination. In this, decision is made on local basis and short transportation time due to direct shipment. The network is suitable in condition when demand of buyer is large enough that optimal replenishment lot size must be equal to the truckload from each supplier to each buyer. The information and product flow is shown in Figure 10.

Figure 10  Direct shipment network (see online version for colours)

Implementation of model: The model presented above was implemented by a retailer who started the business in 2002 with large stores, in which order arrived was large enough that directly comes from supplier locations. Ordering was managed locally within the store. But when it moved towards small stores, the model requirement was changed significantly, as there were not enough orders to defend direct shipment (Chopra et al., 2001).

3.5.2 Direct shipping with milk runs

Milk run is a path in which pickup delivers product of a single supplier to various retailers or move from various suppliers to a single customer location. In this model, either one supplier delivers directly to various retailer of lorry pick from different suppliers for single customer. For this method, milk run for each path should be decided by executive.

The advantage of milk run is it reduces transportation cost. It is useful when quantity of each supplier location is too small to fill the lorry and suppliers are closely located to each other such that their combined product utilises maximum lorry space. Figure 11 explains the model in a better way.

Source: Chopra, Meindl and Kalra, 2001
Implementation of model: ABC Company uses milk run system to sustain JIT manufacturing system by continuous small deliveries in both USA and Japan, which are required on regular interval and suppliers or retailers are located closely to reduce transportation cost. Various assembling plants are located close to each other in Japan, so they utilises milk run from a single supplier to various plants. While in USA, it uses milk run system from different suppliers to each assembly plant (Chopra et al., 2001).

3.5.3 All shipments via DC with storage

In this model, suppliers ship the products to a central distribution centre where it is stored for a while then it is shipped to each buyer locations when needed. This model is also essential for the heavy shipments in the inbound side when large quantity of product is stored in a DC as an inventory and then shipped to buyer locations in small lots when needed. DC is located close to the final destination which reduces the outbound transportation cost. This model reduces the transportation cost at the suppliers’ end which would occur by supplying each store directly as well as it reduces inventory at the buyer locations due to small lot shipments. Figure 12 is the perfect illustration of the model.

Figure 11 Milk runs from different suppliers to different buyer locations (see online version for colours)

Source: Chopra, Meindl and Kalra, 2001

Figure 12 All shipments via DC (see online version for colours)

Source: Chopra, Meindl and Kalra, 2001
Implementation of model: XYZ Company is known for conveying the most elevated quality items to its more than 2 million clients around the world. Its suppliers ship the products to its distribution centre in large quantities, from where they are shipped to nearby stores in smaller quantities (Chopra et al., 2001).

3.5.4 All Shipment via intermediate transit point with cross-docking

In this transportation technique, there exists an intermediate transit point (could be a DC), where shipments from different suppliers are cross-docked and sent to buyer locations. Each inbound truck from suppliers carry product for different buyers, and each outbound truck carries product from various suppliers to buyers.

The advantage of cross-docking is the very little inventory storage at the facility. Hence the faster supply chain can be obtained. This model is appropriate when the inbound and outbound side coordination is simple, also when the economies of scale on both sides of transportation are achievable.

Implementation of model: ABC Company has a DC Chicago from which it delivers its products to the customers of northern and western outskirts using milk runs. But when it increased his reach to other cities, it applied the cross-docking system which is proved to be more efficient, as both the markets are small enough to uphold milk run system via DC. Large trucks were utilised for delivery to local cross-dock facility, while small trucks were used for delivery to local markets. Hence, by adoption of cross-docking, ABC Company saved a large amount of cost as no storage was required at any location (Chopra et al., 2001).

3.5.5 Shipping via DC using milk runs

In this approach, milk run system is used from DC with a condition that lot size for each buyer location should be small. In this way, outbound cost is reduced by the integration of small shipments. A significant improvement in coordination is needed for the implementation of this model. Also routing and scheduling should be carefully handled. The information and product flow is best explained by Figure 13.

Figure 13 Shipping via DC using milk runs (see online version for colours)

Source: Chopra, Meindl and Kalra, 2001
Implementation of model: In the case of XYZ Company, fresh food supplies are cross-docked and sent to different buyer locations (retail outlets) in small shipments using milk runs. This model helped in reducing its transportation cost. The performance characteristics of models are shown in Table 5 (Chopra et al., 2001).

Table 5 Performance characteristics of transportation models (see online version for colours)

<table>
<thead>
<tr>
<th></th>
<th>Inventory cost</th>
<th>Transportation cost</th>
<th>Coordination requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Direct shipping</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Direct shipping with milk runs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>All shipments via central DC with inventory storage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>All shipments via central DC with cross-dock</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Shipping via milk runs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Key: ‘✓’ shows that particular option is suitable for mentioned condition.

4 Conclusion

Forward supply chain offers a competitive edge and reveals the secret to market success. It encompasses all the steps of distributing a material right from finished goods inventory to the consumer thus acting as a bridge. However, executing the task of conceptualising such a network that decreases the capital investment, operating cost and risk is challenging. Therefore, this research intends to escalate the forward supply chain concept and related models over the industrial horizon. The tables represented in each section of this paper will help industries to select the most appropriate model depending upon their requirements. These models have been devised considering different combination of situations. This paper gives a precise description of the usage of tools and techniques that may be most appropriate for the specific combination of multiple situations of forward supply chain of particular firm. Adoption of the optimised model will minimise the total cost and maximise the customer flexibility and service, which in turn will enlarge the companies’ surplus. Hence forward supply chain is a way for industries to leverage its key resources.
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References


