In today’s era of supply chain, growing competence among suppliers together with well organized transportation networks making it more versatile and ensures better communication between buyers and suppliers with more cost effective movement of goods in shortest possible times. Suppliers frequently offers discount schedules based on all units model, which divides the range of possible order quantities into intervals with progressively lower unit costs , [Rubin & Benton, (2003)]. Transporters these days are looking for more innovative ways to attract customers by thriving to satisfy their ever increasing demand of cost effective transportation by offering freight policies such as truck load (TL) and less than truck load (LTL).

The few studies performed on the subject of quantity discounts and freight also reveal interesting results. Shina and Benton (2007) quoted that quantity discounts provide a practical foundation for inventory coordination in supply chains. The main objective of this study is to develop a quantity discount model that resolves the practical challenges associated with implementing quantity discount policies for supply chain coordination between a supplier and a buyer Munsona and Hub (2010) analyzed that Multi-site organizations must balance conflicting forces to determine the appropriate degree of purchasing centralization for their respective supplies. The ability to garner quantity discounts represents one of the primary reasons that organizations centralize procurement. Li and Liu (2006) examined that if both the buyer and supplier can find a coordination mechanism to make joint decisions, the joint profit in this situation is more than the sum of their profits in the decentralized decision situation. They show that quantity discount policy is a way that may be implemented to achieve coordination.

Darwish (2008) emphasised that, transportation costs has enhanced the need to develop models with transportation consideration explicitly. However, in stochastic inventory models, the transportation cost is considered implicitly as part of fixed ordering cost and thus is assumed to be independent of the size of the shipment. Swenseth and Godfrey (2002) included freight rate discounts on ordering decision when over declaring a shipment is possible to exploit a smaller unit transportation cost. Freight rate discounts depending on shipment size has become a common practice. Many companies rely on the third party carrier for transportation of goods from supply location to retail or consumption point Burks et al., (2004) quoted that TL firms have almost three times as many large trucks as LTL firms and operate more than three times the annual total miles, a consequence of the fact that TL firms use their vehicles more intensely (mean annual miles) than LTL firms. Pooley, (1993) explores the carrier selection problem of choosing either a LTL or a multiple-stop TL motor carrier to deliver products. Specifically the paper presented a methodology for analyzing the cost implications of different carrier selection decisions.

The chapter consists of two sections. The models in Section I are targeted towards computing optimal order for integrated procurement-distribution problem. It incorporates quantity discounts and freight policies for multi items that are perishable in nature, which are supplied from single source to various destinations. It is assumed that there is finite planning horizon and dynamic demand to make ordering decisions. We have considered all unit and incremental quantity discounts as a base model with two freight policies. In distribution system, two modes of transportation are used namely TL and LTL. A finite planning horizon is assumed when demand is dynamic for multiple perishable items. It is supposed that there is constant rate of deterioration as a percentage of defective items of the stored units (ending inventory) which incurs a constant rate of inspection. Section II incorporates quantity discounts and freight policies for multi items that are perishable in nature, which are supplied from single source to multiple destinations under fuzzy environment. It is assumed that, there is finite planning horizon on which demand and total costs are fuzzy in nature. A fuzzy optimization problem is converted to crisp mathematical programming problem using membership function. The real life cases are discussed to validate the procedures.
3.1 PROCUREMENT DISTRIBUTION COORDINATION FROM SINGLE-SOURCE TO MULTIPLE-DESTINATION FOR PERISHABLE PRODUCTS

3.1.1 Problem Description & Formulation

This section discusses the current problem in a chain of hospitals and formulates a mathematical model based on the description.

3.1.1.1 Problem Description

A problem is studied on a chain of cancer hospitals which has four major hospitals in one of the big cities of Canada and uses nuclear medicines to treat their patients suffering from bone cancer. As nuclear medicines are very specialized and rare, they can be purchased from specialized suppliers having privileges and permissions from the government to sell these sophisticated medicines. Four types of nuclear medicines ‘Technetium-99m’(99m), ‘Iodine -123’(123), ‘Thallium-201’(201), and ‘Gallium – 67’(67) are procured for the four hospitals (H1, H2, H3 and H4)in the city. Due to perishable nature, medicines are sealed in specialized cartons which need specialized care in terms of vibrations, temperature etc. during transportation. Due to this, supplier gives discounts on the bulk purchase of the medicines. Even while using the best transportation methods there is inevitable decay of at least 5% per lot with inspection cost of 40, 40 , 45 and 55 dollars for four product’s carton respectively that is approximately 10% of the purchase cost of the medicines. Transporter, also offers various freight policies like TL, LTL and combination of two to transport the cartons of medicine from source to four hospitals with proper handling and care with each truck carrying 500 kgs. The cost for sending the cartons on per kg basis is $6, while the weights for four product’s carton are 2, 2, 4, 4 kilograms respectively.

The hospital is interested in managing the holding cost on medicines, the inspection cost (as they requires special care, periodic inspection and environment for the storage), procurement cost and transportation cost to optimize the purchase quantity which can give maximum possible advantage. The data pertaining to various costs during the procurement, carrying the medicines, inspecting and distribution of medicines incurred for first four months (periods), which can be used to analyze and help hospitals to reduce their costs is given in Appendix B (Table 3.1.1 – 3.1.5)
3.1.1.2 Assumptions

1) Demand is dynamic
2) Supply is instantaneous i.e. no shortages are allowed
3) Initial inventory of each product for the beginning of planning horizon is zero.
4) Two modes of transportation are used, namely truck load (TL) and less-than truckload (LTL)
5) Constant rate of deterioration for perishable items, as a percentage of defective items of stored units.
6) Constant rate of inspecting the multiple perishable items.

3.1.1.3 Sets

• Product set with cardinality $P$ and indexed by $i$.
• Period set with cardinality $T$ and indexed by $t$.
• Quantity discount break point set with cardinality $L$ and indexed by small $l$.
• Destination set with cardinality $M$ and indexed by $m$.

3.1.1.4 Decision Variables

$X_{it}$ amount of item $i$ ordered in period $t$
$R_{ilt}$ If the ordered quantity falls in $l^{th}$ price break then the variable takes value 1 otherwise zero
$I_{it}$ Inventory level at the end of period $t$ for product $i$
$IN_i$ Inventory level at the beginning of planning horizon for product $i$
$\delta_{mt}$ Total weighted quantity transported in period $t$ to destination $m$
$\alpha_{mt}$ Total number of trucks in period $t$ to destination $m$
$y_{mt}$ Amount in excess of truckload capacity (in weights) at $m^{th}$ destination in $t^{th}$ period.
$u_{mt}$ Reflects usage of either both TL and LTL policies or only TL policy

$$u_{mt} = \begin{cases} 
1, & \text{if considering TL and LTL both} \\
0, & \text{otherwise} 
\end{cases}$$
3.1.1.5 Parameters

\[ C \text{  Total inventory cost} \]
\[ \beta_{mt} \text{  Fixed freight cost for each truck load for destination } m \text{ in period } t \]
\[ D_{imt} \text{  Demand for item } i \text{ in period } t \text{ for destination } m \text{ in period } t \]
\[ h_i \text{  Inventory holding cost per unit of item } i \]
\[ w_i \text{  Per unit weight of product } i \]
\[ a_{ilt} \text{  Quantity threshold beyond which a price break becomes valid in a period } t \text{ for product } i \text{ for } l^{th} \text{ price break} \]
\[ d_{ilt} \text{  Discount factor that is valid if more than } a_{ilt} \text{ unit are purchased, } 0<d_{ilt}<1 \]
\[ d_f \text{  Discounted slab} \]
\[ \omega \text{  Weight transported in full truckload} \]
\[ \phi_{it} \text{  Unit purchase cost for } i^{th} \text{ item in } t^{th} \text{ period} \]
\[ s \text{  Cost of shipping a weighted quantity in LTL mode} \]
\[ m_i \text{  Rate of inspection of the } i^{th} \text{ item} \]
\[ \eta \text{  Percentage of the defective items of the stored units} \]

3.1.1.6 Quantity Discounts

Quantity Discount slab for the ordered products are defined as:

\[
d_f = \begin{cases} 
  d_{ilt} & a_{ilt} \leq X_{ilt} \leq a_{i(l+1)t} \quad \text{where} \quad i = 1, \ldots, P, \quad l = 1, \ldots, L, \quad t = 1, \ldots, T \\
  d_{iLT} & X_{ilt} \geq a_{iLT} 
\end{cases}
\]

As discussed above, \( d_{ilt} \) specifies the fact that when the order size at period \( t \) is larger than \( a_{ilt} \), it results in discounted prices for the ordered products.

3.1.1.7 The Mathematical Formulation

The model for integrated procurement-distribution all-unit discount problem is given as:
Min \( C = \sum_{t=1}^{T} \left[ \sum_{i=1}^{P} \left( h_i^{I_{it}} + m_i^{X_{it}} + \sum_{l=1}^{L} R_{ilt} d_{ilt} \phi_{ilt} X_{ilt} \right) \right] \)  

\[ \ldots(3.1.1) \]

\( I_{it} = I_{it-1} + X_{it} - \sum_{m=1}^{M} D_{imt} - \eta I_{it} \quad \forall \ i = 1, \ldots, P \ , \ t = 2, \ldots, T \)  

\[ \ldots(3.1.2) \]

\( I_{i1} = I_{N_i} + X_{i1} - \sum_{m=1}^{M} D_{im1} - \eta I_{i1} \quad \forall \ i = 1, \ldots, P \)  

\[ \ldots(3.1.3) \]

\[ (1-\eta) \sum_{i=1}^{T} I_{it} + \sum_{t=1}^{T} X_{it} \geq \sum_{m=1}^{M} \sum_{t=1}^{T} D_{imt} \quad \forall \ i = 1, \ldots, P \]  

\[ \ldots(3.1.4) \]

\( X_{it} \geq \sum_{l=1}^{L} a_{ilt} R_{ilt} \quad \forall \ i = 1, \ldots, P \ , \ t = 1, \ldots, T \)  

\[ \ldots(3.1.5) \]

\[ \sum_{l=1}^{L} R_{ilt} = 1 \quad \forall \ i = 1, \ldots, P \ , \ t = 1, \ldots, T \]  

\[ \ldots(3.1.6) \]

\[ \sum_{m=1}^{M} \delta_{mt} = \sum_{i=1}^{P} \sum_{l=1}^{L} w_{i} X_{it} \sum_{l=1}^{L} R_{ilt} \quad \forall \ t = 1, \ldots, T \]  

\[ \ldots(3.1.7) \]

\( \delta_{mt} \leq (y_{mt} + \alpha_{mt} \omega) u_{mt} + (\alpha_{mt} + 1) \omega (1-u_{mt}) \quad \forall \ m = 1, \ldots, M \ , \ t = 1, \ldots, T \)  

\[ \ldots(3.1.8) \]

\( \delta_{mt} = (y_{mt} + \alpha_{mt} \omega) \quad \forall \ m = 1, \ldots, M \ , \ t = 1, \ldots, T \)  

\[ \ldots(3.1.9) \]

\( X_{it}, I_{it}, \delta_{mt}, \alpha_{mt}, y_{mt} \geq 0 \ and \ integer \ R_{ilt}, u_{mt} \in \{0,1\} \)  

\( \forall \ i = 1, \ldots, P \ , \ t = 1, \ldots, T \ , \ L = 1, \ldots, L \ , \ m = 1, \ldots, M \)

The model for integrated procurement-distribution incremental discount problem for \( t \) periods, \( i \) products from single source to multiple destination is given below with changed objective function is as follows:

Min \( C = \sum_{t=1}^{T} \left[ \sum_{i=1}^{P} \left( h_i^{I_{it}} + m_i^{X_{it}} + \sum_{l=1}^{L} R_{ilt} d_{ilt} \phi_{ilt} X_{ilt} \right) \right] + \sum_{q=1}^{Q} \sum_{l=1}^{L} \frac{d_{iql} \phi_{iql} (a_{iql} - a_{iql-1}) + d_{iql} \phi_{iql} (X_{iql} - a_{iql-1})}{\sum_{q=1}^{Q} \sum_{l=1}^{L} d_{iql} \phi_{iql} (a_{iql} - a_{iql-1}) + d_{iql} \phi_{iql} (X_{iql} - a_{iql-1})} \)  

\[ \ldots(3.1.10) \]

Subject to (3.1.2)- (3.1.9)
### 3.1.1.8 Analysis of Model Formulation

The objective function (3.1.1) and (3.1.10) of the optimization problem is to minimize the sum of total cost incurred in ending inventory carrying cost at the destination reflected by the first term, inspection cost given by second term, purchasing the goods reflected by the third term of the objective function; and the last term reflects the transportation cost at final destinations. For transportation cost, first term defines the both TL & LTL policies while the second term defines only TL policy. The cost is calculated for the duration of the planning horizon. Constraints (3.1.2 –3.1. 4) are the balancing equations, which calculate the ending inventory level during period $t$. In eq. (3.1.2), ending inventory depends upon the inventory left in the last period, the quantity $X_i$ ordered in period $t$, at demand $D_{imt}$ and decayed inventory. Eq. (3.1.3) calculates inventory level at the end of the first period for all the products using the inventory level at the beginning of the planning horizon, and the net change at the end of period one. Eq. (3.1.4) takes care for shortages i.e. the sum of ending inventory and optimal order quantity is more than the demand of all the periods. Eq. (3.1.5) shows that the order quantity of all products during period $t$ exceeds the quantity break threshold. Eq. (3.1.6) restricts the activation at exactly one level, either discount or no discount situation. The integrator for procurement and distribution is eq. (3.1.7), which calculates transported quantity according to product weight. In eq. (3.1.8), the minimum weighted quantity transported is calculated and further eq. (3.1.9) measures the overhead units above truckload capacity in weights.

### 3.1.2 Results and Discussions

The vital objectives, the firms are concerned about are how much to order and how to minimize the total cost. Here, we have tried to answer these questions with the help of case in procurement-distribution scenario of a supply chain. The solution of the problem is given in Appendix B (Table 3.1.6) though for understanding, here we are discussing the usage of the all unit based model optimum policy from supplier’s warehouse (WH) to all the hospitals in first month.

Order size of 99m from supplier’s WH to all the hospitals in first period is 340 cartons in which firm will have to pay 94% of purchase cost, while that of 123 drug is 450
cartons 85% purchase cost. The purchases for 201 and 67 drugs are 244 and 366 cartons with purchase cost of 92% and 96% respectively. Ending inventory for the four types of drugs are 108, 111, 0 and 114 respectively. Regarding the shipment policy (in weighted quantity) during period 1 to all the hospitals is 4,020 kgs by carrying 8 full lorries at the cost of full load of truck and 20 kgs on per kg basis cost i.e. usage of TL & LTL both.

The total costs incurred by hospitals are $2,200,548 and $2,271,906 when all unit based model and incremental based model are used respectively. Costs at a glance are given in Table 3.1.7(Appendix B).

3.2 PROCUREMENT DISTRIBUTION COORDINATION FROM SINGLE-SOURCE TO MULTIPLE-DESTINATION FOR PERISHABLE PRODUCTS UNDER FUZZY ENVIRONMENT

In the changing market scenario, supply chain management is getting phenomenal importance amongst researchers. Studies on supply chain management have emphasized the importance of long term strategic relationship between the supplier, distributor and the retailer operated in an uncertain environment. In such a scenario, it is the need of today, to run the supply chain in this environment and omit the effects of uncertainty that leads to inferior supply chain design.

In the crisp environment, the parameters of total cost such as holding cost, purchase cost, rate of deterioration etc. are known with certainty, which does not fit in real world business situations. In these situations, these parameters and variables are considered as fuzzy in nature, that allows vagueness and brings it close to practical problems. The defuzzification is used to determine the answers equivalent to crisp values simultaneously dealing with uncertainties. Chang et. al.(2004) presented a lead-time production model based on continuous review inventory systems, where the uncertainty of demand during lead-time was dealt with probabilistic fuzzy set and the annual average demand by a fuzzy number only. Chang et. al.(2006) presented a model in which they considered a lead-time demand as fuzzy random variable instead of a probabilistic fuzzy set. Dutta et. al. (2007) considered a continuous review inventory system, where the annual average demand was treated as a fuzzy random
variable. The lead-time demand was also assessed by a triangular fuzzy number. Maity and Maity (2007) developed multi-item inventory models with stock dependent demand, and two storage facilities were developed in a fuzzy environment where processing time of each unit is fuzzy and the processing time of a lot is correlated with its size.

Under fuzzy environment, the global supply chain can be very complex and link-by-link understanding of joint policies can be very useful, Ben- Daya et. al. (2008). Some of the previously discussed joint policies are as follows. Hwang et. al. (1990) investigated the problem of determining optimal order quantity when all units’ quantity discounts are available on purchasing price and freight cost. The freight costs are usually in the form of discounts tariffs in the quantity, which reflects economies of scale. Transportation becomes a major cost component in supply chains; companies look for effective tools to reduce wasted capacity of trucks. A common solution is providing quantity discounts: a supplier can provide higher prices (upcharge) when the buyer does not order (near-) full truckload (TL) orders. There are many potential advantages of quantity discounts. However, unless enough care is given to the design of a discount scheme, much of the potential benefits could be lost, [Altinal(2000)].

Cheung and Lee (2002) model forced shipment co-ordination in order to have full TL shipments. Corbett and Groote (2000) considered coordinating the supply chain when the buyer has some private information. Mendoza and Ventura (2008) developed an unconstrained integrated inventory-transportation model to decide optimal order quantity for inventory system over a finite horizon. Least has been said about perishability/deterioration of stock (which is the main factor in determining the productivity of stock) and its implication on the joint policies of procurement and distribution of products. Following factor may lead to deterioration of stock viz. damage, spoilage, obsolescence, decay, decreasing usefulness etc. The first model where the factor of perishability was considered as noteworthy is projected by Corbett and Groote (2000) who pointed out that inventory decay could exert a significant impact on the overall inventory cost, while considerable cost saving could be achieved if the inventory analysis took the inventory decay into consideration. Maity and Maity (2007) built up an inventory model for perishable items with limited
storage space. They took demand rate for the items are finite; items deteriorate at constant rates and are replenished instantaneously. All the above authors studied about constant rate of deteriorating items but none of them included quantity discounts and freight policies.

3.2.1 Problem Description & Formulation

This section discusses the current problem in a well established retail food shop and formulates a mathematical model based on the description.

3.2.1.1 Problem Description

With the Christmas around the corner and surging tourists in the city, a chain of food joint has started its three retail points(J1, J2 and J3) at different places in the city specialized in offering fruit pudding. Fruits: “Apple”, “Banana”, “Papaya”, “Pomegranate” are sourced from the supplier’s warehouse in the city, which has a small cold storage and fruit inspection department, so that quality of fruits can be maintained at all times and will cater to all the three retail points, in a frozen packets, thrice in two months. To boost its sales, supplier offered quantity discounts. Retailer hired a transporter who is the masters of cold transportation to transport the supplies from warehouse to its retail points. Transporter also offers some schemes based on the mode of transportation opted to ferry the items where weight transported in each full vehicle $\omega= 1500$ kgs; cost of shipping one unit in LTL mode of transportation, $s=2$.

Supplier also hired a quality team to inspect the fruit items while in storage in order to maintain the highest possible quality, noting that there is around 5% of decay with inspection cost of $5/ pack.

Now the main challenge is to reduce various cost components viz. purchase, transportation, inspection cost and holding cost in order to get maximum benefits. Also the relevant data is provided in Appendix B (Table 3.2.1 -3.2.7).
3.2.1.2 Assumptions

All the assumptions of this section are same as in Section 3.1 except that demand and total cost are fuzzy in nature.

3.2.1.3 Sets

The sets and indices are same as in section 3.1

3.2.1.4 Decision Variables

The decision variables are same as in Section 3.1

3.2.1.5 Parameters

The additional parameters to work on fuzzy demand and total cost in this section are as follows:

\[ \tilde{C} \quad \text{Fuzzy total cost} \]
\[ C_0 \quad \text{Aspiration level of fuzzy total cost} \]
\[ C_0^* \quad \text{Tolerance level of fuzzy total cost} \]
\[ \tilde{D}_{imt} \quad \text{Fuzzy demand for product } i \text{ in period } t \text{ for destination } m \]
\[ D_{imt} \quad \text{Defuzzfied demand for product } i \text{ in period } t \text{ for destination } m \]

Rest of the parameters used, are same as in Section 3.1

3.2.1.6 Quantity Discounts

Discount slab for procurement of products is same as defined in Section 3.1

3.2.1.7 The Fuzzy Optimization Model Formulation

Due to the imprecise and unreliable information in real world, crisp mathematical programming approach is unable to provide any mechanism for dealing with practical problems. This is caused to use fuzzy optimization method with fuzzy parameters.
Therefore, we formulate fuzzy optimization model on vague aspiration and tolerance levels on total cost. The decision maker may decide his own levels on the basis of past experience and knowledge possessed by him.

\[
\begin{align*}
\text{Min } C &= \sum_{t=1}^{T} \sum_{i=1}^{P} \left( h_i I_{it} + m_i X_{it} + \sum_{l=1}^{L} R_{ilt} d_{ilt} \right) + \sum_{t=1}^{T} \sum_{m=1}^{M} (\gamma_{mt} + \alpha_{mt} \beta_{mt}) u_{mt} + (\alpha_{mt} + 1) \beta_{mt} (1 - u_{mt}) \\
&= \sum_{i=1}^{P} \sum_{t=1}^{T} h_i I_{it} + \sum_{i=1}^{P} \sum_{t=1}^{T} m_i X_{it} + \sum_{t=1}^{T} \sum_{m=1}^{M} R_{ilt} d_{ilt} + \sum_{t=1}^{T} \sum_{m=1}^{M} (\gamma_{mt} + \alpha_{mt} \beta_{mt}) u_{mt} + (\alpha_{mt} + 1) \beta_{mt} (1 - u_{mt})
\end{align*}
\]

(3.2.1)

\[
I_{it} = I_{i(t-1)} + X_{it} - \sum_{m=1}^{M} \tilde{D}_{imt} - \eta I_{it} \quad \forall i = 1, \ldots, P, \ t = 2, \ldots, T
\]

(3.2.2)

\[
I_{i1} = I_{i1} + X_{i1} - \sum_{m=1}^{M} \tilde{D}_{im1} - \eta I_{i1} \quad \forall i = 1, \ldots, P
\]

(3.2.3)

\[
(1 - \eta) \sum_{t=1}^{T} I_{it} + \sum_{t=1}^{T} X_{it} \geq \sum_{t=1}^{T} \sum_{m=1}^{M} \tilde{D}_{imt} \quad \forall i = 1, \ldots, P
\]

(3.2.4)

\[
X \in S = \{ X_{it}, I_{it}, \delta_{mt}, \alpha_{mt}, \beta_{mt} \geq 0 \text{ and integer}; R_{ilt}, u_{mt} \in \{0,1\} \}
\]

where \( i = 1, \ldots, P; t = 1, \ldots, T; l = 1, \ldots, L \)

\[
X_{it} \geq \sum_{l=1}^{L} a_{ilt} R_{ilt} \quad \forall i = 1, \ldots, P; t = 1, \ldots, T
\]

(3.2.5)

\[
\sum_{t=1}^{T} R_{ilt} = 1 \quad \forall i = 1, \ldots, P; t = 1, \ldots, T
\]

(3.2.6)

\[
\delta_{mt} = \sum_{i=1}^{P} \left[ w_i X_{it} \sum_{l=1}^{L} R_{ilt} \right] \quad \forall m = 1, \ldots, M; t = 1, \ldots, T
\]

(3.2.7)

\[
\delta_{mt} \leq (\gamma_{mt} + \alpha_{mt} \omega) u_{mt} + (\alpha_{mt} + 1) \omega (1 - u_{mt}) \quad \forall m = 1, \ldots, M; t = 1, \ldots, T
\]

(3.2.8)

\[
\delta_{mt} = (\gamma_{mt} + \alpha_{mt} \omega) \quad \forall m = 1, \ldots, M; t = 1, \ldots, T
\]

(3.2.9)

3.2.1.8 Analysis of Model Formulation

Equation (3.2.1), the fuzzy objective function is to minimize the cost incurred in holding ending inventory, cost of purchasing the products, and cost of inspection on ordered quantity in period \( t \), reflected (where the inspection rate can be taken same at all the destination in all period for product \( i \)) by the first term of the objective.
function; the transportation cost from the source to the destination, is the second term. The cost is calculated for the duration of the planning horizon. The ordering cost is a fixed cost not affected by the ordering quantities and therefore is not the part of objective function. Equation (3.2.2) – (3.2.4) are the balancing equations where equation (3.2.2) finds total ending inventory of \( i^{th} \) product in \( t^{th} \) period by reducing the fuzzy demand and fraction of perished inventory in \( t^{th} \) period from total of ending inventory of previous period and ordered quantity in \( t^{th} \) period. Equation (3.2.3) finds total ending inventory of \( i^{th} \) product in first period by reducing the fuzzy demand and fraction of perished inventory of the same period from total of initial inventory in the planning horizon and ordered quantity at first period. Equation (3.2.4) shows that total fuzzy demand in all the periods is less than or equal to total of ending inventory and ordered quantity in all the periods i.e. shortages are not allowed. Equation (3.2.5) \& (3.2.6) find out the order quantity of all products in period \( t \) which may exceed the quantity break threshold, and avails discount on ordered quantity at exactly one quantity discount level. Eq. (3.2.6) restricts the activation at exactly one level, either discount or no discount situation. The integrator for procurement and distribution is eq. (3.2.7), which calculates transported quantity according to product weight. In eq. (3.2.8), the minimum weighted quantity transported is calculated and further eq. (3.2.9) measures the overhead units from TL capacity in weights.

3.2.2 The Crisp Formulation

In this section we converted fuzzy optimization problem for the procurement- distribution SC to crisp formulation using fuzzy mathematical approach by applying the sequential steps of the algorithm given in chapter 2. The formulation is given as under:

Maximize \( \theta \)

subject to: \( \mu_c(X) \geq \theta \)

\[
I_{it} = I_{it-1} + X_{it} - \sum_{m=1}^{M} \bar{D}_{imt} - \eta I_{it} \quad \forall \ i = 1, \ldots, P; t = 1, \ldots, T
\]

\[
I_{i1} = IN_i + X_{i1} - \sum_{m=1}^{M} \bar{D}_{i1m1} - \eta I_{i1} \quad \forall \ i = 1, \ldots, P
\]
\[
(1-\eta) \sum_{t=1}^{T} I_{it} + \sum_{t=1}^{T} X_{it} \geq \sum_{t=1}^{T} \sum_{m=1}^{M} D_{imt} \quad \forall i = 1, \ldots, P
\]

\[
X \in S = \{X_{it}, I_{it}, D_{imt}, a_{imt}, y_{imt} \geq 0 \text{ and integer}; R_{il}, u_{imt} \in \{0,1\}\}/\text{satisfying eq (3.2.5) to (3.2.9); } i = 1, \ldots, P; t = 1, \ldots, T; l = 1, \ldots, L; m = 1, \ldots, M; \theta \in [0,1]\}
\]

The problem can be solved by the standard crisp mathematical programming algorithm. The various demand parameters \( D_{imt} \) are ranking fuzzy numbers represented as \( A = (a^1, a^2, a^3) \). With the help of experts and experienced people of the company, management assigns the value of these fuzzy numbers. Using the defuzzification function \( F_2(A) = (a^1 + 2a^2 + a^3)/4 \) we have defuzzified these numbers (Table: 3.2.7- Appendix B)

### 3.2.3 Results and Discussions

The goal of the firms are concerned about how much to order and how much to store for future purposes, especially in case when products are highly perishable and demand is uncertain in nature. Here we have attempted to find the solution of the current procurement-distribution problem, when buyer wishes to avail discounts by bulk purchasing for particular period of time. Here the procurement-distribution strategies are discussed for the first period. It is found that ordered quantity for Apples is 803 units in first period with discount of 20\% on purchase cost and inventory to hold would be 420 units after fulfilling the demands. 650, 1000, 378 units of bananas, papaya and pomegranate will be purchased for the first period with discount of 15\% on both banana and papaya and no discount on pomegranate. Distribution in first period from J1 is 10,415 kgs with TL mode by 7 trucks including overhead quantity of 1,415 kgs. Rest of the procurement and distribution policies for fruits (for all periods) is provided in Appendix B (Table: 3.2.8-3.2.9). Total cost incurred by food chain is $1,072,799 when aspiration and tolerance levels given by the firm were $1,000,000 and $2,000,000 with reducing the imprecision by 92\%.