Rolling Planning Method for Logistic System for Controlling Inventory and Stock-out Under Unsteady Demand

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Abstract. In this paper, rolling planning method for logistics system is proposed for minimizing logistics cost, controlling inventory, and stock out parts due to unsteady demand for a particular planning period. Demand variability is the main challenge for any supply chain network. One strategy to tackle this challenge is to practice a make-to-order supply system. However, there is a risk to have delays on the supply, when the final customers generate the order because the product requires a specific production time and a lead time to arrive from the factory to the customer. For handling unsteady demand, the main problem is the generation of stock-out products or in opposite case, the generation of dead stock due to a large number of storage products. For solving these problems, rolling planning method is proposed. The aim of this method is to estimate the optimal production, delivery quantities and to hold satisfied inventory level for minimizing stock out parts over the planning period. The proposed model and solution approaches are implemented in a numerical example. The solution has shown that the proposed rolling planning model for logistics system handle unsteady demand successfully for controlling inventory and stock out parts over the given planning period.

Keywords: Unsteady Demand, Rolling Method, Logistics System, Stock-out, Safety Stock.

1. Introduction
Inventory control is a fundamental key in any supply chain system. It plays an important role on the profit optimization, improving customers’ satisfaction by reducing the number of stock-out products. Demand is variable in real supply chain system. This variability can be easily solved by the following make-to-order policy but this policy is not suitable for all products. For example, consumer items are typical items. For handling these items, producers follow make-to-stock policy. Under this policy, producers, wholesalers, and retailers can stock many items for meeting customers’ demands. However, a large inventory easily generates overstock while a small inventory generates stock out in supply chain network. So, the challenge is to simultaneously reduce the inventory and stock-out parts. In many conventional supply chains, production and distribution planning are treated separately. However, they are mutually related problems that must be tackled in an integrated way [1]. The main characteristics of the past studies are mentioned in Table 1 in summarised form. According to past studies, most of the researchers have tried to construct multistage logistics model considering deterministic demand [1-8], stochastic demand [9-12] and fuzzy demand [13-15]. However, these are not sufficient to cope with realistic problem because real customers’ demands are unsteady in nature and nobody has developed logistics model based on unsteady demand. Hence, extensions are needed for the previous model to make the model more realistic.
Table 1: Summary of past studies

| Authors                          | Deterministic Demand | Stochastic Demand | Fuzzy Demand | Unsteady Demand |
|----------------------------------|----------------------|-------------------|--------------|-----------------|
| Fahimnia, Luong and Marian [1]   | O                    | X                 | X            | X               |
| Seyedhosseini and Ghereyshi [2]  | O                    | X                 | X            | X               |
| Wang and Cheng [3]               | O                    | X                 | X            | X               |
| Han et al. [4]                   | O                    | X                 | X            | X               |
| Coccola et al. [5]               | O                    | X                 | X            | X               |
| Altiparmak et al. [6]            | O                    | X                 | X            | X               |
| Gan, Li and Si [7]               | O                    | X                 | X            | X               |
| Su et al. [8]                    | O                    | X                 | X            | X               |
| Manupati et al. [9]              | X                    | O                 | X            | X               |
| Aaron et al. [10]                | X                    | O                 | X            | X               |
| Nourifar, R. et al. [11]         | X                    | O                 | X            | X               |
| Zhang, Shang and Li [12]         | X                    | O                 | X            | X               |
| Gharehyakheh and Moghaddam [13]  | X                    | X                 | O            | X               |
| Sakalli [14]                     | X                    | X                 | O            | X               |
| Jamrus et al. [15]               | X                    | X                 | O            | X               |

Notation: “O” = Considered and “X” = Did not Considered.

In this study, rolling planning method for logistics system is proposed to control inventory and stock-out parts and to minimize logistic cost under unsteady demands in make-to-stock production. The proposed model has following characteristics: (i) Initial inventory at the store will be estimated based on average customers’ demands and adding the safety inventory and initial inventory at the plant and DCs will be calculated based on the average demand and add the sum of all the variances of the stores times the safety factor “$\delta = 1.88$". (ii) During the demand consumption at the stores (when $t = 1$), the production volume of the plant will be equal to the initial inventory of that plant and after initial period when $t \geq 2$ the plant will produce the products based on the rolling planning method, which means that the production quantities at period “$t$" will be the sold quantities on all the stores in period “$t-1$”. (iii) Inventory will be revised at the end of each period. (iv) Products will be delivered from plant to DCs and DCs to stores based on order and arrive according to lead time (LT). (v) LT between plant and DCs requires one period of time and LT between DCs and stores requires another one period of time (vi) Real customers’ demands will be unsteady which follow normal distribution with a known mean and a standard deviation. (vii) If stock-out occurs at any store, it will be delivered next period.

2. Model

Figure 1 shows the time chart of the orders and the deliveries to each location. The dotted lines represent new orders requiring delivery and the solid lines denote the delivery of products. Here, the plant, DCs, and the stores have identical times at the end and the start of every period. Demand is generated at the retail shops between the start and the end of every period. A logistics plan is prepared when a new order for a delivery arrives at the DCs from the retail shops. Then, from the logistics plan, the number of products transported from DCs to shops and the number of products transported from the plant to DCs are determined. The shop requests new orders from the DCs after the end of the period. Products transported from DCs arrive at shop by the start of the next period according to the logistics plan. In addition, the inventory of DCs is examined, and the DCs request new orders from the plant. The plant transports products to the DCs according to the orders requested from the DCs. The products arrive at the DCs by the start of the next period. Therefore, products produced in the plant in the t-th period arrive at shops at the start of the (t+2)-th period. Figure 2 represents the two-stage delivery model with inventory representation and figure 3 shows the flow chart of rolling planning method. The mathematical model of this problem has 45 constraint functions including objective function among them a few of them are denoted as follows:

Indexes: i: Plant ($i = 1, 2, \ldots I$), j: Distribution centres, DCs ($j = 1, 2, \ldots J$), k: Clusters ($k = 1, 2, \ldots K$), t: Periods ($t = 1, 2, \ldots T$), s: Stores ($s = 1, 2, \ldots S$), p: Products ($p = 1, 2, \ldots P$).
Parameters: \( \hat{D}_{t,p,k}^{S} \): Real demand at period “t” of cluster “k” for product “p”, \( c_{t,j} \): Delivery cost from plant “i” to DC “j”, \( cb_{j,k} \): Delivery cost from DC “j” to Clusters “k”, \( CIP_{p} \): Inventory capacity at the DC “j”, M: Large integer number.

Decision Variables: \( P_{t,p,i} \): Production quantity of product “p” at plant “i” at the period of “t”, \( O_{t+1,p,i}^{D} \): Quantities delivered at the end of period “t” from plant and arrived before t+1 to DC “j” for product “p”, \( O_{t+1,p,j,k}^{S} \): Quantities delivered at the end of period “t” from DC and arrived before t+1 to Cluster “k” for product “p”, \( I_{t,p,j}^{S} \): Inventory in Clusters “k” at end of period “t” for product “p”, \( I_{t+1,p,j}^{S} \): Inventory in DC “j” at the end of period “t” of product “p”, \( I_{t+1,p,k}^{S} \): Inventory at the end of period “t” for plant “i” and product “p”, \( A_{p,t,k} \): Number of stock-out parts at period “t” for product “p”.

Objective function: Minimize the logistics cost from Plant to DC and from DC to cluster for product “p” on period “t”. The equation is shown as follow:

\[
\text{minimize} \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{i=1}^{I} O_{t+1,p,j,k}^{S} c_{t,j} + \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{J} \sum_{f=1}^{F} O_{t+1,j,f,k}^{S} cb_{j,f} + \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{J} \sum_{f=1}^{F} O_{t,p,j,k}^{S} \tag{1}
\]

Initial inventory for each cluster is calculated by equation (2) which considers the average customer demands and adding the safety inventory.

\[
l_{t,p,k}^{S} = \sum_{i=1}^{I} \left( D_{i,p}^{S} + \sigma_{S,p} \sqrt{L_{T}} \right) \tag{2}
\]

where, \( D_{i,p}^{S} \): Average Demand at store “s” for product “p”, \( \sigma_{S,p} \): Standard Deviation for “s” stores for product “p”, \( \delta \): Safety factor, \( L_{T} \): Lead Time, for practical purposes the lead time is considered one unit of time for all the deliveries from the plant to DC and from DC to each store. For meeting the customer demands at each store, the distribution centers contain safety inventory for the supply of the products. The initial inventory for each DC is given by adding the demand for the average demand plus \( \delta \) times the square root of the sum of all the variances of the stores and is given by the following formula:

\[
l_{i,p}^{D} = \frac{\sum_{s=1}^{S} D_{s,p}^{S} + \delta \times \sqrt{\sum_{s=1}^{S} \sigma_{s,p}^{2}}}{i} \tag{3}
\]

For the initial inventory at the manufacturing site, \( I_{t,p}^{F} \) is given by equation (4) and the same values of the production quantities \( P_{t,p,i} \) at the first period are defined by equation (5). The quantities are calculated based on the average demand and add the sum of all the variances of the stores times the safety factor.

\[
l_{t,p}^{F} = \frac{\sum_{s=1}^{S} D_{s,p}^{S} + \delta \times \sqrt{\sum_{s=1}^{S} \sigma_{s,p}^{2}}}{i} \tag{4}
\]

\[
P_{t=1,p,i} = \frac{\sum_{s=1}^{S} D_{s,p}^{S} + \delta \times \sqrt{\sum_{s=1}^{S} \sigma_{s,p}^{2}}}{i} \tag{5}
\]

Production quantity at period “t >1” follows a rolling planning schedule that is these quantities are defined based on the real customer’s demand from period “t-1” as given in equation (6).

\[
P_{t>1,p,i} = \sum_{k=1}^{K} \hat{D}_{t-1,p,k}^{S} (V t, k) \tag{6}
\]

Inventory at the end of the first period (t = 1) for each cluster of product “p” is calculated based on the initial inventory that is being consumed by the real demand and adding the stock out parts in that period as given in equation (7).

\[
i_{t=1,p,k}^{S} = I_{t=1,p,k}^{S} - \hat{D}_{t-1,p,k}^{S} + A_{t,p,k} \tag{7}
\]

Inventory at the end of the period “t” when t > 1 for each cluster of product “p” is defined by the previous period inventory adding the arrival parts from the DC subtracting the real demand and considering the ordering of the stock out parts as given in equation (8). Equation (9) is the restriction of avoiding stock out parts considering the inventory and the delivered quantities on the previous term at each store. Inventory at the end of the first period (t= 1) for each DC is defined by the initial inventory subtracting the quantities to be delivered to each cluster for the second period as given in equation (10).
Inventory in the DC “j” at end of period “t >1” of product “p” is the result at the end of the period is the sum of the inventory at the beginning of the period and the received quantities from the plant, subtracting the quantities to be delivered to each cluster as given in equation (11).

\[
i_{t-1,j,p,k}^S + \sum_{j=1}^{J} \sum_{l=1}^{L} o_{t-1,t-1,j,l}^P - \sum_{k=1}^{K} o_{t-1,j,k}^P (\forall p, k, t \in T, t \geq 2)
\] (8)

\[
i_{t-1,j,p,k}^S + \sum_{j=1}^{J} o_{t-1,t-1,j,p,k}^P - A_{t-1,j,p,k} + A_{t,j,p,k} (\forall p, k, t \in T, t \geq 2)
\] (9)

\[
i_{t-1,j,p,f}^P = i_{t-1,j,p,f}^P + \sum_{j=1}^{J} o_{t-1,t-1,j,p,f}^P - \sum_{k=1}^{K} o_{t,j+1,p,f}^P (\forall p, j, t \in T, t \geq 2)
\] (10)

Equation (12) is defined as the inventory at plant “i” at the end of the first period (t = 1). Equation (13) is defined as the inventory at plant “i” at period “t” of product “p” after the first period (t>1). The inventory is defined by sum of the previous inventory and the production quantity subtracting the quantities that will be delivered at the end of the period to each DC.

\[
i_{t-1,j,p,f}^P = i_{t-1,j,p,f}^P + \sum_{j=1}^{J} o_{t-1,t-1,j,p,f}^P - \sum_{k=1}^{K} o_{t,j+1,p,f}^P (\forall p, j, t \in T, t \geq 2)
\] (11)

Equation (14) and (15) denote constraints related to delivery quantity from DC “j” to Cluster “k” and from plant “i” to DC “j” when t >1.

\[
\sum_{p=1}^{P} i_{t-1,j,p,k}^S + \sum_{j=1}^{J} o_{t-1,t-1,j,p,k}^P - \sum_{k=1}^{K} o_{t,j+1,p,k}^P (\forall p, j, t \in T, t \geq 2)
\] (14)

\[
\sum_{p=1}^{P} i_{t-1,j,p,f}^P + \sum_{j=1}^{J} o_{t-1,t-1,j,p,f}^P - \sum_{k=1}^{K} o_{t,j+1,p,f}^P (\forall p, j, t \in T, t \geq 2)
\] (15)

Equations (16) and (17) show the inventory capacity constraint at DC “j” of the 1st period and when t ≥ 2.

\[
\sum_{p=1}^{P} i_{t-1,j,p,f}^P + \sum_{j=1}^{J} o_{t-1,t-1,j,p,f}^P - C_{j}^P (\forall p, t = 1, j)
\] (16)

\[
\sum_{p=1}^{P} i_{t-1,j,p,f}^P + \sum_{j=1}^{J} o_{t-1,t-1,j,p,f}^P - C_{j}^P (\forall j, t \in T, t \geq 2)
\] (17)

Equation (18) shows the total delivery quantity constraint from “t” period at DC “j” to Cluster “k” for product “p”. If there is a stock out event at any store, the binary variable \(B_{j,p}^S\) will be 1 and will not allow to delivery parts. Same types of constraints are introduced first period and when t ≥ 2.

\[
\sum_{j=1}^{J} (i_{t-1,j,p,k}^S - i_{t-1,j,p,k}^S + A_{t,j,p,k}) - B_{j,p}^S \times M \leq \sum_{j=1}^{J} \sum_{k=1}^{K} o_{t,j+1,p,k}^P (\forall p, t, k)
\] (18)

3. Numerical Experiment

In order to evaluate the performance of the proposed model, a numerical experiment is performed. Assumed, I = 1, J = 2, K = 3, S = 20, T = 5, LT =1, and P = 2 (A and B), unit logistic costs from plant to DC1 and DC2 are 14 and 15 respectively and from DC1 to K1, K2, K3 are 15, 5,150 and DC2 to K1, K2, K3 are 150, 15 and 15 respectively. Random data based on normal distribution are generated to get as real demand. Mean demand and standard deviation of products A and B are predetermined as 120, 80 and 20, 20 respectively for 20 stores. By using this data, initial inventories for clusters, DCs, and a plant are estimated as shown in Table 2. Unsteady customers’ demands are given in Table 3.

4. Results and Discussion

Initially, products A and B are produced at plant considering the initial inventory of a plant, and after the initial period when t > 1, products A and B are produced in the plant according to the rolling planning method which is given in Table 4. At the end of every period, products are delivered from plant to DCs based on order repeatedly as shown in Table 5, and then ending inventory at the plant is also calculated periodically which is given in Table 6. Again, in the same way, initially and subsequently, products are delivered from DCs to clusters based on order as shown in Table 7 and then ending inventory at the DCs is calculated periodically which is given in Table 8. In terms of clusters, customers’ unsteady demands for every period which are given in Table 3 are fulfilled by clusters...
from their stock items, and then ending inventory of clusters for every period is revised which is given in Table 9. Finally, according to equation (1), the total logistic cost is calculated by this proposed model as shown in Table 10. It is observed that by evaluating the proposed model there is no stock-out situation as shown in Table 11. For testing the feasibility of the proposed model, the model is performed by setting another safety factor $\delta = 0$ and get the total logistic cost as given in Table 10 which is slightly lower than the previous result. But, under this condition, stock-out is occurred as shown in Table 11. It’s proved that the proposed model is generating the results satisfactorily. It is mentioned that if safety factor $\delta = 0$ is considered, service level will be only 50% which means that there is a possibility to stock out about 50% which is not convenient to hold customer satisfaction while if safety factor $\delta =1.88$ is considered, service level will be 97% which is very convenient to hold customer satisfaction. Therefore, by evaluating inventory level and stock-out situation, we consider that the determined logistic cost, which is 592822, is acceptable in this model.

**Figure 1.** Time Chart  
**Figure 2.** Two-Stage Inventory Representation  
**Figure 3.** Flow Chart of Rolling Planning Method
5. Conclusion
In this study, a rolling planning method for logistics system is proposed that simultaneously reduces the total inventory, logistics cost, and stock-out. The proposed model considers the following controls: production, standard inventory for meeting unsteady demands and the distribution of products from plant to DCs and from DCs to shops to minimize discrepancy between requirements and supply. In this study, stock-out and over-stock are reduced in make-to-stock production system which is very essential to control inventory in supply chain network. In future studies, this model can be extended by integrating delivery routes for finding the optimal logistics cost in a large-scale problem.

Table 2. Initial inventory at clusters, DCs and plant.

|       | A   | B   | A   | B   |
|-------|-----|-----|-----|-----|
| K1, K2, K3 | 800 | 534 | 1051| 784 |
| DC1, DC2   | 1200| 800 | 1285| 885 |
| I          | 2400| 1600| 2570| 1770|

Table 3. Real unsteady customers’ demands.

|       | K1 | K2 | K3 |
|-------|----|----|----|
| Periods | A   | B   | A   | B   | A   | B   |
| T1     | 851 | 502 | 929 | 552 | 687 | 490 |
| T2     | 902 | 564 | 764 | 598 | 711 | 450 |
| T3     | 807 | 624 | 874 | 597 | 659 | 477 |
| T4     | 807 | 591 | 782 | 638 | 724 | 533 |
| T5     | 785 | 581 | 842 | 582 | 747 | 561 |

Table 4. Production volume at plant.

| Products | T1  | T2  | T3  | T4  | T5  |
|----------|-----|-----|-----|-----|-----|
| A        | 2570| 2467| 2377| 2340| 2313|
| B        | 1770| 1544| 1612| 1698| 1762|

Table 5: Delivery volume from plant to DCs.

| DCs       | Products | T1   | T2   | T3   | T4   | T5   |
|-----------|----------|------|------|------|------|------|
| DC1       | A        | 1666 | 1681 | 1589 | 2912 | 0    |
|           | B        | 1954 | 1544 | 114  | 2048 | 0    |
| DC2       | A        | 1893 | 0    | 659  | 1471 | 0    |
|           | B        | 1586 | 0    | 0    | 1094 | 0    |

Table 6. Inventory at plant at the end of every period.

| Products | T1   | T2   | T3   | T4   | T5   |
|----------|------|------|------|------|------|
| A        | 1581 | 2367 | 2496 | 453  | 2766 |
| B        | 0    | 0    | 1498 | 54   | 1816 |

Table 7. Delivery volume from DCs to clusters.

| DCs       | Periods | A   | B   | A   | B   | A   | B   |
|-----------|---------|-----|-----|-----|-----|-----|-----|
| DC1       | T1      | 851 | 502 | 434 | 383 | 0   | 0   |
|           | T2      | 902 | 564 | 764 | 598 | 0   | 0   |
|           | T3      | 807 | 624 | 874 | 597 | 0   | 0   |
|           | T4      | 807 | 591 | 782 | 638 | 0   | 0   |
|           | T5      | 785 | 581 | 842 | 582 | 0   | 0   |
| DC2       | T1      | 0   | 0   | 495 | 169 | 687 | 490 |
|           | T2      | 0   | 0   | 0   | 0   | 711 | 450 |
|           | T3      | 0   | 0   | 0   | 0   | 659 | 477 |
|           | T4      | 0   | 0   | 0   | 0   | 724 | 533 |
|           | T5      | 0   | 0   | 0   | 0   | 747 | 561 |
Table 8. Inventory at DCs at the end of every period.

| Periods | DC1  | DC2  |
|---------|------|------|
|         | A    | B    | A    | B    |
| T1      | 0    | 0    | 103  | 226  |
| T2      | 0    | 792  | 1285 | 1362 |
| T3      | 0    | 1115 | 626  | 885  |
| T4      | 0    | 0    | 561  | 352  |
| T5      | 1285 | 885  | 1285 | 885  |

Table 9. Inventory at clusters at the end of every period.

| Periods | K1  | K2  | K3  |
|---------|-----|-----|-----|
|         | A   | B   | A   | B   |
| T1      | 200 | 282 | 122 | 232 |
| T2      | 149 | 220 | 287 | 186 |
| T3      | 244 | 160 | 177 | 392 |
| T4      | 244 | 193 | 269 | 146 |
| T5      | 266 | 203 | 209 | 304 |

Table 10. Total logistic cost.

| Safety factors | $\delta = 0$ | $\delta = 1.88$ |
|----------------|-------------|-----------------|
| Total Logistic Cost | 582618 | 592822 |

Table 11. Stock-out at clusters at the end of every period.

| Periods | K1  | K2  | K3  |
|---------|-----|-----|-----|
|         | A   | B   | A   | B   |
| T1      | 180 | 18  | 0   | 0   |
| T2      | 133 | 94  | 0   | 0   |
| T3      | 81  | 153 | 0   | 0   |
| T4      | 7   | 258 | 0   | 0   |
| T5      | 42  | 382 | 0   | 0   |

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