# Determination of Inventory Replenishment Factors with Lateral Transshipment in a Multiple Warehouses and Multiple Retailers Distribution System

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***Abstract***

The objectives of this research are to study the reactive lateral transshipment of multiple warehouses and multiple retailers distribution system and to analyze the effects of related factors composing of demand dispersion and filling rate. The developed model is simulated by varying the demands at each location and the filling rate of demands at each location to observe the expected number of stockout in the system. The ten replications of each scenario of different demand distribution are simulated and the results show that the total number of item's stockout increases when demand dispersion is high. Retailer with the lowest demand in a distribution results in the highest number of units' stockout. By varying the filling rate, the distribution with low dispersion demand among retailers trends to has lowest number of units stockout resulting in decreasing total system cost.

***Keywords***: Lateral Transshipment, Filling Rate, Inventory, Multiple Warehouses and Multiple Retailers, Simulation

## I. INTRODUCTION

The lateral transshipment policy is a virtual distribution system of products in logistic network. The local warehouses share theirs' inventory in order to achieve customer service level at retailers when products are not available at the primary warehouse. The lateral transshipment considered in this research is reactive lateral transshipments responded to situations where one of the stocking points faces a stock out. When a primary warehouse is out of stock, demand is satisfied by the nearby warehouses using rush shipping. Therefore, the inventory costs of holding item and backordering item are compensated by rush transportation from any nearby warehouses.

The inventory management is significant activity of logistics system since inventory cost account for half of logistics cost. [1] has reviewed researches about inventory management published in major logistics journals. They conclude that there are two major themes from logistics researches focused on inventory management. The first one is integrating logistics decisions between inventory decision and transportation decision or warehousing decision and the second one is inventory management through collaborative model which is more recently focused. The virtual inventory management is a collaborative model which has been studied extensively such as the cross filling policy as presented by reference [2]-[7]. [2] studied the consolidate effect on safety stock and regular stock under cross filling allocation rule.

This research presents the effect of filling demand from more than one primary stock to the overall inventory level which seem to be reduced. In addition, cross filling does not favor regular stock but do favor in reducing safety stock. [3] focuses on the significance of available information in the typical supply chain distribution. The inventory control through supply network depend on the variability management and present the cooperated joint venture model as virtual distribution. Demand distribution is a significant factor effecting inventory level [2]. For cross filling policy, when demands at each location are different, the total safety stock trends to decrease [2]. Since aggregate inventory of consolidation results in safety stock decreasing, [4] study the interaction between the coefficient of variation of demand and the ratio between inventory ordering and holding costs and indicates that the key variable for consolidation is the ratio between the standard deviations of lead time.

Inventory management is significant to retail management as study by [5], [10] and [11]. [5] study the limitation of shelf stocking for multiple item and developed inventory replenishment model to minimize the retail space with the situation that there is no stocking out possibility since this case is 100% of substitutable products. For multiechelon inventory system, [6] present the virtual allocation rule to study the dense and small retailers while [11] study the effect of adopting lateral transshipment between retailers in decreasing the amount of stockout. [7] presents a model of decentralized inventory sharing among suppliers in distribution network when product is expensive and has low demand. Reference [7] considers the independent suppliers when demand is Poisson distribution and apply the queuing theory using dynamic programing to study the total cost of two suppliers as for study. [12] study the benefits of sharing and transshipment of expensive, low-demand items in the supply chain and conclude that sharing and transshipment of items does not always, reduces the overall costs of holding, shipping, and waiting for inventory while sharing of inventory typically benefits all the participants in decentralized supply chains.

Most recent researches focus on inventory management of distribution network and looking for virtual distribution system as presented by [14]. Lateral transshipment policy is an interesting method extensively study [10-14]. Most researches consider the lateral transshipment in the same echelon, however, this research focuses on the emergency or reactive lateral transshipment which warehouse replenishes item directly to the lower echelon like retailers instead of replenishment in the same echelon since customer is willing to wait for items. In addition, factors involving inventory model of reactive lateral transshipment are rarely studied. The distribution networks normally contain multiple locations of plants, warehouses, and retailers. Inventory levels at these locations have been determined by the optimization of the cost related to inventory and transportation. The improvement of business logistics via information system support virtual inventories management which the shortage products of primary supply location are served by the other supply locations. The compensation of shortage cost with rush delivery by the secondary or tertiary warehouse must be considered in order to keep their customer service level representing product availability.

In the virtual inventory control of N stocking location, lateral transshipment becomes important, since the decentralized storage is widely adopted [2]. The logistics decisions of multiple stocking locations become complex. When the fill rate for the primary stocking location is less than 100%, the secondary or the tertiary stocking locations are considered. Orders filling from more than one stocking points result in the least risk of stocking out. This paper considers a priority rule of replenishment which are the available inventories from the secondary and tertiary stocking points. The warehouses are used as primary and secondary inventories of items for all demand zones. Customers are assigned to the nearest warehouse that defines their primary serving warehouse with the lowest transportation cost rate as shown in figure 1. Some demands are satisfied by the secondary and tertiary warehouses when the items are unavailable at primary warehouse. The weekly demand forecast is random variable with demand mean and standard deviation. The three different demands' average and standard deviation are assigned to retailers. The transportation cost rate of secondary and tertiary warehouse is greater than the primary warehouse. Therefore, the stockout cost is compensated by the extra transportation cost. The more units of stockout, the more extra transportation cost in order to keep customer service level. However, safety stock is used to support demand variation and decrease the probability of stockout. The manager have to decide how much safety stock to be keep and how much stockout will be accepted. Thus, the best inventory decision depends on the demand variation, inventory holding cost of safety stock, stockout cost, order filling rate, and transportation cost.

This research aims to simulate the reactive lateral transshipment of three warehouses and three retailers distribution system and to study the effect of the demand, the dispersion of demand among these locations and the filling rate to the number of units' stockout at each demand's location.

The simulation of three demand points and three stocking points is performed by using Arena simulation program. The retailers of each zone, which are Retailer 1, 2 and 3, are supplied by the primary warehouse A, B, and C, respectively. However, some demands that may not be able to respond by the primary warehouse will be supplied by the secondary and the tertiary warehouse, respectively. For example, Retailer 1 is supplied by warehouse A with the filling rate of 95%, however, when the replenishment order from warehouse A have not arrived and more demand occurred during this period, the warehouse B will provide rush delivery instead in order to fulfill customer order. Thus, warehouse B is considered to be the secondary supplier for retailer 1 and warehouse C is the tertiary supplier of retailer 1 when the first and second suppliers cannot supply the required items as illustrated in figure 1. In addition, the sensitivity analysis is performed to determine the effect of demands' variation and the different level of filling rate.

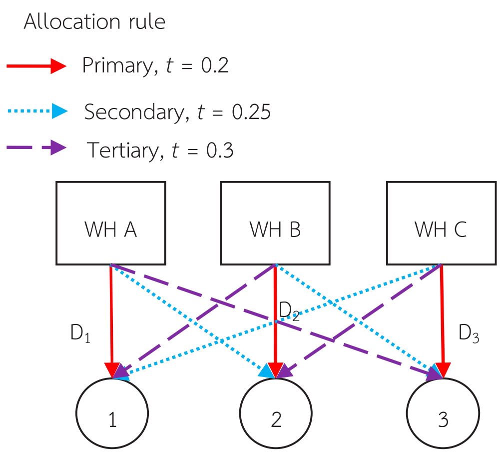


Fig. 1 Retailers are supplied by three warehouses [2]

## II. RESEARCH METHODOLOGY

To solve lateral transshipment problem of multiple warehouses when the required item is not available at primary warehouse, the secondary warehouse and the tertiary warehouse will make rush delivery of that item to customer instead. The objective function is formulated by considered related costs of the whole system.

### A. *Problem Statement and Basic Assumptions*

The distribution of three warehouses and three retailers is simulated by using Arena software. The first objective is to analyze the effect of filling rate and the demand dispersion to the safety stock level at each location. The second objective is to study the effect of demand dispersion and filling rate to the number of units' stockout. The inventory management method of the considered problem is the push system. When the inventory level reach the reorder point, the new order is placed and arrives according to its replenishment interval as shown in figure 2. However, this problem is complicated when a warehouse have planned the safety stock for the responsible retailers' zone but other retailers outside the responsibility request rush delivery of available item. Therefore, the demand variation is important factor to the overall safety stock of logistics network.

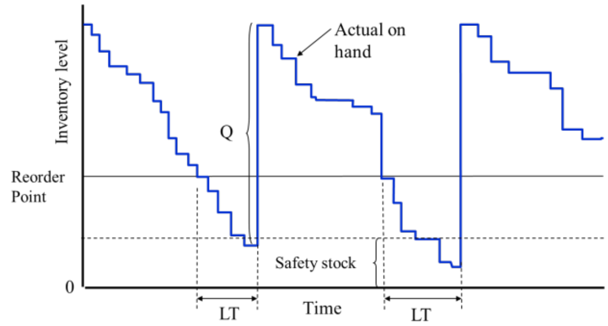


Fig. 2 Inventory Management [9]

The objective function of the problem is to minimize the total logistics cost related to ordering cost, carrying cost, stockout cost, and rapid transportation cost. We consider a demand $i$ can be fulfilled by warehouse $j$ as $Q_{ij}$ with different filling rate from warehouse $j$. The mathematical model is constructed based on the following assumptions:

1) Customers' demands are random with normal distribution occurring at retailers.

2) Related costs are inventory holding cost of safety stock, stockout cost and transportation cost.

3) Warehouses adopt push inventory system with safety stock allowance.

4) Inventory cost and transportation cost occur at warehouses.

5) When products are shortage, the replenishment can be done by secondary or tertiary warehouse depend on the proportional of filling rate.

6) The probability of stockout at retailer is represented by the order filling rate.

7) When items need to be shipped from other warehouses, all quantity can be satisfied.

The related notations to mathematical model are as follow:

$Q_{ij}$ is replenishment quantity of customer *i* from warehouse *j*, when *i* = 1, 2,..., *m* and *j* = 1,2,..., *n* (unit)

$q_j$ is the quantity shipped by lateral transshipment

$D_i$ is average demand of customer *i* (unit per week)

$S_{d_i}$ is demand standard deviation of customer *i* (unit per week)

$SS_i$ is the safety stock of customer *i* (unit)

$C$ is item price (dollars)

$S_i$ is inventory setup cost (dollars/order)

$I$ is percentage of inventory holding cost (percent per year)

$h_i$ is holding cost of item at warehouse *i*

$k_i$ is stockout cost of item at warehouse *i*

$FR_i$ is filling rate in percentage or service level of warehouse *i*

$P_{Stockout}$ is probability of stockout with stockout cost of $k_i$ and some of them will be replenished by lateral transshipment policy depend on the filling rate of $FR_j$

$Z_i$ is standard deviation of normal distribution depend on the filling rate (*FR*)

$LT_{ij}$ is replenishment lead time from supplying by warehouse *j* to customer *i* (week)

$R_i$ is reorder point of customer *i* (unit)

$t_{ij}$ is transportation cost rate per unit distance from warehouse *j* to customer *i*

$\alpha$ is the penalty cost from rush delivery per unit of product of

$dist_{ij}$ is the rush distance between customer *i* to warehouse *j*

$S_{ij}(Q)$ is ordering cost from warehouse *j* to customer *i*

$H_{ij}(Q)$ is holding cost from warehouse *j* to customer *i*

$B_{ij}(Q)$ is backordering cost from warehouse *j* to customer *i*

$T_{ij}(Q)$ is transportation cost from warehouse *j* to customer *i*

$C_{ij}(Q)$ is total logistics cost from warehouse *j* to customer *i*

The push inventory system with stochastic demands occurring at retailers is applied. The classical economic order quantity [8] is considered. Demand at each retailer is normal distribution with average demand per period and a standard deviation of demand. To determine the optimal quantity and timing of Lateral Transshipment, the four key cost components; ordering cost, carrying cost, holding cost and rush transportation cost of the total logistics cost should be minimized as equation (1).

$$C_{ij}(Q_{ij},q_j)=\sum_{i=1}^{m}\sum_{j=1}^{n}(S_{ij}(Q_{ij})+H_{ij}(Q_{ij},q_j)+B_{ij}(Q_{ij},q_j)+T_{ij}(Q_{ij},q_j)) \quad (1)$$

The inventory decisions for each retailers which are replenishment order quantity, safety stock, and reorder point are calculated as equation (2), (3), (4), and (4) respectively [8].

$$Q_{ij}=\sqrt{\frac{2SD_i\times 50}{h_j}} \quad (2)$$

$$P_{stockout}=\frac{ICQ_{ij}}{k_iD_i} \quad (3)$$

$$SS_i=S_{d_i}Z_i\sqrt{LT_{ij}} \quad (4)$$

$$R_i=D_i(LT)+SS_i \quad (5)$$

Thus, total holding cost is the cost of holding regular stock, safety stock and lateral transshipment quantity (q) as equation (6).

$$H_{ij}(Q_{ij},q_j)=IC(\frac{\sum_{j=1}^{n}Q_{ij}}{2}+\sum_{i=1}^{m}S_{d_i}Z_i\sqrt{LT_{ij}}+\sum_{j=1}^{n}q_j) \quad (6)$$

For stockout cost, the number of product stockout is compensated by lateral transshipment quantity ($Q_{ij}$) represented by equation (7)

$$B_{ij}(Q_{ij},q_j)=\sum_{i=1}^{m}\sum_{j=1}^{n}[k_i(E_ZS_{d_i}-q_j)\frac{D_i}{Q_{ij}}] \quad (7)$$

The ordering cost or inventory setup cost is calculated as equation (8),

$$S_{ij}(Q_{ij}) = \sum_{j=1}^{n} S_i \frac{D_j}{Q_{ij}} \quad (8)$$

and the transportation cost is calculated as follow;

$$T_{ij}(Q_{ij}, q_j) = (\sum_{j=1}^{n} t_{ij} dist_{ij}) \frac{D_j}{Q_{ij}} + \alpha \sum_{j=1}^{n} q_j \quad (9)$$

Each customer *i* has different level of demand. Some customers have high demands whereas some have low demands.

*B. Optimization*

When demands are considered to be random variable with the parameters of average demand and standard deviation, the optimal solution can be obtained by applying the derivative function to total cost equation. In case of lateral transshipment, the system is dynamic management and involving the estimation of safety stock quantity, thus simulation technique is more efficient. This section presents the equations related to optimal solution for multiple warehouses problem. The items holding cost of two warehouses compose of holding economic order quantity, safety stock, and lateral transshipment quantity as shown in equation (10). The shortage cost and inventory setup cost for multiple warehouses problem is represented as equation (11) and (12), respectively.

$$H_{ij}(Q_{ij}, q_j) = IC \begin{bmatrix} \frac{(Q_{11} + Q_{22})}{2} + (S_{d_1} Z_1 \sqrt{LT_1} + S_{d_2} Z_2 \sqrt{LT_2} \\ + (q_{12} + q_{21}) \end{bmatrix} \quad (10)$$

$$B_{ij}(Q_{ij}, q_j) = k_2 (E_{Z_2} S_{d_2} - q_{12}) \frac{D_1}{Q_{11}} + k_1 (E_{Z_1} S_{d_1} - q_{21}) \frac{D_2}{Q_{22}} \quad (11)$$

$$S_{ij}(Q_{ij}) = S_1 \frac{D_1}{Q_{11}} + S_2 \frac{D_2}{Q_{22}} \quad (12)$$

$$T_{ij}(Q_{ij}, q_j) = (t_{11} dist_{11} + \alpha q_{12}) \frac{D_1}{Q_{11}} + (t_{22} dist_{22} + \alpha q_{21}) \frac{D_2}{Q_{22}} \quad (13)$$

Since demands are random and uncertain, the optimal $Q_{ij}$ from equation (2) is not accurately optimal value. The economic order quantity from equation (2) does not include the number of item stockout ($k_i E_Z S_{d_i}$), thus, $Q_{ij}$ will vary and result in varying of $P_{Stockout}$ and $SS_i$. Equation (14) and (15) are the solutions of replenishment quantity and probability of stockout without lateral transshipments.

$$Q = \sqrt{\frac{2D_i\,[S + k_i E_Z S_{d_i}]}{IC}} \quad (14)$$

$$P_{stockout} = 1 - \frac{QIC}{D_i k_i} \quad (15)$$

Consequently, the simulation is the research method considered to be more efficient with random events.

*C. Instance Problem*

The instance problem is a distribution of three warehouses and three retailers with different demand levels. The demands are normal distribution with the average weekly demand and standard deviation of 77 and 25, 350 and 150, and 750 and 300 for retailer1, 2, and 3, respectively. The inventory parameters are 25% of holding cost, 10 dollars per order for setup cost and 2 dollars per unit for shortage cost. Suppose that the item has a value of 200 and the lead time for replenishment an item is 6 weeks. The simulation model is illustrated as shown in figure 3.

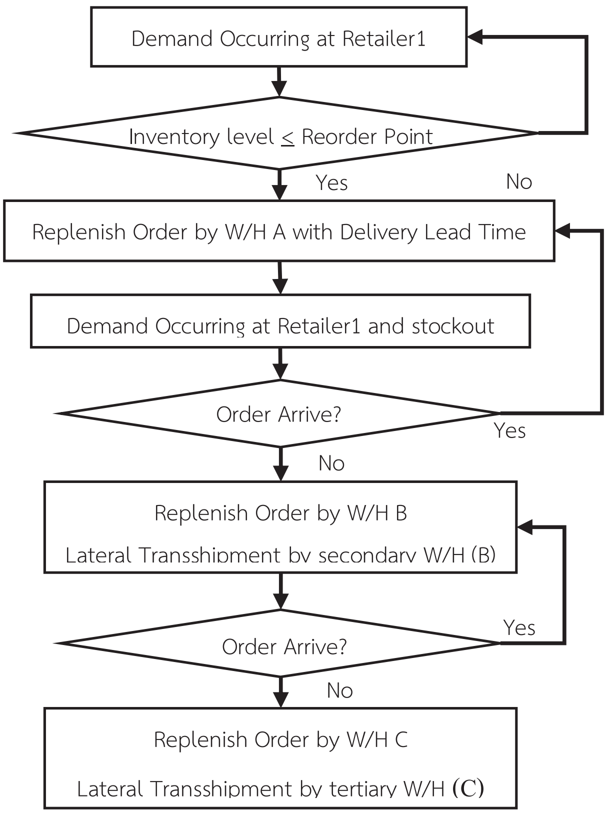


Fig. 3 Conceptual Model for Simulation

The primary warehouse has to replenish orders to retailers with order filled rate of 95% and the less demand is filled by the secondary and the tertiary warehouses.

The instance problem is a distribution of three warehouses with three retailers which has order filled rate of 95% by primary warehouse, 4% by secondary warehouse and 1% by tertiary warehouse. Transportation rate is lowest for the primary warehouse and increases for the secondary and tertiary warehouse. Suppose that, the rush distance for the secondary warehouse and the tertiary warehouse are more than the primary warehouse about 25% and 50%, respectively. Thus, the variable transportation cost per unit of travelling distance and per item of rush delivery for the instance problem is 0.2, 0.25, and 0.3.

## III. EXPERIMENTAL RESULTS

The research problem is developed as the three warehouses and three retailers' distribution system by using Arena simulation. Then, the simulation is performed in different scenarios to observe the effect of related factors which are demand and filling rate to the number of units' stockout.

### A. *Simulation Model*

The problem was created on Arena simulation modelling program with 3 modules. The first module is supplying activity which will replenish item when the inventory level at a retailer reach its' reorder point as shown in figure 4. The second module, as shown in figure 5, is creating orders at each retailer according to its' uncertain demands varying between retailers. The third module is shown in figure 6 which simulate the replenishment activities of three warehouses. The 95% of orders are replenished by the primary warehouse of that retailer. The less orders of 4% are supported by the secondary warehouse and the left of 1% are replenished by the tertiary warehouse.

The developed model was simulated by varying demands and order filling rate with ten replications for each scenario. The considered demands are randomly normal distribution with three different levels assigned to retailers.

### B. *Experimental Results*

The model was simulated in four scenarios to evaluate the effect of demand dispersion. The random demands of three retailers with low, middle and high values of demands is assigned as shown in table I to table IV. The order quantity, safety stock and reorder point are calculated as equation (1), (2), and (3), respectively. For each scenario, instead of calculating the total system cost, the maximum and the average number of stockout are recorded and reported as shown in the following table because the research objective is to study the behaviour of stockout from varying the related factors.

TABLE I: The Simulation Results with Low Demands

| Scenario I | Retailer1 | Retailer2 | Retailer3 |
|---|---|---|---|
| Demands | 10 | 350 | 900 |
| Standard DEV | 5 | 150 | 320 |
| Order quantity | 14.14 | 83.67 | 134.16 |
| Safety stock | 20.21 | 606.25 | 1293.33 |
| Reorder Point | 80.21 | 2,706.25 | 6,693.33 |
| Max. No. Stockout | 19,947.71 | 448.99 | 927.72 |
| Avg. No. Stockout | 14,929.12 | 334.54 | 709.43 |
| Max. Stockout Cost | 39,895.41 | 897.99 | 1,855.45 |

TABLE II: The Simulation Results with Medium Demands

| Scenario II | Retailer1 | Retailer2 | Retailer3 |
|---|---|---|---|
| Demands | 77 | 350 | 750 |
| Standard DEV. | 25 | 150 | 300 |
| Order Quantity | 39.24 | 83.67 | 122.47 |
| Safety stock | 101.04 | 606.25 | 1,212.50 |
| Reorder Point | 563.04 | 2706.25 | 5712.50 |
| Max. No. Stockout | 13,525.59 | 532.77 | 1,020.24 |
| Avg. No Stockout | 9,987.35 | 396.97 | 774.63 |
| Max Stockout Cost | 27,051.18 | 1,065.55 | 2,040.48 |

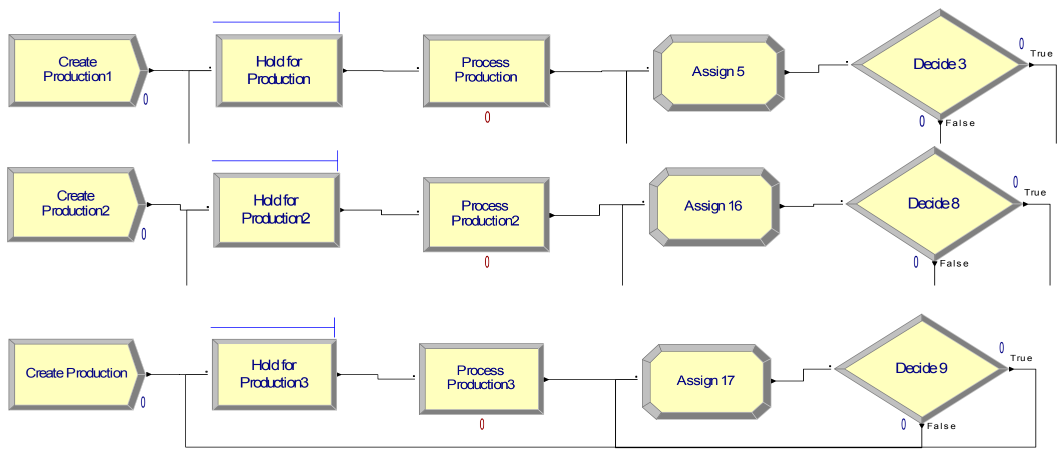


Fig. 4 Supplying Module

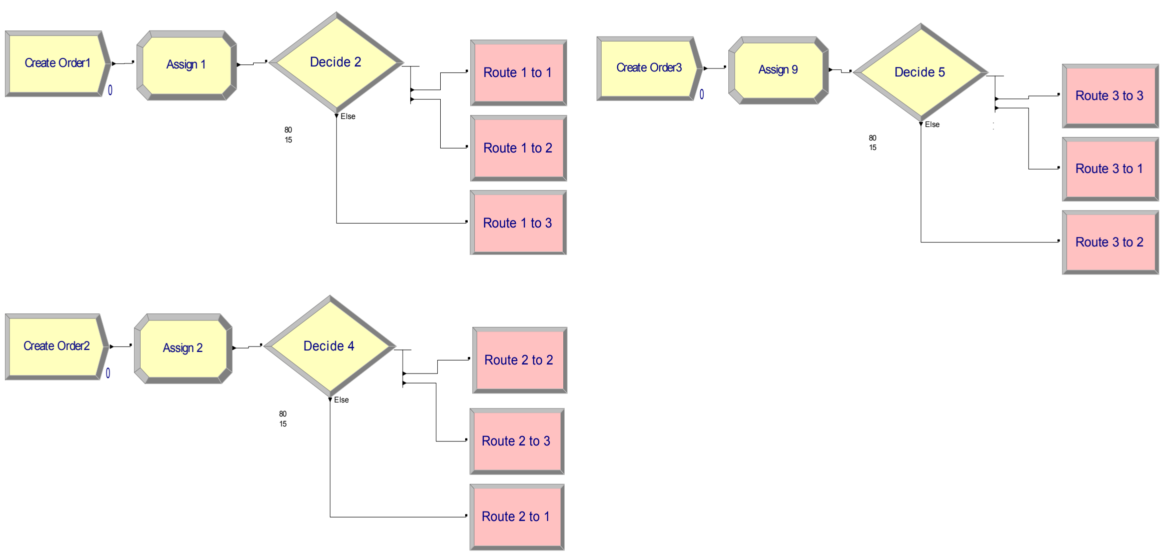


Fig. 5 Distribution Module

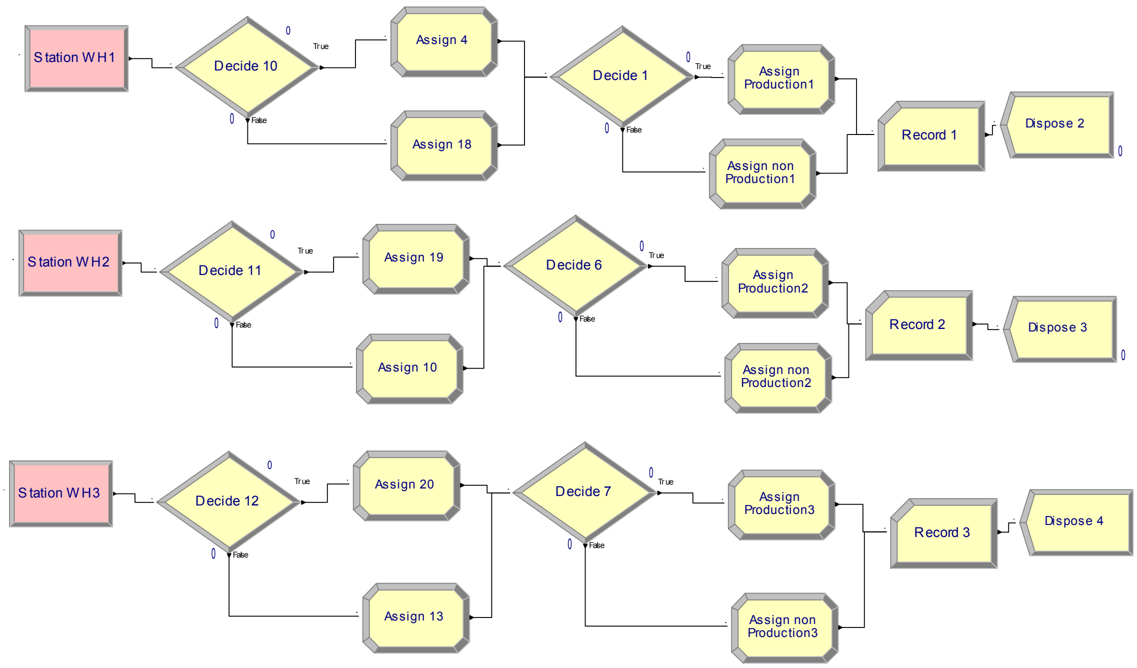


Fig. 6 Replenishment Module

According to table II, the three retailers' average demands are set nearby comparing to average demands in table I. After performing the simulation, the total average number of units' stockout decrease when the network has demands close by. For equally assigned demands as shown in table III, the simulation results show significantly decreasing in average number of units' stockout. For table IV, demand average and variation is increased about 4 times comparing to the second scenario. The average number of units' stockout increases about 5.5 times comparing to the results from the second scenario.

TABLEIII: The Simulation Results with Equal Demands

| Scenario III | Retailer1 | Retailer2 | Retailer3 |
|---|---|---|---|
| Demand | 400 | 400 | 400 |
| Standard DEV | 194 | 194 | 194 |
| Order quantity | 89.44 | 89.44 | 89.44 |
| Safety stock | 784.08 | 784.08 | 784.08 |
| Reorder Point | 3,184.08 | 3,184.08 | 3,184.08 |
| Max.No.Stockout | 3,184.08 | 3,184.08 | 3,184.08 |
| Avg No Stockout | 1,467.62 | 1,751.26 | 2,090.46 |
| Max Stockout Cost | 1,134.23 | 1,318.03 | 1,620.59 |

TABLE IV: The Simulation Results with High Demands

| Scenario IV | Retailer1 | Retailer2 | Retailer3 |
|---|---|---|---|
| Demand | 385 | 1750 | 3750 |
| Standard DEV | 125 | 750 | 1500 |
| Order quantity | 87.75 | 187.08 | 273.86 |
| Safety stock | 505.21 | 3031.24 | 6062.49 |
| Reorder Point | 2,815.21 | 13,531.24 | 28,562.49 |
| Max. No. Stockout | 67,796.00 | 2,595.87 | 7,269.04 |
| Avg No Stockout | 49,990.00 | 1,934.18 | 5,015.13 |
| Max Stockout Cost | 13,5591.90 | 5,191.75 | 14,538.08 |

By varying the filling rate from 95% (FR = 0.95) to 80% (FR = 0.8), the average number of units' stockout increases as shown in table V. Thus, the deviation percentage of amounts of item stockout is calculated in order to evaluate the effect of filling rate varying from 95% to 80% as the following equation:

$$\%Deviation = \frac{NumberofStockout_{(FR=0.8)}}{NumberofStockout_{(FR=0.95)}} \times 100 \qquad (14)$$

TABLE V: The Results Comparison between Filling Rate of 0.8 and 0.95

| Cases Study | Location | Demand Distribution | Average Number of Stockout (Unit) | |
|---|---|---|---|---|
| | | | Filling Rate=0.8 | Filling Rate=0.95 |
| Scenario 1 | Retailer1 | N(10,5) | 22,080.64 | 14,929.12 |
| | Retailer2 | N(350,150) | 4,484.38 | 334.54 |
| | Retailer3 | N(900,320) | 2,735.73 | 709.43 |
| | Total | | 29,300.75 | 15,973.09 |
| Scenario 2 | Retailer1 | N(77,25) | 15,128.24 | 9,987.35 |
| | Retailer2 | N(350,150) | 4,143.92 | 396.97 |
| | Retailer3 | N(750,300) | 2,593.81 | 774.63 |
| | Total | | 21,865.97 | 11,158.95 |
| Scenario 3 | Retailer1 | N(385,125) | 76,204.30 | 49,989.63 |
| | Retailer2 | N(1750,750) | 20,833.69 | 1,934.18 |
| | Retailer3 | N(3750,1500) | 13,699.80 | 5,015.13 |
| | Total | | 110,737.79 | 56,938.94 |
| Scenario 4 | Retailer1 | N(400,194) | 2,787.53 | 1,134.23 |
| | Retailer2 | N(400,194) | 3,598.94 | 1,318.03 |
| | Retailer3 | N(400,194) | 3,716.95 | 1,620.59 |
| | Total | | 10,103.42 | 4,072.85 |

By calculating %Deviation according to results in table V;

$$\%Deviation_{scenarioI} = \frac{29,300.75}{15,973.09} \times 100 = 183.44\%$$

$$\%Deviation_{scenarioII} = \frac{21,865.97}{11,158.95} \times 100 = 195.95\%$$

$$\%Deviation_{scenarioII} = \frac{110,737.79}{56,938.94} \times 100 = 194.49\%$$

$$\%Deviation_{scenarioII} = \frac{110,737.79}{56,938.94} \times 100 = 194.49\%$$

Consequently, the 15 percentage decreasing of filling rate (95% to 80%) results in the increasing of the average number of item's stockout of 192.1 percentage.

### *C. Results Discussion*

According to the simulation results from table I to table IV, the discussion is summarized into 3 issues. Firstly, the distribution system has lower dispersion of demand as shown in table II comparing to table I, the maximum average value of total number of item's stockout is 9,987.35 units (table II), while the maximum average value of total number of item's stockout is 14,929.12 units (table I). As the result, when the demands among retailers are more difference, the distribution system trends to have higher total number of items' stockout. Secondly, the results for all scenarios (table I to table IV) show that the retailer with the lowest demand trends to have the significant high in number of units' stockout. Lastly, the system with the equal demand, the number of item's stockout trend to be low and equally.

## IV. CONCLUSION

The simulation of reactive lateral transshipment replenishment of multiple warehouses and multiple retailers' distribution system by varying the retailers' average demands shows consequence to the average number of item's stockout. When retailers in the network have equal average demands, the average number of item's stockout decreases significantly. The distribution system with equal average demands gives lowest number of item's stockout. By varying filling rate from 95% to 80%, the number of item's stockout dramatically increase about 192 percentage in average for every scenarios.

For future research, the sensitivity analysis of related factors such as inventory holding cost and setup cost could be performed.

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