◆ **Research Paper**

Analysis of Multi-Level Inventory Distribution System for an Item with Low Level of Demand

Lee, Jin Seok*
Yoon, Seung Chul**

Abstract

The main objective of this research is to analyze an order point and an order quantity of a distribution center and each branch to attain a target service level in multi-level inventory distribution system. In case of product item, we use the item with low volume of average monthly demand. Under the continuous review method, the distribution center places a particular order quantity to an outside supplier whenever the level of inventory reaches an order point, and receives the order quantity after elapsing a certain lead time. Also, each branch places an order quantity to the distribution center whenever the level of inventory reaches an order point, and receives the quantity after elapsing a particular lead time. When an out of stock condition occurs, we assume that the item is backordered. For considering more realistic situations, we use generic type of probability distribution of lead times. In the variable lead time model, the actually achieved service level is estimated as the expected service level. Therefore, this study focuses on the analysis of deciding the optimal order point and order quantity to achieve a target service level at each depot as a expected service level, while the system-wide inventory level is minimized. In addition, we analyze the order level as a maximum level of inventory to suggest more efficient way to develop the low demand item model.

1. Introduction

To satisfy customers dispersed regionally, inventories are necessary to be stored in several locations. When customers are too far from where the product is produced or supplied, a firm may use a central distribution center as an upper level of distribution

* Dept. of Business Administration, Graduate School, Dankook Univ.
** Dept. of Business Administration, Dankook Univ.

system which supplies the product item to regional branches.

In this system the distribution center orders particular order quantity to an outside supplier(vendor) whenever on-hand plus on-order inventory level reaches an order point under the continuous review method. The order replenishment is received after elapsing a lead time.

Each branch places an order to its distribution center using the same continuous review method and receives the order replenishment after elapsing a particular lead time during an order cycle. The customers access to the local branches to buy the product item. This research basically uses above ordering policy.

Also we assume following circumstances. First, the level of demand for an item is low and monthly demand of distribution center and each branch has a Poission distribution. Second, we use two cases for the actual lead times. That is, some lead times fall on the scheduled lead time(on time case), others fall behind the scheduled lead time(late lead time case). We assume the late lead times follow an exponential distribution with a expected value of late lead times for the distribution center and each branches. Third, whenever demands can not be filled because of shortages, the number of shortages are backordered. Forth, branches are independent each other on inventory status. Finally, we use an order level(OL) as an upper limit of inventory. That is, whenever on-hand plus on-order quantity of inventory falls on the order point(OP), each stockkeeping unit orders as much as ($OL-OP$) quantity to its upper level of stockkeeping unit. By using this (OL, OP) system, we can search the proper order level, order point, and order quantity to achieve a target service level effectively without analyzing cost data.

Based on the above policy and data, this research will develop the optimal search method for the inventory distribution system in such a way to achieve a target service level for each branch, while total system-wide inventory level is minimized. In multi-level inventory distribution system, the distribution center plays key roles. Basically, each branch can not attain a target service level, without managing the distribution center properly.

2. Inventory Analysis for Distribution Center and Each Branch.

Following data are used for the inventory analysis in the distribution center and each branch.

(Data for distribution center)

λ = average monthly demand

L = scheduled lead time in month

$P(L'=L)$ = probability that an actual lead time(L') falls on the scheduled lead time(L)

$P(L'>L)$ = probability that an actual lead time(L') falls behind the scheduled lead time(L)

$E(L'|L'>L)$ = expected value of lead time when actual lead time(L') falls behind the scheduled lead time(L)

In the above data, λ is estimated by summing average monthly demands of all branches. also, $P(L'=L)+P(L'>L)$ is equal to 1 and probability density function for the late lead time case $f(L'|L'>L)$ is $f(L')$ / $P(L'>L)$. As mentioned in the introduction part, L' for the late lead time case has an exponential distribution with the expected value $E(L'|L'>L)$.

(Data for branch i)

P_i = probability of demand assigned to branch i

l_i = scheduled lead time for branch i

N = number of branches

In the above data, $\sum_{i=1}^{N} P_i$ is equal to 1 and P_i can be decided based on the proportion of past demand history for branch i.

2.1 Inventory Analysis for Distribution Center

To find the order level(OL) and order point(OP) which gives a particular services level(SL) in an order cycle, SL is defined as

$$SL = 1 - \frac{\textit{Expected number of shortages in an order cycle}}{\textit{Expected demand in an order cycle}}$$

The definition with various situations is explained in references [2], [3] and [10]. Thus the SL has following relationship in our research. That is,

$$\begin{aligned} SL &= 1 - \frac{E(X > OP)}{OL - OP} \\ &= 1 - \frac{\sum_{X > OP}^{\infty} (X - OP) \cdot P(X)}{OL - OP} \\ &= 1 - \frac{\sum_{X > OP}^{\infty} X \cdot P(X) - OP \cdot \sum_{X > OP}^{\infty} P(X)}{OL - OP} \end{aligned} \tag{1}$$

Here, X indicates a lead time demand and is assumed to have the Poisson distribution with the expected value ($\lambda \cdot L$) from the data. Again the OL means the upper limit of inventory, and (OL-OP) quantity is the same as an order quantity. Also, the order quantity (OL-OP) of an order cycle shuold be greater than the lead time demand ($\lambda \cdot L$), since the (OL-OP) quantity is the same as the expected demand for the order cycle. By using the equation (1), OL and OP which gives a particular SL can be easily searched. For example, when λ=4 and L= 0.3 months, the relations among OL, OP, SL are

OL	1	2	2	3	3	3	4	4	4	4	5	5	5	5	5
OP	*	0	*	0	1	*	0	1	2	*	0	1	2	3	*
SL	*	0.40	*	0.60	0.75	*	0.70	0.83	0.92	*	0.76	0.87	0.95	0.98	*

In the example, if we want SL of 95%, we need to set the OL and OP as 5 and 2 respectively, and the order quantity is 3.

As discussed earlier, the inventory status of each branch depends on the inventory status of distribution center. That is, the lead time distribution of each branch is determined by the probability of an out of stock condition and the time for which a demand is in a backorder condition in the distribution center. The probability of an out of stock condition, $P(O)$, is computed by the relations

$$\begin{aligned} P(O) &= P(X > OP) \\ &= 1 - P(X \le OP) \\ &= 1 - \sum_{X=0}^{OP} P(X) \end{aligned} \tag{2}$$

Here the X indicates the lead time demand.

The expected time for which a demand is in a backorder condition is determined by the following relationship. In an order cycle, when an out of stock condition occurs, the expected number of backorder, B, will be

$$B = \frac{E(X > OP)}{P(O)}$$

Further, when the out of stock condition occurs in an order cycle, the expected time for which a demand is in a backorder condition, τ_B, is computed by

$$\tau_B = \frac{1}{2} \cdot \frac{B \cdot L}{OP + B} \tag{3}$$

from the relation of time and quantity. The detail explanation about $P(O)$ and τ_B are in the reference [1]. These $P(O)$ and τ_B play an important role in determining the lead time distribution of each branch.

Our research applies variable lead times(L's). Based on the above concepts and equations (1), (2), and (3), when $L'=L$, the expected values of SL, $P(O)$, and τ_B are computed by

$$E(SL \mid L' = L) = SL \tag{4}$$

$$P(O \mid L' = L) = 1 - P(X \le OP) \tag{5}$$

$$E(\tau_B \mid L' = L) = \frac{1}{2} \cdot \frac{B \cdot L}{OP + B} \tag{6}$$

Basically, when $L'=L$, these expected values are determined by using the scheduled lead time L.

Also, when $L'>L$, those three expected values are computed by the relations

$$E(SL \mid L'>L) = \int_{L'>L}^{\infty} SL' \cdot f(L' \mid L'>L)dL' \quad (7)$$

$$P(O \mid L'>L) = \int_{L'>L}^{\infty} P(O)' \cdot f(L' \mid L'>L)dL' \quad (8)$$

$$E(\tau_B \mid L'>L) = \int_{L'>L}^{\infty} \tau'_B \cdot f(L' \mid L'>L)dL' \quad (9)$$

Here, the probability density $f(L'|L'>L) = f(L') / P(L'>L)$, and when $L'>L$, L' has an exponential distribution with the expected value $E(L'|L'>L)$ in the data. Related calculations about the exponential probabilities are explained in reference [4].

By combining those two cases, the expected values in terms of all L's, $E(SL)_c$, $P(O)_c$, and $E(\tau_B)_c$ for the distribution center are determined by the relations

$$E(SL)_c = E(SL \mid L'=L) \cdot P(L'=L) + E(SL \mid L'>L) \cdot P(L'>L) \quad (10)$$

$$P(O)_c = P(O \mid L'=L) \cdot P(L'=L) + P(O \mid L'>L) \cdot P(L'>L) \quad (11)$$

$$E(\tau_B)_c = E(\tau_B \mid L'=L) \cdot P(L'=L) + E(\tau_B \mid L'>L) \cdot P(L'>L) \quad (12)$$

<Table 1> shows the results of computation for various data values. For the computation, we use following basic data. Additionally we set the OL as 12 simply for the purpose of table presentation.

λ = 8
L = 0.8
$P(L'=L)$ = 0.7
$P(L'>L)$ = 0.3
$E(L'|L'>L)$ = 1.2

The table shows sensitivities based on changes of each variable value. For example, if the scheduled lead time(L) is reduced to 0.5 months from 0.8 months, OL and OP corresponding to $E(SL)$ of 90% is 12 and 6 respectively. The blanks with (*) are not computed, since the cases have smaller order quantities($OL-OP$) than average lead time demands. We did not show the $P(O)_c$, $E(\tau_B)_c$ on the table, because the main purpose of these value is to get the lead time distribution of each branch. Also we use 500 exponentially distributed L's with $E(L'|L'>L)$ in case of $L'>L$ to attain those expected values more correctly.

2.2 Inventory Analysis for Branch i

The generating methods of sl_i, op_i, and ol_i for branch i are basically same as those of distribution center. First, the average monthly demand (λ_i) and scheduled lead time demand (λ_{1_i}) are calculated by the relations

<Table 1> Calculated Results of $E(SL)$, OL and OP at Distribution Center

	OL	12	12	12	12	12	12	12	12
	OP	0	1	2	3	4	5	6	7
λ									
5		0.62	0.68	0.74	0.80	0.85	0.89	0.92	0.95
6		0.55	0.59	0.65	0.71	0.77	0.82	0.86	0.89
7		0.47	0.51	0.56	0.62	0.68	0.73	0.78	*
8		0.40	0.44	0.48	0.53	0.58	0.64	*	*
9		0.33	0.36	0.40	0.44	0.49	*	*	*
10		0.27	0.30	0.32	0.36	*	*	*	*
L									
0.5		0.60	0.66	0.72	0.77	0.83	0.87	0.90	0.92
0.6		0.53	0.58	0.64	0.69	0.75	0.80	0.84	0.88
0.7		0.47	0.51	0.56	0.61	0.67	0.73	0.78	*
0.8		0.40	0.44	0.48	0.53	0.58	0.64	*	*
0.9		0.34	0.37	0.41	0.45	0.50	*	*	*
1.0		0.28	0.30	0.33	0.37	*	*	*	*
$P(L'=L)$									
0.8		0.42	0.46	0.51	0.56	0.62	0.67	*	*
0.7		0.40	0.44	0.48	0.53	0.58	0.64	*	*
0.6		0.38	0.41	0.46	0.50	0.55	0.61	*	*
0.5		0.36	0.39	0.43	0.47	0.52	0.57	*	*
0.4		0.34	0.37	0.40	0.45	0.49	0.54	*	*
0.3		0.32	0.34	0.38	0.42	0.46	0.51	*	*
$E(L' \mid L'>L)$									
1.0		0.43	0.47	0.51	0.56	0.62	0.68	*	*
1.2		0.40	0.44	0.48	0.53	0.58	0.64	*	*
1.4		0.39	0.42	0.46	0.51	0.56	0.62	*	*
1.6		0.38	0.42	0.46	0.50	0.55	0.61	*	*
1.8		0.38	0.41	0.45	0.50	0.55	0.60	*	*
2.0		0.37	0.41	0.45	0.49	0.54	0.59	*	*

$$\lambda_i = \lambda \cdot P_i \tag{13}$$

$$\lambda_{l_i} = \lambda_i \cdot l_i \tag{14}$$

Here, the λ indicates the average monthly demand of distribution center, and the λ is generally determined by summing the average monthly demands of all branches. Thus, λ_i for branch i is decided with the probability P_i. Therefore service level(sl_i), order level(ol_i), and order point(op_i) for branch i during an order cycle are decided by the relation

$$\begin{aligned} sl_i &= 1 - \frac{E(x_i > op_i)}{ol_i - op_i} \\ &= 1 - \frac{\sum_{x_i > op_i}^{\infty} (x_i - op_i) \cdot P(x_i)}{ol_i - op_i} \end{aligned} \tag{15}$$

as the same way to search in the distribution center. The x_i is a lead time demand for branch i and follows the Poisson distribution.

The lead time distribution for branch i is determined by the inventory status of the distribution center. When an out of stock condition does not occur in the distribution center, the branch i receives the order quantity on time(on the scheduled lead time l_i). However, when an out of stock condition occurs in the distribution center, the lead time for branch i (l'_i) will be greater than the scheduled lead time l_i. Also the late lead times are assumed to be an exponential distribution as assumed in the distribution center. Thus, for an actual lead time l'_i, the probabilities and expected value have following relationships

$$P(l'_i = l_i) = 1 - P(O)_c \tag{16}$$

$$P(l'_i > l_i) = P(O)_c \tag{17}$$

$$E(l'_i \mid l'_i > l_i) = l_i + E(\tau_B)_c \tag{18}$$

The $P(O)_c$ and $E(\tau_B)_c$ are computed from the equations (11) and (12).

Now, the expected service level for all lead times for branch i is determined through the following procedures. When $l'_i = l_i$, the expected service level is

$$E(sl_i \mid l'_i = l_i) = sl_i \tag{19}$$

and sl_i is decided from the equation (15). Also when $l'_i > l_i$, the expected service level can be found by

$$E(sl_i \mid l'_i > l_i) = \int_{l'_i > l_i}^{\infty} sl'_i \cdot f(l'_i \mid l'_i > l_i) dl'_i \tag{20}$$

Here, the probability density $f(l'_i \mid l'_i > l_i)$ is equal to $f(l'_i)\ /\ P(l'_i > l_i)$.

By combining those two cases, the expected service level for branch i ($E(sl_i)$) is computed by the relation

$$E(sl_i) \;=\; E(sl_i \mid l'_i = l_i) \cdot P(l'_i = l_i) \;+\; E(sl_i \mid l'_i > l_i) \cdot P(l'_i > l_i) \qquad (21)$$

<Table 2> shows various results for the relations among ol_i, op_i, and $E(sl_i)$. The basic data are

(Distribution Center)

λ = 8

L = 0.8

$P(L'=L)$ = 0.7

$P(L'>L)$ = 0.3

$E(L' \mid L'>L)$ = 1.2

(Brach i)

$P_i = 1/N$ (i = 1, 2, · · · ,N)

l_i = 0.4 (i = 1, 2, · · · ,N)

In above example, the OL and OP for the distribution center are found as 10 and 3 respectively. Also, we set ol_i=1, 2, 3, and 4 to compute various $E(sl_i)$ as an example. For example from the table, when N=3(that is, P_i=0.33), if λ is reduced to 6, ol_i and op_i are set as 4 and 2 respectively to get $E(sl_i)$ of 0.95. Those blanks with (*) are indicated the cases that order quantities(ol_i-op_i) are smaller than lead time demands. Thus, these cases are not accepted.

3. Search for Optimization

The expected service level found throughout the above sections means the actual service levels which will be achieved in the future under the variable lead time situation. So to get the target service level as the expected service level for each branch, we need to set the proper order level, order point, and order quantity for the distribution center and each branch. Throughout the many computational tests, we found the fact that there are several combinations of order levels and order points for the distribution center and each branch to give same value of expected service level for each branch. In this research, the purpose of optimization is to select the optimal combination of (OL, OP), (ol_i, op_i) among the several combinations to give the same value of target service level for each branch.

In terms of optimization, we use the overall system-wide average inventory level as a constraint. That is, we select the optimal combination of (OL, OP), (ol_i, op_i) to attain the target service level ($E(sl_i)$) for each branch, while the entire system-wide average inventory level keeps its minimum level. Recall that the order quantity is (OL-OP) for the distribution center, and (ol_i-op_i) for branch i. In our model, the average on-hand inventory is computed from following relations. The average on-hand inventory for distribution center (H), and the average on-hand inventory for branch i (h_i) are respectively

<Table 2> Calculated Result of $E(sl_i)$

		oli	1	2	2	3	3	3	4	4	4	4
		opi	0	0	1	0	1	2	0	1	2	3
N=3	λ											
	6		0.09	0.51	0.63	0.67	0.82	0.89	0.75	0.88	0.95	0.97
	8		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	10		*	0.14	*	0.40	0.52	*	0.55	0.68	0.78	*
	L											
	0.6		*	0.36	*	0.57	0.72	*	0.68	0.81	0.90	*
	0.8		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	1.0		*	0.27	*	0.51	0.65	*	0.64	0.77	0.86	*
	$P(L'=L)$											
	0.7		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	0.5		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	0.3		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	$E(L' \mid L'>L)$											
	1.2		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	1.5		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
	1.8		*	0.31	*	0.54	0.67	*	0.65	0.78	0.87	*
N=5	λ											
	6		0.41	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	8		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	10		0.05	0.46	0.58	0.64	0.79	0.87	0.73	0.86	0.93	0.96
	L											
	0.6		0.24	0.61	0.76	0.74	0.88	0.94	0.81	0.92	0.97	0.99
	0.8		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	1.0		0.16	0.56	0.70	0.71	0.85	0.92	0.78	0.90	0.96	0.98
	$P(L'=L)$											
	0.7		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	0.5		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	0.3		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	$E(L' \mid L'>L)$											
	1.2		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	1.5		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
	1.8		0.19	0.58	0.72	0.72	0.86	0.93	0.79	0.91	0.96	0.98
N=7	λ											
	6		0.58	0.79	0.92	0.86	0.96	0.99	0.89	0.97	0.99	1.00
	8		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	10		0.24	0.62	0.76	0.74	0.88	0.94	0.81	0.92	0.97	0.99
	L											
	0.6		0.45	0.72	0.87	0.82	0.93	0.98	0.86	0.96	0.99	1.00
	0.8		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	1.0		0.38	0.69	0.83	0.79	0.92	0.97	0.84	0.94	0.98	0.99
	$P(L'=L)$											
	0.7		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	0.5		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	0.3		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	$E(L' \mid L'>L)$											
	1.5		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	1.2		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99
	1.8		0.40	0.70	0.85	0.80	0.92	0.97	0.85	0.95	0.98	0.99

$$H = \frac{[(OL-OP)+OP-\lambda\cdot L] + [OP-\lambda\cdot L]}{2}$$
$$= \frac{OL+OP}{2} - \lambda\cdot L$$
$$h_i = \frac{ol_i+op_i}{2} - \lambda\cdot P_i\cdot l_i \quad (22)$$

Here the term $(OL-OP)+(OP-\lambda\cdot L)$ indicates the average inventory at the beginning of an order cycle, and $(OL-\lambda\cdot L)$ is the average inventory at the end of an order cycle. h_i for branch i is calculated by using the same method. These concepts are fully explained in the references [5] and [9].

Computer search is used for the optimization procedures, since the model has many variables and complexity to derive the optimal function. The brief summary of search procedures are followings.

i) Starting from OL=1, ol_i=1 (in this case, OP and op_i are set 0 automatically), compute $E(sl_i)$, i = 1, 2,· · ·, N, with other given data. Succeedingly, increasing the OL and ol_i one by one, repeat the computation for $E(sl_i)$ until the target $E(sl_i)$, i = 1, 2,· · ·,N, is found. And set all combinations of (OL, OP) and (ol_i, op_i) to give the target $E(sl_i)$ as feasible solutions.

ii) For the feasible solutions, compute the corresponding values of $(H+h_i)$, and select (OL, OP), (ol_i, op_i) which gives the minimum quantity of $(H+h_i)$. Repeat these processes for all branches.

iii) Among the results of procedure ii), select the biggest value of OL(with corresponding OP) as the optimal solution for the distribution center. At the same time, select the corresponding values of ol_i and op_i as the optimal solution for branch i.

<Table 3> shows the results of optimal search for (OL, OP), (ol_i, op_i) to achieve the target $E(sl_i)$ based on various data values. For example, when N=5(that is, P_i=0.2), to achieve the target $E(sl_i)$ of 95%, we should set the OL, OP as 7, 4, and ol_i, op_i as 4, 1. The order quantity is 3 at the distribution center and 3 at each 5 branch. At this time, the system-wide total average inventory of the distribution system is 12.6.

4. Summary and Conclusion

Throughout the analysis in part 2, we suggest methods to determine OL, OP and order quantity of an item with low level of demand incorporating to both demand and lead time variations. Also in part 3, we discuss about the optimal search method to find the optimum level of order level, order point, and order quantity which produce the expected service level as a target service level for each regional branch.

This model has following advantages. First, in case of an item with a low level of demand, proper order point and order quantity to fit the target service level can be easily

<Table 3> Result of Optimal Search

λ = 8
L = 0.8
$P(L'=L)$ = 0.7
P(L'>L) = 0.3
E(L'|L'>L) = 1.2

N	P_i	l_i	$E(sl_i)$	Results for Optimal Search				
				OL	OP	ol_i	op_i	Tot. Ave. Stock*
3	1/3	0.3	0.95	7	4	3	2	8.2
			0.90	7	4	3	1	6.7
			0.85	8	5	2	1	6.2
			0.80	7	4	2	1	5.2
5	1/5	0.4	0.95	7	4	4	1	12.6
			0.90	8	5	2	1	8.6
			0.85	8	5	3	0	8.6
			0.80	7	4	3	0	7.6
7	1/7	0.5	0.95	7	4	3	1	13.49
			0.90	7	4	2	1	9.99
			0.85	7	4	3	0	9.99
			0.80	7	4	3	0	9.99
9	1/9	0.6	0.95	7	4	3	1	16.9
			0.90	7	4	4	0	16.9
			0.85	7	4	3	0	12.4
			0.80	8	5	2	0	8.9

* : System-Wide Total Average Stocks = $H_c + \sum_{i=1}^{N} h_i$

found without the estimation of carrying, ordering, backorder, and other costs. Also, when branches do not have enough storage spaces for a particular item, they can not order and receive large amount of order quantity even though the order quantity is economic order quantity. In this situation, this model will be well applied by considering th relations among order level, order point, and service level. Second, many companies currently experience late lead times. This model incorporates actual lead times with the variable demands for entire analyses. Further, by suggesting the analytical ways about the relations between inventory status at the distribution center and inventory status at branches, we can smooth the replenishment flow between two level of stockkeeping units with very limited data values.

As those of related researches, references [6] and [7] may be recommended. These researches show the methods to find optimal level of customer services with considerations of stock level. However, those models use constant lead time.

Finally, to expand this study, we recommend the analysis about lost sale situation and lateral sourcing methods among those branches. In general, when an item has a low level of demand, the level of inventory for a particular service level would be considerably different between backorder and lost sale cases[8].

References

[1] Brown, R.G.; Smoothing, Forecasting, and Prediction of Discrete Time Series, Prentice-Hall, N.J., pp.370-372, 1962.

[2] Brown, R.G.; Decision Rules for Inventory Management, Holt, Rinehart and Winston, Inc., N.Y., pp.79-103, 1967.

[3] Montgomery, C.D. and Runger, C.G.; Applied Statistics and Probability for Engineers, John Wiley & Sons, Inc., N.Y., pp.159-162, 1994.

[4] Johnson, A.L., and Montgomery, C.D.; Operations Research in Production Planning, Scheduling, and Inventory Control, John Wiley & Sons, Inc., N.Y., pp.59-66, 1974.

[5] Schwarz, L.B.; "A Single Continuous Review Deterministic One-Warehouse N-Retailer Inventory System", Management Science, Vol.31(4), pp.555-566, April, 1973.

[6] Schwarz, L.B., Deuemeyer, B.L., and Bandinelli, R.D.; "Fill-Rate Optimization in a One-Warehouse N-Retailer Distribution System", Management Science, Vol.31(4), pp.488-498, April, 1985.

[7] Smith, B.S.; Computer Based Production and Inventory Control, Prentice-Hall, N.J., pp.130-138, 1989.

[8] Tersine, J.R.; Principles of Inventory and Materials Management, North-Holland, N.Y., pp.211-222, 1988.

[9] Thomopoulos, T.N.; Applied Forecasting Methods, Prentice-Hall, N.Y., pp.314-324, 1980.

[10] Yoon, Seung-Chul; Inventory Management - Methods and Applications, Sigong-Sa, Seoul, pp.323-347, 1997.