A Simulation Model for Optimal Inventory Level of R.O.K Navy's Repair Parts

Seong-Gyu Jeon*, Yong Jin Kim**

Abstract

The weapon system of The Navy is the small quantity producing system on multiple kinds. It is consisted of various equipment and the subordinate parts of those which can repair the damaged part. The operating procedure concerning warship's repair parts managed under these systems is as follows. Firstly, if demand of repair parts occurs from warship which is the operating unit of weapon, then the Fleet(the repair & supply support battalion) is in charge of dealing with these requests. If certain request from warship is beyond the battalion's capability, it is delivered directly to the Logistic Command. In short, the repair and supply support system of repair parts can be described as the multi-level support system. The various theoretical researches on inventory management of Navy's repair parts and simulation study that reflects reality in detail have been carried out simultaneously. However, the majority of existing research has been conducted on aircraft and tank's repairable items, in that, the studies is woefully deficient in the area concerning Navy's inventory management. For that reason, this paper firstly constructs the model of consumable items that is frequently damaged reflecting characteristics of navy's repair parts inventory management using ARENA simulation. After that, this paper is trying to propose methodology to analyze optimal inventory level of each supply unit through OptQuest, the optimization program of ARENA simulation.

Key Words : *the multi-level support system, repair parts, optimal inventory level, simulation*

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* Ph.D. Candidate, Graduate School of Logistics, Inha University, Korea E-mail: 209sc@hanmail.net

** Corresponding author, Associate Professor, Asia-Pacific School of Logistics, Inha University, Korea E-mail: youngjin@inha.ac.kr

1. Introduction

The logistic environment for general industry has been changed rapidly. Much effort has been put into the area not only for the speed and the cost of logistics service but also for quality of service. Many researches regarding inventory management for optimal inventory level which reacts to the demand promptly and minimizes cost simultaneously have been conducted. The logistic environment for the military has been changed rapidly due to its willingness to react to the environmental change actively. The military logistics has been adopting and applying highly sophisticated civilian logistics system to complete their mission within available military budget.

The R.O.K Navy(hereinafter referred to as Navy) has been operating its weapon system, the warship, to accomplish its given mission. The weapon system of the Navy is the small quantity batch production system. It is consisted of various equipment and the subordinate parts of those which can repair the damaged part. As for 2010, the total number of the Navy's repair parts management item is 236,289. It takes up most of Navy's management items(Woo et al. 2012). The operating procedure concerning warship's repair parts managed under these systems is as follows. Firstly, if demand of repair parts occurs from warship which is the operating unit of weapon, then the Fleet(the repair & supply support battalion) is in charge of dealing with these requests. If certain request from warship is beyond the battalion's capability, it is delivered directly to the Logistic Command. In short, the repair and supply support system of repair parts can be described as the multi-level supporting system. The optimal Equipment Operational Availability of warship's weapon system is closely related to repair and supply support system of numerous repair parts. Under current repair and supply support system, the proper inventory management of repair parts is the key element to get smooth supports from related department. However, the Navy has not been adopting optimal inventory level management model that considers multi-level repair parts support system and is closely related to Equipment Operational Availability. Instead, the Navy has been operating inventory management according to daily demand rate which is based on past repair parts demand records and each unit's supply level that is uniformly fixed. These situations are not much different for The Air force or The Army. In case of The Air force, they invented SLAM¹⁾ model so that they have been using it restrictively as reference materials when they decide optimal inventory level(Kim, 2013; Yoon, 2011).

¹⁾ SLAM(Spare Levels for Availability Method) : It is the inventory selection model considering Equipment Operational Availability by adopting LMI's Aircraft Availability Model(O'Malley, 1983). The Air force has been using it as reference material when they decide optimal inventory level for the applicable aircraft.

Repair parts can be largely categorized as consumable items and repairable items. Consumable items are one-offs so that if mechanical problem occurs, they will be replaced by new items. As for repairable items, the damaged parts will be fixed so that they can be re-used when the problem occurs. METRIC(Sherbrooke, 1968) model can be considered as the typical research model for existing repair parts multi-level inventory management. These model computes repair parts inventory level that minimizes EBO(Expected Backorder) within available budget restraint. After METRIC model, it has evolved to Vari-METRIC(Slay, 1984) model that maximizes Equipment Operational Availability. However, METRIC based model has many hypotheses as premises so that there is a severe limit to reflect reality properly. Recently, various simulation based research has been conducted to overcome these limitations. Nevertheless, most of those researches have been given too much emphasis on aircraft and The Army's certain equipment such as tank. Therefore, the research on The Korean Navy's warship repair parts inventory model is severely deficient. For that reason, this paper firstly constructs the model of consumable items that is frequently damaged reflecting characteristics of Navy's repair parts inventory management using ARENA simulation. After that, this study proposes a methodology to analyze optimal inventory level of each supply unit through optimization using OptQuest of ARENA.

The structure of this paper is as follows. In chapter two, the repair parts inventory management process of The Navy is explained and the literature review is conducted. In chapter three, simulation modelling has been performed. In chapter four, computer simulation is conducted and accompanying result analysis is illustrated. Finally, in chapter five, the conclusion is drawn by summarizing this paper and interpreting what it means.

2. Theoretical Background and Literature Review

2.1 The Navy's Repair Parts Inventory Management Process

The military has been implementing various training to maintain combat-readiness condition. The logistics unit maintains certain inventory level to support supplies required for training. As you can see from Figure 1, in case of The Navy, there is one Logistics Command which is composed of supply depot, the supply support unit, and maintenance depot, the maintenance support unit. There are three supply units and maintenance units region by region, in that, supply and maintenance support has been carried out for each assigned warship.

If demand for maintenance occurs from the warship, repair for the damaged part will be conducted autonomously within the warship itself to a limited extent. If it is beyond the warship's own capability, the field maintenance support will be provided from each assigned maintenance unit. Even when it is beyond the field maintenance support capability, the repair act will be conducted by maintenance depot which is the military's final maintenance stage. If it is unable to provide maintenance service from the military itself, the contract maintenance will be implemented. To respond promptly to demand for repair parts under these maintenance system, The Navy endeavors to keep certain inventory level for maintenance support item. They inspect the list for the demand for maintenance and approve the items to deal with it. Therefore, certain inventory level is set for several support units. Some examples are supply depot, each warship's supply support battalion and maintenance depot where its capability is limited to some items.

Figure 1.

Navy's Repair Parts Supply/Maintain Supporting System

The items which require permission from the support units are called ASL (Authorized Stockage List). ASL is the item that is approved by the authority to keep it as inventory in military supply unit. The inventory level for ASL is called the supply level. It is essential for maintaining current supply operational level and replenishing future forecasted demand. In addition, it is approved by standard which are either the days of supply or the amount of the items.

As you can see through Figure 2, the supply levels are categorized into two groups (Broadly and Narrowly) and The Navy is operating their system according to these classifications. The broadly classified group is not just ordinary distribution chain but supply chain with civilian company other than military itself which connotes lead time. Simply, it is the business relation among 'Supplier-Logistics Command-Supply support

battalion'. However, the narrowly classified group is about supply chain for simple distribution. It is the business relation between 'Supply support battalion-User units (Warship)'.

Figure 2.
Component of Supply Level

As for broadly classified group, supply level is RO(Requirement Objective) and it is constituted of PROLT(Procurement Lead Time), SL(Safety Level) and PC(Procurement Cycle). Firstly, PROLT is the required days of supply or the number of supply items during time period from occurrence of procurement demand to completion of release preparation; it is the condition where over 85 percentages of items has been received. Secondly, SL is the required days of supply or the number of supply items to maintain supply's operational ability regardless of abnormal demand increase and lead time increase. Lastly, PC is the required days of supply or the number of supply items for supply operations during procurement lead time of Logistic Command.

As for narrowly classified group, supply level is RO(Requisitioning Objective) and it is constituted of OST(Order & Shipping Time), SL(Safety Level) and OL(Operating Level). OST is very similar to RO of broadly classified group. It is the required days of supply or the number of supply items during time period from occurrence of procurement demand to completion of release preparation; it is the condition where over 85 percentages of items has been received. OL is required days of supply and the number of supply items to maintain supply operational level between receipts of replenishments or between claims of replenishment. SL is the same concept of SL under broadly classified group system. SO (Stockage Objective) is the maximum amount of inventory that can be stocked according to previously set supply level. It is the sum of SL and OL. RP(Reorder Point) is the sum of SL and OST(RO of broadly classified group). It is the threshold for claiming replenishment to

maintain supply operational level without using SL.

The supply level for supply items of The Navy's supply unit will be decided by a method illustrated in Table 1 and 2. Ro for supply depot when AD(Annual Demand) for supply items is decided is "SL for number of days of AD + The amount of required procurement during actual procurement period + AD". RO for supply support battalion is the amount of items claimed for the number of days which is the sum of supply levels among each supply support battalion.

Table 1.

Supply level of supply depot

(unit : amount)

SL	PROLT	RO
$AD \times \frac{00}{365}$	$AD \times \frac{Actual\ PROLT}{365}$	SL + PROLT + AD

* AD : Annual demand for every items

Table 2.

Supply level of Supply Support battalion

(unit : days)

SL	OST	OL	RO
00	00	00	00

Source: Navy internal data(2014)

Jang(2012) points out that supply level decision method illustrated above is not optimized on entire Navy's repair parts supply chain level due to its dependence solely on the number of demand. In addition, he indicates that existing method is not connected to Equipment Operational Availability which is directly linked to keeping combat-readiness condition, in that, it is difficult to decide feasibility of supply level. For that reason, recently, the military puts effort into implementing decision method regarding characteristics of each items and Equipment Operational Availability.

2.2 Literature Review

2.2.1 Research on Inventory Management of the General Company's Multi-level Supply Chain

Kim and Park(2001) suggest five ways of inventory control on multi-level supply chain level and analyze on a scale of logistics cost, customer service level, lead time through simulation method. Lee and Son(2009) suggest the genetic algorithm for optimal order quantity and vehicle allocation plan which minimizes inventory cost while satisfying retailer's demand whose supply chain is of fixed size ordering inventory policy and supplier leading inventory policy. Kim and An(2007) compare existing inventory management system with integrated inventory management model which decides retailer's order cycle using heuristic method to minimize total cost. Jung(2012) analyzes effectiveness of logistic center's integrated inventory management policy and Cross Docking policy under service level constraints considering total cost.

Simulation research on inventory management of the general company's multi-level supply chain is mainly of inventory management related policy, inventory cost and service level among 'Supplier-Logistic Center-Retailer'. Numerous research has been conducted which minimizes total logistics cost while satisfying certain level of customer service level by reflecting characteristics of general company's inventory management that maximizes supply chain value.

2.2.2 Research on Military Repair Parts Inventory Management

The major research regarding military repair parts inventory management was initially suggested by Sherbrooke(1968). The model proposed by Sherbrooke is called METRIC(Multi-Echelon Technique for Recoverable Item Control) which is useful for deciding optimal inventory level of repairable repair parts under multi-level maintenance/supply system. This model minimizes EBO(Expected Backorder) of military base within available budget restraint. After Sherbrooke, Muckstadt(1973) invented Mod-METRIC model considering indenture of repair parts on the basis of original METRIC model. In addition, Slay(1984) invented Vari-METRIC model which maximizes Equipment Operational Availability supplementing the concept of original METRIC model by complementing distribution of total inventory during resupply process. These METRIC models are based on theoretical assumptions(i.e. deterministic demand, infinite repair

capability) so that it is difficult to carry out modelling process reflecting real situation.

To overcome these limitations, recently many researches have been conducted using simulation. Chung and Yun(2008) maximizes optimal repairable repair parts inventory level for military base which minimizes total cost while satisfying target availability under MIME(Multi Indenture Multi Echelon) maintenance/supply system of tank equipment using genetic algorithm and heuristic search method. Kim et al.(2012) optimizes the total number of concurrent spare parts per item considering maximum Equipment Operational Availability within budget restraint using simulation method and multi regression model. Park and Moon(2011) firstly compose a model with equipment in multi-level maintenance/supply chain and evaluate how Equipment Operational Availability change under maintenance capability level susceptible to budget restraint and restriction on reserve stock quantity. Therefore, Park and Moon(2011) analyze capability of maintenance for keeping certain level of Equipment Operational Availability and optimal level for reserve stocks by considering

Moon et al.(2006) verify the change about the amount of inventory per item(high demand/low price item, low demand/high price item) and backorder by changing main inventory position and safety inventory amount through simulation method. Kim et al.(2013) suggest the model based on existing multi-level inventory model considering The Navy's maintenance/supply system which reflects practical operational concept gradually such as planned maintenance, mortality rate, convertible supply, and cannibalization. In that, Kim et al analyze operational availability per inventory level of repairable repair parts for each model.

The simulation research on military repair parts inventory management is different from general company's inventory management. It reflects military's own characteristics. Since maintaining the best combat-readiness condition is the top priority for the military rather than putting emphasis on economic side such as minimizing the cost, the research is mostly of on maximizing Equipment Operational Availability under budget restraint. In addition, it can be said that these simulation research on military repair parts inventory management overcomes limitations of existing METRIC based model. In that sense, the simulation research is much more practical than existing research. However, most of these researches are difficult to applying to real situation because it was done by using theoretical model and numerical experiment. Moreover, the greater part of the research illustrated above was conducted on repair parts of air craft and tank. In that, the research on The Navy part is very scarce.

Against this backdrop, this paper studies the methodology that suggests optimal inventory level linked to Equipment Operational Availability from entire supply chain perspective using simulation. For more practical research, the modelling procedure of

current situation was carried out using DELIIS/N's data which is the inventory management program of The Navy. The object item for the simulation is consumable repair parts of the Navy's equipment which is frequently broken. The modelling procedure was conducted on multi-level inventory management system using ARENA simulation. After that, the result was analyzed thoroughly using OptQuest which is the built-in optimization program of ARENA simulation.

3. Simulation Model

This study adopts ARENA simulation as methodology which enables analysis of total system method and optimization of numerous scenarios by implementing convenient flow chart types and creating object-oriented modelling environment(Kelton et al., 2007; Rossetti, 2009).

3.1 The Simulation Modelling Range and Research Process

It is impossible to construct the model which reflects reality perfectly(Kelton et al., 2007; Rossetti, 2009; Sterman, 2000). Therefore, the range of modelling was limited to analyze optimal supply level of repair parts for supply unit. The analysis was conducted on supply level of supply depot(supply level approved) and 1/2 supply support battalion by following the Navy's repair parts supply chain order which is 'Logistic Command(Supply depot)- Fleet's 1/2 supply support battalion- User unit(Warship)'. In case of 3 supply support battalion, the size of unit itself is so small that there are only few kinds of approved items. In addition, the approved level is also low. Therefore, it is not appropriate to include the 3 supply support battalion as subject of the research. For that reason, the 3 supply support battalion was excluded.

The object items for analysis are selected as ASL for 5 years from '09 to '13. Especially, those items are selected if average supply level is above certain figure which is appropriate for measuring change in supply level per each supply unit. Among ASL items, repair parts are classified according to 5 functions such as warship, firepower and item unit price. As in Table 3 and 4, a single item was selected from each low price group and middle price group among warship's function item which takes up most of items.

Table 3.

The composition ratio for ASL selected item of '13 by functional standard

Classification	Maneuver	General	Communication	Warship	Firepower
Ratio(%)	0.6	20.2	6.5	62.0	8.6

Table 4.

The composition ratio for ASL selected warship's functional item of '13 by unit price standard

Classification	Low price group (less than 200,000 won)	Middle price group (200,000 ~1,000,000 won)	Middle-high price group (1,000,000 ~ 5,000,000 won)	High price group (more than 5,000,000 won)
Ratio(%)	85.6	12.4	1.4	0.6

As in Table 5 and 6, the selected items for research object are all procured in a government purchase way by Defense Acquisition Program Administration. The average procurement cycle is 1 year. The applicable equipment is diesel engine²⁾. Two items are classified according to unit price which belongs to either low price group or middle-low price group. The item 'Y's total number of annual demand and the amount of demand are bigger than those of item 'Z'. As for the item 'Y' and the item 'Z', their total number of annual demand is less than 20, in that, it follows typical demand characteristics of military repair parts whose demand itself is very low.

Table 5.

The current state of the selected items for research object

Item	Unit price in won as for '13	The method of procurement	Procurement cycle	Applicable equipment
Y	24,000 won	Domestic- government purchase	Average 1 year	Diesel engine
Z	463,000 won			

²⁾ It is confirmed through the study of Sohn et al.(2012) that the diesel engine is the second most frequently broken parts among the equipment of the Navy's destroyer.

Table 6.

The current state of annual demand during '09 ~ '13 (unit : number)

Item	Supply depot			Supply support battalion 1			Supply support battalion 2		
	Number of items	The amount of demand	Annual demand at a time	Number of items	The amount of demand	Annual demand at a time	Number of items	The amount of demand	Annual demand at a time
Y	17.8	396.8	21.5	8.0	112.6	13.8	7.6	116.0	15.8
Z	4.3	54.0	11.5	7.6	80.8	10.7	4.6	100.2	19.7

The research procedure is as follows. Firstly, the modelling process was conducted on current repair parts supply chain through simulation. Secondly, the total number of daily average backorder and the total number of daily average inventory management cost for each supply unit were computed using Table 7's annual average data for 5 years from '09 to '13 . Lastly, the daily average inventory management cost computed above needs to be restricted up to the maximum level and then optimization analysis was conducted to calculate supply level for supply unit which minimizes the total number of backorder using OptQuest.

Table 7.

The current state of annual average supply level of supply unit per item during '09 ~ '13 (unit : number)

Item	Supply depot				Supply support battalion 1		Supply support battalion 2	
	AD	SL	RO	Expected procurement period	SL	RO	SL	RO
Y	623.2	50.2	1047.8	229.6	9.2	35	5.8	21.6
Z	231	19.2	382.2	219.6	3.8	14.4	4.4	16.4

3.2 Constructing Simulation Model

Supply unit for simulation modelling is consisted of supply depot, 1 supply support battalion, and 2 supply support battalion. Each of supply unit is consisted of demand arrival module, demand/backorder process and reorder module, reorder arrival and record of demand occurrence module.

Generally, military's inventory management policy follows order of price system. High price item(mainly repairable item) follows 'one demand, one order'(S-1, S) inventory management policy. Low-price item (mainly consumable item) follows (s, S) inventory management policy(Lee et al., 2012). This paper applies (s, S) inventory management policy for 1/2 supply support battalion. In addition, (R, s, S) inventory management policy which is the combination of (R, S) inventory management and (s, S) inventory management was applied for supply depot. The average procurement period for government purchase system from Defense Acquisition Program Administration is 200 days. The procurement is only carried out once a year on average according to each year's budget policy, however, if needed extra procurement will be conducted within available budget. The average procurement period for government purchase system from Defense Acquisition Program Administration is 200 days. That is why (R, s, S) policy was used.

3.2.1 Demand arrival module

Figure 3.

Demand arrival module for each supply unit

The demand arrival for each supply unit was obtained from the distribution which was acquired by ARENA's Input Analyzer. The suitability verification for input distribution was done by χ^2 , Kolmogorov-Smirnov(K-S). Those two verification methods are basic

probabilistic hypothesis testing method to test if theoretical distribution is well fit for data. If more than one p-value result from those two verification methods turns out over 0.1, it is considered to be suitable for the theoretical distribution (Kelton et al., 2007; Rossetti, 2009). As in Table 8, it turned out that two items are all suitable for theoretical distribution after suitability verification test, in that, they were applied to analysis model.

The total amount of demand per demand arrival was entered onto the system supposing the demand for 5 years per each unit follows discrete probability distribution.

Table 8.

The verification test of demand arrival interval distribution per unit

Item	Verification method and Input distribution	Corresponding p-value		
		Supply depot	Supply support battalion 1	Supply support battalion 2
Y	x^2	0.602	0.244	p-value < 0.005
	K-S	p-value > 0.15	p-value > 0.15	p-value > 0.15
	Input distribution	0.999+WEIB(88.9, 0.702)	0.999 + WEIB(38.1, 0.718)	0.999 + EXPO(66.2)
Z	x^2	-	p-value < 0.005	p-value < 0.005
	K-S	0.148	p-value > 0.15	p-value > 0.15
	Input distribution	0.999 + EXPO(18.3)	0.999 + EXPO(43.6)	0.999 + EXPO(47.4)

3.2.2 Demand, Backorder Processing and Re-order Module

Figure 4.

Demand, backorder processing and re-order module

It is assumed that the entire quantity will be supported for every arrival demand without cancelling any of it. The modelling built-in formula is identical to (1).

$$IP(t) = I(t) + IO(t) - B(t) \quad (1)$$

where,

$IP(t)$: Inventory Position

$I(t)$: Inventory on Hand, the quantity on hand in warehouse at t period t

$IO(t)$: On Order, the quantity of item ordered at t period but not received

$B(t)$: Backorder, the quantity of item that didn't satisfy demand at t period, be released if subsequent order quantity arrives

The modelling built-in formula for decision of re-order and the quantity of re-order are identical to (2) and (3).

$$IP(t) \leq s(\text{re-order point}) \quad (2)$$

$$\text{The quantity of re-order} = S(\text{requisitioning objective}) - I(t) \quad (3)$$

3.2.3 Reorder Arrival and Record of Demand Occurrence Module.

Figure 5.

Reorder arrival and record of demand occurrence module

The procurement period from supply depot or suppliers to receiving item was entered into the system as average procurement period. The order quantity arrival lead time from

supply support battalion or supply depot was entered into the system by using Uniform Distribution. The occasional event such as Emergency transport was not considered. The number of orders was entered into the system using the number of orders for a year. In that, degree of alteration can be checked if supply level optimization is achieved.

3.3 The Simulation Validity Verification

To secure validity of this simulation model, the verification was conducted considering research of Sargent(2013), Kelton et al.(2007), Rossetti(2009) and Sterman(2000).

Firstly, Check Model which is inner function of ARENA was used to test error of model itself. As in Figure 6, receiving process after demand occurs and then it is claimed to supply depot when entity animation is formed for each demand occurrence place(supply depot, 1 supply support battalion, 2 supply support battalion). This whole process was tested by using tracing entity animation to check if system works normally.

Figure 6.
Entity animation tracing verification

The robustness of model was tested through limit condition test. As in Figure 7, the reaction to abnormal demand where demand of supply depot at specific time occurs 100 times more than that of average demands. When rapid increase in demand occurs, the system doesn't stop or the error never happens rather the system is getting stabilized after increasing order quantity for deficient demand quantity.

Figure 7.

The change in inventory on hand for item 'Y' when limit demand occurs

In addition, the demand data used in this paper is actual demand occurred for 5 years which is brought from the Navy's DELIIS/N and then be entered into the system through ARENA Input Analyzer in the form of probability distribution. In that, data validity was secured.

4. Simulation Results and Analysis

This paper adopts characteristics of military inventory management that prioritize maintaining best combat-readiness situation which differs from general company's inventory management where cost minimization is priority to optimize supply level for each supply unit on repair parts supply chain. This study uses minimization of repair part's backorder amount per supply unit as result index to maximize Equipment Operational Availability which is directly connected to combat-readiness condition under budget restraint. This is because much of research (Kim et al., 2013; Kim et al., 2012; Sohn et al.,

2012) considers repair part's supply level as direct factor for Equipment Operational Availability. In addition, inventory cost should be considered due to budget restraint, however, it is difficult to obtain objectified data for computing inventory cost. As for inventory holding cost, it was computed by multiplying item unit price and daily average inventory on hand per supply unit. As for backorder occurrence cost, it was computed by multiplying a constant number 2 considering loss of opportunity cost(Woo, 2001; Moon et al., 2006). As for ordering cost, the number of order is very small and the cost per order is extremely low. Moreover, only periodic transport(once a week) was considered for ordering cost. That is why the ordering cost was not considered in this paper.

This study uses OptQuest tool which is built in program of ARENA simulation to optimize supply level. The algorithms that are used in OptQuest are mainly Heuristic method such as tabu search and scatter search. By selecting one method out of two(tabu, scatter search) or by combining two methods, it is possible to find optimal solution quickly and credibly within input control range(Kelton et al., 2007; Rossetti, 2009).

The formula for optimization analysis is as follows.

$$\text{Min Total daily average backorder} = \sum_{i=0}^2 \overline{B}_i \quad (4)$$

S.T.

$$TC_{daily\ avg}^* \leq avg\ TC_{daily\ avg}$$

$$s_i < S_i$$

$$AA_{s_i} \leq s_i \leq BB_{s_i}$$

$$AA_{S_i} \leq S_i \leq BB_{S_i}$$

where,

$i = 0, 1, 2$ (0 : supply depot, 1 : supply support battalion 1,
2 : supply support battalion 2)

$$\overline{B}_i = \frac{1}{T} \int_0^T B_i(t) dt : \text{daily average backorder of supply unit } i$$

$$\overline{I}_i = \frac{1}{T} \int_0^T I_i(t) dt : \text{daily average inventory on hand of supply unit } i$$

$$TC_{daily\ avg}^* = C_{unit} \left(\sum_{i=0}^2 \overline{I}_i + 2 \sum_{i=0}^2 \overline{B}_i \right)$$

: daily average inventory cost of supply level item that is optimized.

$avg TC_{daily\ avg}$: daily average inventory cost after entering annual average data from '09 ~ '13

$AA_{si} \sim BB_{si}$: The range of s value of supply unit i considering operational performance from '09 ~ '13

$AA_{Si} \sim BB_{Si}$: The range of S value of supply unit i considering operational performance from '09 ~ '13

The formula (4) is the object function that minimizes the total of daily average backorder per supply unit. As for the constraint function, total daily average inventory management cost under current Navy's supply level operational policy was computed by entering average data of 5 years. The constraint function is restricted by maximum budget emerged from these cost. There is also other constraint which is s value is smaller than S value. The range of enterable (s , S) value is based on existing operational data.

The simulation procedure was conducted 30 times repetitively for 3650 days(10 years) including system stabilization period of 730 days to secure statistical validity. The result is identical to Table 9, Table 10 and Figure 8. In addition, as shown in Table 11, it was illustrated that both items show significance difference on current management value and optimization value of total daily average backorder through t-test at significance level of 0.05.

Table 9.

The optimization result per supply unit using (s,S)OptQuest

Classification		Supply depot		Supply support battalion 1		Supply support battalion 2	
		s	S	s	S	s	S
Y	The modelling value of current operation	400	1,048	18	35	11	22
	OptQuest optimization value	438	999	23	28	15	18
Z	The modelling value of current operation	140	382	5	14	7	16
	OptQuest optimization value	160	339	10	16	12	13

As for item 'Y', (s , S) value for each supply unit are (400, 1,048) for supply depot, (18, 35) for supply support battalion 1 and (11, 22) supply support battalion. In addition, total daily average inventory cost under current supply level is 9,758,000 won and total daily average backorder value is 9.08. After OptQuest optimization, total daily average inventory cost is 9,631,000 showing 1.3 percentage of decrease, in that, total daily average backorder value is 3.83 showing 58 percentage of decrease. Therefore, significant improvement has been confirmed.

Table 10.

The OptQuest optimization result of each supply unit

Classification		Supply depot		Supply support battalion 1		Supply support battalion 2		Total daily average backorder	Total cost
		Daily average backorder	Annual average number of order	Daily average backorder	Annual average number of order	Daily average backorder	Annual average number of order		
Y	The modelling value of current operation	7.47	1.01	0.49	4.16	1.12	6.65	9.08	9,758,000 won
	OptQuest optimization value	3.05	1.11	0.11	6.58	0.67	9.14	3.83	9,631,000 won
	Difference							5.25 (58% decrease)	127,000 won (1.3% decrease)
Z	The modelling value of current operation	3.90	1.01	1.46	6.59	2.97	7.69	8.33	78,042,000 won
	OptQuest optimization value	2.28	1.18	0.57	6.19	1.69	11.34	4.54	77,410,000 won
	Difference							3.79 (46% decrease)	632,000 won (0.8% decrease)

Figure 8.

The change in daily average backorder per item of each supply unit

Table 11.

The verification result of total daily average backorder per item through

t-test(n=30)

Classification		Total daily average backorder		
		Average	Standard deviation	t-test
Y	The modelling value of current operation	9.08	6.28	4.004*
	OptQuest optimization value	3.83	3.51	
Z	The modelling value of current operation	8.33	5.99	3.139*
	OptQuest optimization value	4.54	2.77	

* $p < 0.05$

As for item 'Z', total daily average inventory cost decreases by 0.8 percent compared to current supply level operational level, in that, total daily average backorder value was improved significantly showing 46 percent of decrease. Since meaningful improvement result was drawn under total inventory cost restraint without making any difference in number of time of order, it can be said that it signifies highly significant meaning by supply level optimization.

5. Conclusion

The general company's logistic environment is changing rapidly to provide quality service while minimizing cost. The same goes for military itself, however, maintaining combat-readiness is emphasized more than cost side due to military's unique characteristics. Therefore, various studies to improve military logistic working environment regarding those situation have been conducted.

This study carries out simulation model research to suggest optimal supply level of repair parts per Navy's supply unit under multi-level maintenance/supply support system. Two items of frequently broken warship equipment are selected as research object item. As for demand occurrence data, data from DELLIS/N are used. The daily average backorder value and total inventory cost value have been calculated through ARENA simulation using 5 years('09~'13) of average data from Navy's inventory management system. In addition, the supply level per supply unit was measured by optimization method through OptQuest minimizing total daily average backorder value while total inventory cost is restricted by maximum cost under current supply level.

As a result, significant improvement has been made for both items showing decrease of backorder value compared to existing value for 46 percent and 58 percent without exceeding total inventory cost of current inventory management system. It is very meaningful in a way that it shows possibility to improve Equipment Operational Availability by simply readjusting supply level considering backorder value without increasing cost under current Navy's inventory management system.

However, this study is conducted only on restricted items. Therefore, this research has its limit in generalization of model and analysis of optimal supply level according to characteristics of item. In addition, the model directly connected to Equipment Operational Availability is not implemented. If much more sophisticated simulation is conducted, for example, multiple items reflecting characteristics of Navy's repair parts are considered and analysis standard is directly connected to Equipment Operational Availability, it will be much more practical research.

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References

- Chung, Il-Han, and Won-Young Yun. (2008) "Spare Part Optimization of MIME Systems Using Simulation and Genetic Algorithms under Availability." *Journal of the Korea Society for Quality Management* 36 (2): 9–19.
- Hyounk, Yoon. (2011) "Optimal Inventory Level Model Considering Demand Rate Uncertainty and Maintenance Capacity". Korea National Defense University.
- Jae-Heon, Jung. (2012) "A Simulation Study for the Inventory Pooling Effect." *Journal of the Society of Korea Industrial and Systems Engineering* 35 (4): 211–18.
- Jang, Gi-Duck. (2012) *Logistics Management : Supply Chain Management Perspective*. Seoul: Korea Institute for Defense Analyses.
- Jeon, Jae-Woan, Hyounk-Gi Kim, and Hun-Koo Ha. (2008) "A Study on Establishing a Strategy of Supply Chain Management : Focusing on Korean Automobile Industry." *JOURNAL OF INTERNATIONAL LOGISTICS AND TRADE* 6 (2): 49–67.
- Kelton, . W David, Randall P Sadowski, and David T Sturrock. (2007) *Simulation with Arena*. 4th Editio. McGraw-Hill Higher Education.
- Kim, Heung-Nam, and Yang-Byung Park. (2001) "A Simulation Study for Inventory Policies in a Multi-Echelon Supply Chain." *Journal of the Korea Society for Simulation* 10 (1): 35–50.
- Kim, Kyun-Grok, Hwa-Young Yong, and Ki-Sang Kwon. (2012) "Optimization for Concurrent Spare Part with Simulation and Multiple Regression." *Journal of the Korea Society for Simulation* 21 (3): 79–88.
- Kim, Myoung-Hun, and Dong-Kyu An. (2007) "Development of Intergrated Inventory Management Model and Determination Inventory Replenishment Period in SCM." *Jouranl of Digital Convergence* 5 (1): 47–53.
- Kim, Sung-Pil, Sun-Ju Park, and Ye-Rim Chung. (2013) "A Simulation Analysis of R.O.K Navy's Inventory Management Model for Repairable Parts." *Journal of the Korea Society for Simulation* 22 (1): 31–40.

- Lee, Hongjoo, and Hosang Jung. (2013) "Scenario Based Global Supply Chain Planning Process Considering Demand Uncertainty." *JOURNAL OF INTERNATIONAL LOGISTICS AND TRADE* 11 (1): 67–86.
- Lee, Hyuk-Soo et al. (2012) *Model for Determining Optimum Inventory Levels of Spare Parts : Base on UH-60 &(K)F-16*. Seoul: Korea Institute for Defense Analyses.
- Lee, Jung-Sook, and Seong-Yong Jang. (2012) "Development of a Simulation Model to Decide the Proper Target Inventory Level for TOC Replenishment Inventory Management Using System Dynamics." *Journal of the Korea Society for Simulation* 21 (3): 25–33.
- Lee, Sang-Heon, and Jong-Woo Son. (2009a) "Inventory-Distribution Problem in Multi-Echelon Supply Chain with Mixed-Inventory Policy." *Journal of the Korean Society For Supply Chain Management* 9 (1): 127–38.
- Moon, Sung-Am, Dong-Jin Kim, and Dong-Kil Park. (2006) "A Study on the Decoupling Point and Safety Inventory in the Navy Supply Chain." *Korean Journal of Logistics* 14 (1): 11–140.
- Muckstadt, John A. (1973) "A Model for Multi-Item, Multi-Echelon, Multi- Indenture Inventory System." *Management Science* 20 (4): 472–82.
- Park, Se-Hoon, and Seong-Am Moon. (2011) "An Operational Availability Analysis in Supply Chain Using Simulation." *Korean System Dynamics Research* 12 (1): 115–30.
- Rossetti, Manuel D. (2009) *Simulation Modeling and Arena*. Publisher Wiley Publishing.
- Sargent, R G. (2013) "Verification and Validation of Simulation Models." *Journal of Simulation* 7 (1). Nature Publishing Group: 12–24.
- Sherbrooke, Craig C. (1968) "METRIC : A MULTI-ECHELON TECHNIQUE FOR RECOVERABLE ITEM CONTROL." *Operations Research* 16 (1): 122–41.
- Slay, M. F. (1984) "VARI-METRIC: An Approach to Modeling Multi-Echelon Resupply When the Demand Process Is Poisson with a Gamma Prior." *Logistics Management Institute, LMI Working Note AF301–3*.

- Sohn, Jung-Mok, Chung-Moo Chang, and You-Dong Won. (2012) "A Case Study of RAM Analysis Using Field Data: Focusing on Korean Warship." *The Journal of The Korea Contents Society* 12 (12): 395-412.
- Sterman, John D. (2000) *Business Dynamics : Systems Thinking and Modeling for a Complex World*. Boston: Irwin/McGraw-Hill.
- Woo, Je-Woong et al. (2012) *Development of a Model for Prediction of Spare Parts Demand*. Seoul: Korea Institute for Defense Analyses.
- Woo, Je-Woong. (2001) "Decision Model of Spare Parts Inventory Level Considering the Availability." *The Quarterly Journal of Defense Policy Studies* 52: 61-97.
- Yoo, Jang-Sun, Shin-Tae Kim, Seong-Rok Hong, and Chang-Ouk Kim. (2008) "Multi-Stage Supply Chain Inventory Control Using Simulation Optimization." *IE Interfaces* 21 (4): 444-55.
- Yoon, Hyouk. (2011) "Optimal Inventory Level Model Considering Demand Rate Uncertainty and Maintenance Capacity". Korea National Defense University.