Periodic Review Model for Determining Inventory Policy for Aircraft Consumable Spare Parts

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Abstract

This research is conducted to develop inventory policy of aircraft consumable spare parts which are needed on aircraft maintenance activity. In this research, we used periodic review model to determine the optimal policy of aircraft spare parts inventory. By using the periodic review model, we find optimal period of inventory review and maximum level of inventory. The optimal decision is determined based on the minimum total cost. We have classified consumable spare parts using ABC method to categorize them based on their dollar contribution and demand frequency. Therefore in this research, we focus on managing the inventory level for spare parts on class C. The result from this study shows that the proposed periodic review policy result in lower total inventory cost compared the the company policy. The proposed policy gives an average saving 35.38 %.

Keywords: Inventory, Spare Part, Periodic Review, ABC Method.

1. INTRODUCTION

Inventory management is one of key success factors that should be considered by manager to win the business in global competition. In modern business environment, the company needs more significant efforts to reduce the operating cost and also increase customer satisfaction. Inventory has significant role to satisfy the customer demand hence, it becomes important asset for any organization. Therefore, it should be managed effectively and efficiently to minimize total cost and to satisfy the customer's requirement. In any real condition, inventory management faces barriers in the form of a tradeoff between minimizing total cost and maximizing service level. Therefore, choosing the correct inventory policy that can be applied in industry now becomes essential to management as there are many inventory policies developed by many scholars.

Maintenance plays an important role in airline industries. The aircraft operational daily activities can be affected by the performance of maintenance. Moreover, the performance of maintenance activities can be determined by how the management can provide spare part continuously during maintenance activity. One of the largest aircraft's MRO company in Indonesia is Garuda Maintenance Facility Aero Asia (GMF). GMF is a company that provides maintenance, repair and overhaul (MRO) service to airline industries. In this company, maintenance is known as the activity to maintain aircraft which consist of line maintenance, base maintenance and engine maintenance while repair is an activity to improve the broken components in aircraft machine. Further, overhaul is an activity to monitor and give major repair to any object in aircraft, including machine or component.

In aircraft industry, spare parts usually can be classified into three categories. First, rotable spare part is the category of spare part that can be rotated among any types of aircraft. Second, repairable spare part is spare parts that have a same character as rotable spare part but having lower price.Third, consumable spare part is the spare parts that can be used once or disposable component. In this research, we focus on managing consumable spare parts due to their magnitude needs in daily MRO activity. Consumable spare parts have higher demand than other spare parts and should be purchased from foreign countries, hence, the replenishment lead time may take a long time. If the spare parts aren't well managed by management, the daily MRO process will probably be interrupted due to the lack of spare part inventories. Moreover, if management decides to hold more spare parts to guarantee that the needs from daily MRO activity must be satisfied, a high inventory cost may occurs. Therefore, controlling consumable spare part accurately is needed by management to ensure that the daily MRO activities run smoothly.

Some researchers focused on developing inventory model based on deterministic environment. Croston [1], Syntetos and Boylan [3], Syntetos and Boylan [4], Syntetos and Boylan [5] proposed deterministic inventory model for spare parts which considering some forecasting methods. The demand of spare parts are forecasted and then the optimal inventory level can be determined by some formulas.

Strijbosch et al [6] developed another model compound bernoulli method and compound poisson method to determine ordering quantity and reorder point. Teunter and Sani [7] gave their research attention on studying the lumpy product. They used order-up-to policy to determine inventory level which previously employed croston method to forecast the demand. Results from this research indicated that integrating croston method and order-up-to policy results in optimal service level. Chang et al [8] implemented r,r,Q policy to manage semiconductor component by assuming stochastic demand. Furthermore, Porras and Dekker [9] determined spare part inventory level at oil company. They used different reorder points to find optimal inventory level in order to minimize total inventory cost. Smidth-Destombes et al. [10] proposed joint optimization of inventory management and maintenance activity. They proposed a heuristic model to derive the optimal solutions and proved that the proposed model performed better than METRIC model. Kilpi et al.[11] developed cooperative strategies for the availability service of repairable aircraft components and determined the factors that give the contribution to the cooperative strategy. They used simulation model to determine optimal cost and used game theory to test the cooperative strategies. Wong et al. [12] investigated the cost allocation problem in context of repairable spare parts pooling with game theoretic model. The results from this study showed that the cost allocation policy affects the companies in making the decision in inventory management. Even many methods have been implemented in determining spare part inventory level, lack of them considering the utilization of continuous review model in reducing total inventory cost.

In this paper we intend to determine spare part inventory level in order to minimize total inventory cost. In this research, we use periodic review policy to determine optimal periodic review and safety stock. The results from many studies proved that periodic review policy can be applied more easily in managing inventory than continuous review policy. This is because using periodic review, the company has less effort on reviewing the inventory level, hence some costs such as information system cost, labor cost can be significantly reduced. Here, we also intend to continue the work of Aisyati, et al. [13] by proposing periodic review as a policy to manage the spare parts in Class C. Previously, Aisyati, et al [13] used ABC classification system to categorize spare part based on their contribution to dollar volume. They focused on determining the optimal inventory level on Class A and B by using continuous review model. Periodic review policy review is popular method which is very useful and easy method to implement in many areas of industries.

2. LITERATURE REVIEW

2.1 Periodic Review Model

The periodic review model is one of the inventory policies that reviews physical inventory at specific interval of time and orders the quantity order as many as the maximum level of inventory Wisner, et al [14]. The safety stock of periodic review model is larger than that of continuous review model. This safety stock is important to meet demand at lead time period (L). One of Periodic Review Model is P model. This model characterize fixed order interval (T) and the quantity order based on the differ of the maximum inventory level (R) and the on hand inventory. We can draw this situation in Figure 1.

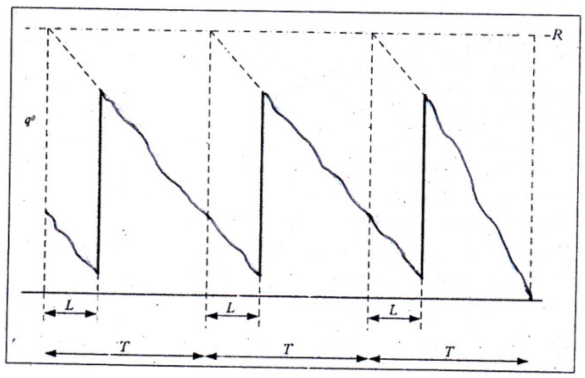

Figure 1. P Model Inventory (Bahagia, [15]).

In this model, the total cost inventory (O_T) is consist of ordering cost, ordering cost, holding cost, dan shortage cost [14].

The ordering cost (O_p) can be determined by multiplying cost of each order(*A*) and order frequency per year (*f*). For order in interval T, the order frequency per year is 1/T. Therefore the ordering cost can be formulated as :

$$O_p = \frac{A}{T} \qquad (1)$$

The holding cost per unit time (O_s) is determined by multiplying the expected of inventory per year (*m*) and holding cost per unit product per year (*h*). In a cycle, the inventory will be at the level (s + TD) at the beginning of the cycle and at the level (s) at the end of the cycle, so the expected of inventory is:

$$m = s + \frac{TD}{2} \qquad (2)$$

In case of shortage, inventory backorder can be met then. The backorder allow negative values so the expected value of s is:

$$s = \int_0^\infty (R-z)f(z)\,dz$$

$$= R - \int_0^\infty zf(z)\,dz$$

If $\int_0^{\infty} zf(z)\,dz = D(L + T)$

$$= D_L + TD$$

so,

$$s = R - D_L - TD \quad \text{(3)}$$

where,

z : Random variable of demand for (T + L) period

f(z) : Probability function of demand z

D_L : Expected of demand for L period

T : Interarrival demand

So, the expected of inventory (*m*) is :

$$m = R - D_L - TD + \frac{TD}{2}$$

$$m = R - D_L - \frac{TD}{2} \quad \text{(4)}$$

By subtituting equation (4) into O_s, holding cost (O_s) can be expressed as :

$$O_s = \left(R\text{-}D_L\text{-}\frac{TD}{2}\right)h \quad \text{(5)}$$

Shortage can be happened when demand fluctuation is occurred in (T+L) periods. Like Q model, shortage cost can be calculated based on the number of stock out. For one year, shortage cost (O_k) can be formulated as follow:

$$O_k = N_T c_u \quad \text{(6)}$$

N_T can be defined by multiplying the number of cycle per year and the number of stock out in a cycle. N_T is as follow:

$$N_T = N \times \frac{1}{T}$$

$$= \frac{N}{T} \quad \text{(7)}$$

Therefore, the shortage cost can be expressed as :

$$O_k = \frac{c_u N}{T} \quad \text{(8)}$$

If backorder is permitted to solve shortage problem, then we can substitute equation (1) until (8) to O_T as follow Bahagia [15]:

$$O_T = O_p + O_s + O_k$$

$$O_T = D_P + \frac{A}{T} + h\left(R\text{-}D_L + \frac{DT}{2}\right) + \frac{c_u}{T}\int_R^{\infty}(z\text{-}R)\,f(z)\,dz \quad \text{.........(9)}$$

Decision variable T and R can be found by taking the first partial derivatives of O_T with respect to T and R respectively and equating them to zero.

$$\frac{\partial O_T}{\partial T} = 0$$

$$= \frac{A}{T^2} + \frac{1}{2}hD\frac{c_u}{T^2}\int_R^{\infty}(z\text{-}R)f(z)\,dz = 0$$

$$T^* = \sqrt{\frac{2\left[A+c_u\int_R^{\infty}(z\text{-}R)f(z)\,dz\right]}{hD}} \quad \text{.........(10)}$$

$$\frac{\partial O_T}{\partial R} = 0$$

$$= h\text{-}\frac{c_u}{T}\int_r^{\infty} f(z)\,dz = 0$$

$$\alpha = \int_r^{\infty} f(z)\,dz = \frac{Th}{c_u} \quad \text{.........(11)}$$

Equation (10) and (11) is implicit function, so the optimal solution can not be found analytically. Considering the iterative procedure from Hadley-Within Method, the algorithm to solve the periodic review is as follows:

a. Find value of T

$$T = \sqrt{\frac{2A}{Dh}}$$

b. Find α and R value by using equation (11).

$$\alpha = \frac{Th}{c_u}$$

If demand has normal distribution, R value will be including demand in ($T+L$) period and can be expressed as :

$$R = D(T + L) + z_\alpha\sqrt{T + L}$$

c. Find the $(O_T)_0$ value by using equation (9).

d. Repeat step b by changing $T_0 = T_0 + \Delta T_0$

- If new $(O_T)_0 > (O_T)_0$, then stop to increase T_0. Next, we try decrease iteration $(T_0 = T_0 - \Delta T_0)$ until we find $T^* = T_0$ that result minimum value of O_T^*.

- If new $(O_T)_0 < (O_T)_0$, increasing iteration $(T_0 = T_0 + \Delta T_0)$ can be continued and can be stopped when new $(O_T)_0 > (O_T)_0$. The value of T_0 that result minimum total cost (O_T^*) is an optimal interval time (T^*)

3. RESEARCH METHODOLOGY

In first stage of our research we define spare parts class C from classification to categorize 60 consumable spare parts [13] There are 36 spare parts in class C presented in Table 1. Secondly, we find all input parameters of spare parts including, the mean of demand per unit time, standard deviation of demand and inventory cost, including holding cost, ordering cost and shortage cost. The mean and standard deviation of demand for selected spare parts is determined from demand data during ten years. Holding cost is determined by considering interarrival demand, expected demand and maximum level of inventory. Shortage cost is determined from the number of cycle per year and the number of stock out in a cycle. The ordering cost is determined by considering cost of each order(*A*) and order frequency per year. Table 1 presents the input parameters and inventory cost of 36 spare parts studied in this research. The final stage of this research, we determine the optimal interval period and maximum level of inventory by using Hadley-Within algorithm described in previous section.

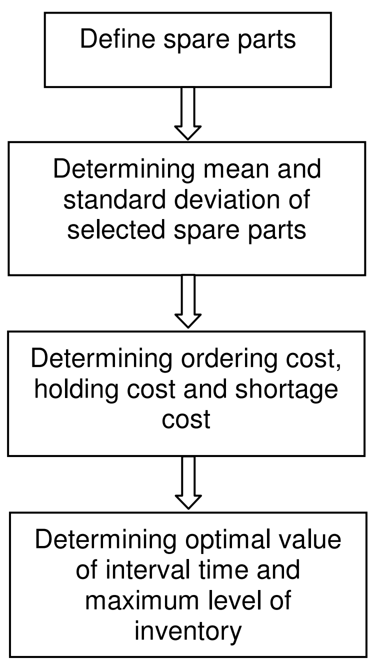

FIGURE 2: Research Methodology.

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No	Spare Parts	Mean (unit)	Standard Deviation (unit)	Holding Cost (IDR)	Shortage Cost (IDR)
1	ABS0368-01	161.8	143.1	43,396	24,888
2	BV03112-03-33	100.5	258.4	77,616	138,953
3	2315M20-3	41.0	68.3	89,526	178,654
4	ASPF-S-V06	71.7	85.7	42,095	20,549
5	65-90305-17	22.6	15.4	77,042	137,040
6	QD1004-125	57.5	99.8	48,149	40,731
7	69-41868-3	61.4	161.4	83,898	159,892
8	CA00075A	57.1	40.0	44,591	28,869
9	FK20159	40.9	102.6	55,449	65,064
10	77870949	8.2	6.9	61,616	85,620
11	65-90305-59	64.5	43.2	43,014	23,615
12	BACH20X3	7.0	5.7	211,071	583,804
13	QA06123	11.4	10.0	48,009	40,262
14	332A1034-25	5.3	3.2	150,274	381,145
15	RG1969	7.7	5.7	52,136	54,020
16	65C27738-2	2.5	1.7	197,991	540,203
17	OF25-021	11.5	8.0	48,632	42,342
18	BACC63BV14B7SN	25.9	19.5	55,321	64,638
19	FK20158	13.9	10.6	56,144	67,380
20	BACR15BB6D7C	17.9	15.1	46,476	35,155
21	MS29526-2	13.4	9.7	44,735	29,350
22	BACB30NN4K4	147.3	134.0	36,347	1,390
23	ABS0367-030	38.8	47.1	39,853	13,075
24	ABS0604-4	106.8	97.8	36,509	1,931
25	F5746293620100	14.1	6.3	39,431	11,672
26	BACR15GF8D7	4.5	3.8	64,499	95,230
27	BACN10YR3C	194.3	196.6	36,046	387
28	MS29513-334	61.9	73.9	36,386	1,520
29	S9413-111	109.9	98.6	36,098	561
30	BACN10JC4CD	56.8	63.1	36,214	948
31	65B10920-171	2.0	1.9	52,708	55,928
32	4551	272.5	303.0	35,969	132
33	1683	228.8	218.4	35,968	126
34	M83248/1-906	16.6	17.4	36,006	252
35	BACB30VF4K12	21.3	25.3	36,423	1,642
36	BACW10BP41CD	46.8	106.1	36,165	783

TABLE 1: Input Parameters and Related Inventory Costs of Spare Parts.

4. RESULTS AND DISCUSSIONS

4.1 Input Parameters

In this research, we focus to manage the spare part inventory in class C which consists of 36 spare parts. We can define spare parts in class C in Table 1. From Table 1 we know spare part 4551 have the largest mean and standard deviation of demand. This shows that the spare part is the most needed spare part.

4.2 Determination of Interval Review Period and Maximum Level of Inventory

Interval period (*T*) and maximum level of inventory (*R*) are determined by employing an iterative procedure described in above section. We develop list of program using MATLAB 2009a. The results from MATLAB program are given in table 2. From this table we can see that there are different values of review period for each spare part. Spare parts BV03112-03-33 and 69-41868-3 have the longest review period that is 2.57 year and 2.48 year. Further, spare part 1683 has the shortest review period (0.0893 year). From table 1 we also can see that the maximum inventory levels are determined in a range of 2-285 units. The demand rate is the factor that affecting the quantity of inventory level.

No	Spare Part	Review Period (year)	Review Period (month)	Maximum Inventory (unit)	Total Cost of Periodic Review (IDR)
1	ABS0368-01	0.9744	12	228	5,142,200
2	BV03112-03-33	2.5725	31	285	19,366,000
3	2315M20-3	1.9	23	83	7,107,700
4	ASPF-S-V06	0.94	11	81	2,198,200
5	65-90305-17	1.08	13	25	1,730,400
6	QD1004-125	1.424	17	90	3,377,300
7	69-41868-3	2.489	30	162	13,096,000
8	CA00075A	0.8	10	55	1,584,000
9	FK20159	1.889	23	82	4,132,000
10	77870949	0.9097	11	7	445,380
11	65-90305-59	0.7354	9	58	1,543,000
12	BACH20X3	0.9026	11	7	1,789,800
13	QA06123	0.8364	10	10	403,730
14	332A1034-25	0.4887	6	3	645,010
15	RG1969	0.7752	9	6	269,840
16	65C27738-2	0.3443	4	2	270,660
17	OF25-021	0.7625	9	9	366,350
18	BACC63BV14B7SN	0.9142	11	30	1,294,200
19	FK20158	0.8938	11	13	64,536
20	BACR15BB6D7C	0.8107	10	15	58,386
21	MS29526-2	0.7031	8	10	35,251
22	BACB30NN4K4	0.2551	3	44	853,100
23	ABS0367-030	0.7285	9	32	863,700
24	ABS0604-4	0.2926	4	62	773,190
25	F5746293620100	0.3738	4	6	160,220
26	BACR15GF8D7	0.9	11	4	241,170

27	BACN10YR3C	0.154	2	133	727,210
28	MS29513-334	0.2793	3	28	428,290
29	S9413-111	0.1618	2	51	431,380
30	BACN10JC4CD	0.2158	3	21	301,770
31	65B10920-171	0.6244	7	2	666,630
32	4551	0.0993	1	231	667,420
33	1683	0.0893	1	164	507,850
34	M83248/1-906	0.1401	2	3	69,685
35	BACB30VF4K12	0.2501	3	5	111,090
36	BACW10BP41CD	0.4032	5	25	480,040

TABLE 2: The Optimal Review Period (T) and Maximum Level of Inventory (R).

No	Spare Parts	Proposed Policy (IDR)	Company Policy (IDR)	Improvement (IDR)	% Savings
1	ABS0368-01	5,142,200	8,324,040	3,181,840	38.22
2	BV03112-03-33	19,366,000	38,401,719	19,035,719	49.57
3	2315M20-3	7,107,700	11,301,439	4,193,739	37.11
4	ASPF-S-V06	2,198,200	3,542,782	1,344,582	37.95
5	65-90305-17	1,730,400	2,243,775	513,375	22.88
6	QD1004-125	3,377,300	5,576,053	2,198,753	39.43
7	69-41868-3	13,096,000	24,349,283	11,253,283	46.22
8	CA00075A	1,584,000	2,176,595	592,595	27.23
9	FK20159	4,132,000	7,089,087	2,957,087	41.71
10	77870949	445,380	602,448	157,068	26.07
11	65-90305-59	1,543,000	2,157,481	614,481	28.48
12	BACH20X3	1,789,800	2,399,871	610,071	25.42
13	QA06123	403,730	540,351	136,621	25.28
14	332A1034-25	645,010	849,674	204,664	24.09
15	RG1969	269,840	373,070	103,230	27.67
16	65C27738-2	270,660	568,043	297,383	52.35
17	OF25-021	366,350	472,756	106,406	22.51
18	BACC63BV14B7SN	1,294,200	1,548,492	254,292	16.42
19	FK20158	64,536	831,050	766,514	92.23
20	BACR15BB6D7C	58,386	771,605	713,219	92.43
21	MS29526-2	35,251	459,814	424,563	92.33
22	BACB30NN4K4	853,100	2,680,775	1,827,675	68.18
23	ABS0367-030	863,700	1,409,832	546,132	38.74
24	ABS0604-4	773,190	1,940,418	1,167,228	60.15
25	F5746293620100	160,220	212,489	52,269	24.60
26	BACR15GF8D7	241,170	358,544	117,374	32.74
27	BACN10YR3C	727,210	3,568,186	2,840,976	79.62

28	MS29513-334	428,290	1,210,700	782,410	64.62
29	S9413-111	431,380	1,616,694	1,185,314	73.32
30	BACN10JC4CD	301,770	954,375	652,605	68.38
31	65B10920-171	666,630	114,158	-552,472	-483.95
32	4551	667,420	5,671,358	5,003,938	88.23
33	1683	507,850	3,876,801	3,368,951	86.90
34	M83248/1-906	69,685	218,092	148,407	68.05
35	BACB30VF4K12	111,090	371,344	260,254	70.08
36	BACW10BP41CD	480,040	1,511,333	1,031,293	68.24

TABLE 3: The Comparison of Proposed Policy and Company Policy.

Table 3 shows the benefit of the proposed method in comparison with company policy. The company makes inventory policy that each spare part must be reviewed in same period (three months). Even this policy can be done easily since the manager only has less effort to control the inventory level of all spare parts, this policy may result in not optimal cost. This is because each spare part has different parameters, then the optimal review period and maximum inventory should be determined individually. From this table, one can see that when comparing with company policy, the proposed method which adopting periodic review policy can produce significant amount of saving in average of 35.38%. The largest saving (92.43%) is produced from spare part BACR15BB6D7C. It is also found that there is one spare part which has negative saving, that is spare part 65B10920-171. Moving the policy from company's policy to proposed policy will reduce the total inventory cost for about IDR 68,091,840 for all spare parts.

5. CONCLUSIONS

In this paper, we focus on determining the optimal review period and maximum inventory level for consumable spare parts by employing periodic review policy. We continue the study of Aisyati et al. (2013) by investigating the optimal inventory level for 36 spare parts in Class C. The results from this study indicate that the periodic review will produce lower total inventory cost compared to the company policy. Moreover, moving from company's policy to the proposed policy will also result significant amount of saving on average 35.38%. However, one spare part that is spare part 65B10920-171 still produce negative saving, hence further comprehensive investigation should be done to it.

Further study can be done by introducing another demand's distribution, such as poisson demand or compound poisson demand. This kind of distribution may be suitable with the spare part demand since it is usually modeled as intermittent demand. Another extension can be done by integrating the inventory policy into maintenance activity. Previously, most of maintenance models discuss only maintenance activity and neglecting its relationship with spare part inventory. Integrating both policies in one model may produce some important insights.

6. REFERENCES

[1] Croston, J.D. "Forecasting and stock control for intermittent demands". *Operational Research Quarterly*, Vol. 42(3), pp. 289–303.1972.

[2] Kaldchschmidt, M., Zotteri, G., and Verganti, R. "Inventory management in a multi-echelon spare parts supply chain", *International Journal of Production Economics*, Vol. 81, pp. 397-413. 2003.

[3] Syntetos, A.A. and Boylan, J.E. "On the bias of intermittent demand estimates". *International Journal of Production Economics*, Vol. 71, pp.457–466. 2001.

[4] Syntetos, A.A. and Boylan, J.E. "The accuracy of intermittent demand estimates". *International Journal of Forecasting*, Vol. 21, pp. 303–314. 2005.

[5] Syntetos, A.A. and Boylan, J.E. "On the stock control performance of intermittent demand estimators*". International Journal of Production Economics*, Vol. 103, pp. 36–47. 2006.

[6] Strijbosch, L.W.G., Heuts, R.M.J. and Schoot, E.H.M. "Improved Spare Parts Inventory Management: A Case Study," Discussion Paper 1998-135, Tilburg University, Center for Economic Research. 1998.

[7] Teunter R. and Sani B. "Calculating order-up-to levels for products with intermittent demand", *International Journal of Production Economics*, Vol. 118, pp. 82–86.2009.

[8] Chang P.L., Chou Y.C. and Huang M.G. "A r,r,Q inventory model for spare parts involving equipment criticality*", International Journal of Production Economics, Vol.97, pp. 66–74. 2005.*

[9] Porras E. and Dekker R. "An inventory control system for spare parts at a refinery: An empirical comparison of different re-order point methods", *European Journal of Operational Research*, Vol. 184, pp. 101–132. 2008.

[10] Smidt-Destombes, K.S., Van Der Heijden, M.C. and Van Harten, "A. Joint optimisation of spare part inventory, maintenance frequency and repair capacity for k-out of N system", *International Journal of Production Economics*, Vol. 118, pp. 260-268.2009.

[11] Kilpi, J., Toyli, J. And Vepsalainen, A. "Cooperative strategies for the availability service of repairable aircraft components", *International Journal of Production Economics*, Vol 117, pp. 360-370. 2009.

[12] Wong, H., Van Oudheusden, D. And Cattrysse, D. "Cost allocation in spare parts inventory pooling", *Transportation Research Part E*, Vol. 43, pp. 370-386. 2007.

[13] Aisyati, A., Jauhari, W.A and Rosyidi, C.N. "Determination Inventory Level for Aircraft Spare Parts Using Continuous Review Model", *International Journal of Business Research and Management, Vol. 4, No. 1,* pp. 1-11.2013.

[14] Wisner, J.D, Tan, K.C. and Leong, G.K. "Principles of Supply Management: A Balanced Approach". South-Wetern Cengage Learning. 2012.

[15] Bahagia, S.N., "*Inventory System*", ITB Press. 2006.