Determination Inventory Level for Aircraft Spare Parts Using Continuous Review Model

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Abstract

In this paper, we determine ordering quantity and reorder point for aircraft consumable spare parts. We use continuous review model to propose a spare part inventory policy that can be used in a aircraft maintenance company in Indonesia. We employ ABC classification system to categorize the spare parts based on their dollar contribution. We focus our research on managing the inventory level for spare parts on class A and B which commonly known as important classes. The result from the research indicates that the continuous review policy gives a significant amount of saving compared to an existing policy used by the company.

Keywords: Inventory, Continuous Review, Ordering Quantity, Reorder Point, ABC Classification System.

1. INTRODUCTION

Inventory management becomes one of primary needs for company to win in a tight global competition. Inventory is a significant 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 practical situation, inventory management faces barriers in the form of a tradeoff between minimizing total cost and maximizing service level. Selecting inventory policy correctly now becomes essential to management as there are many inventory policies provided in the inventory literature.

Garuda Maintenance Facility Aero Asia (GMF-AA) is a company that provides maintenance, repair and overhaul (MRO) service to airlines. Maintenance is activity to maintain aircraft that comprises of line maintenance, base maintenance and engine maintenance. Repair is a activity to improve the broken components in aircraft machine. Overhaul is activity to monitor and give major repair to any object in aircraft, including machine or component.

Spare part is major component that be used in aircraft maintenance process. Aircraft can mostly be categorized into three types. Spare parts which can be rotated among any types of aircraft are called Rotable spare part. Spare parts that have a character same as rotable spare part but having lower price are called repairable spare part. The spare parts that can be used once or disposable component are called consumable spare part. The consumable spare parts are very important component in GMF-AA due to their magnitude needs in daily MRO activity. Besides having higher demand than other spare parts, consumable spare parts must be ordered from foreign countries, hence, the replenishment 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.

Spare parts inventory system has been studied extensively by many researchers. Croston [1] was probably the first researcher introduced spare part inventory model. The proposed model was developed by integrating single exponential smoothing into inventory model. Kaldchschmidt et al. [2] argued that croston method was very important tool to determine inventory level of spare part in supply chain which has intermittent demand. Syntetos and Boylan [3] and Syntetos and Boylan [4] gave critics to croston method which still results a bias in forecasting the spare part. Therefore, Syntetos and Boylan [5] proposed a model for controlling spare part inventory to reduce the level of error in forecasting spare part. Unfortunately, the both models, including croston [1] and Syntetos and Boylan [5] were not suitable to adopt since most inventory environment in real condition is stochastic.

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.

An important work that must be considered firstly before deciding the correct inventory method is spare part classification. Silver et al. [10] and Tersine [11] proposed ABC classification system to categorize items based on their contribution to dollar volume. They also proposed a suitable inventory models that can be implemented for each classes. Chu et al. [12] developed inventory classification system with fuzzy ABC method. In this proposed method, inventory classification system is not only developed by considering dollar volume's contribution, but also incorporating expert judgments.

In this paper we would like to determine order quantity and reorder point for aircraft spare parts in GMF-AA to minimize total inventory cost. Previously, we use ABC classification system to segment spare part based on their contribution to dollar volume. We utilize continuous review model to determine the inventory level. Continuous review is widely used by researchers to solve the inventory problem and known as an useful and easy method to implement in many areas. Considering aircraft spare parts are very important factors and expensive element, continuous review is suitably implemented due to its ability in maintaining a lower inventory level.

2. LITERATURE REVIEW

2.1 ABC Classification System

ABC classification system is a method that classifies the spare parts based on how critical the spare parts for the company. This method segment the spare parts into three categories, that are A, B and C. A items make up roughly 20 percent of the total number of items and represent 80 percent of the dollar sales volume. B items comprise roughly 30 percent of the items and represent 15 percent of the dollar volume. C items comprise roughly 50 percent of the items and represent only 5 percent of dollar volume [10]. The A items must received more attention from manager. The B items are of secondary importance in relation to class A items and the class C items are relatively unimportant items, hence, the manager can manage them as simple as possible. The steps of ABC classification are described as follows:

1. Listing the spare parts and their demand.

2. Determining the contribution of the spare part by multiplying the demand for each item and the value or price of item.

3. Computing the percentage of spare part contribution by dividing the contribution of each spare part with the total contribution of the spare parts.

4. Sorting the spare parts so that the percentages of spare part contribution are listed from higher value to lower value. The category of spare part could be found by using the above description from [10].

2.2 Continuous Review Model

The continuous review model is one of the inventory policies that manage the inventory through monitoring the inventory level continuously until if the inventory level drops to the reorder point r, the ordering of size Q should be done. Reorder point is determined for each stock keeping unit as demand forecasting during supply time. Reorder point is commonly defined as the summation of demand during lead time and safety stock. The assumptions that be used in continuous review model are as follows:

a. The demand per unit time is probabilistic with mean D and standard deviation σ

b. The price of item is not influenced by ordering size.

c. Reorder point is determined using net inventory.

d. The backorder cost is set independently to the length time of backorder.

e. Ordering cost is constant and independent to ordering size.

f. Holding cost is proportional to the item price and storage time.

g. Warehouse space, capital and supplier capacity are sufficient.

The notations that will be used in developing continuous review model are as follows:

D demand in units per unit time

σ standard deviation of demand per unit time

A ordering cost incurred for each order size of Q

k safety factor

SS safety stock for the buyer

ES expected number of backorder

H holding cost per unit per unit time

π backorder cost per unit backordered

q the ordering quantity

f(.) probability density function of standard normal distribution

F(.) cumulative distribution function of standard normal distribution

Considering the frequency of ordering is (*D/q*) and ordering cost is *A*, the ordering cost per unit time can be formulated by:

$$TC_1 = \frac{D}{q}A \quad (1)$$

The holding cost per unit time is determined by multiplying the average inventory level and safety stock and holding cost per unit product. Safety stock is formulated by multiplying safety factor *k* and standard deviation of demand during lead time. Thus, holding cost per unit time is as follows:

$$TC_2 = H\left(\frac{q}{2} + k\sigma\sqrt{L}\right) \quad (2)$$

The backorder cost per unit time can be found by multiplying the backorder cost per unit backordered and the expected number of unit backordered per unit time. Let x as continue random variable with normal distribution with mean μ and standard deviation σ >0. Then, the probability density function of x can be expressed as

$$f(x) = \left(\frac{1}{\sigma\sqrt{2\pi}}\right)e^{\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]} \quad (3)$$

Since the demand during lead time is *DL* with standard deviation $\sigma\sqrt{L}$, the reorder point can be formulated as *ROP* = *DL* + *SS*. Shortage occurs when the demand during lead time is bigger than the inventory level at that period (x > *ROP*). Thus, the expected number of shortage can be expressed by:

$$ES = \int_{x=p}^{\infty}(x - rop)f(x)dx$$

$$ES = \int_{x=q+ss}^{\infty}(x - DL + SS)\ \frac{1}{\sqrt{2\pi}\sigma\sqrt{L}}\, e^{\frac{-(x-DL)^2}{2(\sigma\sqrt{L})^2}}\, dx \quad (4)$$

By substituting z = $\left(\frac{x\text{-}DL}{\sigma\sqrt{L}}\right)$ and $dx = \sigma\sqrt{L}dz$ into equation (4), we will find:

$$ES = \int_{z=\frac{SS}{\sigma\sqrt{L}}}^{\infty}\left(2\sigma\sqrt{L}\text{-}SS\right)\frac{1}{\sqrt{2\pi}}e^{\frac{-z^2}{2}}\,dz$$

$$ES = -SS \int_{z=\frac{ss}{\sigma\sqrt{L}}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}}\, d z + \sigma\sqrt{L} \int_{z=\frac{ss}{\sigma\sqrt{L}}}^{\infty} z \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} dz \quad \text{...(5)}$$

Let F_s (z) is *cumulative distribution* function dan f_s (z) is probability density function for standard normal distribution with mean 0 and standard deviation 1. By considering equation (5) and the definition of standard normal distribution, we will have:

$$1 - F_s(y) = \int_{z=y}^{\infty} f_s(\mathrm{z})\, dz$$

$$= \int_{z=y}^{\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} dz \quad \text{..(6)}$$

By substituting $w = \frac{z^2}{2}$ into equation 2.6, the expected number of shortage (*ES*) is given by:

$$ES = -SS \left[1 - F_{s\left(\frac{SS}{\sigma\sqrt{L}}\right)}\right] + \sigma\sqrt{L} \int_{w=\frac{ss}{2(\sigma\sqrt{L})^2}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-w}\, dz$$

$$ES = -SS \left[1 - F_{s\left(\frac{SS}{\sigma\sqrt{L}}\right)}\right] + \sigma\sqrt{L} f_s\left(\frac{SS}{\sigma\sqrt{L}}\right)$$

$$ES = \sigma\sqrt{L}\{f_s(k) - k\, [1 - F_s(k)]\}$$

$$ES = \sigma\sqrt{L}\, \psi(k) \quad \text{...(7)}$$

where $\psi(k) = \{f_s\,(k) - k[1 - F_s(k)]\}$

$f_s(k)$ is probability density function of standard normal distribution and $F_s(k)$ is cumulative distribution function of standard normal distribution, respectively. Therefore, the backorder cost per unit time is formulated by

$$TC_3 = \left(\frac{D}{q}\right) \pi\sigma\sqrt{L}\, \psi(k) \quad \text{...(8)}$$

Total inventory cost comprises of ordering cost, holding cost and backorder cost, hence, the cost can be expressed by:

$$TC\,(q,k) = \left(\frac{D}{q}\right) A + H\left(\frac{q}{2}\right) + k\sigma\sqrt{L} + \left(\frac{D}{q}\right) \pi\sigma\sqrt{L}\, \psi(k) \quad \text{..(9)}$$

Decision variable *q* and *k* can be found by taking the first partial derivatives of *TC(q,k)* with respect to *q* and *k* and equating them to zero.

$$\frac{\partial TC_{total}(q,k)}{\partial k} = 0$$

$$\frac{-D}{q^2} \mathrm{A} + \frac{H}{2} - \frac{\mathrm{D}}{\mathrm{q}^2}\, \pi\sigma\sqrt{\mathrm{L}}\, \psi(\mathrm{k})$$

$$\mathrm{q} = \sqrt{\frac{2\mathrm{D}(\mathrm{A} + \pi\sigma\sqrt{\mathrm{L}}\, \psi(\mathrm{k})}{\mathrm{H}}} \quad \text{..(10)}$$

$$\frac{\partial TC_{\text{total}}(q,k)}{\partial k}=0$$

$$\partial\sqrt{LH}+\frac{\pi D\sigma\sqrt{L}(F_s\,(k)\text{-}1)}{q}=0$$

$$F_s\,(k) = 1-\frac{\mathrm{qH}}{\mathrm{\pi D}} \quad\text{.......}(11)$$

It can be seen in equation (10) and (11) that both equations express the relationship between *q* and *k*. Therefore, the solution of the above continuous review model can be found by searching the convergence values of *q* and *k* which minimizes total cost. Considering the iterative procedure from Ben-Daya and Hariga [13], the algorithm to solve the continuous review is as follows:

1. Set the initial value of *q* by
   $$q=\sqrt{\frac{2AD}{H}}$$
2. Substitute *q* into equation (11) to find *k*.
3. Find the new value of *q* by using equation (10).
4. Find the new value of *k* by using equation (11).
5. Repeat step 3-4 until no changes occur in the values of *q* and *k.*
6. Compute total cost with equation (9) by employing the convergence values of *q* and *k* in step 5.

3. RESEARCH METHODOLOGY

In first stage of our research we employ ABC classification to categorize 60 consumable spare parts. The classification is done under consideration of dollar volume contribution for each spare part. Secondly, as we intend to focus in determining the inventory level of spare part in class A and B, we provide their 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 interest rate, storage cost and labor cost. Shortage cost is determined from the added cost that must be included in rush order. In this research, it is formulated by 20 % of spare part price. The ordering cost is determined by considering internet cost as a major component in ordering activities and administration cost. Table 1 presents the input parameters and inventory cost of 24 spare parts studied in this research. The final stage of this research, we determine the inventory level of the spare parts by using an iterative procedure described in previous section.

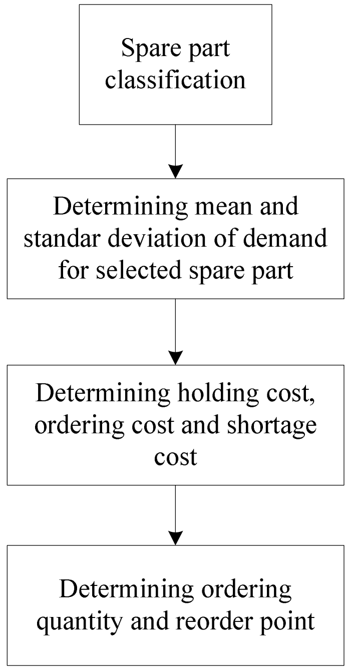

FIGURE 1: Research Methodology.

No.	Spare part	Mean (unit)	Standar deviation (unit)	Lead time (day)	Holding cost (IDR)	Shortage cost (IDR)
1	CH34736	58	61	44	393,432	1,191,674
2	335-299-401-0	90	180	95	75,766	132,788
3	S9413-11	96	83	21	288,694	842,545
4	MFFA632/2	6	10	23	6,292,279	20,854,498
5	740001	98	107	10	93,357	191,424
6	D717-01-100	8	7	23	504,483	1,561,843
7	FK16588	5	4	21	1,721,942	5,620,039
8	088-1031-006	6	5	11	867,097	2,770,557
9	KB29665	32	18	23	174,458	461,759
10	4L83-046	102	167	7	550,175	1,714,149
11	QA03963	26	19	29	127,021	303,636
12	5709-4	14	7	35	358,843	1,076,377
13	362-509-9002	7	7	29	397,937	1,206,690
14	65-90305-15	44	33	7	106,871	236,471
15	16135-62	11	8	7	340,241	1,014,369
16	335-299-401	169	185	26	41,971	20,137
17	453A1810-33	5	4	23	364,744	1,096,046
18	AB0473993	14	6	88	151,381	384,838
19	740007	76	62	20	58,489	75,198
20	QA03362	23	65	11	332,351	988,069

21	MS20995C32	16	19	44	58,245	74,382
22	65-90305-20B	87	70	11	76,315	134,618
23	AC9380F4010	16	18	8	149,125	377,316
24	F5746293620200	25	69	10	242,024	686,979

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

4. RESULTS AND DISCUSSIONS

4.1 Spare Part Classification

From ABC classification we found that class A comprises of 11 spare parts, class B comprises of 13 spare parts and class C comprises of 36 spare parts. Spare parts in class A give the contribution about 79.6%, spare parts in class B contributes 14.7% and spare parts in class C contributes 5.6% to rupiah volume. The results from ABC classification is given in table 2. In this research, we focus to manage the inventory in class A and class B due to its criticality for management. 24 spare parts in this classes give significant contribution (94.3%) to the management, hence, controlling them tightly may results in significant amount of inventory cost saving. One of the tight inventory management policies that can be used to manage spare parts in this classes are continuous review. In practical situation, the continuous model has an ability to maintain lower inventory level although it needs more attention from inventory manager. Even the ABC classification can be used to categorize the spare part, considering more factors such as spare parts severity and spare part severity, may provide more attractive results. Each spare part may have different severity level based on its usefulness in aircraft machine.

4.2 Determination of Ordering Quantity and Reorder Point

Ordering quantity (*q*) and reorder point (*ROP*) are determined by employing an iterative procedure described in above section. We develop list of program using MATLAB 2009a. The results from MATLAB are given in table 3. As can be seen in this table that some spare parts such as CH34736, S9413-11, 4L83-046 have reorder point level higher than its ordering quantity. It is understandable, because the spare parts have high uncertainty indicated by high standard deviation of demand. Having high standard deviation of demand, the model will produce high safety stock. This condition absolutely will increase the reorder point level.

No	Spare part	Class	No.	Spare part	Class	No.	Spare part	Class
1	CH34736	Class A	21	MS20995C32	Class B	41	OF25-021	Class C
2	335-299-401-0	Class A	22	65-90305-20B	Class B	42	BACC63BV14B7SN	Class C
3	S9413-111	Class A	23	AC9380F4010	Class B	43	FK20158	Class C
4	MFFA632/2	Class A	24	F5746293620200	Class B	44	BACR15BB6D7C	Class C
5	740001	Class A	25	ABS0368-01	Class C	45	MS29526-2	Class C
6	D717-01-100	Class A	26	BV03112-03-33	Class C	46	BACB30NN4K4	Class C
7	FK16588	Class A	27	2315M20-3	Class C	47	ABS0367-030	Class C
8	088-1031-006	Class A	28	ASPF-S-V06	Class C	48	ABS0604-4	Class C
9	KB29665	Class A	29	65-90305-17	Class C	49	F5746293620100	Class C
10	4L83-046	Class A	30	QD1004-125	Class C	50	BACR15GF8D7	Class C
11	QA03963	Class A	31	69-41868-3	Class C	51	BACN10YR3C	Class C
12	5709-4	Class B	32	CA00075A	Class C	52	MS29513-334	Class C

13	362-509-9002	Class B	33	FK20159	Class C	53	S9413-11	Class C
14	65-90305-15	Class B	34	77870949	Class C	54	BACN10JC4CD	Class C
15	16135-62	Class B	35	65-90305-59	Class C	55	65B10920-171	Class C
16	335-299-401	Class B	36	BACH20X3	Class C	56	4551	Class C
17	453A1810-33	Class B	37	QA06123	Class C	57	1683	Class C
18	AB0473993	Class B	38	332A1034-25	Class C	58	M83248/1-906	Class C
19	740007	Class B	39	RG1969	Class C	59	BACB30VF4K12	Class C
20	QA03362	Class B	40	65C27738-2	Class C	60	BACW10BP41CD	Class C

TABLE 2: Spare Part Classification.

No	Spare part	Ordering quantity (unit)	Reorder Point (unit)
1	CH34736	21	32
2	335-299-401-0	108	24
3	S9413-11	17	36
4	MFFA632/2	2	3
5	740001	16	27
6	D717-01-100	2	3
7	FK16588	1	2
8	088-1031-006	1	2
9	KB29665	4	10
10	4L83-046	20	37
11	QA03963	5	9
12	5709-4	2	5
13	362-509-9002	2	3
14	65-90305-15	4	9
15	16135-62	1	2
16	335-299-401	20	12
17	453A1810-33	1	2
18	AB0473993	2	9
19	740007	12	33
20	QA03362	12	11
21	MS20995C32	11	2
22	65-90305-20B	12	20
23	AC9380F4010	3	4
24	F5746293620200	12	11

TABLE 3: The Optimal Ordering Quantity (*q*) and Reorder Point (*ROP*).

No	Spare parts	Total cost of continuous review (IDR)	Total cost of existing policy (IDR)	Percentage of saving (%)
1	CH34736	18,187,000	4,902,703	-271
2	335-299-401-0	8,169,300	13,862,968	41
3	S9413-11	13,901,412	20,078,123	31
4	MFFA632/2	33,837,686	70,745,161	52
5	740001	3,821,039	3,473,933	-10
6	D717-01-100	2,151,860	79,050,683	97
7	FK16588	4,144,690	24,162,508	83
8	088-1031-006	1,976,609	11,963,751	83
9	KB29665	2,020,408	3,719,859	46
10	4L83-046	30,401,784	20,010,096	-52
11	QA03963	1,593,800	2,986,025	47
12	5709-4	2,003,358	3,149,088	36
13	362-509-9002	1,805,116	17,474,439	90
14	65-90305-15	1,291,958	2,725,353	53
15	16135-62	1,055,404	9,176,663	88
16	335-299-401	6,794,353	5,371,262	-26
17	453A1810-33	909,717	1,967,814	54
18	AB0473993	1,259,292	3,064,476	59
19	740007	2,373,446	3,327,663	29
20	QA03362	7,506,171	10,635,221	29
21	MS20995C32	612,238	2,238,758	73
22	65-90305-20B	2,211,054	4,131,125	46
23	AC9380F4010	993,351	1,752,534	43
24	F5746293620200	5,551,371	7,958,346	30
Total		154,572,418	309,928,552	31

TABLE 4: The Comparison of Continuous Review Total Cost and Existing Policy Total Cost.

The proposed continuous review policy gives significant average savings of 31% compared to an existing policy which is used by the company. The comparison of proposed policy and an existing policy is resumed in table 4. This table shows the total inventory cost of proposed policy and an existing policy and presents the savings of moving from existing policy to proposed policy. The company uses a periodic review policy which based on his experience in controlling the spare parts. The parameters in an existing policy are determined using the experience of warehouse operator which may fail to detect the true inventory level. Moreover, as we know from inventory literature that periodic review policy will make inventory level higher than continuous review. However, even the proposed policy results in lower cost compared to existing policy, interestingly some spare parts show different condition. Spare parts CH34736, 740001, 4L83-046 and 335-299-401 show that an existing policy performs better than continuous review policy. It can be understood that the continuous review model may fail to result better inventory policy since the demand of the spare parts is too lumpy. The other models such as the model which accommodated poisson demand or compound poisson demand probably more suitable to perform in this condition. It is due to the both model's ability to capture the essence of the demand. Furthermore, this study used the spare part demand from spare part data in warehouse, therefore the demand in real aircraft maintenance activity is neglected. It should be noted here that, assuming demand to be independent with the real spare part demand in maintenance may result in higher cost since there a gap between inventory management and maintenance activity. To develop the efficiency of company, both activities should be synchronized in one decision model to decrease the total cost incurred in the system. An integrated information system which integrates the information from both activities is also required by the company to increase the system feasibility in enhancing the capability of the company in reducing total cost.

5. CONCLUSIONS

In this paper, we determine the ordering quantity and reorder point of aircraft spare part using continuous review model. Previously, we classify the 60 spare parts by using ABC classification system. The results from this research show that the proposed continuous review model results in lower total cost compared to an existing policy. The amount of average savings that can be gained by this proposed policy is about 31%. However, an existing policy still performs better in reducing total cost for some spare parts.

Future research can look into determining the inventory level of spare part which total cost has not been minimized by continuous review model. The inventory model accommodating poisson demand or compound poisson demand may suitable to use in solving this problem. Furthermore, the spare part classification can be extended by integrating other qualitative attribute into ABC classification system. The attribute such as spare part severity and spare part criticality probably can be included into spare part classification. The fuzzy method can be used to assess the level of spare part severity and criticality. Other future research direction may focus on integrating inventory decision with maintenance activity. Our study assumes that the demand parameter was a given parameter, however it may not represent the actual system in aircraft repair facility hence, integrating inventory decision with the schedule of maintenance may give valuable insights.

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