SIMULATION OF THE INVENTORY COST FOR ROTABLE SPARE WITH FLEET SIZE IMPACT

Weigang ZHANG[1] and Xiaofeng WANG[2]

ABSTRACT: Through the analysis of rotable spare's feature and inventory cost structure, a simulation model based on characteristics of spare part demand under different maintenance policies is proposed to calculate the inventory cost of rotable spare with fleet size impact and avoid the computational complexity of the analytic method. Simulation results present our model could forecast rotable spare inventory cost for multiple aircrafts under different parameter settings. And further analysis of inventory cost expectation, variance and marginal cost shows fleet size has a significant influence on inventory cost, especially shortage cost, of rotable spare, and factors such as component reliability distribution also has significance impacts on calculation. This will provide some theoretical reference for researches on multi-echelon inventory, spare pooling and airline fleet planning etc.

KEY WORDS: rotable spare, aircraft fleet size, inventory cost, simulation

1 INTRODUCTION

As an important factor affecting the demand for spare parts, fleet size has been one of the prerequisites and foundations for aircraft spare research. In general, the expansion of fleet size helps reduce the overall randomness of the demands for parts, thereby increasing the utilization and marginal benefit of spare parts. Therefore, there may be significant differences in the average spares quantity and inventory cost per aircraft under different fleet sizes. This makes it necessary to consider the impact of fleet size in the spare parts management research, including optimization of spare parts inventory (Kennedy, 2002; Tracht, 2013), multi-echelon repair and spare pooling In the multi-echelon inventory study for aircraft spare parts (Costantino, 2013; Fritzsche, 2012), it is usually necessary to allocate the spare parts inventory locations and stock quantities based on the fleet sizes and spare parts demands corresponding to the central and sub-warehouses. The research on spare pooling (Kilpi, 2004; Kilpi, 2009;. Karsten, 2014; Wang, 2015) also needs to analyze and calculate the marginal costs of spare parts under different fleet sizes in different airlines to evaluate their shared benefits. Therefore, it is one of the key preconditions for the above studies and applications as how to evaluate and calculate the costs of aircraft spares with different characteristics under different fleet size.

[1]College of Aeronautical Engineering, Civil Aviation University of China, Tianjin, 300300, China;

[2]Economics & Management College, Civil Aviation University of China, Tianjin, 300300, China

E-mail: wgzhang@cauc.edu.cn; xf-wang@cauc.edu.cn

Rotable spare is a classification of high-cost spare parts that can be repeatedly restored to a fully serviceable condition in airlines (Ghobbar, 2003; Gu, 2015; Willemain, 2004). Unlike general consumables, rotables have only a small variety, but they are of high cost and occupy a lot of capital, so they are the key targets of spare parts management in airlines. However, rotable spares are usually slow moving spare parts, with long mean time between failures (MTBF) and relatively sparse demands, and faulty ones can be reused again after being repaired, which is the update process in the reliability calculation, with high calculation complexity, so in current studies, it is commonly assumed that the service life and maintenance interval are subject to the exponential distribution or that the spare parts demand is subject to the Poisson's distribution[5-14], and for other distribution types and factors like maintenance, the analytical solving is relatively difficult.

Simulation is an important method in the current researches on equipment maintenance (Fei, 2017; Jia, 2016; Li, 2017; Liang, 2016; Liu, 2015; Pourmahmoud, 2016; Roşca, 2015; Straka, 2016) and also commonly used in the spare parts management research. For example, Willemain, Barata and Do et al. (Willemain, 2002; Barata, 2002; Do, 2015) discuss the on-condition maintenance and repairable rate by taken spare requirement into account, Lee (Lee, 2008) and Lowas (Lowas, 2016) study the spare parts with multi-echelon inventory optimize and lumpy demand respectively by simulation, and TVan (TVan, 2013) also studies the influence of imperfect maintenance to spare parts inventory with simulation. But they either only focus on the one-time maintenance with single spare part, or make too simple assumptions of the maintenance method and seldom considers the impacts of fleet size, so there have been some deficiencies in the analysis of aircraft spare costs, especially marginal costs, which are detrimental to investment analysis. Applying the simulation method in the evaluation of rotable spare inventory cost and taking the joint effects of factors like fleet size, turnover time and maintenance method into account not only help simplify the evaluation of airline inventory costs and shortage costs, but also serve as an important basis for research on aircraft spares strategies like spare pooling and fleet planning.

This paper is organized as follows: it first introduces the purchase and usage process of rotable spares and analyzes the inventory cost of rotable spares in airlines according to the characteristics of aviation maintenance; then according to the aviation maintenance methods and the spare parts demand generation mechanism, it analyzes the evaluation of the support demand for spare parts in a single-machine environment to lay a foundation for subsequent simulations; at last, based on the above studies, this paper constructs a simulation model for evaluating rotable spare inventory cost with fleet size impact and discusses the simulation results.

2 COST AND REQUIREMENT OF ROTABLE SPARE

2.1 Inventory cost structure of rotable spare

A spare parts purchase decision, in its essence, can be approximately expressed as a problem to determine the quantity q, where q=0,1,..., of rotable spare V with certain constraints and minimize the expectation of $C(q)$, where $C(q)=C_Q(q)+C_L(q)$ denotes the total cost of spare parts with quantity q in future period, $C_Q(q)$ and $C_L(q)$ represent the inventory holding cost and shortage cost respectively.

Inventory holding cost refers to the costs incurred by an airline to acquire spare parts and ensure their availability. For rotable spares, it can be generally expressed as follows:

$$C_Q\left(q\right)=\sum_{i=0}^{q}P_i+\sum_{i=0}^{q}\sum_{j=0}^{n}C_{R,i,j}+\sum_{i=0}^{q}\sum_{l=0}^{m}C_{S,i,l}+\sum_{i=0}^{q}C_{J,i} \quad (1)$$

where P_i is the initial purchase cost of spare part i, $C_{R,i,j}$ is the cost of j-th repair with i, $C_{S,i,l}$ is the storage cost of spare i in the l-th inventory period, and $C_{J,i}$ stands for other cost of i, such as value loss of the spare part at the end of the period. As $C_{R,i,j}$ has something to do with the number of faults occurring and little to do with the spares quantity, this factor is not taken into account in the subsequent study in this paper.

Shortage cost is the profit loss suffered by the airline when the requirement for spare part is not met in time. It mainly includes the loss of flight operation and the additional cost incurred for unplanned acquisition of aircraft spares, as shown below:

$$C_L\left(q\right)=\sum_{u=0}^{N}\left(L_{O,u}+L_{P,u}\right) \quad (2)$$

where N is the absolute frequency of requirement for spare part V during the planned period, $L_{O,u}$ and $L_{P,u}$ denote the operation loss and unplanned acquisition cost of spares in the u-th guarantee respectively. If there is no shortage of spare parts, then $L_{O,u} = L_{P,u} = 0$.

Operation loss, $L_{O,u}$ i.e. downtime loss, refers to the operation loss induced by flight delay or cancellation due to shortage of spare. In aviation maintenance, it will be varied greatly with the type of maintenance(such as line or hangar) and spare part(Go, No Go or Go If).

Unplanned acquisition cost of aircraft spares $L_{P,u}$ refers to the additional purchase and repair costs paid by an airline to take emergent orders (AOG), manufacturer assistance or speed the repair up in case of spare shortage.

The approximate calculation of $L_{O,u}$ and $L_{P,u}$ can be formulated as follows:

$$L_{O,u}=\begin{cases}0 & t_u^K\le T_\eta\\ \left(t_u^K-T_\eta\right)\cdot C_u & t_u^K>T_\eta\end{cases} \quad (3)$$

$$L_{P,u}=\begin{cases}0 & Q'_u\ge r_u\\ C_Q\left(q',K\right) & Q'_u\ge r_u\end{cases} \quad (4)$$

where T_η denotes the time limit to reserve failure without replace broken parts. With the No Go spare part, there usually has T_η =0 in the line maintenance. C_u and r_u are the operation loss of the airline per unit time and require quantity of spares in the *u*-th guarantee. Q'_u is the quantity of spares in stock and available at the moment. $t^K_u \geq 0$ is the time to acquire spare part in *u*-th guarantee with the acquisition method *K*, and t^K_u=0 if and only if $Q'_u \geq r_u$, i.e. the quantity of spares available is greater than requirement. $C_Q(q', K)$ is the cost of unplanned acquisition for *q'* spares with the method *K*.Analysis of requirement with rotable spare

According to maintenance time and content aviation maintenance can be classified into hard-time maintenance, on-condition maintenance and condition monitoring. Since the requirement of spare part about hard-time maintenance is usually determined, this paper mainly discusses on-condition maintenance and condition monitoring.

Condition monitoring is a method by which no preventive maintenance is arranged for the parts if no serious failure consequence exists. As no preventive maintenance is involved, a part will be replaced or repaired only when it broke down, i.e. within the restorative maintenance of condition monitoring method.

Let *v* be an aircraft part subject to condition monitoring. $T_f \sim F(t)$ is the failure time of *v*, where $F(t)$ is the service life distribution of *v*. There will be a restorative replacement requirement D_v^f=1 for part *v* if and only if $t \geq T_f$.

Unlike condition monitoring, on-condition maintenance involves not only restorative maintenance, but also preventive maintenance, which includes some regular inspections and part will be replace when an inspection reveals potential failure which indicates a functional failure is imminent. The restorative maintenance is only carried out when there is a functional failure resulting the part cannot perform the required function.

According to the general principle for on-condition maintenance, the requirement of spare for preventive and restorative maintenance are analyzed as follows:

Let *v* be an aircraft part subject to on-condition maintenance, $OC_v=\{M_i|i\in N\}$ be the set of inspections and T^i_M as the inspecting moment of M_i. Assume $T_P \sim F_P(t)$ be the time of part developed to potential failure, and $T_{F|P} \sim F_{F|P}(t)$ be the time of part developed from potential failure to functional potential failure, then according to the principles for on-condition maintenance, the requirement of preventive replacement for part *v*, D^a_v=1 if and only if there is an effective on-condition inspection between potential failure and functional failure, i.e. $\exists\, M_i \in OC_v$: $T_P \leq T_M^i \leq t < T_P + T_{F|P}$, where "effective" means the potential failure in the part be identified. Otherwise, there will be a requirement of restorative replacement for part *v* D_v^f=1 when $t \geq T_P + T_{F|P}$.

3 SIMULATION MODELING

To simplify analysis, this paper makes the following assumptions for the simulation:

1) When there exist multiple spare parts available, they will be issued on an FIFO (first-in first-out) basis;

2) The requirements of spare part have the same importance; in other words, under no circumstance will the stock be kept from being issued for future requirement, and instead, they will be issued whenever they are demanded;

3) The unplanned acquisition method only involves accelerated repair, and the operation loss is far beyond the unplanned acquisition cost;

4) The replacement time = 0, repairable rate = 100%, and after repair, the reliability will be restored to the design level;

5) The flight hours/take-off and landing times per day of the fleet can be forecasted.

With above assumptions, the simulation algorithm model and flow chart are shown as Figure 1:

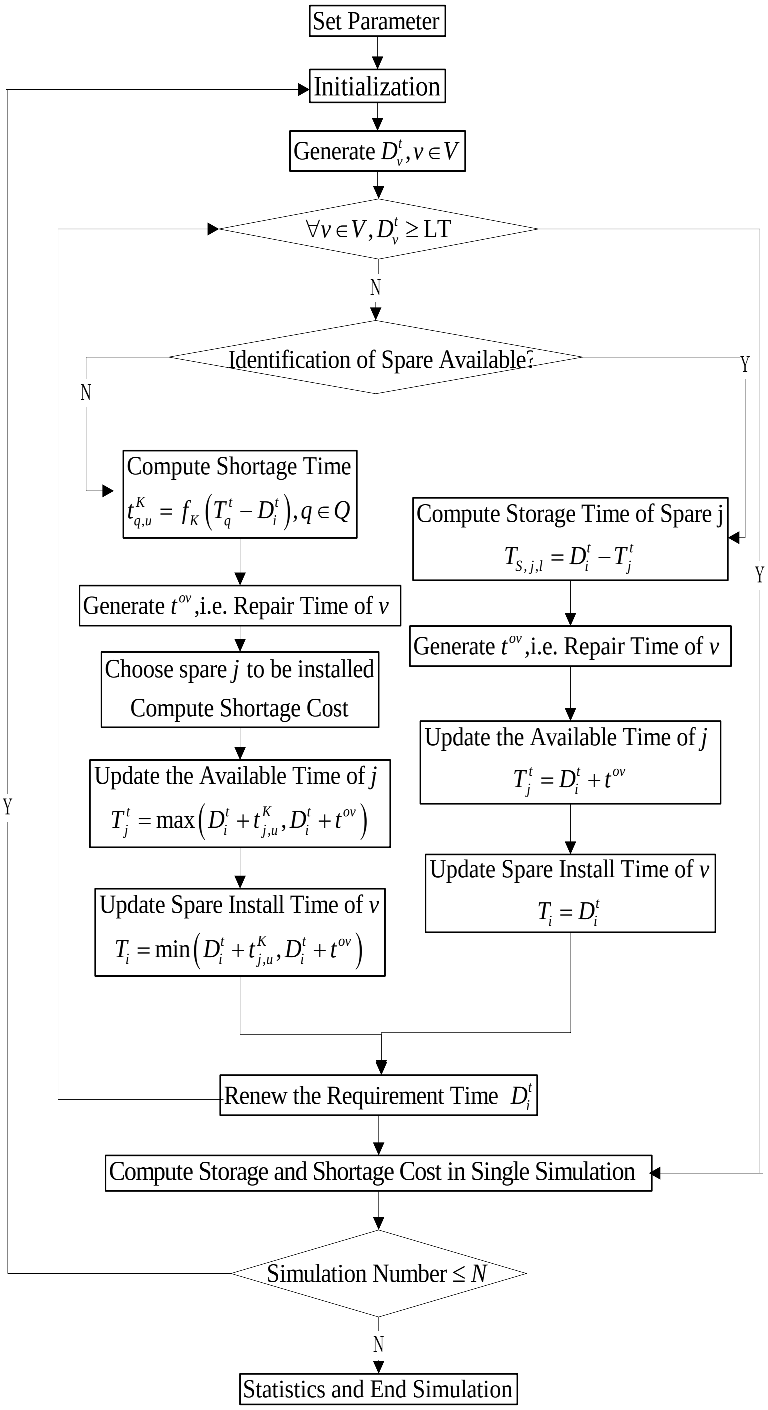

Figure 1 Simulation algorithm model and flowchart

1) Set simulation parameters: input fleet size V, spares quantity Q, simulation number N, time of prediction period LT, reliability distribution function $F(t)$ or $<F_P(t), F_{F|P}(t)>$, on-condition maintenance parameter T_M^0 and t_M, and daily inventory cost C_S;

2) Initialize parameters: set the part installation time T_v, $v\in V$ and the available time of spare parts T_q^t, $q\in Q$ to be the aircraft and spare parts introduced time. For an aircraft or spare part already in place, there will be T_v=0 or T_q^t=0;

3) Generate the requirement time of spare: for any aircraft $v\in V$, generate the requirement time D_v^t. The simulation processes for condition monitoring and on-condition maintenance are as follows:

①Condition monitoring: generate t~$F(t)$ and set $D_v^t= T_v+t$, $v\in V$;

②On-condition maintenance: generate $T_P \sim F_P(t)$ and $T_{F|P} \sim F_{F|P}(t)$ respectively; compute the functional failure time $T_F = T_P + T_{F|P}$, and the spare part demand time of aircraft v as Figure 2:

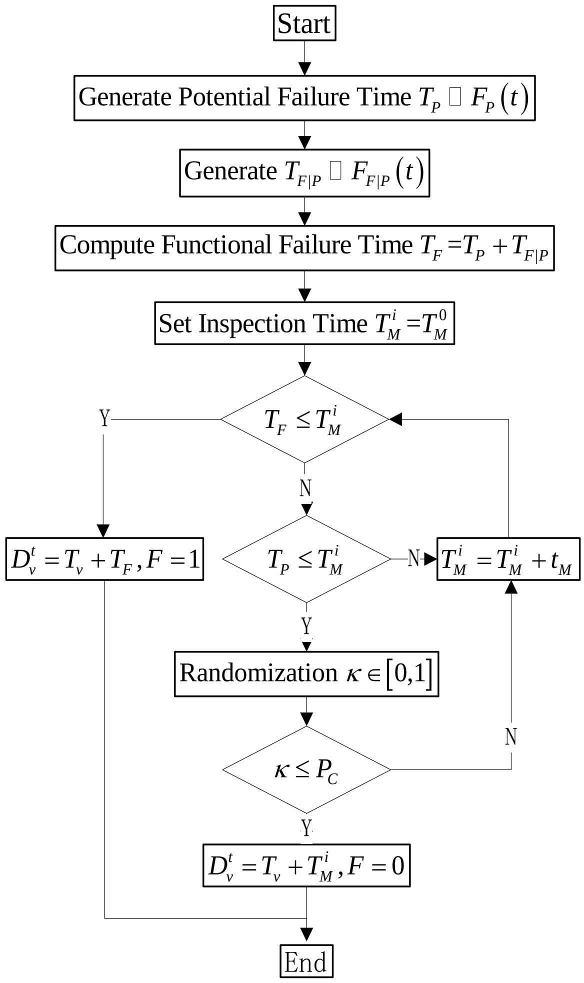

Figure 2 Simulation of the spare requirement time with on-condition maintenance

In the figure 2, T_M^i is the moment of i-th inspection; T_M^0 is the time of first inspection and t_M is the interval between inspections. $P_c \in [0,1]$ is the probability that a potential failure can be identified with one inspection; F is the require type for spare part and F=1 denotes the restorative replacement and F=0 denotes the preventive replacement.

4) Calculate the storage cost and shortage cost of spare parts in a single support;

① Compute the current requirement $D_i^t = \min\{D_v^t, v \in V\}$, and check if there are any spare parts available, i.e. $\exists\, q \in Q: T_q^t \leq D_i^t$;

②If there are any spare parts available, then supply the spare parts with FIFO , i.e. choose $j \in Q$ satisfied $T_j^t = \min\{T_q^t,\ q \in Q\}$; and set the shortage cost $L_{o,u} = L_{P,u} = 0$ and storage cost $C_{S,j,u} = T_{S,j,u} \times C_s$, where $T_{S,j,u} = D_i^t - T_j^t$ is the storage time of the part and C_s is the unit storage cost;

③ If there is no spare part available, then calculate the shortage time of each spare part $t^K_{q,u} = f_K(T_q^t - D_i^t)$, where $f_K(\ )$ is the function of spare acquisition time by method K, and generate the repair time t^{ov} of the detached part. Let $t^K_{j,u} = \min\{t^K_{q,u},\ q \in Q\}$ is the earliest available time of the spare part. Then to minimize the supply time, it will has the shortage time $t_{O,u} = \min\{t^K_{j,u},\ t^{ov}\}$. From this, there will have the operation loss $L_{O,u} = (t_{O,u} - T_\eta) \times C_u$, and the unplanned acquisition cost $L_{P,u} = (T_q^t - D_i^t) \times C_p$, where C_p is the unit cost to speed up repair. The storage cost $C_{S,j,u}$ =0.

5) Update the available time T_j^t of spare j and the time T_i of the spare part installed on aircraft i:

① If there is any spare part available, there will have $T_j^t = D_i^t + t^{ov}$ and $T_i = D_i^t$;

② If there is no spare part available, the installation time will be the earliest arrival time of the spare part j and detached part, i.e. $T_i = D_i^t + t_{O,u} = D_i^t + \min\{t^K_{j,u}, t^{ov}\}$. The available time for the spare j is $T_j^t = D_i^t + \max\{t^K_{j,u}, t^{ov}\}$, i.e. the latest arrival time of spare j and the detached part;

③ For other spare parts and aircrafts, the available and installation time remain unchanged.

6) Update D_i^t , the require time of the aircraft i, accord with step 3);

7) Terminate current simulation if the requirement time of all parts exceeds the prediction period LT;

8) When the simulation number $n \geq N$, end the simulation.

4 SIMULATING AND ANALYSIS

To verify our simulation model and discuss the impacts of fleet size on inventory cost, we develop a simulation program with Matlab and Visual Basic and carry out a series of simulations. Consider the space limitation, only a brief analysis about total cost is introduced at here.

Let the fleet size $V \in [1,30]$, $Q \in [1,10]$, LT=15000 hours, the purchase price (excluding residual) is 600, the shortage time with speeded repair $t_{q,u}^{K=1} = |k \times (T_q^t - D_i^t)|$, $0 < k \leq 1$, where k is the conversion ratio, and| | denotes the rounding operation.

With the exponential distribution and Weibull distribution of lifetime, 100 simulation tests are carried out respectively with condition monitoring and on-condition maintenance, and the simulation parameters are listed in Table 1 and Table 2:

Based simulation results, the average total cost with the spares quantity under different fleet sizes are shown as Figure 3:

Table 1. Parameters for condition monitoring

	CM1	CM2	CM3
$F(t)$	$Exp(1/2000)$	$W(2000,2.5)$	$W(2000,2.5)$
t^{ov}	$N(30,10)$	$N(30,10)$	$N(30,10)$
C_μ	30	30	30
C_s	0.01	0.01	0.01
k	1	1	0.5
C_p	0	0	1

Table 2. Parameters for on-condition maintenance

	OC1	OC2	OC3
$F_P(t)$	$Exp(1/1000)$	$W(2000,2.5)$	$W(1000,2.5)$
$F_{F\|P}(t)$	$Exp(1/2000)$	$W(3000,2.5)$	$W(2000,2.5)$
T_M^0	500	1000	500
t_M	500	500	500
P_C	0.7	0.7	0.7
t^{ov}	$N(30,10)$	$N(30,10)$	$N(30,10)$
T_η	20	20	20
C_μ|P	5	5	5
C_μ|F	30	30	30
C_s	0.01	0.01	0.01
k	1	1	0.5
C_p	0	0	1

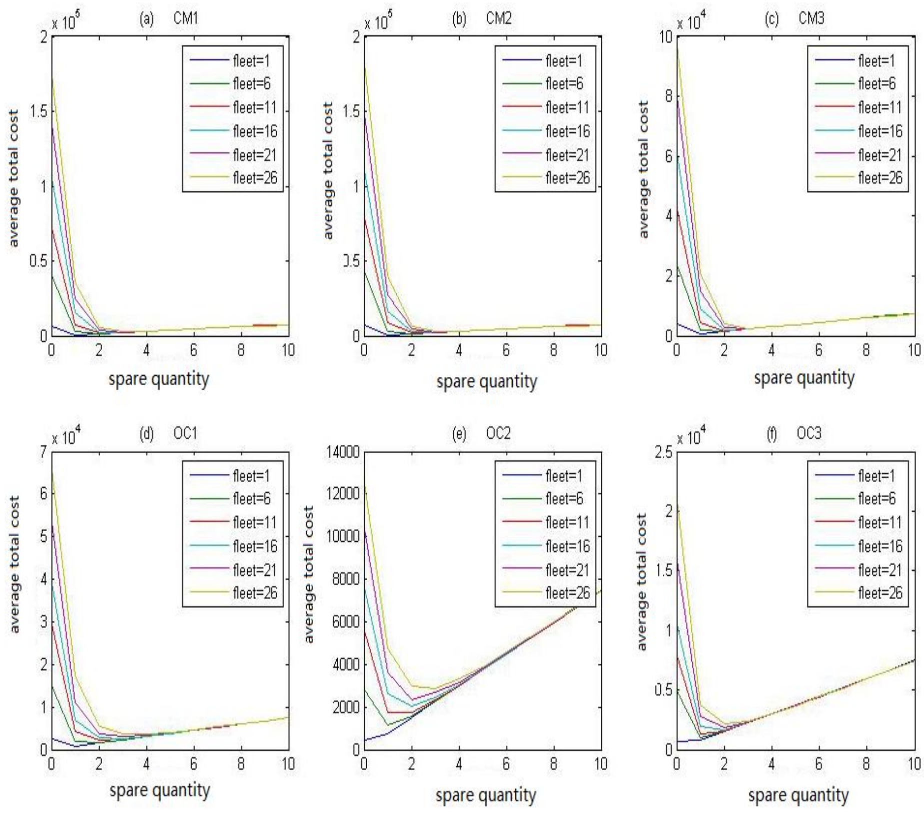

Figure 3. Average total cost with the spares quantity under different fleet sizes

It can be seen from Figure 3 that when the spares quantity is the same, the average total cost increases obviously with the increase of fleet size. When the fleet size is large, the average total cost decreases first and then increases with the increase of spares quantity. Only when OC2 and OC3 fleet sizes are small (=1), the average total cost increases with the increase of spares quantity. According to specific data, there are fewer restorative replacements of spare parts, and as preventive replacement allows longer shortage time, the shortage cost is less than the spare part purchase price. Through comparison of CM2 and CM3, it can also be seen that, when there is an unplanned acquisition method that can reduce the shortage time, it will help reduce the inventory cost.

The standard deviations of the samples are shown as Figure 4:

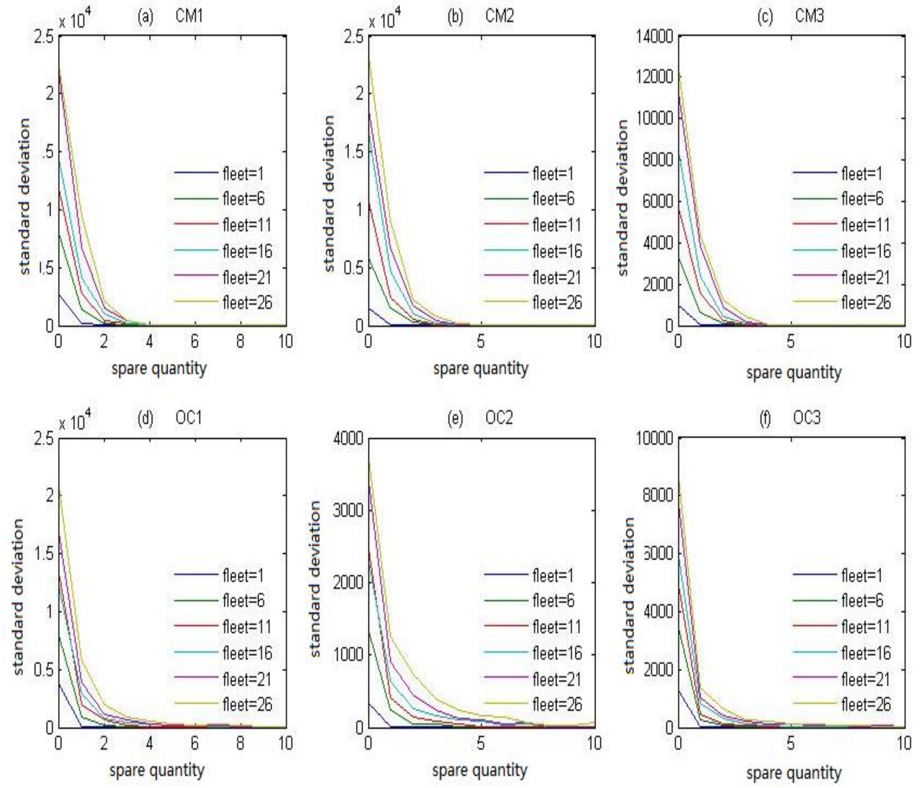

Figure 4 Standard deviations of simulated costs under different fleet sizes

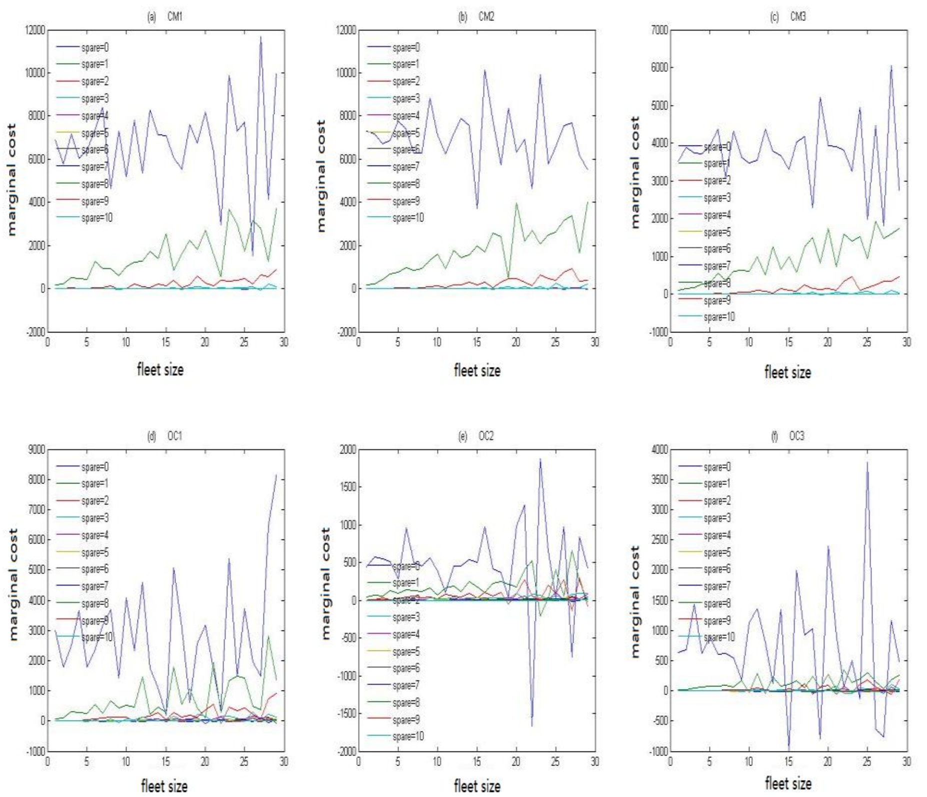

Figure 5 Marginal cost of fleet size

It can be seen that when the fleet size is constant, the standard deviation of the samples decreases with the increase of spares quantity. Further observation of the standard deviation of inventory carrying cost and that of the shortage cost (data omitted here) shows that with the spares quantity increasing, the standard deviation of shortage cost will rapidly drop to 0, while that of the storage cost will be a small value (<10) correlated to fleet size. At the same time, with the increase of fleet size, the standard deviation of the samples also significantly increases, especially in the case where the spares quantity is low, indicating that with the expansion of fleet size, the absolute risk of the inventory will be increased. Through comparison of CM2 and CM3, it can be seen that unplanned acquisition will help reduce this risk.

To analyze the impact of increase fleet size on inventory cost, the marginal costs of different fleet size, which can be formulated as $C^V(Q)$-$C^{V-1}(Q)$, where $C^V(Q)$ is the average total cost when the fleet size =V and the spares quantity =Q, are calculated and shown as Figure 5:

From Figure 5, it can be seen that when spare quantity = 0, the additional costs induced by fleet size expansion are a series of random numbers whose means is relatively stable and variance increasing significantly with expansion of fleet size. When the spares quantity is small (=1 or 2), the marginal cost shows an increasing trend along with expansion of fleet size, that is, the expansion of fleet size will increase the inventory cost. Considering the spares quantity is constant at this time, it can be deemed that the increase of inventory costs at this time can be mainly attributed to shortage cost. For the spares quantity>5, the marginal costs are some small negative values, indicating that when the spare quantity is large, the increase of aircrafts will improve the utilization of spare and reduce the storage cost of spare parts.

With all these curves, it is not hard to see that, as the spares quantity increases, the marginal cost of fleet size at low spares quantity is generally higher than the that under high spares quantity. The lower the spares quantity is, the greater the difference will be, so when the spares quantity is constant, the higher the spares quantity is, the less the inventory cost will be affected by fleet size. Based on the above studies, it can be seen that the larger the fleet size is, the higher the optimal spares quantity of rotable spare will be. So for an airline, when its experience shows that the spares quantity is relatively reasonable, the larger the fleet size is, the less the inventory cost will be affected by the changes in the fleet size.

5 CONCLUSION

Based on the analysis of the stock and service process of rotable spare and inventory cost structure with aviation maintenance, a simulation model is proposed in this paper to evaluate the inventory costs under different fleet sizes, which is important in some fields such as multi-echelon inventory, pooling and aircraft investment, with the consideration of mechanism for spare requirement in condition monitoring and on-condition maintenance.

From the simulation process and results, it can be seen that our simulation model can imitate the rotation and service process of spare part in an airline, and realize the evaluating of inventory holding and shortage cost for rotable spare under various conditions. This is not only beneficial to evaluate and calculate the inventory costs and risks for airlines, but also provide important reference for practical and theoretical research on spare parts pooling and aircraft investment. However, due to space limitations, we only analyze the total cost of spare parts from the view of fleet size and other factors, such as spare part price, reliability distribution, maintenance method, distribution of turnover time, unplanned acquisition method and spare part and fleet introduction time etc., are hardly involved. We will give a further discussion with these factors and improve some assumptions in our model, such as the service priority for Go If spare parts, incomplete maintenance, degradation and disposal etc., in the future.

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7 REFERENCES

► Barata J., Soares C.G., Marseguerra M. (2002). Simulation modelling of repairable multi-component deteriorating systems for on condition' maintenance optimisation. Reliability Engineering & System Safety, 76(3): 255-264.

► Costantino F., Di Gravio G., Tronci M. (2013). Multi-echelon, multi-indenture spare parts inventory control subject to system availability

and budget constraints. Reliability Engineering & System Safety, 119: 95-101.
- ►Do P.,Voisin A., Levrat E.(2015).A proactive condition-based maintenance strategy with both perfect and imperfect maintenance actions. Reliability Engineering&System Safety,33:22-32.
- ►Fei J.B., Wen H. (2017). Experimental research on temperature variation and crack development in coalfield fire, International Journal of Heat and Technology, 35(1):559-566.
- ►Fritzsche R. (2012). Cost adjustment for single item pooling models using a dynamic failure rate: A calculation for the aircraft industry. Transportation Research Part E: Logistics and Transportation Review, 8(6): 1065-1079.
- ►Ghobbar A.A, Friend C.H. (2003). Evaluation of forecasting methods for intermittent parts demand in the field of aviation: a predictive model. Computers & Operations Research, 30(14): 2097-2114.
- ►Gu J., Zhang G., Li K.W. (2015). Efficient aircraft spare parts inventory management under demand uncertainty. Journal of air transport management, 42: 101-109.
- ►Jia C.X., Qiu W.N., Pu X.Z. (2016). New residual current compensation method for single-phase grounding fault in power network based on capacitive current detection and analysis, Modelling, Measurement and Control A, 89(1): 205-223.
- ►Karsten F., Basten R.J.I. (2014). Pooling of spare parts between multiple users: How to share the benefits? European journal of operational research, 233(1): 94-104.
- ►Kennedy W.J, Patterson J.W., Fredendall L.D. (2002). An overview of recent literature on spare parts inventories. International Journal of production economics, 76(2): 201-215.
- ►Kilpi J., Töyli J., Vepsäläinen A. (2009). Cooperative strategies for the availability service of repairable aircraft components. International Journal of Production Economics, 117(2): 360-370.
- ►Kilpi J., Vepsäläinen A.P.J. (2004). Pooling of spare components between airlines. Journal of Air Transport Management, 10(2): 137-146.
- ►Lee L.H., Chew E.P., Teng S. (2008). Multi-objective simulation-based evolutionary algorithm for an aircraft spare parts allocation problem. European Journal of Operational Research, 189(2): 476-491.
- ►Li J., Zhang W.M. (2017). Experimental research on hydraulic characteristic of centrifugal pump in plateau, International Journal of Heat and Technology, 35(1): 585-593.
- ►Liang H.Y., Zhou H.Q., Zhou S.L. (2016). Mathematic simulation on the coordinated forces exerted on in-service joint supports, Modelling, Measurement and Control B, 85(1):123-133.
- ►Liu N., Zheng Z.C., Li G.X. (2015). Effect of non-newtonian effect of lubricant on the lubrication performance of piston ring-cylinder liner components for diesel engine, International Journal of Heat and Technology, 34(4):722-726.
- ►Lowas A.F, Ciarallo F.W. (2016). Reliability and operations: Keys to lumpy aircraft spare parts demands. Journal of Air Transport Management, 50: 30-40.
- ►Marseguerra M., Zio E., Podofillini L. (2002). Condition-based maintenance optimization by means of genetic algorithms and Monte Carlo simulation. Reliability Engineering & System Safety, 7(2): 151-165.
- ►Pourmahmoud N., Abbaszadeh M., Rashidzadeh M. (2016). Numerical simulation of effect of shell heat transfer on the vortex tube performance, International Journal of Heat and Technology, 34(2): 293-301.
- ►Roşca L.E., Bondrea I. (2015). Probabilistic evaluation of abs maneuver failure for an electronic brake system by tolerances analysis, Academic Journal of Manufacturing Engineering, 13(3): 35-45.
- ►Straka Ľ., Hašová S. (2016). The critical failure determination of the constructional parts of autonomous electroerosion equipment by applying boolean logic, Academic Journal of Manufacturing Engineering, 14(2):80-86.
- ►Tracht K., Von der Hagen F., Schneider D. (2013). Applied repairable-item inventory modeling in the aviation industry. Procedia CIRP, 11: 334-339.
- ►TVan H.A, Scarf P.A, Cavalcante C.A.V. (2013). The effect of maintenance quality on spare parts inventory for a fleet of assets. IEEE Transactions on Reliability, 62(3): 596-607.
- ►Wang W., Yue S. (2015). An inventory pooling model for spare units of critical systems that serve multi-companies. Transportation Research Part E: Logistics and Transportation Review, 76: 34-44.
- ►Weckman G.R., Shell R.L., Marvel J.H. (2001). Modeling the reliability of repairable systems in the aviation industry. Computers & industrial engineering, 40(1): 51-63.
- ►Willemain T.R., Smart C.N., Schwarz H.F. (2004). A new approach to forecasting intermittent demand for service parts inventories. International Journal of forecasting, 20(3): 375-387.