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Maintenance, Repair, and Overhaul Performance Indicators for Military Aircraft

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ABSTRACT

Modern day military and commercial aircraft systems are an integration of a large number of sub-systems and components. Each of these systems has different reliability characteristics and different probability distributions governing their failure rates. Space constraints and structural layout of the aircraft govern the position of each component. The accessibility, reliability, and snag diagnostic-ability determines the maintainability of the aircraft. The peculiarities involved in aircraft maintenance are discussed and performance measurement indices for O, I and D level maintenance are presented in this paper. These performance measurement indices are intended for use by aircraft maintenance managers for instituting process improvements for achieving best flight and maintenance safety records, improve operational availability of the aircraft and reduce costs.

Keywords: Reliability, aircraft maintenance, performance measurement

1. INTRODUCTION

Post world war-II and cold war era saw accelerated development and production of military aircraft. During this period, both NATO and east block countries invested huge sums of money and came up with extraordinary designs of airframes, aero-engines and avionics. These designs, complimented by state of the art manufacturing capabilities resulted in reliable and lethal military aircraft. The contemporary military aircraft have a large number of integrated systems and sub-systems with varying reliability, accessibility and maintainability characteristics. These systems are to be maintained by skilled and professionally trained maintenance crew.

To manage all the activities involved in maintenance and operations; it is important to map the processes and evaluate the performance by quantifying the efficiency of the crew and the process. Neely[1], *et al.* reviewed the performance measurement system design and defined performance measurement as the process of quantifying the efficiency and effectiveness of action. Parida and Kumar[2] stated that what cannot be measured cannot be managed effectively and emphasized that managers and asset owners have to measure the contribution of maintenance towards their business goals. Parida and Chattopadhyay[3] proposed a maintenance performance measurement framework focused on both internal and external effectiveness. Zisis[4], *et al.* described the effectiveness of performance measurement in service quality. Jiang[5], *et al.* measured the preventive maintenance effects and a relationship between preventive effect and cost saving was developed. Rouse[6], *et al.* presented the performance analysis tools to support change management in an aircraft servicing company. Swanson[7] presented the performance measurement tools for proactive and aggressive maintenance concept. Garg and Deshmukh[8] presented generic maintenance architecture at different echelons and proposed improvements. Duer[9] analysed the maintenance of a radar system and presented ANN and expert knowledge base models for improving the maintenance efficiency. Wang and Lin[10] analysed series-parallel systems with perfect maintenance of each component and presented minimisation of non-periodic maintenance costs.

The objectives of this study are to develop performance measurement indices for quantifying aircraft maintenance activities on one of the contemporary fighter aircraft fleet of Indian Air Force; validate the indices and identify the organisational systems required to be in place for effectively utilising the measures to enhance the maintenance efficiency. The peculiarities involved in aircraft maintenance are discussed, various terms used in formulating performance measurement indices are defined and the assumptions made are listed. The performance measurement of maintenance, repair and overhaul (MRO) and performance measurement indicators for organizational (O), intermediate (I), and depot (D) level maintenance are presented. The application of the presented indices for improving the maintenance efficiency is discussed.

2. AIRCRAFT MAINTENANCE

Aviation maintenance is peculiar from maintenance of other equipment due to the degree and intensity of the requirement of equipment, manpower, infrastructure, fault diagnosis, cost and time. Here, specialist technical crews perform varied tasks in a time critical environment and sometimes in difficult ambient conditions. In spite of the best possible infrastructure and qualified maintenance crew, as good as new status is not always restored after the maintenance. Crocker[11] discussed the Type-I and II errors and brought out that maintenance cannot restore as good as new status. Jones and Warrington[12] compared the maintenance free operating period paradigm

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with the inherent disadvantages of using MTBF as reliability metric. Kumar[13], *et al.* modeled and analysed the component reliabilities and identified root causes of excessive downtime leading to production loss and quality problems. Owotoki and Mayer-Lindenberg[14] discussed the peculiarities of aircraft monitoring and maintenance domain and revealed the shortcomings of the BITE monitoring methodology. Qi[15], *et al.* presented a bath-tub and spoon-shaped models for reliability and maintainability respectively. Quan[16], *et al.* discussed the importance of preventive maintenance schedules and trade-offs between work force and optimized maintenance times. Sriram and Haghani[17] described the periodical maintenance requirements (Types-A, B, C, and D checks) and presented mathematical models for maintenance scheduling based on flight hours. Swanson[7] brought out that proactive and aggressive maintenance strategies would be expected to lead to improvements in maintenance performance while a reactive strategy would hurt performance.

Degradation in the performance of any airborne component is natural. The design and manufacturing specifications, the utilised environment and the care taken by the operators govern the rate of degradation. However, in addition to the natural degradation in strength and performance, electrical and mechanical components do fail prematurely. The reliability characteristics of the components govern the failure patterns. While mechanical components follow a normal or Weibull failure time distribution, avionics follow an exponential or log-normal failure time distribution. Upadhya and Srinivasan[18] presented the failure models for mechanical and avionics systems and showed that availability of aircraft reduces over the time and more so if there are logistics delays. Shawlee and Humphrey[19] discussed the environmental factors that are responsible for the aging of avionics and explained that the exponential or constant failure rate models should not be used always as they do not consider the aging issues of avionics. Degradation of semiconductor based avionics effect the performance of the components and requires re-tuning and re-adjustment of parameters and governing algorithms. Further, electrical discontinuities, deterioration of insulation, failure of couplers, terminators and connectors call for additional diagnosis and corrective maintenance on avionics. While fault isolation may be comparatively less time consuming in the case of mechanical failures, correct isolation of electrical discontinuities requires special test equipment and skilled maintenance crew.

3. DEFINITIONS AND ASSUMPTIONS

The various terms used in formulating the performance measurement indices are defined as follows:

(a) *Performance Measurement*: Performance easurement is defined as the process of quantifying the efficiency and effectiveness of action. A performance measure can be defined as a metric to quantify the efficiency and/or effectiveness of an action.

(b) *Operational Availability*: Operational availability is the degree to which the aircraft are in an operable and a committable state at the start of the mission when the mission is called for at an unknown (random) time.

(c) *Net Fleet Serviceability*: The net fleet serviceability is obtained by the ratio of the number of aircraft in the fleet available for operations to the total number of aircraft in the fleet. The total number of aircraft includes the aircraft undergoing scheduled maintenance and the aircraft awaiting spare parts.

(d) *Work Package and Work Record*: The number and quantum of checks required to be carried out during each level of maintenance is stipulated by the OEM or formulated by the user. In I and D levels, the checks are issued in the form of work packages (WPs) in which all the activities required to be carried out are listed chronologically with the standard values and tolerances; and the results recorded in the work records (WRs).

(e) *Comfort Conditions*: The environmental conditions that influence humans pleasantly by inducing a sense of physical and psychological ease are known as comfort conditions. Factors such as temperature, humidity, odours, dust, aesthetics, acoustics, lighting etc. are to be optimized to achieve ideal comfort conditions to enhance efficiency of the crew performing a particular task.

The maintenance performance indicators are formulated with the following assumptions:

- There are no supply chain delays.
- The maintenance crew is trained and skilled, and gang size is adequate for executing the maintenance task.
- There are no production holdups due to equipment or tool constraints.
- Complete technology to carry out O, I, and D level maintenance is available.

4. MAINTENANCE PERFORMANCE INDICATORS FOR MRO

Maintenance of aircraft and associated tools, testers and ground support equipment (TTGE) costs over half the total cost of the operations. Therefore, it is essential to implement maintenance performance system to measure the value created by maintenance process. Maintenance managers must know that what is being done is what is needed by the business process; and if the maintenance output is not contributing/creating any value for the business, it needs to be restructured. This brings the focus on doing the right things keeping in view the organizational goal. The restructuring if required, would be governed by operational as well as customer rules and objectives.

Every flight (sortie) of an aircraft is cost intensive. Every flying hour logged reduces the residual life of the aircraft and components. The downtime of an aircraft amounts to loss of business and reduced operational preparedness. A sound maintenance, repair and overhaul (MRO) policy is the key to limited downtime and increased efficiency. Maintenance (M), repair (R) and overhaul (O) are three different processes and use of same performance indicators may not be feasible. Therefore, different approaches are to be adopted to measure the performance of M, R, and O. The issues that need to be considered for each of the three processes are listed below:

Maintenance : Maintenance is preventive in nature. Activities are carried out as per servicing schedules at stipulated periodicities. At times, based on condition monitoring data, predictive maintenance is also carried out. After the scheduled maintenance activities, it is expected that the system is serviceable and available till the time between the next scheduled maintenance of similar type. If the system fails before the next scheduled maintenance, then the reason for the failure; whether it is random in nature or due to maintenance inadequacies need to be established. Statistical analysis of the failure rates and the reason(s) for the failure would assist the decision maker to review the maintenance periodicities and/or adopt reliability improvement measures.

Repair : Repair is corrective in nature. Condition monitoring data, symptoms and the observations made by the pilot/crew are considered for fault diagnosis The faulty component is repaired or replaced as per the scope. The complete system is tested for serviceability. If the system fails before the next scheduled maintenance, then the reasons for the failure need to be established. The repair/restoration procedure could be reviewed accordingly.

Overhaul : Overhaul is a detailed examination of all components and subsystems and is a combination of preventive, corrective and predictive maintenance. Overhaul is done in an industrial-type facility. Such a facility may either be civilian, military, or both. Standard depot-level maintenance includes overhaul, repair, and modification of aircraft, components, and equipment. The time taken for completing the overhaul (D level inspection and repairs), the quantum of the job carried out, the extent to which the systems are restored to as good as new state and the guaranteed period of failure free operation are a few factors which determine the performance of an overhaul.

Maintenance performance indicators (MPIs) are utilised to evaluate the effectiveness of maintenance carried out. An indicator is a single measure or a product of several measures (metrics). A performance indicator is a measure capable of generating a quantified value to indicate the level of performance, taking into account single or multiple aspects. Maintenance performance indicators could be used for monitoring the performance of employees, customer satisfaction, overall equipment effectiveness (OEE), financial reports, productivity, reliability, availability, and maintainability (RAM), etc. When designing MPIs, it is important to relate them to both the process inputs and the process outputs. If this is carried out properly, then MPIs can provide or identify areas for benchmarking, measure personnel performance and assist decision making towards enhancing maintenance efficiency and overall business objectives.

Various MPIs are used in civil aviation and are well documented in civil aviation publications and reference books. The financial state of a commercial airliner is considered as a direct indicator of the health of the airliner as it covers all aspects including operating, maintenance and administrative costs; losses due to poor maintenance and management, losses due to accidents/incidents etc. In military aviation, operational preparedness and reliability of the aircraft contribute directly towards the mission effectiveness (whenever launched). In this study, action research-based analysis and development of performance measurement indices have been carried out for determining the maintenance efficiency in a military fighter aircraft fleet[20].

4.1 Operational Availability Index or Serviceability Index

Operational availability index ($I_{\text{op availability}}$) or serviceability index (I_s) (for a period) is the percentage of the ratio between sum of number of days each aircraft is serviceable to the sum of number of days each aircraft should have been serviceable.

$$I_s \text{ or } I_{\text{op availability}} = \frac{\sum_{i=1}^{n} d_i^s}{\sum_{i=1}^{n} d_i^a} .100\% \quad (1)$$

where

n number of aircraft in the squadron

d_i^s number of days aircraft i is serviceable

d_i^a number of days aircraft i should have been serviceable

It is advantageous to use this index over the actual net serviceability as this index would indicate true operational availability; it can be used as a measure of the maintenance efficiency of the squadron. The aircraft on the ground for want of spares and the ones undergoing scheduled inspections do not affect the serviceability index. An example of the variation of the fleet serviceability and serviceability index of a squadron is shown in Fig. 1.

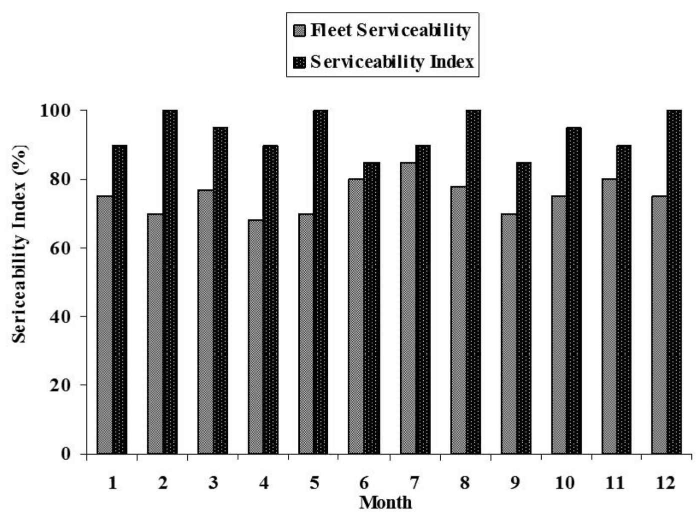

Figure 1. Variation of fleet serviceability and serviceability index.

4.2 Aircraft Uptime

Aircraft uptime (T_{up}) is the measure of availability of individual aircraft. The index for the aircraft uptime is expressed as follows:

$$T_{up} = \left[\frac{t_{up}^{a}}{t_{up}^{d}}\right].100\% \quad (2)$$

where

t_{up}^{d} desired aircraft uptime

t_{up}^{a} actual aircraft uptime

The desired aircraft uptime t_{up}^{d} can be provided as a target to the maintenance managers before the start of the measurement/ assessment period. The T_{up} achieved with the available resources and within the constraints would be a measure of the maintenance efficiency. An example of variation of the desired and actual up time of different aircraft is shown in Fig. 2.

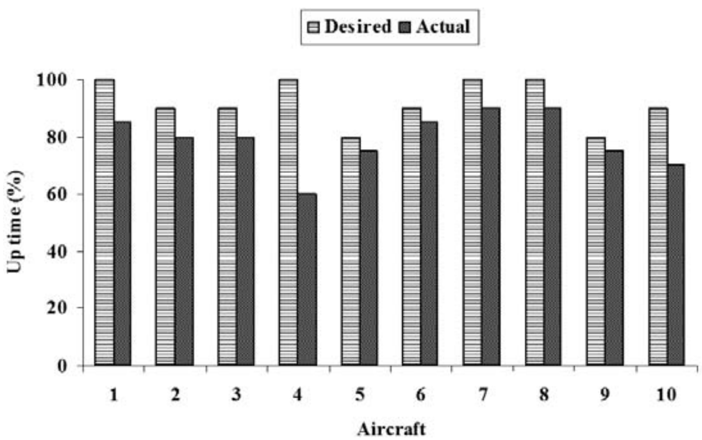

Figure 2. Variation of desired and actual up time.

4.3 Time Index

Time index (T_i) is the ratio between the difference of the desired inspection time (rectification time) and extra time to the desired inspection time (rectification time).

$$T_i = \frac{t_i^d - t_e}{t_i^d} \quad (3)$$

where

T_i time index

t_i^d desired inspection (rectification time)

t_e extra time

$t_e \geq 0$

and $0 \leq T_i \leq 1$

The desired inspection / rectification time t_i^d is estimated from statistical data. The extra time t_e is to be minimized. If the task is being completed before time, i.e. t_e is negative, then t_i^d needs to be revised.

4.4 Index for Breakdowns Caused by Poor Preventive Maintenance

The index for breakdowns caused by poor preventive maintenance (I_{bd}) is the ratio between the difference of the total number of breakdowns and number of breakdowns that should have been prevented to total number of breakdowns

$$I_{bd} = \frac{t_{bd} - t_{bd}^{p}}{t_{bd}} \quad (4)$$

where

t_{bd} total number of breakdowns

t_{bd}^{p} number of breakdowns that should have been prevented

and $0 \leq I_{bd} \leq 1$.

Failure of mechanical components is considered to follow normal or Weibul distribution. Therefore, the probability of premature failure of well maintained mechanical components is very less; except under conditions of undetected material failure. Avionics are expected to follow an exponential or log-normal failure pattern. The longevity of avionics can be improved by providing stable external and internal power supply, secured electrical harnesses, stable conductivity, and grounding, etc.

4.5 Work Accomplishment Index

Work accomplishment index (W_i) is the ratio between the difference of the total number of work packages (WPs) for the task and the number of WPs not carried out to the total number of WPs for the task.

$$W_i = \frac{N_{wp}^{t} - N_{wp}^{nc}}{N_{wp}^{t}} \quad (5)$$

where

W_i work index

N_{wp}^{t} total number of WPs for the task

N_{wp}^{nc} number of WPs not carried out

and $0 \leq W_i \leq 1$.

The endeavor of the maintenance managers should be to minimize the number of WPs not carried out, i.e $N_{wp}^{nc} \rightarrow 0$.

4.6 As Good as New Index

Maintenance cannot restore as good as new status[11]. When the measured physical and performance parameters meet the ones stipulated by the designer of a new system, the system is considered to be in as good as new state. The as good as new index (C_{new}) is developed by analysing the work records (WRs) on each component/ system. The WR meeting new (manufacturing) standard indicates as good as new status of the system and the system is expected to perform like a new one till the next maintenance cycle.

The as good as new index C_{new} is expressed as follows:

$$C_{new} = L_c \prod_{i=1}^{j} \left(\frac{N_i^{new}}{N_i}\right) \quad (6)$$

where

N_i total number of WRs from a category

N_i^{new} number of WRs from a category meeting new (manufacturing) standards

i category of the system

L_c life coefficient or per cent residual life. $[0 \leq L_c \leq 1]$

N_i increases with exploitation of the aircraft as new checks and inspection schedules get added. This is primarily due to exploitation defects and lack of data during the design and schedule formulation stage. The variation of N_i and N_i^{new} with technical life is given in Fig. 3. It is desired that N_i^{new} is close to N_i.

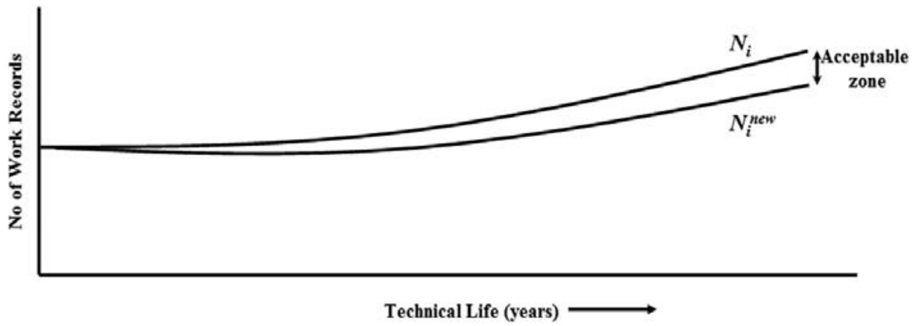

Figure 3. Variation of N_i and N_i^{new} with technical life.

4.7 Efficiency of Fault Diagnosis η_{fd}

It is proposed to measure the efficiency of fault diagnosis by comparing the value of time taken to pin-point and rectify the snag from the average time taken for rectifying same or similar snags in the past. As it is desired to minimize this time, a signal to noise ratio analysis for smaller the better care-about is carried out and the improvement is ascertained.

$$S/N_S = -10\log_{10}\left[\left(\sum y_i^2\right)/n\right] \tag{7}$$

where

S/N_S	signal to noise ratio for smaller the better
y_i	time taken for correct rectification of each snag
n	number of snags in a given period
η_{fd}	max (S/N_s)

4.8 Environmental Condition Index

It is proposed to measure the adequacy of environmental conditions by comparing the prevalening conditions with the standard stipulated comfort conditions. The environmental condition index (I_{ec}) is expressed as follows:

I_{ec} = [1–(difference between standard value of comfort condition and prevalent condition)/ (standard value of comfort condition)]

$$I_{ec} = \prod_{i=1}^{n}\left[\frac{p_i^p}{p_i^c}\right] \tag{8}$$

where

I_{ec}	environmental condition index
p_i^c	standard value of comfort condition *i*
p_i^p	prevalent value of condition *i*

p_i^c and $p_i^p \neq 0$.
and $0 \leq I_{ec} \leq 1$.

The indices expressed in Eqns (1) to (8) are applicable for O and I level maintenance of contemporary military fighter aircraft. The same indices could be used for different aircraft. However, numerical values of these indices could vary for different aircraft following different maintenance philosophies and working conditions.

5. APPLICATION OF PERFORMANCE MEASUREMENT INDICES

The operational preparedness of a military aircraft squadron is assessed by the mission availability of the aircraft and aircrew. It is the responsibility of the maintenance managers to ensure highest possible mission availability of the aircraft. The scheduled maintenance arising can be optimised by staggered utilisation of the aircraft and time bound accomplishment of the scheduled preventive maintenance activities. The effectiveness of maintenance[11] would determine trouble free operation of the aircraft system till the next maintenance cycle.

The proposed indicators have direct application for enhancing the O, I, and D level maintenance efficiency in military aviation. These indicators address the quality requirements during maintenance, reliability of systems after maintenance, maintenance efficiency, mission preparedness, minimization of down time and improvement of the overall operational availability of military aircraft. The set of indicators described above have been tested and analysed by applying actual data obtained from operating bases, and in a few cases; samples from actual data. The data comprised of the daily aircraft availability, the number of missions flown, the snags encountered by each aircraft, the rectification times, environmental conditions, etc. Amongst the indicators proposed, maximisation of serviceability index and the aircraft uptime are the desired end results, therefore, termed as desired indices. The rest of the indices contribute towards achieving the desired end results, and therefore, are termed as contributory indices. The attributes governing each of the contributory indices are indicated in Table 1.

A well established maintenance control centre (MCC) with integral planning, direction and control, and data analysis cells function at aircraft operating establishments. These centres critically monitor each aircraft availability, utilization and stagger. The serviceability index I_s, equipment uptime T_{up} and time index T_i can be quantified and analysed by the MCCs. The index for breakdowns caused by poor preventive maintenance I_{bd}, work accomplishment index W_i and as good as new index C_{new} are to be estimated by separate quality assurance cells with failure modes, effect and criticality analysis (FMECA) capabilities. Efficiency of fault diagnosis η_{fd} can be calculated by the MCC based on statistical and ERP data analysis. Lastly, the environmental condition index I_{ec} can be estimated by using measured prevalent values. The system requirements for MPIs for improving the measured values are listed in Table 2.

6. CONCLUSIONS

Aircraft maintenance is a complicated activity. In spite of having a good built-in test (BIT) facility within the aircraft and smart condition monitoring and test equipment, it is difficult to carry out prognosis for preventive and predictive maintenance and diagnosis for corrective maintenance. The reliability, accessibility, diagnostic ability and ease of maintenance play an important role in keeping the aircraft fly worthy and in reducing the downtime. The performance measurement indices presented in this paper are intended for use by aircraft maintenance managers for instituting process improvements

Table 1. Attributes governing contributory indices

Benchmark methods Workmanship Quality assurance Expertise	Insulation and grounding Condition monitoring Stable power supply	Light Noise Temperature Humidity Ergonomics	Procedures ERP Motivation Focus	Supervision Flying and reporting skills Diagnosis skills Training Experience	Tools and testers Calibration Equipment handling Supply chain Operational requirements
As good as new index C_{new}	Index for breakdown caused by poor PM I_{bd}	Environment condition index I_{ec}	Time index T_i	Efficiency of fault diagnosis η_{fd}	Work accomplish-ment index W_i
Reliability factors		Maintenance environment		Op Availability Factors	

Table 2. System requirements for MPIs

Index		Application	Remarks on data and results	Systems required to be in place
Serviceability index	I_s	O and I levels	Deterministic	Maintenance control centre (MCC) for critically monitoring each aircraft availability, utilization and stagger
Equipment uptime	T_{up}	O and I levels	t_{up}^{d} is determined by normalized statistical data	
Time index	T_i	O, I, and D levels	t_i^{d} is determined by normalized statistical data	
Index for breakdowns caused by poor preventive maintenance	I_{bd}	O and I levels	t_{bd}^{p} can be considered during FMECA	Quality assurance, FMECA and data analysis
Work accomplishment index	W_i	O, I, and D levels	Deterministic	
As good as new index	C_{new}	O, I, and D levels	Deterministic	
Efficiency of fault diagnosis	η_{fd}	O and I levels	Non deterministic	Statistical and ERP data analysis
Environmental condition index	I_{ec}	O, I, and D levels	Deterministic	Environment condition monitoring

for achieving best flight and maintenance safety records, improve the operational availability and reduce costs. In this paper, it was assumed that the qualifications and skill levels of the maintenance crew are adequate and all ground and test equipment required for maintenance are available. However, in a practical scenario, the fluctuations in these factors do play a vital role in determining the performance of maintenance.

REFERENCES

1. Neely, A.; Gregory, M. & Platts, K. Performance measurement system design: A literature review and research agenda. *Int. J. Oper. Prod. Mgmt.*, 1995, **15**(4), 80-116.
2. Parida, A. & Kumar, U. Applications and case studies: Maintenance performance measurement (MPM): Issues and challenges. *J. Qual. Maint. Engg.*, 2006, **12**(3), 239-51.
3. Parida, A. & Chattopadhyay, G. Methodology and theory: Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). *J. Quality Maint. Engg.*, 2007, **13**(3), 241-58.
4. Zisis, P.; Garefalakis, A. & Sariannidis, N. The application of performance measurement in the service quality concept: The case of Greek service organization. *J. Money, Investment Banking*, 2009, **9**, 21-47.
5. Jiang, R.; Ji, P. & Tsang, A.H.C. Methodology and theory: Preventive effect of optimal replacement policies. *J. Quality Maint. Engg.*, 2006, **12**(3), 267-74.
6. Rouse, P.; Putterill, M. & Ryan, D. Integrated performance measurement design: Insights from an application in

aircraft maintenance. *Manag. Accoun. Res.,* 2000, **13**, 229-48.

7. Swanson, L. Linking maintenance strategies to performance. *Int. J. Prod. Eco.*, 2001, **70**(3), 237-44.
8. Garg, A. & Deshmukh, S.G. Multi-echelon repair inventory systems: Select issues in modular electronic equipment. *Def. Sc. J.,* 2010, **60**(5), 514-24.
9. Duer, S. Expert knowledge base to support maintenance of a radar system. *Def. Sc. J.,* 2010, **60**(5), 531-40.
10. Wang, C & Lin, T. Minimisation of non-periodic preventive maintenance cost in series-parallel systems. *Def. Sc. J.,* 2011, **61**(1), 44-50.
11. Crocker, J. Effectiveness of maintenance. *J. Quality Maint. Engg.*, 1999, **5**(4), 307-313.
12. Jones, J.A. & Warrington, L. An analysis of the effect of a reliability paradigm shift on leading british aerospace companies. *Quality Rel. Engg. Int.,* 2002, **18**, 285-92.
13. Kumar, S. Chattopadhyay, G. & Kumar, U. Reliability improvement through alternative designs : A case study. *Rel. Engg. Sys. Safety*, 2007, **92**, 983-91.
14. Owotoki, P. & Mayer-Lindenberg, F. Comprehensible hierarchical intelligent (CHI) framework for monitoring and preventive maintenance of aircraft systems. *In* IEEE Proceedings of 3rd International workshop on Intelligent Solutions in Embedded Systems, Hamburg Germany, 2005. pp. 175-85.
15. Qi, Y. Zhigang, L. & Bifeng, S. New concept for aircraft maintenance management (II) : The establishment of the spoon-shaped curve model. *In* Proceedings of Annual Reliability Maintenance Symposium, 2003. pp. 68-73.
16. Quan, G. Greenwood, G.W. Liu, D. & Hu, S. Searching for multi objective preventive maintenance schedules: Combining preferences with evolutionary algorithms. *Euro. J. Oper. Res.,* 2007, **177**(3), 1969-984.
17. Sriram, C. & Haghani, A. An optimization model for aircraft maintenance scheduling and re-assignment. *Transportation Res. Pt. A*, 2003, **37**, 29-48.
18. Upadhya, K.S. & Srinivasan, N.K. Availability of weapon systems with multiple failures and logistic delays. *Int. J. Quality Rel. Mgmt.*, 2003, **20**(7), 836-846.

19 Shawlee, W.II & Humphrey, D. Aging avionics—What causes it and how to respond. *IEEE Trans. Components Packaging Tech.*, 2001, **24**(4), 739-40.

20. French, S. Action research for practicing managers. *J. Mgmt. Develop.*, 2009, **28**(3), 187-204.

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