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DEVELOPMENT OF A TWO-DIMENSIONAL
AIRCRAFT MAINTENANCE ESTIMATION METHOD

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ABSTRACT

In the aircraft operation there are few situations, in which the preventive maintenance cannot be used. For example this situation can be the aircraft wartime operation. Similar maintenance philosophy can be observed in printing-machine operation too, when corrective maintenance should be used. In cases mentioned above the needed maintenance work depends on the failure rate of equipment and work expenditure of repair basically. The failure rate and repairing time is stochastic parameter, which has a distribution function, mathematical expectation and variance. The method developed by the author estimates work expenditure of repair using a two-dimensional probability model. The reliability of this estimation is characterized by one collective probability not by multiplication of estimation's probabilities of expectable failure number and repair work expenditure. The paper will show the new two-dimensional maintenance estimation method theoretically, possibility of use and experiments of first application of developed method.

Keywords: maintenance management, capacity estimation, stochastic modelling

1. INTRODUCTION

The operation of technical systems is a stochastic process. In the aircraft operation there are few situations, in which the preventive maintenance cannot be used. For example this situation can be the aircraft wartime operation. Similar maintenance philosophy can be observed in printing-machine operation too, when corrective maintenance should be used.

In cases mentioned above the needed maintenance work depends on the failure rate of equipment and work expenditure of repair basically. The failure rate and repairing time is stochastic parameter, which has a distribution function, mathematical expectation and variance.

The estimation of expectable values of failure number depends on planed flying hours, or other performance parameters can be solved by some probability, that is uncertainty. The work expenditure of repair can be estimated depend on expectable failure number by some probability too. The probability of whole (two-step) estimation process is multiplication of probabilities mentioned above.

The method developed by the author estimates work expenditure of repair using a two-dimensional probability model. This method estimates the expectable values of failure number and work expenditure of repair "by one step". The reliability of this estimation is characterized by one collective probability not by multiplication of estimation's probabilities of expectable failure number and repair work expenditure.

The paper will show the new two-dimensional probabilistic maintenance estimation method theoretically, possibility of use and experiments of first application of developed method.

The paper will be organized as follows: Section 1 shows the main goal of investigation. Section 2 words the maintenance management problem. Section 3 presents theoretical solution of the problem. Section 4 shows a similar case study.

2. WORDING OF MAINTENANCE ESTIMATION PROBLEM

One of the most frequent questions in the maintenance management is to determine optimal maintenance capacity, depend on planed working performance (for example flying hours). Needed maintenance capacity can be counted out by:

- ➜ working performance: T;
- ➜ failure rate: λ;
- ➜ repairing time of one failure: m.

The first parameter is basically planed, and other two are uncertain/stochastic ones.

The failure rate $\lambda(t)$ can be identified of as the conditional probability density that a failure occurs in a short specified interval, under the condition that no failure has occurred before time t. The unit of measure of λ is $\left[\dfrac{1}{\text{performance unit}} \right]$. The failure rate can be estimated statistically by equation

$$\lambda = \frac{n}{N\Delta t} \; , \tag{1}$$

where: n —— number of element's failures during Δt performance interval;

N —— number of elements;

Δt —— investigational performance interval.

During operation failure rate of a given technical system changes, and its statistical determination by equation (1) has any uncertainty. So the failure rate λ can be considered as a random variable, which can be characterized by its expectation $\hat{\lambda}$, variance $\tilde{\lambda}$, probability density $f(\lambda)$ and distribution function $F(\lambda)$.

To demonstrate it, Figure 1 shows histograms of so called type B failure coefficients (Fig. 1.a.) and type B failure rates (Fig. 1.b.) during operations Desert Storm and Proven Force [5][8].

Knowing planed working performance and failure rate, expected number of failures can be determined by equation

$$\hat{n} = T\hat{\lambda} \; . \tag{2}$$

a.) B–type Failure Coefficients

$$\left[\frac{1}{100 \text{ sorties}} \right]$$

b.) B–type Failure Rates

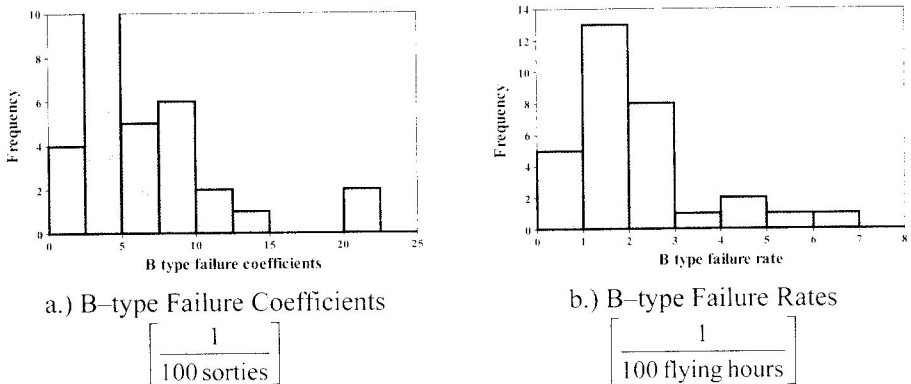$$\left[\frac{1}{100 \text{ flying hours}} \right]$$

Fig. 1 Histograms of type B failure coefficients (a) and rates (b)

The repairing time of one failure m is also a random variable. Therefore it can be described by its expectation $\hat{m}$, variance $\widetilde{m}$, probability density $f(m)$ and distribution function $F(m)$.

According to the aforesaid, the expected value of the needed maintenance capacity $\hat{M}$ can be determined by equation

$$\hat{M} = \hat{m}\,\hat{n} \ . \tag{3}$$

During the estimation if we liked to determine the interval of the maintenance capacity at a given estimation reliability, we have to take into consideration the probability distributions of the failure rate and repairing time of a single failure. According to the method mentioned above, the accuracy of failure number estimation — see equation (2):

$$P_{\lambda} = \int_{\lambda_{\min}}^{\lambda_{\max}} f(\lambda)d\lambda = F(\lambda_{\max}) - F(\lambda_{\min}) \ , \tag{4}$$

where: λ_{min} — the minimum value of failure rate assessment interval;
λ_{max} — the maximum value of failure rate assessment interval.

And the accuracy of needed maintenance capacity of one failure — see equation (3):

$$P_{m} = \int_{m_{\min}}^{m_{\max}} f(m)dm = F(m_{\max}) - F(m_{\min}) \ , \tag{5}$$

where: m_{min} — the minimum value of maintenance work assessment interval;
m_{max} — the maximum value of maintenance work assessment interval.

Then, the accuracy of complete estimation:

$$P_{B} = P_{\lambda}P_{m} \ . \tag{6}$$

It is important to mention that in actual practice just these minimum and maximum values have to be determined depend on required estimation accuracy.

3. THEORETICAL SOLUTION

The main goal of this study is to elaborate a needed maintenance work estimation method, which uses the failure rate and repairing time of one failure as random variables, while the required estimation accuracy is ensured. As the first approximation supposes that the failure rate and repairing time of one failure are independent random variables and they are of normal (Gauss) distribution. From maintenance management point of view the independence of the parameters mentioned above is defensible. (For example, in the case study — see Section 4 — the correlation coefficient between failure rate and repairing time of one failure is "only" 0,173.)

The above-mentioned task can be solved by using two different methods.

In case of the first one, accuracies of failure rate and repairing time estimations are stipulated such a way that the accuracy of the complete estimation — see equation (6) — has to be good. In the present case — using equations (4) and (5) — λ_{min}, λ_{max}, m_{min} and m_{max} can be determined. Then minimum and maximum values of the required maintenance work are determined by equations:

$$M_{min} = T\lambda_{min}m_{min}$$
$$M_{max} = T\lambda_{max}m_{max} \qquad (7)$$

The main problem of this method is the determination of the optimal relation for the required accuracy of failure rate and repairing time estimation, since they depend on the accuracy of the complete estimation. This problem can be eliminated if the maintenance estimation is solved by using— through simplifier conditions — two-dimensional normal probability density function. In this case the density function in question is:

$$f(\lambda,m) = \frac{1}{2\pi\tilde{\lambda}\tilde{m}}e^{-\frac{1}{2}\left[\left(\frac{\lambda-\hat{\lambda}}{\tilde{\lambda}}\right)^2 + \left(\frac{m-\hat{m}}{\tilde{m}}\right)^2\right]} \qquad (8)$$
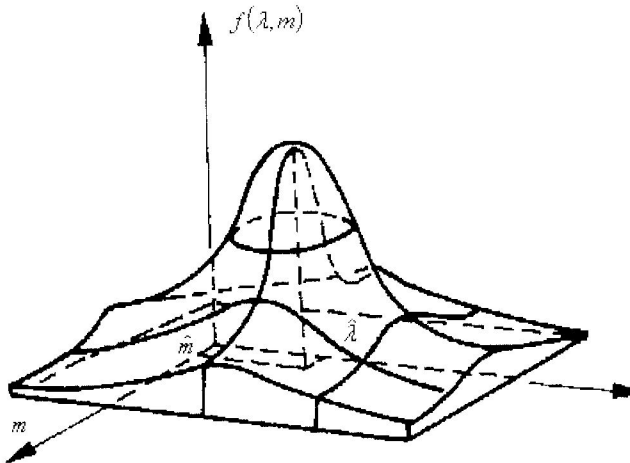
which is demonstrated in Figure 2.

Fig.2 Bivariate Gaussian probability density function of the two-dimensional Aircraft Maintenance Estimation Method

From the reference [3], the distribution described by equation (8) can be characterized by formula

$$\left(\frac{\lambda-\hat{\lambda}}{\tilde{\lambda}}\right)^2 + \left(\frac{m-\hat{m}}{\tilde{m}}\right)^2 = \Omega^2 \qquad (9)$$

describing the level-ellipse. The probability of the event, that a point of co-ordinate pair $(\lambda;m)$ falls within the ellipse can be determined by using bivariate χ^2-distribution in form:

$$P_B = F_{\chi^2(2)}\left(\Omega^2\right) . \qquad (10)$$

With the knowledge of the accuracy of (maintenance management) estimation, Ω^2 can be determined.

In the present case the task is to search for points of co-ordinate pair $(\lambda;m)$ of the level ellipse, where the multiplication of λ and m has any extremum. Then the mini-

mum and maximum values of the required maintenance work are determined by the following equations:

$$M_{min} = T\{\lambda m\}_{min}$$
$$M_{max} = T\{\lambda m\}_{max}$$

(11)

4. CASE STUDY

To demonstrate the possibility of using the two-dimensional maintenance estimation method developed, a case study will shortly be shown.

Failures and repairing data of an equipment group at an East Hungarian company were investigated during two years. Histograms of the failure rate and that of the repairing work of one failure are shown in Figures 3 and 4. Table 1. summarizes the numerical statistical data.
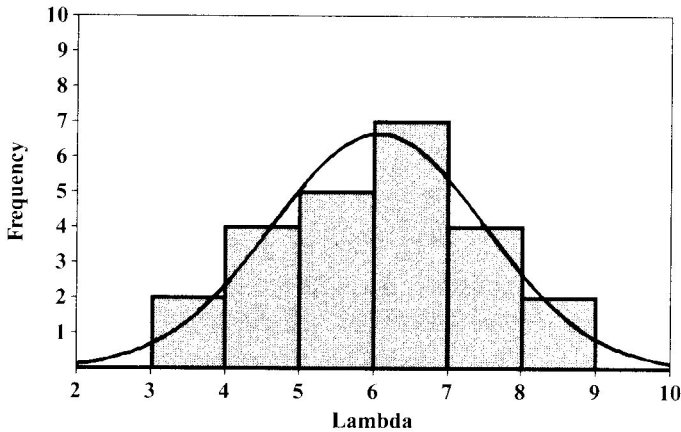

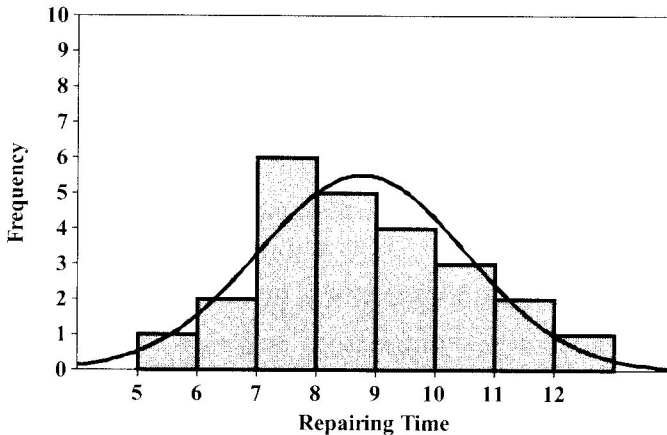Fig. 3 Histogram of Failure Rates $\left[\dfrac{1}{1000\ hours}\right]$

Fig. 4 Histogram of Repairing Times [*working hour*]

	Failure Rate $\left[\dfrac{1}{1000 \text{ hours}}\right]$	Repairing Time [*repairing hour*]
Mean	6,063	8,762
Variance:	1,439	1,738
Number of samples:	24	24
Confidence:	0,738	0,891
Correlation coefficient:	0,173	

Table 1 Results of Statistical Analysis

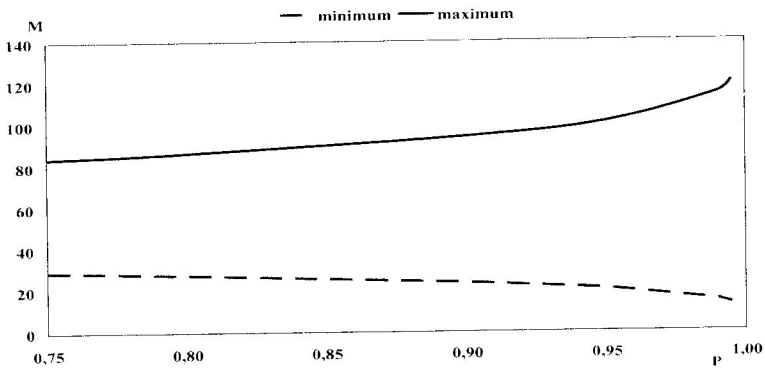Results of estimation depend on required accuracy is demonstrated by Figure 5 and Table 2.

Fig. 5 Results of Estimations

P	$(\lambda m)_{min}$	$(\lambda m)_{max}$
0,75	29,236	83,886
0,80	27,652	86,595
0,90	23,600	94,106
0,95	20,388	100,763
0,990	14,769	114,414
0,995	12,880	119,772

Table 2 Results of Estimations $\left[\dfrac{\text{repairing hour}}{1000 \text{ hours}}\right]$

The graph shows exactly the provisional result, that if accuracy increases the estimated interval increases too.

5. CLOSING REMARKS, FUTURE WORK

The paper introduced a new maintenance estimation method, which uses two-dimensional stochastic model, i.e. the two-dimensional normal distribution function of the failure rates and the repairing time of one failure.

During prospective scientific research activities related to this field of mathematics and technical management science, author intends to improve and develop the intro-

duced method for the more complicated cases, if the failure rates and repairing time of one failure:

→ are no longer independent random variables;
→ are no longer of joint normal (Gaussian) distribution.

6. REFERENCES

[1] **Aven, T.:** Risk analysis and science, International Journal of Reliability, Quality and Safety Engineering, Vol. 11, No. 1 (2004) p. 1–15.

[2] **Karlin, S. - Taylor H.M.:** Sztochasztikus folyamatok, Gondolat, Budapest, 1985.

[3] **Korn, G.A. - Korn, T.M.:** Matematikai kézikönyv műszakiaknak, Műszaki Könyvkiadó, Budapest, 1975., pp. 995.

[4] **Lukács O.:** Matematikai statisztika, Műszaki Könyvkiadó, Budapest, 1987.

[5] **Methler, Ph.L.:** Command Management Review, Desert Shield, Desert Storm, Proven Force, Aug 1990 – February 1991, HQ USAFE LG, Ramstein, Germany, 1991.

[6] **Pokorádi, L.:** Application of Markov Process Theory to Investigation of Aircraft Operational Processes, Proceedings of 19th Congress of the International Council of the Aeronautical Sciences, Anaheim, California, USA, 1994., volume 3, p. 2172–2180.

[7] **Pokorádi, L.:** Investigation of Aircraft Operational System with Markov-Matrix, Proceeding of 4th Mini Conference on Vehicle System Dynamics Identification and Anomalies, (Ed. by Prof. I. Zobory), Budapest, 1994, p. 437–444.

[8] **Pokorádi L.:** Repülőgépek üzemeltetési folyamatainak markovi modellje, Kandidátusi értekezés, MTA DT., Budapest, 1996.

[9] **Pokorádi, L.:** Markovian Modelling Wartime Operation of Military Aircraft, "International Aerospace Congress 1997", Sydney, Australia, Volume 2, p. 537–549.