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An approach to risk-based maintenance strategy of a printing press

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Abstract

The unexpected failures, downtime associated with breakdown and make ready, loss of production and higher maintenance costs are the major problem in any printing press. Risk based maintenance strategy helps in designing an alternative methodology to minimise the risk by identifying the breakdown pattern and then increasing the reliability. Reliability analysis is necessary for every type of machinery for fault detection, risk assessment and evaluation, and maintenance planning. The probability of failures that hinder the reliability can be influenced by some technical, administrative or management actions. The aim of the proposed study is to analyse reliability and availability for maintenance planning on the basis of risk index and overall equipment effectiveness. And maintenance of equipment is prioritized based on the risk which helps in reducing the overall risk of the press.

Keywords: reliability, availability, risk index, overall equipment effectiveness

1. Introduction

Plant's machine and equipment will not remain safe or reliable if it is not maintained properly. General objective of the maintenance process of a machine is to achieve the possible safety with the lowest possible cost. In the present study the concept of risk-based maintenance (RBM) strategy has been adopted to identify the high risk machines and then attempts have been made to minimize the actual failure rate with a statistical approach. This helps us to minimize any unexpected production loss due to various components' downtime. The present study is conducted on the basis of regular visits to the printing press continuously for three months in order to get appropriate data. These data are processed and then analysed so that tolerable risk can be achieved.

2. Theoretical background of the study

2.1 Maintenance strategy

The basic aim of maintenance strategy is to minimize hazards which are caused by the unexpected failure of the equipment. To increase the machine's life and to reduce the risks caused by failure of the equipment, risk-based approaches are used in present days.

Risk-based approach is a technique for identifying, characterizing, quantifying, and evaluating the loss from an event. Risk analysis approach integrates probability and consequence analysis at various stages (Khan and Haddara, 2013). Risk assessment can be quantitative or qualitative. The output of a quantitative risk assessment will typically be a number. The number (i.e. cost impact per unit time) could be used to prioritize a series of risked items. Risk can be written as given in Equation [1].

$$\text{Actual risk} = \text{Failure probability} \times \text{Consequence of failure} \quad [1]$$

The proposed RBM strategy aims at reducing the overall risk of failure of the operating facilities. In areas of high and medium risk, a focused maintenance effort is required. The RBM suggests a set of recommendations on how many preventive tasks are to be performed. The implementation of RBM will reduce the likelihood of an unexpected failure. The RBM methodology is comprised of following three main modules which are interactively linked. These are risk determination (which consists of risk identification and estimation), risk evaluation (in where acceptance criteria are set to compare with existing risk) and maintenance planning (in where reduction of risk level is executed by the help of proper planning).

2.2 Failure analysis

Failure is an event that affects not only a system but the system criteria also. On a given system the failures may change with the change of time. Failures do not generally occur at a uniform rate, but follow a specific distribution with time as shown in Figure 1. This distribution can be divided into three regions (Dhillon, 2008), namely infant mortality period (where the failure rate progressively improves), useful life period (where the failure rate remains constant) and wear-out period (where failure rates begin to increase).

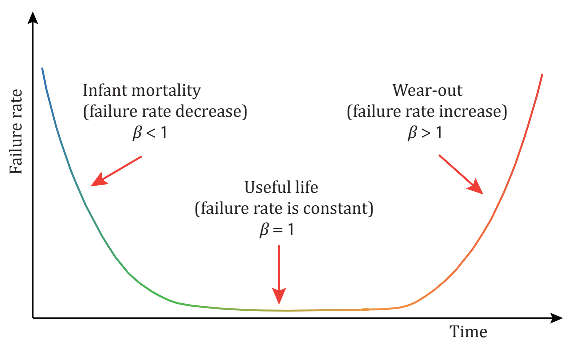

Figure 1: Bath-tub curve of a system describing failure rates at different periods

To the best of the knowledge Weibull distribution is the most widely used distribution in reliability engineering and the failures caused by fatigue, corrosion, mechanical abrasion, diffusion and other degradation processes can be easily analysed. The two parameter Weibull distribution needs two factors, namely scale factor (η) and shape factor (β). Beta (β) describes the shape of the distribution. If $\beta > 1$, the failure rate is increasing due to the accelerated wear and tear of components. If $\beta < 1$, the failure rate is decreasing due to early stage of machine. When the failure rate is constant (for $\beta = 1$), the distribution follows exponential probability law and when failure rate is not constant (i.e. non-linear hazard model) it follows Weibull distribution.

It is also important to note that failure probability is also termed as unreliability in failure analysis. Moreover, if the type of distribution is not known in advance, then the distribution that best fits the failure or repair times can be found using different statistical methods. Anderson-Darling (AD) test (Anderson and Darling, 1952) is used to find best-fit or goodness-of-fit tests which can be implemented with great ease by the use of software tools or Weibull analysis. The AD test is the popular test that determines whether the given set of data is drawn from the probability distribution. In addition to its use as a test of fit for distributions, it can be used in parameter estimation as the basis of minimum distance estimation procedures. It will also help to take decision for choosing the most appropriate statistical distribution method. It is known that lowest AD test value posses best fitted distribution, for example among the three probability distribution like normal, exponential and Weibull, AD value is the lowest for Weibull distribution for its best distribution pattern (Murthy, Xie and Jiang, 2004).

2.3 Reliability analysis

Reliability can also be described as the probability that an item or process operates properly for a specified amount of time under stated conditions (both environmental and operational conditions) without failure (Kumar, 2016). The cumulative density function for reliability $R(t)$ is denoted as $F(t)$ which is also related to failure probability and in combination with the fact that the area under the probability density function (PDF) (denoted as $F(t)$) is always equal to 1. Obviously, the reliability function $R(t)$ can be expressed by Equation [2].

$$R(t) = 1 - F(t) = 1 - \int_0^t f(t)dt \qquad [2]$$

The mathematical formulations of PDF for normal, exponential and Weibull distribution plotting are given in Equations [3], [4] and [5].

$$f(t) = \frac{1}{\sigma} \cdot \sqrt{2\pi} \cdot e^{-\frac{(t-\xi)^2}{2\sigma^2}} \qquad [3]$$

$$f(t) = \lambda e^{-\lambda(t-\gamma)} \qquad [4]$$

$$f(t) = \left(\frac{\beta}{\eta}\right) \cdot \left(\frac{t}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad [5]$$

where ξ is mean of time between failure (MTBF), σ is standard deviation of MTBF, λ is the scale parameter, γ is the location parameter, η is characteristic life or scale parameter, β is shape factor value and t is operating time.

Moreover, the technique of AD test and linear regression analysis confirms the validity of use of Weibull distribution for the different components of the printing press. The analysis determines the best-fit line in the least square sense. The least square test has been used to obtain the rate of failure. Linear regression analysis has been carried out by using the probability Equation [6] (Bose, et al., 2013).

$$R_{x,f(x)} = \frac{p}{q} \qquad [6]$$

where

$$p = \Sigma[x \cdot f(x)] - \frac{[\Sigma x \cdot \Sigma f(x)]}{N}$$

$$q = \sqrt{\left[\Sigma(x^2) - \frac{(\Sigma x)^2}{N}\right] \cdot \left\{\Sigma f(x^2) - \frac{[\Sigma f(x)^2]}{N}\right\}}$$

x is breakdown time, $f(x)$ is cumulative percentage of failure, N is total operating time, $R_{x,f(x)}$ is correlation coefficient. From the concept of probability, it is known that the correlation coefficient must be in between +1.0 to −1.0. If the correlation coefficient estimates positive value, then the failure rate is increasing and so Weibull distribution can be applied for the estimation of reliability (Kar, 2019).

2.4 Availability analysis

Availability is the probability that a system is not failed or undergoing a repair action/maintenance job when it needs to be used. So the estimation of availability plays vital role for both reliability and maintainability aspects. Availability or inherent availability A_{in} is the function of preventive or scheduled maintenance action and it is expressed (Leitch, 1995) by Equation [7].

$$A_{in} = MTBF/(MTBF + MTTR) \qquad [7]$$

where MTTR is defined as the mean time to repair. In real operation administration delay time and logistic delay time should be taken into consideration. Operational availability A_{op} is the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily. It may be expressed by Equation [8].

$$A_{op} = MTBF / (MTBF + MDT) \qquad [8]$$

where MDT is the mean downtime that includes restoration delay time, logistics delay time and administrative delay time.

2.5 Estimation of consequence and risk index

This study also deals with the estimation of consequence and risk index which are very much essential for maintenance planning. The important expressions for consequences and risk index (Khan and Haddara, 2003) are given in Equations [9] and [10].

$$\text{Consequence} = MC + PLC \qquad [9]$$

where MC represents machine cost and PLC represents production loss cost of the respective components.

$$\text{Risk index} = \text{Actual risk} / \text{Acceptable risk} \qquad [10]$$

2.6 Overall equipment effectiveness

The effectiveness of facilities is its best possible return generated and calculated as percentage of each group of six big losses (Maideen, et al., 2016). The six big losses are breakdown, set-up and adjustments, small stops, reduced speed, production rejects or scraps and start-up losses. The identified losses can be measured in terms of overall equipment effectiveness (OEE) which is a function of availability, performance rate and quality rate as expressed by Equation [11].

$$\text{OEE} = \text{Availability (\%)} \times \text{Performance rate (\%)} \times \text{Quality rate (\%)} \qquad [11]$$

where

$$\text{Availability} = \left(\frac{\text{Planned prod. time} - \text{Unplanned downtime}}{\text{Planned prod. time}}\right) \cdot 100\ \%$$

$$\text{Performance} = \left(\frac{\text{Actual prod. output}}{\text{Expected prod. output}}\right) \cdot 100\ \%$$

$$\text{Quality} = \left(\frac{\text{Actual prod. input}}{\text{Actual prod. output}}\right) \cdot 100\ \%$$

Planned production time is nothing but the loading time for the job (Kar, 2019) in which total observation time is taken where planned downtime is not considered, i.e.

$$\text{Planned prod. time} = \text{Observation time} - \text{Planned downtime} \qquad [12]$$

Planned downtime is the machine setup time, loading and unloading time, schedule maintenance time or schedule breaks, etc.

On the other hand unplanned downtime is simply the minor stoppage time loss, sudden breakdown time loss, idle time, uncertain changeover time loss for loading and unloading of material, machine breakdown and its corresponding setup time loss, etc., which are directly concerned with the losses related to availability and performance. It is also important to mention that production output is the combination of production input and rework item and scrap.

3. Press and its components

The present study is conducted in the production system of a daily newspaper company situated in Kolkata, India. One of the key processes of this production system is the web fed offset printing process which has one number of four colour web-offset printing machine. The print production house has the following components shown in Table 1. It is also important to mention that press has two compressors but only one compressor has been taken into consideration for the study as the second compressor is used for emergency backup purpose only.

Table 1: Different components (machines) used in the print production house (approximate values)

Component	Manufacturer	Year of manufacture	Plate size (mm)	Printing area (mm)	Capacity
Web-offset four colour press (printing machine)	Orient Xcell	2009	780 × 510	700 × 395	41200 impressions/h
Computer to plate 1 (CTP 1)	Epson	2014	780 × 510	–	20 plates/h
Computer to plate 2 (CTP 2)	Epson	2009	780 × 510	700 × 395	15 plates/h
Exposure unit	Technova	2005	780 × 510	–	30 plates/h
Compressor	–	2009	–	–	–

4. Data collection and analysis

Basic data collected from the printing press are operating time, breakdown time and number of failures of the components. Data collected for web-offset printing machine is given in Appendix A. Time between failures of different machines has been compiled from the daily maintenance reports during the period from 1st August to 31st October 2018. During this investigation the average temperature inside the press was 28–32 °C and average relative air humidity was 70–80 %. Moreover, as the printing job was mostly associated with newsprint thus the press uses the paper of the same grammage and printing was done mainly in night shift though 35 % of the printing was done in both day and night shifts. Furthermore, it is assumed that the operational conditions are the same for all the machines.

It has been observed that the correlation coefficients of the different components of the press show positive values. Hence Weibull distribution is applied in the present study.

Failure probability for different components has been estimated by Equation [6] and the reliability function for the components has been calculated by using Equation [2]. Table 2 shows the corresponding results of the failure and reliability analysis for different components of the press.

Table 2: Reliability and failure probability of different components

Component	Failure probability	Reliability (%)
Printing machine	0.553	44.69
CTP 1	0.735	26.46
CTP 2	0.539	46.10
Exposure unit	0.777	22.33
Compressor	0.178	82.22

Figure 2 shows Weibull plot for regression analysis of web-offset printing machine. It also shows the values of shape and scale parameters, i.e. β = 1.840 and η = 283.73), which were estimated by Minitab17.

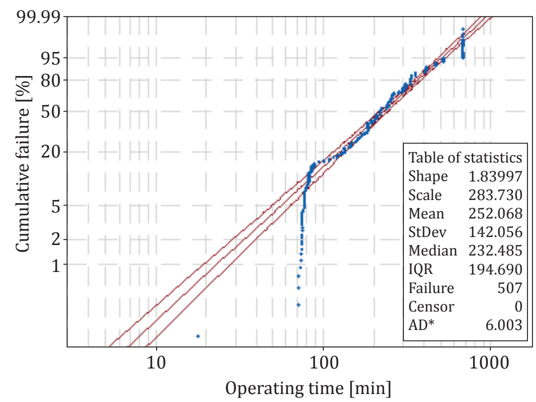

Figure 2: Weibull plot of web-offset printing machine obtained from Minitab17

Figure 3 shows the distribution of PDF that describes the failure characteristics of the printing machine by using software Minitab17.

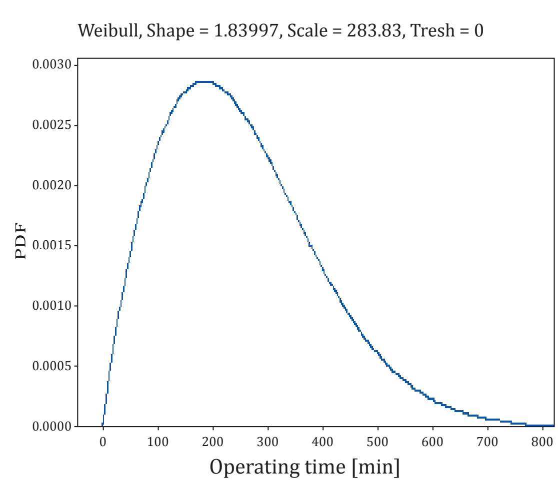

Figure 3: PDF distribution of printing machine obtained from Minitab17

Figure 4 shows the probability plots of the printing machine obtained by normal, exponential and Weibull distribution. It is clear from Figure 4 that Weibull analysis is appropriate as it is best fitted and its AD value is lowest (i.e. 6.003) from the normal and exponential analysis.

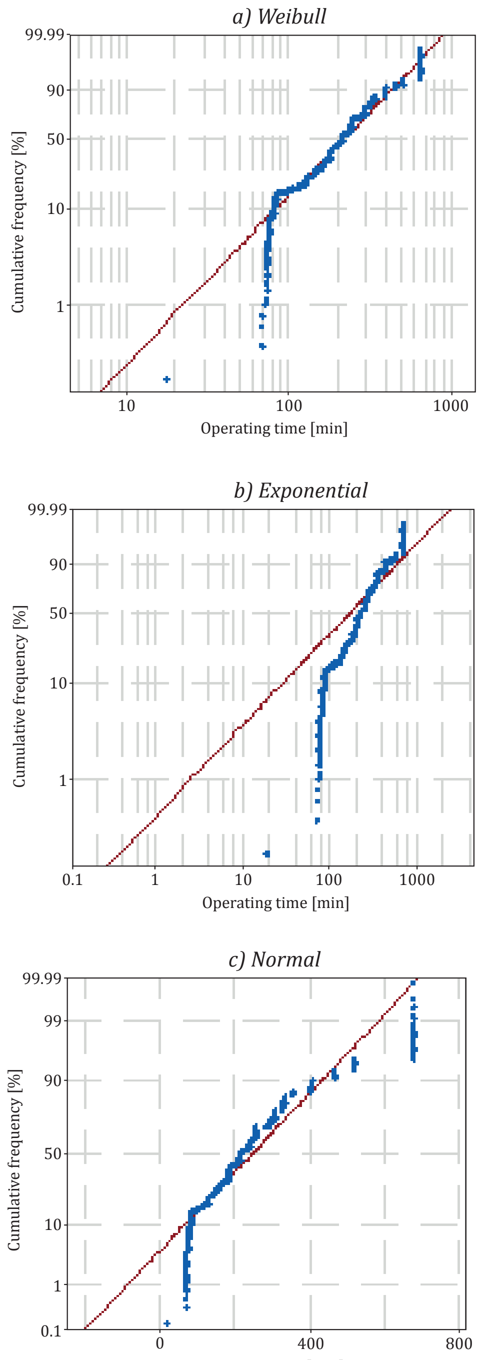

Figure 4: Probability plot of printing machine deriving Anderson-Darling value obtained from Minitab17 (Anderson-Darling (adj): (a) Weibull = 6.003, (b) Exponential = 49.444, (c) Normal = 14.219)

The estimation of availability for web-offset printing machine is described in Appendix B. Figure 5 shows the corresponding availability plot.

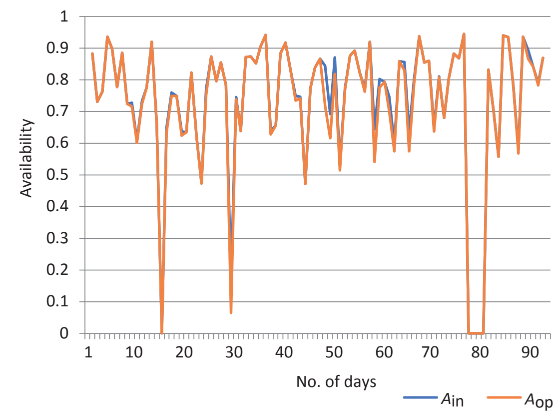

Figure 5: Availability of web-offset printing machine in the period of 92 days

The availability of different components of the press are shown in Figure 6 which indicates that both type of availability of the exposure unit possess low availability. This may be due to the loading and unloading which have been considered as failure. Whereas printing machine and compressor posses high availability during three months under study.

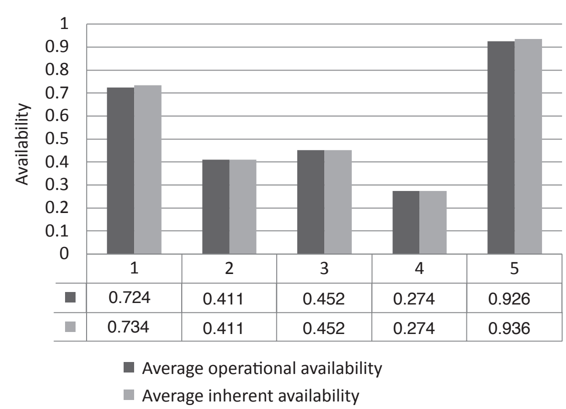

Figure 6: Bar diagram of various availability of components: 1 – printing machine, 2 – CTP 1, 3 – CTP 2, 4 – exposure unit, 5 – compressor

Considering acceptable risk criteria of 2 252.05 EUR which is obtained from accounts department of the press, risk indices of different components are shown in Table 3. It is seen that exposure unit is having highest failure rate but after risk analysis it is clear that the web-offset printing machine of the press is facing the maximum failure and risk scenario. This may be due to the high consequences of the printing machines.

Moreover, make-ready time and change-over adjustment time for the printing machine are higher than that of the other components.

Table 3: Consequence, failure probability, actual risk (calculated from Equation 1) and risk index of different components

Component	Consequence (EUR)	Failure probability	Actual risk (EUR)	Risk index
Printing machine	10 062.29	0.553	5 565.79	2.47
CTP 1	543.96	0.735	400.05	0.18
CTP 2	294.72	0.539	158.85	0.07
Exposure unit	319.58	0.777	248.23	0.11
Compressor	460.53	0.178	81.88	0.04

On the basis of risk level, Pareto analysis of all the components of the printing press has been done by using Minitab17, results are shown in Figure 7. Which equipment is needed to be chosen for maintenance planning can be decided from this Pareto analysis.

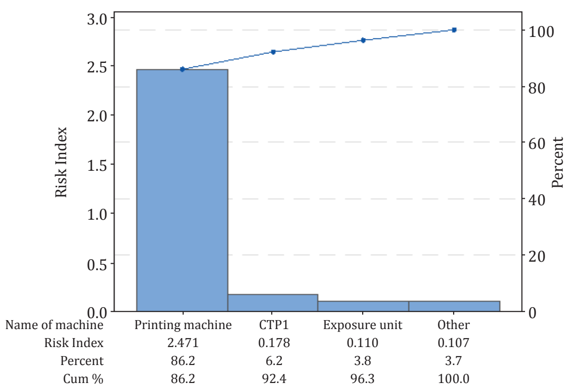

Figure 7: Overall Pareto analysis of different components

The OEE of the component is measured on the basis of high risk. Here web-offset printing machine is at high risk thus OEE of web-offset printing machine is calculated here (Table 4).

Table 4: The overall equipment effectiveness of the printing machine

Parameter	Value
Observation time (min)	20 472
Planned production time (min)	19 436
Planned downtime (min)	1 036
Unplanned downtime (min)	4 539
Operating time (min)	14 886
Actual production output	7 737 591
Capacity per given time (impressions/min)	687
Expected output (impressions)	10 226 682
Amount defect and reproduced (impressions)	96 364
Availability loss (%)	76.65
Performance loss (%)	75.66
Quality loss) (%)	98.75
OEE (%)	57.27

From these calculated losses, the OEE for four colour web-offset printing machine is determined from Equation [11] and found to be 57.27 %. Therefore, it is clear that OEE confirms the validity of high risk components. It indicates that this component requires further maintenance planning for improvement.

5. Maintenance planning

The strategy for maintenance planning should be adopted to lower the risk to meet the acceptable criterion, to reduce the probability of failure, to reduce the failure number and AD value, and thus to increase the reliability, availability and OEE.

Table 5: Risk reduction results for the printing machine

Parameter	Value
Actual risk (EUR)	5 565.79
Target (modified) probability of faliure	0.224
Risk reduction (EUR)	2 252.05
Modified reliability	0.776

Table 5 shows that the risk (in EUR) had decreased to 2 252.05 EUR (which is the safe limit of acceptable risk criteria) from 5 565.79 EUR and its corresponding probability of failure also decreased from 0.553 to 0.224. Therefore the modified probability of failure for web-offset four colour printing machine is 0.224. As a result reliability will also increase from 44.69 % to 77.62 %. Now the suitable preventive maintenance time interval (i.e. time interval for repair, servicing or replacement) can be estimated from corresponding reliability functions. And this is the approach towards risk-based maintenance to improve overall efficiency of a printing press.

6. Conclusion

The reliability prediction of the printing press depends on the failure frequency and availability pattern of each component. Here the maintenance program has been presented based on the reduction of the risk factor.

This approach ensures that reliability of components is increased after implementation of maintenance planning suggested. This will contribute to the availability of the plant as well as its safe operation.

The present study also helps to identify the critical components based on risk factor and overall equipment effectiveness factor. It can be concluded that by adapting risk-based maintenance analysis or technique it can be easily analysed as to when and which machine is to be checked and replaced by the help of Pareto analysis. Also this technique can be used to find a suitable preventive maintenance interval. The study undoubtedly confirms that the risk-based maintenance strategy works precisely well in a printing press.

After determining the probability of failure as function of a controllable factor (interval period between preventive maintenance), management has a mechanism to adjust the risk for the studied process. The proposed methodology influences not only risk management but also knowledge management because it is a quantitative method to estimate probabilities of failures and associated costs. Finally, this quantitative methodology may support top management in complying with the requirements of quality management standard.

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Appendix A: Data of web-offset printing machine for failure analysis

The collected basic data for the printing machine in press section is as follows. Cumulative failure y has been calculated by using the Equation [A1].

$$y_{i+1} = \frac{F_{i+1}}{\sum_{i=0}^{n} F_i} + F_i \quad [A1]$$

For calculation of correlation coefficient $R_{x,\,f(x)}$ the Equation [6] was used.

Day No.	Operating time (min)	Breakdown time (min)	No. of failures	Cumulative failure (%)
1	75	10	2	0.39
2	209	81	9	2.17
3	356	111	8	3.75
4	131	9	2	4.14
5	71	8	3	4.73
6	77	22	3	5.33
7	77	10	2	5.72
8	76	29	2	6.11
9	331	131	11	8.28
10	302	200	11	10.45
11	157	60	5	11.44
12	83	24	2	11.83
13	115	10	2	12.23
14	75	39	5	13.22
15	0	0	0	13.22
16	186	108	16	16.37
17	300	100	9	18.15
18	147	49	4	18.93
19	88	53	5	19.92
20	85	49	4	20.71
21	102	22	4	21.50
22	78	47	3	22.09
23	194	216	12	24.46
24	204	67	6	25.64
25	124	18	3	26.23
26	86	22	2	26.63
27	77	13	2	27.02
28	83	23	4	27.81
29	18	257	1	28.01
30	258	91	11	30.18
31	246	139	10	32.15
32	164	24	3	32.74
33	83	12	2	33.14
34	75	13	2	33.53
35	77	8	1	33.73
36	80	5	1	33.93
37	186	110	8	35.50
38	248	130	7	36.88
39	150	20	4	37.67
40	78	7	1	37.87
41	108	22	4	38.66
42	75	27	4	39.45
43	186	65	6	40.63

Day No.	Operating time (min)	Breakdown time (min)	No. of failures	Cumulative failure (%)
44	175	196	7	42.01
45	239	70	9	43.79
46	161	31	5	44.77
47	78	12	2	45.17
48	286	113	6	46.35
49	223	139	9	48.13
50	203	45	3	48.72
51	310	293	25	53.65
52	411	124	14	56.41
53	240	34	6	57.59
54	83	10	2	57.99
55	74	16	2	58.38
56	255	79	9	60.16
57	81	7	1	60.36
58	257	218	14	63.12
59	204	59	5	64.10
60	127	33	2	64.50
61	147	63	5	65.48
62	134	99	13	68.05
63	474	78	12	70.41
64	682	140	25	75.35
65	219	162	24	80.08
66	528	140	12	82.45
67	75	5	1	82.64
68	253	43	6	83.83
69	331	54	8	85.40
70	340	194	17	88.76
71	408	97	9	90.53
72	168	79	5	91.52
73	262	64	5	92.50
74	83	11	2	92.90
75	79	12	2	93.29
76	86	5	1	93.49
77	0	0	0	93.49
78	0	0	0	93.49
79	0	0	0	93.49
80	0	0	0	93.49
81	144	29	3	94.08
82	171	72	6	95.27
83	82	65	3	95.86
84	95	6	1	96.06
85	86	6	2	96.45
86	183	51	6	97.63
87	122	93	4	98.42
88	89	6	1	98.62
89	85	13	2	99.01
90	80	15	2	99.41
91	79	22	2	99.80
92	73	11	1	100.00

N = 14 886 $\sum x$ = 5 575 $\sum F$ = 507 $\sum f(x)$ = 4 728.99 p = 269 883 q = 487 917 $R_{x,f(x)}$ = 0.55

Appendix B: Estimation of availability of printing machine

The estimation of availability for web-offset printing machine is as follows (for abbrevs and quantities refer to text).

Day No.	Operational time (min)	Failure no.	MTBF (min)	Down time (min)	Repair time (min)	MTTR (min)	A_{in}	MDT (min)	A_{op}
1	75	2	37.5	10.0	10.0	5.0	0.882	5.0	0.882
2	220	9	24.5	81.0	81.0	9.0	0.731	9.0	0.730
3	356	8	44.5	111.0	111.0	13.9	0.762	13.9	0.762
4	131	2	65.5	9.0	9.0	4.5	0.936	4.5	0.935
5	71	3	23.7	8.0	8.0	2. 7	0.899	2.7	0.898
6	77	3	25.7	22.0	22.0	7.3	0.778	7.3	0.777
7	77	2	38.5	10.0	10.0	5.0	0.885	5.0	0.885
8	76	2	38.0	29.0	29.0	14.5	0.724	14.5	0.723
9	331	11	30.1	131.0	124.0	11.3	0.727	11.9	0.716
10	302	11	27.5	200.0	195.0	17.7	0.608	18.2	0.601
11	157	5	31.4	60.0	57.0	11.4	0.734	12.0	0.723
12	83	2	41.5	24.0	24.0	12.0	0.776	12.0	0.775
13	115	2	57.5	10.0	10.0	5.0	0.920	5.0	0.920
14	75	5	15.0	39.0	39.0	7.8	0.658	7.8	0.657
15	0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.000
16	186	16	11.6	108.0	101.0	6.3	0.648	6.8	0.630
17	300	9	33.3	100.0	95.0	10.6	0.759	11.1	0.750
18	147	4	36.8	49.0	49.0	12.3	0.750	12.3	0.750
19	88	5	17.6	53.0	50.0	10.0	0.638	10.6	0.624
20	85	4	21.3	49.0	49.0	12.3	0.634	12.3	0.634
21	102	4	25.5	22.0	22.0	5.5	0.823	5.5	0.822
22	78	3	26.0	47.0	47.0	15.7	0.624	15.7	0.624
23	194	12	16.2	216	216.0	18.0	0.473	18.0	0.473
24	204	6	34.0	67.0	60.0	10.0	0.773	11.2	0.752
25	124	3	41.3	18.0	18.0	6.0	0.873	6.0	0.873
26	86	2	43.0	22.0	22.0	11.0	0.796	11.0	0.796
27	77	2	38.5	13.0	13.0	6.5	0.856	6.5	0.855
28	83	4	20.8	23.0	23.0	5.8	0.783	5.8	0.783
29	18	1	18.0	257.0	90.0	90.0	0.167	257.0	0.065
30	258	11	23.5	91.0	88.0	8.0	0.745	8.3	0.730
31	246	10	24.6	139.0	139.0	13.9	0.638	13.9	0.638
32	164	3	54.7	24.0	24.0	8.0	0.872	8.0	0.872
33	83	2	41.5	12.0	12.0	6.0	0.874	6.0	0.873
34	75	2	37.5	13.0	13.0	6.5	0.852	6.5	0.852
35	77	1	77.0	8.0	8.0	8.0	0.906	8.0	0.905
36	80	1	80.0	5.0	5.0	5.0	0.941	5.0	0.941
37	186	8	23.3	110.0	105.0	13.1	0.639	13.8	0.628
38	248	7	35.4	130.0	130.0	18.6	0.656	18.6	0.656
39	150	4	37.5	20.0	20.0	5.0	0.882	5.0	0.882
40	78	1	78.0	7.0	7.0	7.0	0.918	7.0	0.917
41	108	4	27.0	22.0	22.0	5.5	0.830	5.5	0.830
42	75	4	18.8	27.0	25.0	6.3	0.750	6.8	0.735
43	186	6	31.0	65.0	63.0	10.5	0.746	10.8	0.741
44	175	7	25.0	196.0	196.0	28.0	0.472	28.0	0.471
45	239	9	26.6	70.0	70.0	7.8	0.773	7.8	0.773
46	161	5	32.2	31.0	31.0	6.2	0.839	6.2	0.838
47	78	2	39.0	12.0	12.0	6.0	0.867	6.0	0.866
48	286	6	47.7	113.0	53.0	8.8	0.844	18.8	0.716
49	223	9	24.8	139.0	99.0	11.0	0.693	15.4	0.616
50	203	3	67.7	45.0	30.0	10.0	0.871	15.0	0.818
51	310	25	12.4	293.0	276.0	11.0	0.529	11.7	0.514

Day No.	Operational time (min)	Failure no.	MTBF (min)	Down time (min)	Repair time (min)	MTTR (min)	A_{in}	MDT (min)	A_{op}
52	411	14	29.4	124.0	120.0	8.6	0.774	8.9	0.768
53	240	6	40.0	34.0	34.0	5.7	0.876	5.7	0.875
54	83	2	41.5	10.0	10.0	5.0	0.892	5.0	0.892
55	74	2	37.0	16.0	16.0	8.0	0.822	8.0	0.822
56	255	9	28.3	79.0	76.0	8.4	0.770	8.8	0.763
57	81	1	81.0	7.0	7.0	7.0	0.920	7.0	0.920
58	257	14	18.4	218.0	142.0	10.1	0.644	15.6	0.541
59	204	5	40.8	59.0	50.0	10.0	0.803	11.8	0.775
60	127	2	63.5	33.0	33.0	16.5	0.793	16.5	0.793
61	147	5	29.4	63.0	50.0	10.0	0.746	12.6	0.700
62	134	13	10.3	99.0	91.0	7.0	0.595	7.6	0.575
63	474	12	39.5	78.0	78.0	6.5	0.859	6.5	0.858
64	682	25	27.3	140.0	115.0	4.6	0.856	5.6	0.829
65	219	24	9.1	162.0	126.0	5.3	0.635	6.8	0.574
66	528	12	44.0	140.0	128.0	10.7	0.805	11.7	0.790
67	75	1	75.0	5.0	5.0	5.0	0.938	5.0	0.937
68	253	6	42.2	43.0	43.0	7.2	0.855	7.2	0.854
69	331	8	41.4	54.0	54.0	6.8	0.860	6.8	0.859
70	340	17	20.0	194.0	180.0	10.6	0.654	11.4	0.636
71	408	9	45.3	97.0	95.0	10.6	0.811	10.8	0.807
72	168	5	33.6	79.0	79.0	15.8	0.680	15.8	0.680
73	262	5	52.4	64.0	64.0	12.8	0.804	12.8	0.803
74	83	2	41.5	11.0	11.0	5.5	0.883	5.5	0.882
75	79	2	39.5	12.0	12.0	6.0	0.868	6.0	0.868
76	86	1	86.0	5.0	5.0	5.0	0.945	5.0	0.945
77	0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.000
78	0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.000
79	0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.000
80	0	0	0.0	0.0	0.0	0.0	0.000	0.0	0.000
81	144	3	48.0	29.0	29.0	9.7	0.832	9.7	0.832
82	171	6	28.5	72.0	72.0	12.0	0.704	12.0	0.703
83	82	3	27.3	65.0	65.0	21.7	0.558	21.7	0.557
84	95	1	95.0	6.0	6.0	6.0	0.940	6.0	0.940
85	86	2	43.0	6.0	6.0	3.0	0.935	3.0	0.934
86	183	6	30.5	51.0	51.0	8.5	0.782	8.5	0.782
87	122	4	30.5	93.0	88.0	22.0	0.580	23.3	0.567
88	89	1	89.0	6.0	6.0	6.0	0.937	6.0	0.936
89	85	2	42.5	13.0	10.0	5.0	0.895	6.5	0.867
90	80	2	40.0	15.0	15.0	7.5	0.842	7.5	0.842
91	79	2	39.5	22.0	21.0	10.5	0.790	11.0	0.782
92	73	1	73.0	11.0	11.0	11.0	0.869	11.0	0.869