Early Warning System in Preventive Maintenance as a Solution to Reduce Maintenance Cost

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Abstract

Early Warning System had been implemented in disaster security system and banking system like the impact of interest rate ratio to stock price. In this research, Early Warning System was designed for a spare part replacement activity resulting in signals to indicate the spare parts which needed to be replaced. Early Warning System application design was stated as the calculation of data obtained for monitoring purposes and as an early warning for maintenance team on D-5 to conduct maintenance or spare part replacement on schedule to ensure that the machine run on its optimum condition. The Early Warning System application for computer based Preventive Maintenance was designed to suit the replacement schedules categorized based on their length. The model base was developed referring to the early warning system model base using the Overview SAP Release 4.6. As a result, the total spare parts replacement time for Flame Planner machine was 28.36% lower and the preventive maintenance cost was 9.45% lower than the cost when using the corrective maintenance method.

Keywords
Early warning system, preventive maintenance, corrective maintenance, component replacement, repair

1. Introduction
Early Warning System (EWS) was a system that provided the time accurate and effective information through an institution to identify certain individual that would pose a threat so that risk could be avoided and effective responses could be prepared beforehand. (Grasso,Veronica F, 2006). The Early Warning System (EWS) had been widely used by various institutions. At the beginning, this application was used to detect natural disasters before they happened. The banking institutions also used this system to detect the impact of the Interest Ratio on Stock Price (Kurniawan, Siswandaru, 2006). The Early Warning System for preventive maintenance was designed to support the computerized maintenance management system. This Early Warning Systems Application (AEWS) would help the maintenance activities to be conducted more effectively like helping to determine which machine needed to be maintain and what certain parts were needed so that the management could make a decision on how much it was going to cost the company and how much would the company save by avoiding the damage. The Early Warning Systems Application would create a maintenance activity database that would greatly help in documenting the maintenance activities reports as well as costs and expenses so that the maintenance department would be able to conduct maintenance activities and increase maintenance quality or innovate further in conducting their activities.

2. Theoretical Background
2.1 Early Warning System
Early Warning System (EWS) referred from the Report Draft of the United Nations Environment Program, Early Warning System: State-of-Art Analysis and Future Direction. International Strategy for Disaster Reduction (ISDR), United Nations (UN) was integrated on 4 main elements: (Grasso,Veronica F. 2006):

1. Risk Knowledge: A risk knowledge that informed users on the negative effects of the risk taken that would happen in the future so that could be anticipated using early warning and preventive system design.
2. Monitoring and Predicting: this system could estimate how big/potential the impact would be towards the society, economy, and environment.
3. Disseminating Information: a communication system would give a warning message to the location that had a potential to be affected by the danger. This message needed to be reliable and simple enough to be understood by either the authorities or public.
4. Responding: a good coordination in an organization and a wonderful plan on the steps needed to be taken were the main key towards an effective early warning. Therefore, an organization's comprehension and knowledge were also two important aspects in investigating the risk that might happen.

This application would support maintenance activities like:

1. Documenting the maintenance, repair, and how to conduct each process,
2. Serial numbered parts,
3. Input of downtime data and the sub model will automatically calculate the MTTF (mean time to Failure),
4. Maintenance and repair documentation and best practices,
5. Documenting Warranty/guarantee.
6. Determining every maintenance activity on each machine and spare parts,
7. Helping decision making, like calculating the machine repair cost using the Corrective Maintenance and Preventive Maintenance system.

2.2 Parameter and Reliability Function

2.2.1. Mean Time To Failure (MTTF)

Mean Time To Failure (MTTF) is the average value of a system's reliability function. MTTF was formulated as:

$$\text{MTTF} = E(T) = \int t\, f(t)\, dt = \int R(t)\, dt$$

2.2.2. Reliability Function for Each Distribution

The MTTF score for each of the 4 statistical distributions are:

1. Normal Distribution

    1. Reliability Function

$$R(t) = 1 - \Phi\left(\frac{t-\mu}{\sigma}\right) \text{............................(2-1)}$$

    2. Probability density function

$$f(t) = \frac{1}{\sqrt{2\pi\sigma}}\, eks\left[-\frac{1}{2}\frac{(t-\mu)^2}{\sigma^2}\right] \quad \text{for: } -\infty < t < \infty \text{..........................(2-2)}$$

MTTF = μ...(2-3)

2. Lognormal Distribution

    1. Reliability Function

$$R(t) = 1 - \Phi\left(\frac{t-\mu}{\sigma}\right) \text{..........(2-4)}$$

    2. Probability density function

$$f(t) = \frac{1}{\sqrt{2\pi\sigma}}\, eks\left[-\frac{1}{2}\frac{(t-\mu)^2}{\sigma^2}\right] \quad \text{for: } -\infty < t < \infty \text{ ....(2-5)}$$

$$MTTF = t_{med} \cdot e^{\frac{\sigma^2}{2}} \text{...........(2-6)}$$

3. Exponential Distribution

    1. Reliability Function

$$R(t) = \exp\left[-\int_0^t \lambda\, dt'\right] = e^{-\lambda t}, t \geq 0 \text{...(2-7)}$$

*by assuming that $\lambda(t) = \lambda, t \geq 0, \lambda > 0$.

    2. Probability density function

$$f(t) = -\frac{d\,R(t)}{dt} = \lambda e^{-\lambda t} \text{..........(2-8)}$$

$$MTTF = \int_0^\infty e^{(-\lambda t)}\, dt = e^{(-\lambda t)}/(-\lambda)\,|_0^\infty = 1/\lambda \text{........(2-9)}$$

4. Weibull Distribution

    1. Reliability Function

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^\beta} \text{.............(2-10)}$$

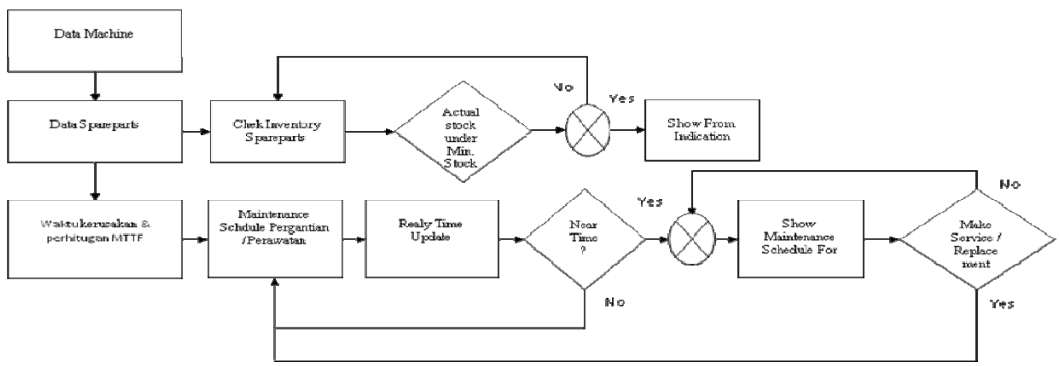
    2. Probability density function

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad \text{...(2-11)}$$

$$MTTF = \theta\Gamma\left(1+\frac{1}{\beta}\right),\ x - 1 + \frac{1}{\beta},\ \Gamma(x) - \textit{tabel gamma} \quad \text{.......(2-12)}$$

2.2.3. Replacement Decision

a. Optimum Component Replacement Model Using EWS



b. Expected Total Repair Cost Calculation Model: was formulated to determine the optimum component replacement time interval to minimize expected total repair cost. The formula was as stated:

$$Tc(tp) = \frac{(Cp * R(tp)) + (Cf * F(tp))}{Tp}$$

Note:

TC (tp) =Total expected component replacement cost (total expected repair cost) per time interval
Cp= One preventive cycle cost
[(Labor cost/hour x average preventive maintenance cost) + component price]
Cf= one failure cycle cost
[(Labor cost/hour + production loss cost) x average preventive maintenance time + component price]
R (Tp) = Probability that component was reliable during that time period
F (Tp) = Probability that component was not reliable/broke down during that time period
Tp= Preventive cycle length
= [(tp + Tp) x R(Tp)] + [(M(tp) + Tf) x (1 – R(tp))]

$$M(tp) = \frac{MTTF}{F(tp)} = \frac{MTTF}{1 - R(tp)}$$

3. Research Methodology

The research stages were:

1. Gaining knowledge of the machines' process for each product
2. Data Base. Inventory collection
3. Time interval between downtime
4. Calculation of Index of Fit and Data Analysis
5. Index of Fit Recapitulation
6. Machine Component MTTR

Determining the Base Early Warning System Model:

1. Downtime interval data input
2. Determining the Optimum Interval
3. Scheduling

Early Warning System Output:

1. Spare part Replacement Schedules

2. D-5 warning information for spare part replacement
3. Minimum inventory warning
4. Service Order Output Form

4. Results and Discussion

4.1. Downtime Interval based on field data

Table1. Interval Based on Data Downtime

No	Driving Unit									
	Brake Bracket	Brake Disk	Roller 1	Pulley 1	Bearing 1	Spring pin 1	Oil Seal	O-Ring	V-belt	V-Pully
	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour
1	11,013	9,141	12,761	8,153	6,397	7,831	8,713	6,911	3,291	4,207
2	11,027	9,267	12,587	8,083	6,872	8,157	8,519	6,427	3,871	3,921
3	11,053	9,171	12,748	8,179	6,174	8,002	8,421	6,262	3,942	4,182
4	11,127	9,318	12,914	8,034	6,934	8,241	9,174	6,784	3,138	4,438
5	11,083	9,412	12,478	8,217	6,716	8,105	9,053	6,358	3,419	4,083

	Free Wheel			Cross Slide			Main Hose Hanger		
	Drive-Side Roller	Roller 2	Bearing 2	Roller shaft	Bearing 3	Spring pin 2	Bracket	Hose	Bearing 4
	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour	/ Hour
1	12,947	14,761	6,591	12,761	6,591	7,831	11,013	4,512	6,591
2	12,862	12,587	6,872	12,587	6,872	8,157	11,027	4,286	6,872
3	12,581	12,748	7,024	12,748	7,024	8,002	11,053	4,981	7,024
4	12,421	12,914	6,977	12,914	6,977	8,241	11,127	4,247	6,977
5	12,804	12,478	6,316	12,478	6,316	8,105	11,083	4,719	6,316

4.2 Spare part replacement average time

Table 2. Spare Part Replacement Average Time

No	Spare parts	N1	N2	N3	N4	N5
Driving Unit						
1	Brake Bracket	82	103	90	131	85
2	Brake Disk	72	75	74	93	71
3	Roller 1	41	43	39	57	38
4	Bearing 1	34	26	42	29	25
5	Spring pin	15	17	32	20	21
6	Oil Seal	16	37	20	21	18
7	O-Ring	39	16	22	18	21
8	V-belt	31	35	29	32	48
9	V-pully	48	56	44	71	45
Free Wheel						
10	Drive-Side Roller	121	147	131	213	183
11	Roller 2	57	31	37	32	43
12	Bearing 2	41	39	48	61	42
Cross Slide						
13	Roller shaft	27	26	52	35	29
14	Bearing 3	68	35	37	41	31
15	Spring pin					
Main Hose Hanger						
16	Bracket 1	31	27	42	24	47
17	Hose	62	38	31	41	69
18	Bearing 4	22	53	27	33	28

4.3 Cost comparison for corrective and preventive maintenance

Table 3. Replacement Cost Using Corrective Maintenance

No	Spareparts	a (IDR/hour)	b (IDR/hour)	c (hour)	d (IDR)	CF (IDR)
Driving Unit						
1	Brake Bracket	IDR 26,026	IDR 85,440	2.18	IDR 750,000	IDR 993,367
2	Brake Disk	IDR 26,026	IDR 85,440	1.55	IDR 350,000	IDR 522,772
3	Roller 1	IDR 26,026	IDR 85,440	0.95	IDR 400,000	IDR 505,893
4	Bearing 1	IDR 13,013	IDR 85,440	0.70	IDR 50,000	IDR 118,917
5	Spring pin	IDR 13,013	IDR 85,440	0.53	IDR 80,000	IDR 132,508
6	Oil Seal	IDR 13,013	IDR 85,440	0.62	IDR 30,000	IDR 90,713
7	O-Ring	IDR 13,013	IDR 85,440	0.65	IDR 45,000	IDR 108,994
8	V-belt	IDR 26,026	IDR 85,440	0.80	IDR 120,000	IDR 209,173
9	V-pully	IDR 26,026	IDR 85,440	1.18	IDR 275,000	IDR 406,901
Free Wheel						
10	Drive-Side Roller	IDR 26,026	IDR 85,440	3.55	IDR 450,000	IDR 845,704
11	Roller 2	IDR 26,026	IDR 85,440	0.95	IDR 150,000	IDR 255,893
12	Bearing 2	IDR 13,013	IDR 85,440	1.02	IDR 80,000	IDR 180,094
Cross Slide						
13	Roller shaft	IDR 26,026	IDR 85,440	0.87	IDR 120,000	IDR 216,604
14	Bearing 3	IDR 13,013	IDR 85,440	1.13	IDR 55,000	IDR 166,580
15	Spring pin	IDR 13,013	IDR 85,440	1.20	IDR 43,000	IDR 161,144
Main Hose Hanger						
16	Bracket 1	IDR 26,026	85,440	0.78	IDR 81,000	IDR 168,315
17	Hose	IDR 13,013	85,440	1.15	IDR 1,200,000	IDR 1,313,221
18	Bearing 4	IDR 13,013	85,440	0.88	IDR 77,000	IDR 163,967
Total Replacement Cost using Corrective Maintenance						IDR 6,560,760

Table 4. Replacement Cost Using Preventive Maintenance

No	Spareparts	a (IDR/hour)	b (IDR/hour)	c (hour)	d (IDR)	Cp (IDR)
Driving Unit						
1	Brake Bracket	26,026	IDR 85,440	1.64	IDR 750,000	IDR 932,433
2	Brake Disk	26,026	IDR 85,440	1.28	IDR 350,000	IDR 493,048
3	Roller 1	26,026	IDR 85,440	0.73	IDR 400,000	IDR 480,999
4	Bearing 1	13,013	IDR 85,440	0.52	IDR 50,000	IDR 101,196
5	Spring pin	13,013	IDR 85,440	0.35	IDR 80,000	IDR 114,459
6	Oil Seal	13,013	IDR 85,440	0.37	IDR 30,000	IDR 66,756
7	O-Ring	13,013	IDR 85,440	0.39	IDR 45,000	IDR 83,068
8	V-belt	26,026	IDR 85,440	0.58	IDR 120,000	IDR 185,022
9	V-pully	IDR 26,026	IDR 85,440	0.88	IDR 275,000	IDR 373,090
Free Wheel						
10	Drive-Side Roller	IDR 26,026	IDR 85,440	2.65	IDR 450,000	IDR 745,385

11	Roller 2	IDR 26,026	IDR 85,440	0.67	IDR 150,000	IDR 224,311
12	Bearing 2	IDR 13,013	IDR 85,440	0.77	IDR 80,000	IDR 155,809
Cross Slide						
13	Roller shaft	IDR 26,026	IDR 85,440	0.56	IDR 120,000	IDR 182,793
14	Bearing 3	IDR 13,013	IDR 85,440	0.71	IDR 55,000	IDR 124,573
15	Spring pin	IDR 13,013	IDR 85,440	0.82	IDR 43,000	IDR 123,403
Main Hose Hanger						
16	Bracket 1	IDR 26,026	IDR 85,440	0.57	IDR 81,000	IDR 144,536
17	Hose	R 13,013	IDR 85,440	0.80	IDR 1,200,000	IDR 1,279,091
18	Bearing 4	R 13,013	IDR 85,440	0.54	IDR 77,000	IDR 130,493
Preventive Maintenance Total Cost						IDR 5,940,462

4.4 Cost saving expectation: cost saving could happen if there was a difference between total failure cost and total preventive cost. The cost saving due to the implementation of preventive maintenance was:

$$\text{Penghematan Biaya} = \frac{TotalFailureCost - Total\ PreventiveCost}{TotalFailureCost} \times 100\%$$

Note:

Total Failure Cost = IDR 6,560,760
Total Preventive Cost = IDR 5,940,462

$$\frac{\text{IDR}6{,}560{,}760 \quad - \quad \text{IDR}5{,}940{,}462}{\text{IDR } 5{,}940{,}462} \quad x \quad 100\%$$

Cost saving = IDR 620,298 (9.45%)

4.5 Optimum replacement time interval parameter: based on the calculation result above, MTTF was determined from the optimum or minimum time to replace a spare part. This optimum time was then set as the reference to implement preventive maintenance for spare parts replacements.

Table 5. Optimum spare part replacement time interval

No	Spare parts	Optimum time / hour
Flame cutting		
1	Brake Bracket	1061
2	Brake Disk	9262
3	Roller	12697
4	Bearing	6619
5	Spring pin	8067
6	Oil Seal	8776
7	O-Ring	6548
8	V-belt	3532
9	V-pully	4166

No	Spare parts	Optimum time / hour
Free Wheel		
10	Drive-Side Roller	12177
11	Roller 2	11498
12	Bearing 2	4146
Cross Slide		
13	Roller shaft	11688
14	Bearing 3	4146
15	Spring pin	8067
Main Hose Hanger		
16	Bracket	11061
17	Hose	4549
18	Bearing 4	4146

Table 6. Optimum Spare Part Replacement Date Schedule

No	Spare parts	Optimum time / hour	Optimum time / day	Optimum time (rounding) / day	Replacement date (start)	New schedule based on calculation
Driving Unit						
1	Brake Disk	1,060.60	53.03	53	8/20/12	10/12/12
2	Brake Bracket	9,261.80	463.09	463	8/20/12	11/26/13
3	Roller	12,697.19	634.86	635	8/21/12	5/17/14
4	Bearing	6,618.59	330.93	331	8/20/12	7/16/13
5	Spring pin	8,067.20	403.36	403	8/21/12	9/28/13
6	Oil Seal	8,776.00	438.80	439	8/21/12	11/2/13
7	O-Ring	6,548.40	327.42	375	8/21/12	7/14/13
8	V-belt	3,520.05	176.00	176	2/24/12	8/18/12
9	V-pully	4,166.20	208.31	208	2/24/12	9/19/12
Free Wheel						
10	Drive-Side Roller	12,177.19	608.86	609	8/20/12	4/20/14
11	Roller 2	11,497.84	574.89	575	8/21/12	3/18/14
12	Bearing 2	4,145.92	207.30	207	8/22/12	3/17/13
Cross Slide						
13	Roller shaft	11,687.55	584.38	584	8/24/12	3/31/14
14	Bearing 3	4,145.92	207.30	207	8/25/12	3/20/13
15	Spring pin	8,067.20	403.36	403	8/26/12	10/3/13
Main Hose Hanger						
16	Bracket	11,060.60	553.03	553	8/28/12	3/4/14
17	Hose	4,549.00	227.45	227	8/29/12	4/13/13
18	Bearing 4	4,145.92	207.30	207	8/30/12	3/25/13

Spare part control tried to determine the amount of minimum inventory needed annually starting from the first step of spare part replacement / month. Spare part replacement / month = optimum replacement time (day) / 1 month (30 days).

Tabel 7.Spare parts required / year.

No	Spare parts	Qty of Spare part	Unit Machine	Total Spare parts	Spare parts replacement / Month	Spare parts required / year	Spare parts group	Minimum inventory / year
Driving Unit								
1	Brake Disk	1	5	5	1.77	34	A	51
2	Brake Bracket	1	5	5	15.44	4	B	8
3	Roller	1	5	5	21.16	3	B	6
4	Bearing	4	5	20	11.03	22	A	33
5	Spring pin	2	5	10	13.45	9	A	13
6	Oil Seal	1	5	5	14.63	4	A	6
7	O-Ring	1	5	5	10.91	5	A	8
8	V-belt	2	5	10	5.87	20	A	31
9	V-pully	1	5	5	6.94	9	B	17
Free Wheel								
10	Drive-Side Roller	1	5	5	20.30	3	D	6
11	Roller 2	4	5	20	19.16	13	B	25

12	Bearing 2	8	5	40	6.91	69	A	104
Cross Slide								
13	Roller shaft	4	5	20	19.48	12	B	17
14	Bearing 3	4	5	20	6.91	35	A	40
15	Spring pin 2	1	5	5	13.45	4	A	7
Main Hose Hanger								
16	Bracket	1	5	5	18.43	3	B	7
17	Hose	1	5	5	7.58	8	A	12
18	Bearing 4	3	5	15	6.91	26	A	30

5. EARLY WARNING SYSTEM APPLICATION DESIGN

5.1 Problem Solving: the present problem could've been solved using the Preventive Maintenance in accordance with the procedure. However, the maintenance conducted this method manually, by doing recaps of the machines and repair data. This process' administration was highly time-consuming and human errors often happen (like mistakes in data entry process). This research developed a software or application to help solve the problem using computer-based system.

5.2 Early Warning System application design: was stated as the calculation of data obtained for monitoring purposes and as an early warning for maintenance team to conduct maintenance or spare part replacement on schedule to ensure that the machine run on its optimum condition. As an information system that communicated with the previously determined calendar that gave daily information on regular maintenance duty. This information would show an early warning at D-5 by giving information on what to do, what tools that must be prepared, and available parts inventory.

5.3 System design steps:

a. Data Base design: Designing the machine's inventory and parts, dividing various parts of a machine into groups.
b. Model Base: Designing the Index of Fix calculation model, calculating the MTTF score, and determining the optimum spare parts replacement time.
c. Interface to Date: Interfacing the optimum time obtained from the Model Base stage into the actual 2013 calendar.
d. Daily/Date Up-date: An application form that consisted of the current day and date information and showed other information concerning the spare parts replacements.
e. Interactive: Model base would interact with the daily updated calendar and the closer it would be to the replacement date, the information would be forwarded to the Exception stage.
f. Exception: The design would share the information.

5.4 Application Use and Implementation.

a. Spare parts data input: Input of spare parts data, minimum inventory, available inventory, purchase data based on the market availability of the product, and field data on downtime interval.
b. Machine data input: Input of machine data, machine parts, spare part data based on each machine, and when to begin the calculation.
c. Monitor Form Calendar: The calendar form would give a signal or alarm based on each spare part category whenever minimum limit was reached.

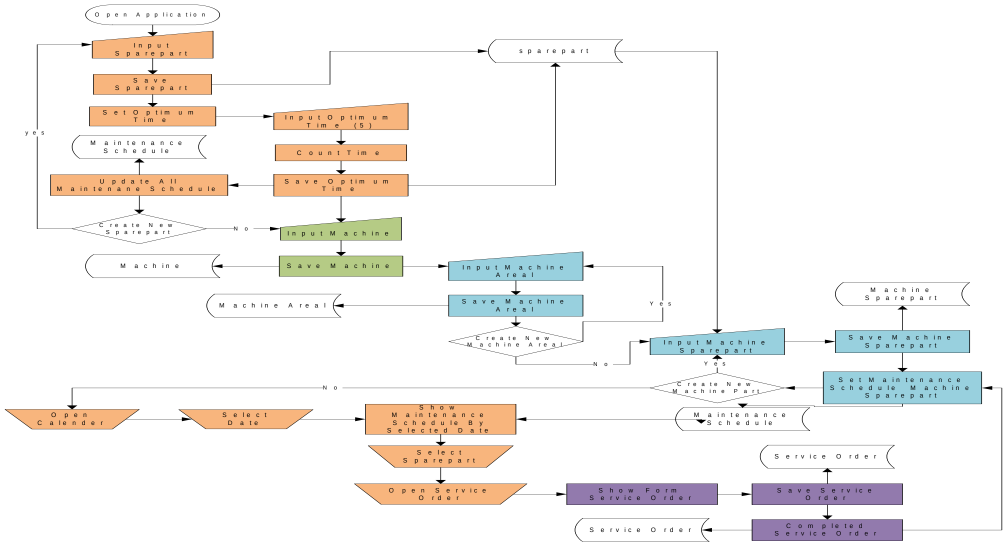


Figure 1. Flow Chart Early Warning System

5.5. Output Form

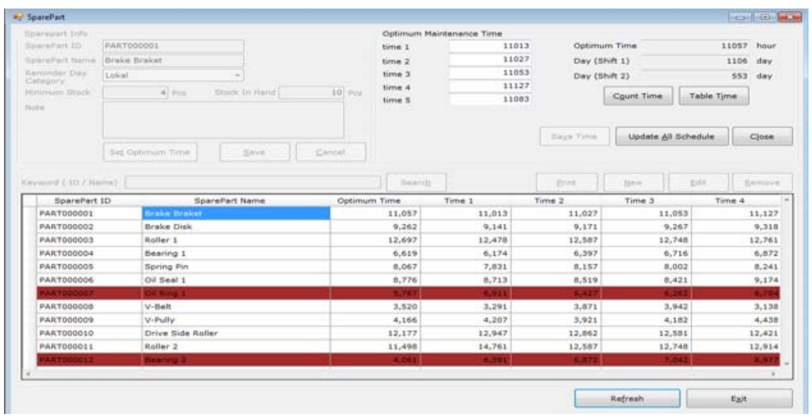


Figure 2. Master – Spare part Form

5. Conclusion

Computer based Early Warning System Application was designed based on the obtained time interval data and calculated using the MTTF, to earn the optimum time as a measure in implementing the preventive maintenance. The comparison of total spare part replacement of the Flame Planner machine using preventive maintenance was 14.8 hours, 28.36% lower compared to corrective maintenance that took 20.7 hours. Maintenance using preventive maintenance system on Flame Planner machine, driving unit area cost IDR 5,940,462; 9.45% lower compared to the cost expensed when using the corrective maintenance that reached IDR 6,560,760.

7. ACKNOWLEDGMENT

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References

Anggono, Willyanto. Julianingsih. Linawati. (2005). *Preventive Maintenance* System

Efendi, Yunus. (2008). Perencanaan Model *Preventive Maintenance* dengan Desain Modularity untuk Penggantian Komponen Mesin Produksi RG 4 yang Optimal di PT.X

Novarina, Erna Rutiah. (2009) Sistem Perawatan Berbasis Pencegahan Menurut Rancangan Modularity Task Dalam Upaya Penurunan Biaya Perawatan Pada PT. Cakrea Compact Aluminium Industries.

Kurniawan, Siswandaru. (2006). Analisa Pengaruh Rasio-Rasio Early Warning System dan Tingkat Suku Bunga SB Terhadap Harga Saham.

B.S Dhillon. 2006. Maintainability, Maintenance, and Reliability for Engineers. New York: Taylor and Francis Group,

Grasso F. Veronica, 2001. Early Warning Systems: State-of-Art Analysis and Future Directions. United Nations Environment Programme (UNEP). Ashbindu Singh (ashbindu.singh@unep.org)

Richard D. Palmer, 2006. Maintenance Planning and Scheduling Handbook Second edition. New York: McGraw-Hill Handbook,

R. Keith Mobley, 2004. Maintenance Fundamentals Second edition. Printed in the United States of America.