CHAPTER 4
PROPOSED PREVENTIVE MAINTENANCE BASED ON COST

This chapter gives a description of the methodology adapted for the maintenance analysis and planning of the company. Since the whole system is large and complex, it is difficult to develop an effective maintenance plan for every machine within the time given. Thus the author first pick up only one machine as an example to perform the analysis. The selected machine is top coat painting machine which is considerably important for the production process. Then the author collects the failure and cost data of the machine and analyzes them by using an appropriate method. After that, the proper preventive maintenance policy of the machine components are determined. Finally, a preventive maintenance scheduling is designed and proposed.

This chapter consists of 4 main sections as following:

1. Data analysis
2. Proposed preventive maintenance policy for the valves
3. Designed maintenance planning for the valves
4. Maintenance planning for the other components
5. Maintenance scheduling
6. Maintenance controlling

4.1 <u>Data analysis</u>

4.1.1 Data collecting

The data collected consist of :

- Machine historical data

The machine historical data collected include the following:

a. machine drawings, machine manual, inspection check sheet, and paint system (appendix A).

b. machine failure and repair record which include dates of failure, cause of machine breakdowns, and corrective actions (appendix B). This record is constructed and summarized from equipment stop daily report (appendix C).

c. maintenance costs data collected are components cost, lubricants cost, and others cost, all are roughly as below in Table 4.1 (cost of machine components and lubricants are from part invoices and store manager interview / others cost is from maintenance and production staffs interview).

Machine components cost		
No.	Component list	Cost (baht/unit)
1	explosion-proof motor	31320
2	explosion-proof servo motor	75000
3	pulse generator	41040
4	limit switchs	1312
5	inverter	161271
6	speed reducer	27717
7	encoder	12671
8	bearing	1064
9	variable resistor	9800
10	proximity sensor	14958
11	plastic spur gear	2349
12	cascade	75600
13	HV controller	580700
14	cable / connector HV	15390
15	mag valve	14950
16	needle valve	109848
17	bypass valve	18000
Lubricants cost		
No.	Lubricant list	Cost (baht/gallon)
1	spaton 220	5961
2	beoon Ep-2	4020
3	millitec 1 Ep-2	7182
Others cost		
1	average staff salary	= 10000 baht
2	average operator salary	= 10000 baht
3	overhead cost / month	= 500000 baht
4	paint color cost / gallon	= 8200-12000 baht
5	thinner cost / gallon	= 800 baht
6	Allen screws no. 5	= 60 baht
7	spanner no. 14,17	= 50 baht
8	pliers	= 150 baht

Table 4.1 Maintenance costs data

- Additional information

Sufficient information collected to construct the thesis completely such as company history, maintenance system, etc. are favorably provided by maintenance engineers and users.

The Top coat painting machine selected to plan the maintenance schedule can be operated under systems' operation with a number of components. These components can be divided into groups as following :

1. Elevation unit
2. Reciprocate unit
3. Tilt unit
4. Tracking unit
5. Gun mounting & HV. Panel unit
6. Paint supply unit

Major components and their function of each group are shown in Table 4.2. This table is constructed from machine manual, inspection check sheet, paint system, and maintenance staffs interview.

Consider the cause of machine breakdowns, they can be classified into 4 types :

1. human errors
2. machine failures
3. previous operation errors
4. unknown causes

And since a pattern of machine failure rate is necessary to complete this study, only machine failures records are considered and collected.

Daily equipment stop reports show that most of the top coat painting machine failures are caused by its two components, purge air valve and soft air valve. Therefore, they will be analyzed and considered

Number	Components list	Function
I	**Elevation unit**	
1	explosion-proof motor	drive elevation source
2	pulse generator	position detection
3	limit switchs	position detection
4	inverter	elevation speed control
5	speed reducer	automatic speed reducer
6	drive chain	motor drive
7	encoder	up-down detection
8	bearing	motor friction force reducer
II	**Reciprocate unit**	
1	explosion-proof motor	drive recipro. source
2	potentiometer	recipro speed control
3	variable resistor	recipro acceleration/deceleration time control
4	drive chain	motor drive
5	speed reducer	automatic speed reducer
6	pulse generator	position detection
7	proximity sensor	position detection
8	encoder	rotate detection
9	bearing	motor friction force reducer
III	**Tilt unit**	
1	explosion-proof motor	drive source
2	pulse generator	position detection
3	proximity sensor	position detection
4	potentiometer	tilt speed control
5	variable resistor	tilt acceleration/deceleration time control
6	speed reducer	automatic speed reducer
7	drive chain	motor drive
8	encoder	rotate detection

Table 4.2 Function of the main machine components

Number	Components list	Function
IV	**Tracking unit**	
1	explosion-proof servo moto	drive source
2	pulse generator	position detection
3	limit switchs	position detection
4	speed reducer	automatic speed reducer
5	encoder	rotate detection
6	drive chain	motor drive
7	plastic spur gear	drive gear
8	bearing	motor friction force reducer
V	**Gun mounting & HV panel unit**	
1	gun mounting	bell gun control
2	cascade	voltage amplifier
3	HV controller	high voltage controller
4	cable / connector HV	high voltage cable and connector
VI	**Paint supply unit**	
1	color change vavle (CCV)	connected, selected paint control
2	purge air vavle	air used to wash dump side control
3	purge thinner vavle	thinner used to wash dump side control
4	needle vavle	discharged paint and thinner control
5	trigger vavle	paint control
6	dump valve	prespray and dump washing control
7	soft air valve	air used to wash head dump control
8	soft thinner valve	thinner used to wash head dump control
9	bypass valve	paint used during prespray/air and thinner used during washing control
10	center valve	solid and clear color selector
11	metalling valve	paint CAM cut control

Table 4.2 Function of the main machine components (cont.)

in depth shown in most of this chapter (for the other components, they will be mentioned in section 4.5). These valves (usually called mag valve) are exactly the same, but they are installed separately and are used for different purposes. Time to failure data which is the time interval between failure of these valves is shown following in the Table 4.3.

4.1.2 Failure data analysis

The collected failure data of the valves will be analyzed to fix the Weibull distribution and find useful parameters. Weibull probability paper will be used to transform failure data into the useful parameters. The number of time to failure data available is not too large, say 14 and 12. Therefore, the cumulative percentage for classes of the frequency distribution can not be used and the median ranks have to be employed.

The failure number column, time to failure column, and median rank column are shown in the Table 4.4 and Table 4.5. Time to failure data are arranged in sequence from minimum to maximum and median rank is from appendix D.

The steps to plot Weibull probability paper is shown in the chapter 3 (Section 3.3.3).

The following Figure 4.1 and 4.2 show Weibull plotting for soft air valve and purge air valve respectively.

Time to failure data (hours)														
No. of failure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Top coat painting machine														
- soft air valve	594	1496	1188	1826	1012	748	506	770	462	1012	1364	1254	1276	1144
- purge air valve	1408	1210	1254	2266	616	286	682	946	1738	550	1760	1364		

Table 4.3 Time to failure data (during Jan1994 to Nov 1996)

Failure Number	Time to Failure	Median Rank
1	462	4.83
2	506	11.7
3	594	18.65
4	748	25.61
5	770	32.58
6	1012	39.54
7	1012	46.52
8	1144	53.49
9	1188	60.46
10	1254	67.43
11	1276	74.39
12	1364	81.35
13	1496	88.3
14	1826	95.17

Table 4.4 Data for plotting Weibull probability paper
(Soft air valve)

Failure Number	Time to Failure	Median Rank
1	286	5.61
2	550	13.6
3	616	21.67
4	682	29.76
5	946	37.85
6	1210	45.95
7	1254	54.05
8	1364	62.15
9	1408	70.24
10	1738	78.33
11	1760	86.4
12	2266	94.39

Table 4.5 Data for plotting Weibull probability paper
(Purge air valve)

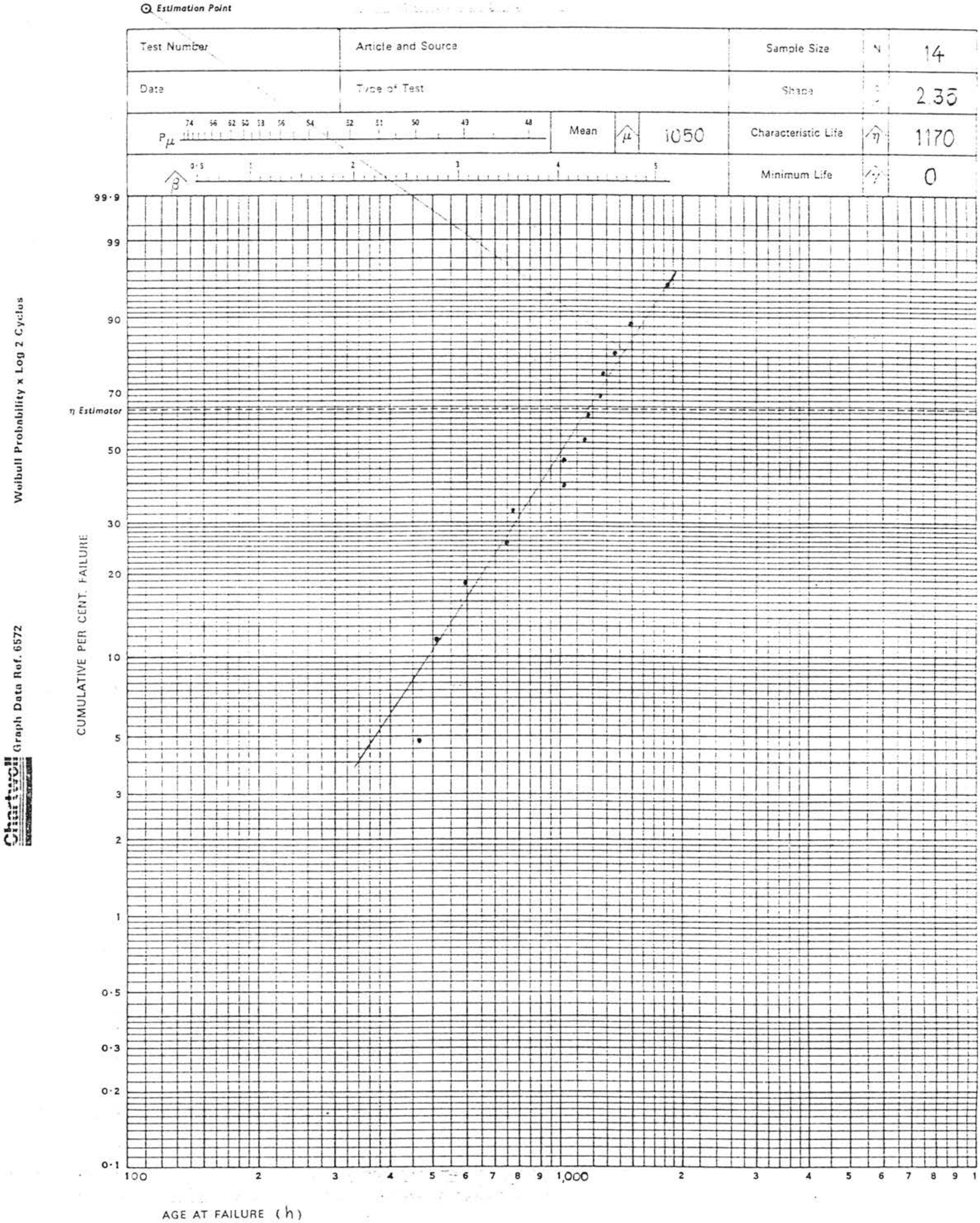

Figure 4.1 Weibull probability paper (soft air valve)

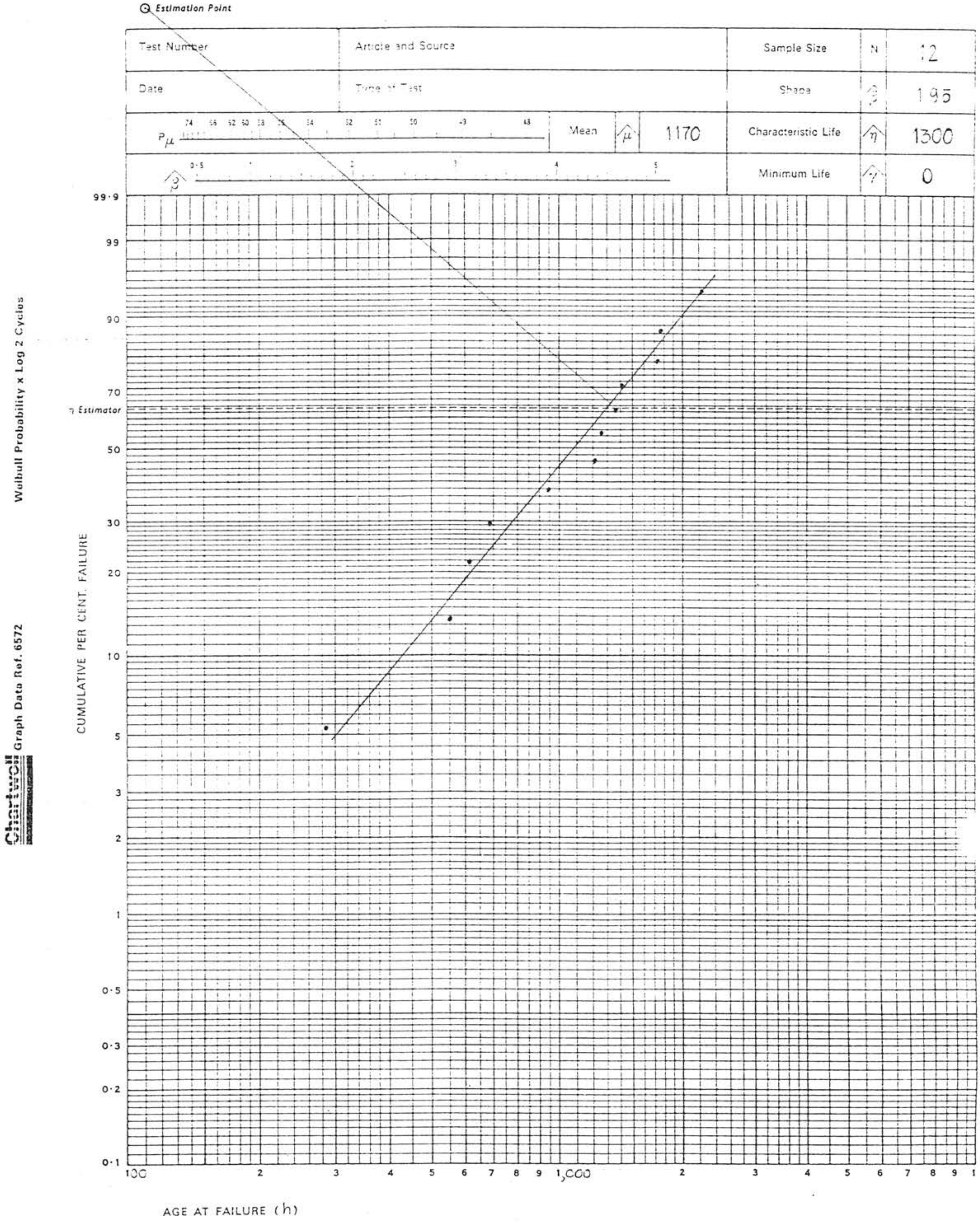

Figure 4.2 Weibull probability paper (purge air valve)

From the Weibull probability papers (Figure 4.1 and 4.2), it shows Weibull parameters as illustrated in Table 4.6.

	β	η	γ	P_μ
Soft air valve	2.35	1170	0	1050
Purge air valve	1.95	1300	0	1170

Table 4.6 Weibull distribution parameters

Mean Life parameter μ should be compared with mean time between failure (MTBF) to verify that the line is drawn correctly, the more they are close, the more reliable the line is. Mean time between failure (MTBF) is defined by the following formula.

$$MTBF = \text{Sum of time to failure} / \text{Number of failure}$$

MTBF of soft air valve and purge air valve are 1047 and 1173 hours respectively. Comparing with P_μ from Table 4.6, it shows that P_μ and MTBF of each valve are very close. The conclusion can be drawn that the lines have been drawn perfectly.

4.1.3 Goodness of fit tests

The previous section, the time to failure data of the valves are claimed that they conform to a Weibull distribution. To check that this claim is correct and reasonable, the goodness of fit test should be performed. Goodness of fit is the comparison of some observed sample distribution with a theoretical frequency distribution. The procedure for performing goodness of fit test is :

1. Formulate the null and alternative hypothesis

Ho : the observations conform to a Weibull distribution

Hi : the observations do not conform to a Weibull distribution

2. Decide on the level of significant, α

Which should be based on the importance of the conclusion. Choose either 10%, 5%, 2.5%, 1%, and 0.5% which are the commonly used values quoted in critical values of chi-square tables (appendix E).

3. Construct a frequency distribution

By classifying the time to failure data into classes. It will result observed frequency (O)

soft air valve

Class Limit (hours)	Frequency
0-300	0
300-600	3
600-900	2
900-1200	4
1200-1500	4
1500-1800	0
1800-2100	1

purge air valve

Class Limit (hours)	Frequency
0-300	1
300-600	1
600-900	2
900-1200	1
1200-1500	4
1500-1800	2
1800-2100	0
2100-2400	1

4. Calculate the cumulative relative frequency

By using the equation 3.14, $F(t) = 1 - \exp -[(t-\gamma)/\eta)]^{\beta}$

5. Calculate the relative frequency

By subtracting the cumulative frequency of each class from the next cumulative frequency of the next class.

6. Calculate the expected frequency (E) for each class

By multiplying the relative frequency by the sample size.

7. Calculated the test statistic, $\chi2$

The test statistic, $\chi^2 = \Sigma\ (O-E)^2\ /\ E$, is calculated and shown in Table 4.7 and Table 4.8 for soft air valve and purge air valve respectively.

Upper Class Limit (hours)	Cumulative Relative Frequency	Relative Frequency	Expected Frequency (E)	Observed Frequency (O)	(O-E)	(O-E)^2	(O-E)^2 /E
300	0.0400	0.0400	0.5600	0	-0.5600	0.3136	0.5600
600	0.1879	0.1479	2.0706	3	0.9294	0.8638	0.4172
900	0.4171	0.2292	3.2088	2	-1.2088	1.4612	0.4554
1200	0.6540	0.2369	3.3166	4	0.6834	0.4670	0.1408
1500	0.8335	0.1795	2.5130	4	1.4870	2.2112	0.8799
1800	0.9362	0.1027	1.4378	0	-1.4378	2.0673	1.4378
2100	0.9808	0.0446	0.6244	1	0.3756	0.1411	0.2259

$\chi^2 = \Sigma\,(O-E)^2 / E = 4.117$

Table 4.7 Goodness of fit worksheet (soft air valve)

Upper Class Limit (hours)	Cumulative Relative Frequency	Relative Frequency	Expected Frequency (E)	Observed Frequency (O)	(O-E)	(O-E)^2	(O-E)^2 /E
300	0.0557	0.0557	0.6684	1	0.3316	0.1100	0.1645
600	0.1986	0.1429	1.7148	1	-0.7148	0.5109	0.2980
900	0.3863	0.1877	2.2524	2	-0.2524	0.0637	0.0283
1200	0.5749	0.1886	2.2632	1	-1.2632	1.5957	0.7051
1500	0.7334	0.1585	1.9020	4	2.0980	4.4016	2.3142
1800	0.8484	0.1150	1.3800	2	0.6200	0.3844	0.2786
2100	0.9217	0.0733	0.8796	0	-0.8796	0.7737	0.8796
2400	0.9633	0.0416	0.4992	1	0.5008	0.2508	0.5024

$\chi^2 = \Sigma\,(O-E)^2 / E = 5.171$

Table 4.8 Goodness of fit worksheet (purge air valve)

The test statistic of time to failure data of soft air valve and purge air valve are 4.117 and 5.171 respectively.

8. Read off the limiting value of χ^2 from critical values of chi-square tables.

Starting with calculate the degree of freedom, v, of both data. The degree of freedom is calculated by following formula.

ν = number of classes - 1, - an additional 1 for each population parameter estimated from the data.

For a Weibull distribution, the values of β, γ, and η are estimated, so ν = number of classes - 4. The degree of freedom of soft air valve and purge air valve is 3 and 4 respectively.

Then seeking the limiting value of χ^2 for significant level of 10%, 5%, 2.5%, 1%, and 0.5% at 3 degree of freedom for soft air valve data and 4 degree of freedom for purge air valve data as shown following.

$\chi^2_{0.1,3}$	= 6.251	$\chi^2_{0.1,4}$	= 7.779
$\chi^2_{0.05,3}$	= 7.815	$\chi^2_{0.05,4}$	= 9.488
$\chi^2_{0.025,3}$	= 9.348	$\chi^2_{0.025,4}$	= 11.143
$\chi^2_{0.01,3}$	= 11.345	$\chi^2_{0.01,4}$	= 13.277
$\chi^2_{0.005,3}$	= 12.838	$\chi^2_{0.005,4}$	= 14.860

9. Compare the calculated value of χ^2 with the value taken from the table.

If the calculated value is less than the tabulated value, accept the null hypothesis that the observations conform to the Weibull distribution. So the results show that the time to failure data of soft air valve and purge air valve data conform to the Weibull distribution at 10% significant level or 90% confidence level.

Typically, χ^2 goodness of fit test is used while the frequency of each class data is more than 5. In this case, the collected time to failure data of the valves are not large enough so the result may be not significant. However considering the Weibull graphs of both valves, they show that the plotted lines are nearly matched to the collected data. So we can say that the data conform to the Weibull distribution.

4.1.4 Cost estimation

Two major costs are of interest in this study: the breakdown cost of valve failure and the cost of valve replacement schedule. The first cost category consists of 2 component.

1. Direct maintenance cost.

It includes labor cost, material cost, cost of tools for replacement and overhead cost.

2. Indirect maintenance cost.

The major costs of this component are production related cost and product cost. Production related cost consists of rework, excessive scrap, idle work and late shipment. Product cost occurs due to poor quality and reliability product, lost sales and warranty claims.

For cost of replacement schedule, it is only direct maintenance cost because indirect cost can be eliminated by an efficient preventive replacement scheduling.

Let say ,

Direct maintenance cost = A

Production related cost = B

Product cost = C

then, The breakdown cost = A + B + C

The cost of scheduled replacement = A

The value of A, B, and C can be calculated by considering every cost of each component that occurs when the valves are replaced or failed. Some of them are collected and some are estimated as following :

1. Direct maintenance cost (A)

This component consists of :

1.1 Labor cost = 60 baht

Typically, when the valves failure are occurred, they will be replaced by a maintenance staff that take about 5 minutes for this activity. However, the staff has to perform other activities such as bringing the part from store, reporting to his chief, doing the paper work of the failure, etc. All of these activities will take the time approximately 1 hour.

when,	the staff salary is 10000 baht,			and
	each staff works about 160 hours a month			
so,	the labor cost	=	10000 / 160	
		=	60 baht / hour	

The labor cost of each valve failure or replacement is 60 baht.

1.2 Material cost = 1865 baht

The material cost is the cost of mag valve which is paid by the company for each valve replacement or failure. Most of the failure causes are from packing and rod. From packing is about 70% chance and 30% from rod. After these components failure, they can be repaired for a number of times, say approximately 10 times before replacing a new valve and each valve repair take about 0.5 labor hour.

when,	a new valve is 14950 baht,			and
	cost of packing repair is 200-300 baht,			and
	cost of rod repair is 500-600 baht,			and
so,	the material cost	=	30 + (14950+10(0.7x250+ 0.3x550) / 10	
		=	1865 baht	

The material cost of each valve failure or replacement is 1865 baht

1.3 Cost of tools for replacement = 1.3 baht (negligible)

The replacement of valve will use a number of tools as Allen screws no. 5, spanner no. 14 and 17, and pliers. Typically, these tools can be used for 2 years and approximately 100 times for each year. The cost of tools for each replacement can be calculated by spreading their price equally over each activity of its life.

when,	Allen screws no. 5 are 60 baht,		and
	spanners no. 14 and 17 are 50 baht,		and
	pliers are 150 baht		
so,	the replacement tools cost	=	(60+50+150) / (2x100)
		=	1.3 baht

The cost of tools for each replacement is 1.3 baht which is very small so this cost will be ignored.

1.4 Overhead cost = 108.4 baht

The overhead cost per month concerning maintenance section is estimated from maintenance manager interview as shown following:

management salary	=	432000
electric power	=	5000
water	=	1500
fuel	=	2000
taxes	=	4000
depreciation	=	125000
insurance	=	3000

Therefore, total estimated maintenance section overhead is approximately 572500 baht a month.

To calculate the overhead cost paid for each valve failure or replacement, the direct labor hours will be used as a base for applying the overhead cost. This base is appropriate in this calculation because labor hours data are easy to compute and nearly accuracy.

when,	there are 33 staffs of maintenance section, and each staff works for 160 hours a month		
so,	the labor hours	=	33 x 160
		=	5280 hours / month
then,	the overhead cost	=	572500 / 5280
		=	108.4 baht / labor hour

Because each valve failure or replacement uses 1 labor hour so the overhead cost is 108.4 baht.

2. Indirect maintenance cost (B+C)

Indirect maintenance cost consists of production related cost and product cost.

2.1 Production related cost (B)

This component consists of :

2.1.1 Rework cost = 1178 baht

When the valve failure is occurred, the paint color of the previous car and the next car will be mixed or air foam will be occurred on painted surface. This car will be sent back for repainting that causes rework cost. This cost consists of cost of labors for scrubbing the painted color, and cost of paint color and thinner used. Ordinary, scrubbing a car uses 6 workers and takes about 3 minutes. Moreover, painting a car uses paint color and thinner approximately 1/10 gallon and 1/5 gallon respectively.

when,	the color cost is 10000 baht / gallon, and the thinner cost is 800 baht / gallon, and the labor cost is 60 baht / hour		
so,	the repainted material cost	=	10000/10 + 800/5
		=	1160 baht
	the labor cost	=	6 x 3 x 60/60
		=	18 baht

then, the rework cost = 1160 + 18
= 1178 baht

Therefore, the rework cost of each valve failure is about 1178 baht.

2.1.2 Excessive scrap cost (negligible)

The excessive scrap may be not occurred when the valves failure because the defective car can be repaired by repainting. So the excessive scrap cost can be negligible.

2.1.3 Idle work cost = 5 baht (negligible)

Because the bell roof machine is the last machine of the paint line, so when the machine is breakdown there is no idle workers in the next process. At the machine itself, there is a production operator performing manual paint for some areas of the roof so if the valve failure is occurred he has to be idle about 5 minutes.

when, the labor cost is 60 baht / hour
so, the idle work cost = 5 x 60/60
= 5 baht

The idle work cost of each valve failure is 5 baht that can be negligible.

2.2 Product cost (C) (negligible)

This component is poor quality product and warranty claims cost

Due to the valve failure, the quality of painted surface of the cars will be poor, however these cars will be passed many inspection stages before launching them to customers. This can ensure that the poor quality product will rarely be sent to the customers then the warranty claims are hardly occurred. Therefore this cost can be ignored.

It can be concluded from the data stated above that :

A	=	60+1865+108	
	=	2033	baht
B	=	1178	baht
C	=	0	baht

Therefore,	The breakdown cost	=	3211 baht
	The cost of scheduled replacement	=	2033 baht

If the market is the producer market, that means demand of the car is more than supply in the market, there is another cost which should be involved in product cost. This cost is opportunity loss.

At the end of the paint line, there are approximately 15 car body shells spared as the buffer stock keeping to run operations of assembly line when the paint line is breakdown. When the machine is breakdown because of valve failure, the machine will be stopped approximately 5 minutes and the plant production rate is 2.4 minutes/unit. Therefore, we can say that the cost of valve failure is the opportunity loss for selling the 2 cars early. This loss can be calculated from benefits which the company can gain if the company invest the 2 body shells cost in other businesses such as commercial banks in stead of investing in buffer stock.

Besides this, the space cost of the body shells is also the other opportunity loss that the company has to pay. However in the case of X company, the production plant was constructed for the long times ago so the spaces that can be saved may be not useful for operating another activities. Then the space cost can be negligible.

Nowadays, Thai economy is in regression stage that the power of purchasing is decreasing causing most of manufacturers plan to reduce their production capacity, involving X company. So the opportunity loss is not involved in this study.

4.2 Proposed preventive maintenance policy for the valves

Basically, to determine a proper preventive maintenance policy for an equipment, three major parameters are considered. These parameters are failure behavior, the impact of its failure on the whole system, and costs of failure and preventive maintenance.

1. Failure behavior of equipment

The behavior can be illustrated by observing the failure rate characteristic of the equipment as time passes. When the rate trends to increase, preventive replacement is the proper policy.

Using Weibull distribution parameters ; shape parameter (β), scale parameter (η) and location parameter (γ) of soft air valve and of purge air valve calculated in previous section 4.1.2, each valve's failure rate are obtained through Equation 3.15. A failure rate-to-time graph is plotted to ease failure behavior defining. As a result, we clearly see from the following graph figure 4.3 that the failure rate of both valves increase as time passes

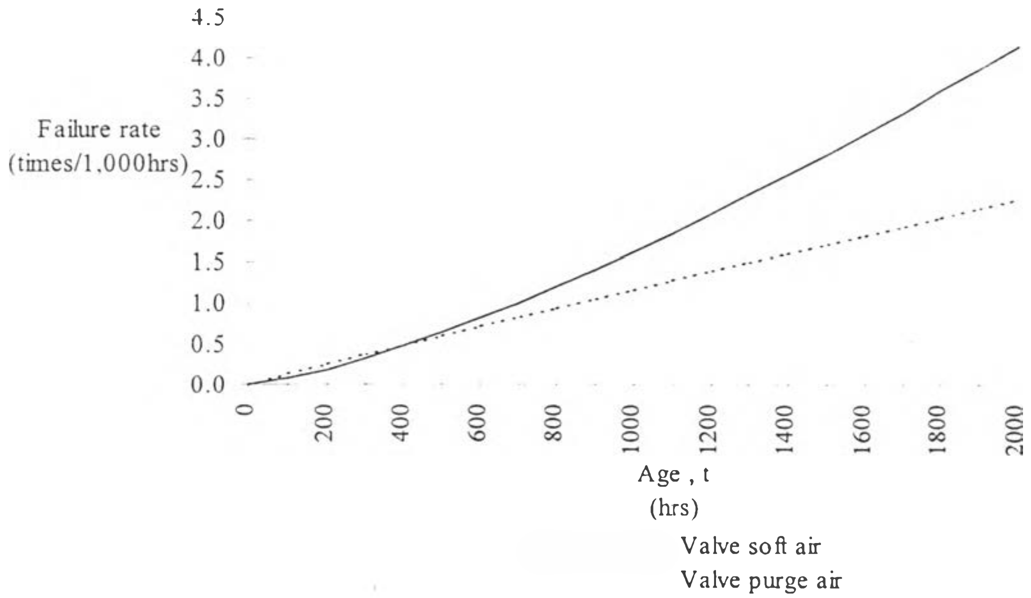

Figure 4.3 Failure rate behavior

Moreover per Weibull theory shown in section 3.1 (Weibull distribution) that ; when $\beta > 1$, f(t) will lie in wear-out stage (Region C in bath tub curve) with increasing failure rate. The shape parameter β used to create the graph is 2.35 for soft air valve and 1.95 for purge air valve. This supports result from our study.

In bath tub curve concept described in section 3.3, "if a part has an increasing failure rate, then preventive replacement will reduce the probability of equipment failure in the future…", therefore preventive replacement is appropriate for this first parameter.

The author would like to further note that since soft air valve increase in sharper rate than purge air valve does, it can be predicted that in an equal period of time soft air valve is likely to need more replacement.

2. Impact of equipment's failure on the whole system

Both soft air valve and purge air valve perform a great role for top coat painting machine, once valve's failure is detected, either soft air valve or purge air valve, the machine has to be stopped immediately for corrective actions. And in some occasion, only one broke down top coat painting machine affects the involved production lines to be halted.

If merely failure of each valve can significantly impact the whole system. Therefore, both soft air valve and purge air valve replacement should be planned.

3. Cost of failure and preventive maintenance of equipment

As described in section 4.1.4, since failure maintenance cost consists of direct maintenance cost (A) and indirect maintenance cost (B+C) while preventive replacement cost consists only direct maintenance cost (A). This leads to the fact that preventive replacement cost is always less than failure maintenance cost.

Since preventive replacement with lower cost is definitely preferable to failure maintenance with higher cost, therefore preventive replacement is a good preventive maintenance policy.

All of above support that the preventive replacement scheduling is one of the preventive maintenance policies that is appropriate for the valves. Therefore, this study proposes a scheduled replacement policy for the valves which can minimize the annual maintenance costs.

4.3 Designed maintenance planning for the valves

There are a number of criterion such as downtime, availability and cost to determine the most appropriate maintenance planning. In this study, cost of maintenance is the criterion for designing a maintenance planning.

For any preventive replacement models, one of the decisive variables is tp, the period for replacement, it can be used to optimize any criterion given. This study will seek for the appropriate value of tp that can minimize the annual maintenance costs of the top coat painting machine.

The procedure to design a preventive replacement planning is:

1. Define cumulative distribution function F(t)

From the Eq. (4.4)

$$F(t) = 1 - \exp -[(t-\gamma)/\eta)]^{\beta}$$

Soft air valve

Substituting $t=tp$, $\beta=2.35$, $\eta=1170$, $\gamma=0$ in the equation.

$$F(tp) = 1 - \exp -[tp/1170]^{2.35}$$

Purge air valve

Substituting $t=tp$, $\beta=1.95$, $\eta=1300$, $\gamma=0$ in the equation.

$$F(tp) = 1 - \exp -[tp/1300]^{1.95}$$

F(tp) is the probability of a failure occurring in tp hours with no scheduled replacement.

2. Define annual scheduled replacement cost

The machine is operated 22 hours a day, 5 days a week, therefore it runs for 5720 hours a year and each scheduled replacement cost is 2033 baht (shown in 4.1.3). With scheduled replacement after tp hours, the scheduled maintenance cost in a year will be :

$$= (5720/tp) \times 2033$$
$$= 1.16 \times 10^{7} / tp \text{ baht}$$

Because soft air valve and purge air valve are the same, therefore this annual cost can be applied to both valves.

3. Define expected annual failure cost.

Firstly, assuming that there is not more than one failure occurred in any replacement interval (tp) and each breakdown cost is 3211 baht (shown in 4.1.4). Then the expected failure cost in each scheduled replacement will be

$$3211 \{1 - \exp -[tp/1170]^{2.35}\} \text{ for soft air valve, and}$$
$$3211 \{1 - \exp -[tp/1300]^{1.95}\} \text{ for purge air valve}$$

The expected annual failure cost for each valve can be calculated by multiplying 5720 / tp to these values.

4. Define the annual total cost.

The total cost per year is the sum of annual scheduled replacement cost and expected annual failure cost

Soft air valve

$$\text{Total cost} = 1.16\text{x}10^7/\text{tp} + 1.84\text{x}10^7 \{1 - \exp -[\text{tp}/1170]^{2.35}\}/\text{tp}$$

Purge air valve

$$\text{Total cost} = 1.16\text{x}10^7/\text{tp} + 1.84\text{x}10^7 \{1 - \exp -[\text{tp}/1300]^{1.95}\}/\text{tp}$$

5. Calculate the replacement interval tp

The replacement interval, tp, of the valves can be obtained by trying to change the value of tp until facing the minimum annual total cost of each valve. This tp is the optimal age replacement of the valve. Because the maintenance policy of the company define that preventive maintenance should be performed on Sunday, so tp will be multiplication of 110 hours (operating hours of the machine in a week).

Table 4.9 shows the total annual cost of soft air valve and purge air valve calculated at varied tp.

tp (hrs)	Total cost (soft air valve) (baht)	Total cost (purge air valve) (baht)
5500	5455	5455
6600	4545	4545
7700	3896	3896
8800	3409	3409
9900	3030	3030
:	:	:
100000	300	300

Table 4.9 Total annual cost at varied tp

The table shows that the annual total cost is reduced when the replacement interval tp is increasing. So there should be not replacement of both soft air and purge air valve. The result may be incorrect because we assume in this calculation that not more than one failure occurs in any replacement interval.

Mean time between failure (MTBF) of the valves which are calculated in the previous section are 1047 hours for soft air valve and 1173 for purge air valve. Moreover the replacement interval of the valves should be closer and less than MTBF based on weekly practical machine hours (110 hours). Therefore, the practical replacement interval should be 990 hours and 1100 for soft air valve and purge air valve respectively.

Following these scheduled programs, the number of scheduled replacements and annual maintenance cost can be calculated as following:

<u>Soft air valve</u>

no. of scheduled replacements	=	5720 / 990
	=	5.78 times
annual maintenance cost	=	5.78 x 2033
	=	11746 baht

<u>Purge air valve</u>

no. of scheduled replacements	=	5720 / 1100
	=	5.2 times
annual maintenance cost	=	5.2 x 2033
	=	10572 baht

Considering the annual maintenance cost of the plan without replacement, the annual cost of the valves can be calculated as following:

Soft air valve

annual maintenance cost = 3211 x 5720/1047

= 17542 baht

Purge air valve

annual maintenance cost = 3211 x 5720/1173

= 15658 baht

It shows that the annual maintenance cost of proposed scheduled replacement plan is less than the plan without replacement. If the company receives these plans, an amount of money will be saved every year as shown below.

Soft air valve

yearly safe of maintenance cost = 17542 - 11746

= 5796 baht

Purge air valve

yearly safe of maintenance cost = 15658 - 10572

= 5086 baht

Receiving these plans the company can save the maintenance cost of the top coat painting machine approximately 10900 baht each year.

To apply the result from this study to the real action, some assumptions should be defined as following :

1. Replacing parts or components makes the machine in its highest performance.
2. The replacement action does not introduce any defects.
3. The time-to-failure distributions are exactly defined.

4.4 Maintenance planning for the other components

From the previous sections, the two major components, soft air valve and purge air valve, are considered and assigned a preventive maintenance planning. For the others, they will be in this section.

To assign a preventive maintenance planning for each component, it starts with studying its breakdown appearance and breakdown cause from machine descriptions (appendix A) and maintenance staffs interview. These data can be used to determine appropriate maintenance activities for the component. Typically, maintenance activities can be divided into five major groups as following :

1) Cleaning activity (C)

   Cleaning activities are for example dust removing, cleaning machine dirty.

2) Lubricating activity (L)

   Lubricating activities purpose is to reduce parts friction which may cause parts wear. Lubricating solutions used are lubricating oil and grease.

3) Inspecting activity

   Inspecting activities are data observing for machine deterioration and can be classified into two items :

   1. External inspection using human senses (Inspection : I)
   2. Fine inspection using measuring equipment (Functional Check : F)

4) Adjusting activity (A)

   After long time operating, some components of the machine will be shifted from its original position for example loosen screw must be tightened.

5) Repairing activity

Repairing activities are machine efficiency recovering and can be classified into two items :

1. Component repairing (Repair : R)
2. Component replacement (Replacement : Re)

After determining appropriate maintenance activities for each component, the next is to find the suitable time interval for the activities. Although this study proposes to use maintenance costs as the criterion for finding the plan, it cannot be used in this case because there is not enough failure data of these components. Lack of failure data leads to do not know probability of a failure in a specific time interval, so the time interval yielding minimum annual cost cannot be calculated. Due to this, the author will find maintenance activities interval of each component from machine manual that machine maker may recommend or from maintenance staffs interview. Table 4.10 is maintenance standard that shows maintenance activities, time interval, maintenance mean, and criterion of each component.

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Maintenance standard	Page	1/2

Abbreviation list			
C :	CLEAN	F :	FUNCTIONAL CHECK
L :	LUBRICATION	A :	ADJUSTMENT
I :	INSPECTION	Re :	REPLACEMENT

	Component list	Breakdown Appearance	Breakdown Cause	Maintenance Standard			
				Activity	Time Interval	Maintenance mean	Criterion
I	**Elevation unit**						
1	explosion-proof motor	overhead	excessive current, temp	F	m	clamp, termo meter	<1.5 A, <Tbooth+15C
2	pulse generator	detection false	chain loosened	I	2m	visual check	Not loose
3	limit switchs	detection false	out of order	I	m	visual check	working condition
4	inverter	uncontrol speed	out of order	I	m	visual check	60-200 mm/sec
5	speed reducer	uncontrol speed	low oil level, excessive temp	I,F	m	visual , thermometer	>eye glass,<Tbooth+40C
6	drive chain	rough moving	bolts loosened	I	2m	visual check	Not loose
7	encoder	detection false	loosen power lock nut	I	6m	visual check	Not loose
8	bearing	ball bearing break, wear	rare lubrication	I,L	m	visual check	working condition
II	**Reciprocate unit**						
1	explosion-proof motor	overhead	excessive current, temp	F	m	clamp, termo meter	<1.5 A, <Tbooth+15C
2	potentiometer	uncontrol speed	out of order	I	m	visual check	10-30 cycles/min
3	variable resistor	uncontrol acceleration time	out of order	I	m	visual check	0.5-20 sec
4	drive chain	rough moving	bolts loosened	I	2m	visual check	Not loose
5	speed reducer	uncontrol speed	low oil level, excessive temp	I,F	m	visual , thermometer	>eye glass,<Tbooth+40C
6	pulse generator	detection false	chain loosened	I	2m	visual check	Not loose
7	proximity sensor	detection false	out of order	I	2m	visual check	working condition
8	encoder	detection false	loosen power lock nut	I	6m	visual check	Not loose
9	bearing	ball bearing break, wear	rare lubrication	I,L	m	visual check	working condition
III	**Tilt unit**						
1	explosion-proof motor	overhead	excessive current, temp	F	m	clamp, termo meter	<1.5 A, <Tbooth+15C
2	pulse generator	detection false	chain loosened	I	2m	visual check	Not loose
3	proximity sensor	detection false	out of order	I	2m	visual check	working condition
4	potentiometer	uncontrol speed	out of order	I	m	visual check	5-15 sec./180
5	variable resistor	uncontrol acceleration time	out of order	I	m	visual check	0.5-20 sec.
6	speed reducer	uncontrol speed	low oil level, excessive temp	I,F	m	visual , thermometer	>eye glass,<Tbooth+40C
7	drive chain	rough moving	bolts loosened	I	2m	visual check	Not loose
8	encoder	detection false	loosen power lock nut	I	6m	visual check	Not loose

Table 4.10 Maintenance standard shows maintenance activities and time interval

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Maintenance standard	Page	2/2

Abbreviation list			
C :	CLEAN	F :	FUNCTIONAL CHECK
L :	LUBRICATION	A :	ADJUSTMENT
I :	INSPECTION	Re	REPLACEMENT

Component list		Breakdown Appearance	Breakdown Cause	Maintenance Standard			
				Activity	Time Interval	Maintenance mean	Criterion
IV	**Tracking unit**						
1	explosion-proof servo motor	overhead	excessive current, temp	F	m	clamp, termo meter	<1.5 A, <Tbooth+15C
2	pulse generator	detection false	chain loosened	I	2m	visual check	Not loose
3	limit switchs	detection false	out of order	I	m	visual check	working condition
4	speed reducer	uncontrol speed	low oil level, excessive temp	I,F	m	visual , thermometer	>eye glass,<Tbooth+40C
5	encoder	detection false	loosen power lock nut	I	6m	visual check	Not loose
6	drive chain	rough moving	bolts loosened	I	2m	visual check	Not loose
7	plastic spur gear	unusually voice	not moving freely	L	2m	hearing	normal voice
8	bearing	ball bearing break, wear	rare lubrication	I,L	m	visual check	working condition
V	**Gun mounting & HV panel unit**						
1	gun mounting	out of control	excessive current, voltage	F	m	HV panel check	working condition
2	cascade	uncontrol voltage	out of order	I	3m	visual check	working condition
3	HV controller	unusually voice	HV chain loosened	I	m	hearing	normal voice
4	cable / connector HV	break, scratch	from working operation	I	2m	visual check	Not break, scratch
VI	**Paint supply unit**						
1	color change vavle (CCV)	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
2	purge thinner vavle	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
3	needle vavle	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
4	trigger vavle	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
5	dump valve	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
6	soft thinner valve	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
7	bypass valve	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
8	center valve	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks
9	metalling valve	valve malfunction	valve leak, sticky	I	m	visual check	No air, paint, leaks

Table 4.10 Maintenance standard shows maintenance activities and time interval(cont.)

4.5 Maintenance scheduling

Data collecting, data analyzing, and maintenance standardization of the previous sections lead to construct the machine maintenance scheduling. For the scheduling in this work, there will be component maintenance plan in 5 years, yearly and monthly. Each maintenance plan must follow the same direction. After implementing these plans we will find how appropriate they are. Plan adjusting and data collecting may be necessary to next plan revising.

Maintenance plans are :

1. Main maintenance plan in 5 years

This is the plan for long term component maintenance in 5 years. By considering maintenance activity in monthly column (m, 2m, 3m and 6m) of all components in maintenance standard table 4.10 to create main maintenance plan in 5 years in a table form. This table indicates another 60 months as shown in table 4.11 from July 1997 to June 2002.

2. Yearly / Monthly maintenance plan

This is the plan for component maintenance in 1 year. This plan in table 4.12 will define monthly (m, 2m, 3m and 6m) maintenance in detail. This table will indicate in what week and month is each activity. Because of the company policy, so these maintenance activities will be performed on weekends.

For Weekly / Daily maintenance plan that indicate maintenance day for a week and maintenance time for a day should be defined by the company themselves based on its convenience.

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Main maintenance plan in 5 years	Page	1/2

Abbreviation list	
C : CLEAN	F : FUNCTIONAL CHECK
L : LUBRICATION	A : ADJUSTMENT
I : INSPECTION	Re : REPLACEMENT

Component list		1997						1998												1999												2000												2001												2002					
		7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
I	**Elevation unit**																																																												
1	explosion-proof motor	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	pulse generator	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
3	limit switchs	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	inverter	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
5	speed reducer	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F
6	drive chain	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
7	encoder	I						I						I						I						I						I						I						I						I						I					
8	bearing	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L
II	**Reciprocate unit**																																																												
1	explosion-proof motor	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	potentiometer	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
3	variable resistor	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	drive chain	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
5	speed reducer	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F
6	pulse generator	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
7	proximity sensor	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
8	encoder	I						I						I						I						I						I						I						I						I						I					
9	bearing	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L	I,L
III	**Tilt unit**																																																												
1	explosion-proof motor	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	pulse generator	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
3	proximity sensor	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
4	potentiometer	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
5	variable resistor	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
6	speed reducer	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F
7	drive chain	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
8	encoder	I						I						I						I						I						I						I						I						I						I					

Table 4.11 Main maintenance plan in 5 years

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Main maintenance plan in 5 years	Page	2/2

Abbreviation list			
C :	CLEAN	F	FUNCTIONAL CHECK
L :	LUBRICATION	A	ADJUSTMENT
I :	INSPECTION	Re	REPLACEMENT

Component list		1997						1998												1999											
		7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
IV	**Tracking unit**																														
1	explosion-proof servo motor	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	pulse generator	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
3	limit switchs	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	speed reducer	I,F	I,F	I,F	I,F	I,F	I,I	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,I	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,I
5	encoder	I						I						I						I						I					
6	drive chain	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
7	plastic spur gear	L		L		L		L		L		L		L		L		L		L		L		L		L		L		L	
8	bearing	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I
V	**Gun mounting & HV panel unit**																														
1	gun mounting	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	cascade	I			I			I			I			I			I			I			I			I			I		
3	HV controller	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	cable / connector HV	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I
VI	**Paint supply unit**																														
1	color change vavle (CCV)	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
2	purge air valve	Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re				
3	purge thinner vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	needle vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
5	trigger vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
6	dump valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
7	soft air valve	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re
8	soft thinner valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
9	bypass valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
10	center valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
11	metalling valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I

Component list		2000												2001												2002					
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
IV	**Tracking unit**																														
1	explosion-proof servo motor	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	pulse generator	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
3	limit switchs	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	speed reducer	I,F	I,F	I,F	I,F	I,I	I,F	I,F	I,I	I,F	I,F	I,F	I,I	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,F	I,I	I,F	I,F	I,F	I,F	I,F	I,F
5	encoder	I						I						I						I						I					
6	drive chain	I		I		I		I		I		I		I		I		I		I		I		I		I		I		I	
7	plastic spur gear	L		L		L		L		L		L		L		L		L		L		L		L		L		L		L	
8	bearing	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I	I,I
V	**Gun mounting & HV panel unit**																														
1	gun mounting	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2	cascade	I			I			I			I			I			I			I			I			I			I		
3	HV controller	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	cable / connector HV	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I	I		I
VI	**Paint supply unit**																														
1	color change vavle (CCV)	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
2	purge air valve	Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re					Re,Re,Re,Re				
3	purge thinner vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
4	needle vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
5	trigger vavle	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
6	dump valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
7	soft air valve	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re
8	soft thinner valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
9	bypass valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
10	center valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
11	metalling valve	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I

Table 4.11 Main maintenance plan in 5 years(cont.)

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Yearly / Monthly maintenance plan	Page	1/2

Abbreviation list			
C	CLEAN	F	FUNCTIONAL CHECK
L	LUBRICATION	A	ADJUSTMENT
I	INSPECTION	Re	REPLACEMENT

No.	Component list / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	1997	Jul				Aug				Sep					Oct				Nov				Dec				
I	**Elevation unit**																										
1	explosion-proof motor	F				F					I				F				I					F			
2	pulse generator	I									I								I								
3	limit switchs	I				I					I				I				I					I			
4	inverter	I				I					I				I				I					I			
5	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
6	drive chain	I									I								I								
7	encoder	I																									
8	bearing	I,L				I,L					I,L				I,L				I,L					I,L			
II	**Reciprocate unit**																										
1	explosion-proof motor	F				F					F				F				I					F			
2	potentiometer	I				I					I				I				I					I			
3	variable resistor	I				I					I				I				I					I			
4	drive chain	I									I								I								
5	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
6	pulse generator	I									I								I								
7	proximity sensor	I									I								I								
8	encoder	I																									
9	bearing	I,L				I,L					I,L				I,L				I,L					I,L			
III	**Tilt unit**																										
1	explosion-proof motor	F				F					F				F				F					F			
2	pulse generator	I									I								I								
3	proximity sensor	I									I								I								
4	potentiometer	I				I					I				I				I					I			
5	variable resistor	I				I					I				I				I					I			
6	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
7	drive chain	I									I								I								
8	encoder	I																									

No.	Component list / Week	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	1998	Jan				Feb				Mar					Apr				May				Jun				
I	**Elevation unit**																										
1	explosion-proof motor	I				F					I				F				F					F			
2	pulse generator	I									I								I								
3	limit switchs	I				I					I				I				I					I			
4	inverter	I				I					I				I				I					I			
5	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
6	drive chain	I									I								I								
7	encoder	I																									
8	bearing	I,L				I,L					I,L				I,L				I,L					I,L			
II	**Reciprocate unit**																										
1	explosion-proof motor	I				I					I				I				F					I			
2	potentiometer	I				I					I				I				I					I			
3	variable resistor	I				I					I				I				I					I			
4	drive chain	I									I								I								
5	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
6	pulse generator	I									I								I								
7	proximity sensor	I									I								I								
8	encoder	I																									
9	bearing	I,L				I,L					I,L				I,L				I,L					I,L			
III	**Tilt unit**																										
1	explosion-proof motor	F				F					I				F				F					F			
2	pulse generator	I									I								I								
3	proximity sensor	I									I								I								
4	potentiometer	I				I					I				I				I					I			
5	variable resistor	I				I					I				I				I					I			
6	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F			
7	drive chain	I									I								I								
8	encoder	I																									

Table 4.12 Yearly / Monthly maintenance plan

X Company			
Manual	Machine maintenance	Section	Maintenance
Issue	Yearly / Monthly maintenance plan	Page	2/2

Abbreviation list			
C	CLEAN	F	FUNCTIONAL CHECK
L	LUBRICATION	A	ADJUSTMENT
I	INSPECTION	Re	REPLACEMENT

	Component list	1997																										1998																									
		Jul				Aug					Sep				Oct				Nov					Dec				Jan				Feb					Mar				Apr				May					Jun			
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
IV	**Tracking unit**																																																				
1	explosion-proof servo motor	F				F					F				F				F					F				F				I					F				I				F					I			
2	pulse generator	I									I								I									I									I								I								
3	limit switchs	I				I					I				I				I					I				I				I					I				I				I					I			
4	speed reducer	I,F				I,F					I,F				I,F				I,F					I,F				I,F				I,F					I,F				I,F				I,F					I,F			
5	encoder	I																										I																									
6	drive chain	I									I								I									I									I								I								
7	plastic spur gear	I									I								I									I									I								I								
8	bearing	I,L				I,L					I,L				I,L				I,L					I,L				I,L				I,L					I,L				I,L				I,L					I,L			
V	**Gun mounting & HV panel unit**																																																				
1	gun mounting	F				F					F				F				F					F				F				F					F				F				F					F			
2	cascade	I													I													I													I												
3	HV controller	I				I					I				I				I					I				I				I					I				I				I					I			
4	cable / connector HV	I									I								I									I									I								I								
VI	**Paint supply unit**																																																				
1	color change vavle (CCV)	I				I					I				I				I					I				I				I					I				I				I					I			
2	purge air valve	Re					Re					Re					Re					Re					Re					Re					Re					Re					Re					Re	
3	purge thinner vavle	I				I					I				I				I					I				I				I					I				I				I					I			
4	needle vavle	I				I					I				I				I					I				I				I					I				I				I					I			
5	trigger vavle	I				I					I				I				I					I				I				I					I				I				I					I			
6	dump valve	I				I					I				I				I					I				I				I					I				I				I					I			
7	soft air valve	Re				Re					Re				Re				Re					Re				Re				Re					Re				Re				Re					Re			
8	soft thinner valve	I				I					I				I				I					I				I				I					I				I				I					I			
9	bypass valve	I				I					I				I				I					I				I				I					I				I				I					I			
10	center valve	I				I					I				I				I					I				I				I					I				I				I					I			
11	metalling valve	I				I					I				I				I					I				I				I					I				I				I					I			

Table 4.12 Yearly / Monthly maintenance plan(cont.)

4.6 Maintenance Controlling

To run any activity, controlling is important to make that activity complete. So is maintenance activity, we must set system and means to control the activity appropriately.

The objective of machine maintenance controlling is to reduce maintenance cost and lessen production cost as much as possible. However this activity is limited by quality and quantity constraints. There are several factors that impact the maintenance controlling :

1) Company management policy
2) Company planning and controlling system
3) Providing and storing spare parts system
4) Repairing site and ware house
5) Maintenance equipment

Regardless of how good machine maintenance controlling is, if the activity does not conform to the above mentioned factors, the maintenance controlling will not be fully efficient. Therefore the company must consider theses factors to control maintenance activities.

From relationship between maintenance section and others, we find that maintenance section involves every other section in the organization especially production section. Close cooperation between maintenance and production section through others in the organization is necessary to run the organization management plan smoothly. Mostly maintenance staff has an attitude that maintenance activity concerns only production line, but nowadays we discover that it relates to marketing and financial section as well. This is because maintenance activity play a great role on how much price or quality the product will be. Close cooperation between sections not only brings maintenance activity into effect but also leads to other section controlling efficiency.

1. Controlling maintenance resources

This is to efficiently control and use maintenance resources of the organization. These resources including maintenance staffs, spare parts, and maintenance equipment must be provided appropriately, adequately, and conform to the defined maintenance plan.

1.1 Maintenance staff

Generally maintenance staffs are all staffs concerning maintenance activity. Maintenance staff has to deal with his section personnel as well as machine operator in production line. To control the maintenance staff resources, we set a maintenance activity schedule.

Typically there are 3 types of maintenance organizing :

a) centralize maintenance organization
b) decentralize maintenance organization which is several maintenance groups in production line
c) mixing 2 types above together

X Company use mixing maintenance organization since there are many production lines and each is very complicate. This organization merges all machine maintenance into one section but distributes maintenance staffs into some important production points. Basically both preventive and corrective maintenance are performed by maintenance section except some daily or weekly inspection activities will be done by machine operators themselves.

Benefit of this type of maintenance organization is that it enables maintenance staff allocation to control all machines, up from planning to machine maintenance. Furthermore it makes this section close to production section, when machine fails it will be access immediately and data search is easy.

1.2 Spare parts

Spare parts is a secondly important maintenance resources to the maintenance staff. When a machine is failed in emergency, if there is no spare parts prepared then the production line will be stopped. Therefore an appropriate number of spare parts must be prepared by keeping insurance item in stock to ensure that once the machine is down, these parts can be immediately replaced. Mostly these spare parts are expensive and hardly fail, however is necessary to keep them in stock.

1.3 Maintenance equipment

Maintenance equipment in this item must be used in maintenance activities. Mostly these equipment are for machine status inspection and for component assembly / disassembly. These equipment have to be maintained and controlled to their ready state.

2. Maintenance data controlling

Purpose of maintenance data controlling is to obtain necessary data to analyze cause of any problems occur in the future. Especially to plan and adjust means of maintenance activities to the most efficiency as possible. In this study maintenance data controlling will focus on data collecting for planning and maintenance plan revising which are machine history records.

Machine history record is like a machine identification card. Production operator must record any problems occurred and use this record to analyze machine failure appearance and define maintenance action for next time.