



## Design of Maintenance Program for a Rubber Processing Plant

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### ABSTRACT

A due diligence study of a rubber processing plant was undertaken to develop a maintenance program that ensures the operational availability of machines that meets the production quota of the factory. The approach adopted includes a field visit to observe rubber processing and inspect maintenance facilities. The plant's rubber processing records were accessed and analysed to establish the operating life characteristics of the system and other key performance indicators. The result shows that the mean time between failures is 9.2 hours and the meantime to repair 102 hours with concomitant 53% operational availability of the processing line. The operating system reliability is 0.42. A review of the equipment manufacturer's document puts the component reliability specification at 0.99 equivalent to 0.90 for 10 components in series to yield 76- an hour mean time between failures on 8-hour run. The operational availability is therefore put at 87% to be achieved on 12-hour mean time to repair corrective maintenance to meet the field production capacity of the company's rubber plantation.

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### INTRODUCTION

As competition intensifies in industries, profit or loss became dependent on the availability of plants and equipment. Hence maintenance has become a strategic function in most industries [1]. The maintenance department provides corrective and preventive maintenance to ensure the reliability of the production line which translates into system availability [2]. Whereas equipment utilization indicates the performance of the production department and gives capacity utilization of the plant, equipment availability indicates the performance/effectiveness of maintenance as measured by failure rate, mean time between failure (MTBF) and mean downtime (MDT) [3]. MDT is the sum of the mean preventive and corrective (repair) time interval inclusive of downtime for logistic and administrative backup [4]. The availability of a system will increase if the system reliability is increased (increase MTBF) or if the time to repair is reduced (decreased MDT) [5].

Maintenance decision includes choice of maintenance method to adopt bearing in mind the merit and demerit of each method in the light of its peculiar equipment. Maintenance strategies of choice are: failure or breakdown maintenance: press on until something break, seizes or catches fire, then cope with the chaos and repair work as best as one may; planned maintenance: either shutdown and replace components on an elapsed operating time basis regardless of condition or carry out an inspection at the regular but necessary arbitrary interval and replacing components as indicated by their condition and condition-based and guided maintenance; predictive- monitor conditions of all-important components, watching for trends, to derive warning of incipient trouble in time for effective action with least inconveniences. Thus condition-monitoring takes planned maintenance a stage further to rationality [6]. Hence to formulate a maintenance strategy and evolve a maintenance plan, the maintenance engineer



must consider the time required to conduct preventive maintenance compared to breakdown maintenance, operating life characteristics of the equipment and cost of maintenance [7]

The rubber processing company is an indigenous company involved in rubber plantation management, exploitation and processing of natural rubber to crumb rubber. The mill has three processing lines with a combined installed capacity of 20mt per hour made up of 8-8-4 tons per hour lines. It produces technical standard rubber TSR 10 and TSR 20 brands of crumb rubber essentially for export. Due diligence inspection conducted between 28, 29 July and 6 August 2021 on the Rubber Factory located at Ughelli in Delta State, Nigeria revealed a state of the art factory installed by M/S Bridgestone and Firestone in 1991. By all standards, it is one of the best rubber factories in Nigeria. Unfortunately, this factory has been underutilized for almost three years.

At the time of visit, only one line out of the three lines of production was being used because of insufficient raw materials to feed the factory and low operational availability of equipment. Other challenges hindering the full utilization of the factory include but are not limited to infrastructural decay, underutilization of infrastructure and machines, broken down equipment, low morale of staff and inadequate operating funds. The factory workshop has up-to-date machines for producing spare parts for the factory. The workshop can fabricate most of the required spare parts for the factory with shaping, machining, surface finishing, joining and change in properties facilities on display.

Thus, the potential to ensure high operational availability of equipment exists but needs informed decisions on maintenance and operation strategy. The aim of the study is therefore to develop a maintenance program for the 4-ton per hour processing line that steps up its operational availability from 53% to 87% that meets the processing need of the company's own rubber plantations production of 8,322 tons per annum.

## METHODOLOGY

To design a maintenance programme for the rubber processing plant the following approach was adopted:

- i. Observe processing and inspect equipment.
- ii. Review of rubber processing records.
- iii. Compare record and result of performance analysis with known standards.
- iv. Carry out maintainability and reliability analysis of equipment to determine availability.
- v. Proffer plant operational availability improvement options.

## ANALYSIS AND RESULTS

### *Observation of the factory Rubber Processing:*

The cup lumps brought from the field and local purchases are stored for maturity, soaked in water for some time to soften and pre-cleaned, then fed into size reducing machines – pre-breaker, slab cutter, hammer mill 1 and 2 to be first broken up into small bits or crumbs before passing through four sets of creeping machines. The crepes are then put into the shredder or extruder then through fine creepers and shredder before being washed in the bank pool and placed in dryer boxes for dripping. And then into the drying chamber to be dried by hot air at 125°C/120°C wet and dry ends respectively by a diesel-fired dryer. The dry crumbs are cooled for 8 minutes, discharged, weighed and pressed into lots of 33.33kg size to form bales. They are technically graded and wrapped in a 0.004mm transparent polythene sheet as figure 1.

Thirty-six bales are packed in a pallet amounting to 1.2 tonnes. After processing, the boxes are removed from the dryers and the contents removed. Some pieces of the leftover get stocked in the boxes. The boxes are therefore soaked and cleaned in the washing station before re-use. Field coagula are only suitable for the production of TSR10 and TSR20 grades, not TSR5 which comes from latex coagula because of the high dirty content. When equipment breaks down the entire line must be stopped until the failure is repaired. Hence the processing plant is fault intolerant [1].



Figure 11: Flow chart for a rubber processing line

### Review of Rubber Processing Record

The maintenance records provided an acceptable level of downtime data for the analysis as shown in Table 1.

**Table 1:** Maintenance Records  
 2021 MACHINE BREAKDOWN: DATE. JANUARY

MACHINE	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	Break downs	Downtime (hr)	Period (hr)	
Slab cutter								121				213													83							3	417	248	
Pre-breaker					104	60																										2	164	248	
Extruder 1											81	60																				3	362	248	
Extruder 2														148																		1	148	248	
Macerator																																0	0	248	
Creper 1				66																												1	66	248	
Creper 2																			57													1	57	248	
Creper 3							33												32	120												3	185	248	
Shredder						42	50												63						91	58						5	304	248	
Dryer				66	91																											72	3	229	248
Press																																0	0	248	



**Capacity Utilization**

The factory runs 2 shifts of 8 hours each with 37 workers per shift and produces 26 tons per shift amounting to 52 tons per day on one production line as and when raw material is available. This is against its daily three lines installed capacity of 326 tons per day of dry rubber on two shifts of 8-hour each. This amounts to 653 Mt tons wet weight of raw rubber per day at 50% dry rubber content (DRC)

on full capacity utilization. The production of TSR10 indicates the plant's high technical quality on plasticity retention index (PRI) – a key quality indicator for rubber products. From the six months production breakdown (January to July 2021) as shown in Table 2, only 603 tons of rubber were sourced and processed as against the installed six months capacity of 41,685 tons, representing 1.4% capacity utilization.

Table 2: 2021 Crumb Rubber Production

Year	Month	Processed (MT)	No. of Days Worked
2021	Jan	155.855	7.5
	Feb	59.815	2.5
	Mar	140.357	8.5
	Apr	0	0
	May	78.540	4
	Jun	92.470	6
	Jul	75.600	4
<b>Total = 602.637</b>		<b>Average = 4.7</b>	

**3.2.2 Operational performance**

Operational performance is analysed along the following performance indicators shown in Table 3:

Table 3: Key Performance Indicators (KPI)

Indicators	Values
Mean Time to Repair (MTTR)	102 hours
Mean Time Between Failure (MTBF)	9.2 days
Cost of unit production	65 NGN/kg
Selling price	483.8 NGN/kg (1344 USD/ton)
Production output per hour	2746 kg
Diesel Drying cost	21.45NGN/KG
% of Diesel cost of the unit cost of production	33%.
Energy (electricity) consumption cost per kg	16.25NGN
% of the energy cost of the unit cost of production	25%
Diesel in litre per ton dried	86litre/ton
Quantity of power per tons	Kwh/ton not available.
Polythene cost per unit cost of production	4.13NGN
Polythene cost as a percentage of the cost of production per unit	6.4%
Polythene cost per ton of rubber produced	4,125 NGN/TON
Spare parts cost per unit cost of production	11.05NGN
Spare part cost as a percentage of the cost of production	17%
Spare part cost per ton of rubber produced	11,050 NGN/TON
Man day per ton	0.71

**Compare the Record and Result of Analysis with Known Standards.**

Operational performance by cost against Industry standards – local and international is shown in Table 4. While the direct cost of production is on the high side, the

overall production cost which includes overheads, transport and storage, laboratory, packaging and storage, utility, delivery to port and factory depreciation is favourable.



**Table 4:** Production cost against standard cost

Description	Indicator	Achieved	Standard
Processing Cost	NGN/Kg	40.00	21.35
Production Cost	NGN/Kg	65.00	86.58

**Table 5:** Other performance indices against standard

Resources	Std % Cost per unit	IHL kg/ton	Std IHL l/ton	IHL Std IHL kwh/ton	Std IHL euro/ton	IHL Std IHL Md/ton	IHL Std IHL euro/kwh
Dryer with gas	18.2	NA	25		516		
Dryer with AGO	12.55	33		38.5 86	329		
Electricity	15.17	25			208.46		0.15
(Polythene 4)	2.01	6.4	1.2		1620		
(Polythene 8)	0.73	0.34			1550		
Spare parts	9.31	17			5.1		
Man-days	13.36				5.85	1.11	0.71

**Maintainability and Reliability Analysis of Equipment**

The monthly summary of reliability (mean time between failures) and maintainability (mean downtime -MDT) records

of the factory is shown in Table 6 indicating the mean time between failure of 9.72 hours and mean downtime of 101 hours. The system series reliability is 0.44 over an 8-hour run.

**Table 6:** Monthly Maintainability and Reliability characteristic of processing line

Month	Failure rate	MTBF	Reliability	MDT
Jan	0.09	11.27	0.49	89
Feb	0.17	5.89	0.26	123
Mar	0.21	4.86	0.19	92
Apr	0.08	12.63	0.53	114
May	0.04	24.80	0.72	80
Jun	0.06	17.14	0.63	85
Jul	0.09	11.27	0.49	158
Aug	0.11	9.19	0.42	98
Sep	0.11	9.23	0.42	77
Oct	0.09	11.27	0.49	104
Nov	0.12	8.57	0.39	92
Dec	0.08	12.31	0.52	99
As	0.10			
Rs(8)			0.44	
MTBF		9.72		
MTTR				101

**Inspection of Maintenance Workshop and Maintenance Culture**

Maintenance workshop is in place with a lot of machines such as lathe, shaping, milling, power saw, drilling, band saw, turning machine and most fabrication needed are carried out there. The factory has a well-defined maintenance team made up of a preparatory team with each shift manned by 2 fitters, 2

welders, 1 plumber, 1 electrician and 1-panel operator. Preventive, corrective, shut down, upgrade, systematic and improvement maintenance is carried out. Personal protective equipment is given to the workers. Most of the machines moving parts are however without protection and cables are exposed with the power line and distribution cables lying on the bare floor instead of being arranged on cable

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trays. Emergency stoppers are not prominent. Some machines were found with oil leakages and no retention to trap them.

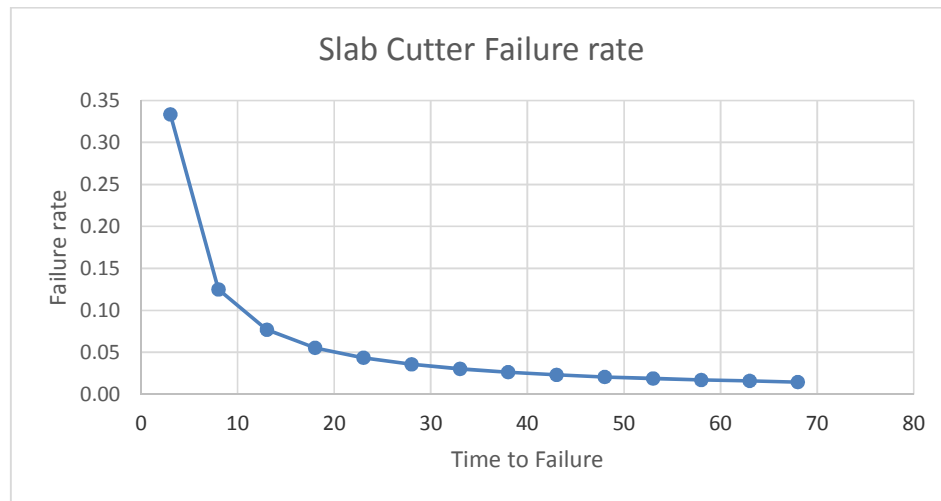
**Operating Life Characteristics of Equipment.**

The Mean downtime (MTD) includes time spent waiting for parts and maintenance

personnel as well as time spent troubleshooting and fixing the failed equipment. Therefore, under fairly general conditions in the factory, the steady-state failure rate of the system is as shown in Table 7 and depicted in Fig 2.

**Table 7:** Failure rate

Rank Order	Failure Time (hrs)	Mean	Median rank	Failure rate
1	3	6.67	4.86	0.33
2	8	13.33	11.81	0.13
3	13	20.00	18.75	0.08
4	18	26.67	25.69	0.06
5	23	33.33	32.64	0.04
6	28	40.00	39.58	0.04
7	33	46.67	46.53	0.03
8	38	53.33	53.47	0.03
9	43	60.00	60.42	0.02
10	48	66.67	67.36	0.02
11	53	73.33	74.31	0.02
12	58	80.00	81.25	0.02
13	63	86.67	88.19	0.02
14	68	93.33	95.14	0.01



**Fig 2:** Line failure distribution

The system operational availability  $A_o$ , and mean time between failure (MTBF) are obtained using equation 2.1 and 2.2

$$A_o = \frac{MTBF}{MTBF + MDT} \quad (2.1)$$

Where  $A_o$  = the operational availability

$MTBF$  = Mean time between failure

$$R(t) = R(\theta) = \exp(-\lambda t) = \exp(-t/MTBF) \quad (2.2)$$

Actual system reliability is given by  $R(\theta) = \exp(-\theta/MTBF)$



From Table 8 the series system reliability is 0.42 using

$$R_s = \prod_{i=1}^n R_i \quad (2.3)$$

Where n = number of components or equipment  
 $i = i^{th}$  component or equipment

Therefore  $R(8) = \exp(-8/MTBF) = 0.42$   
 $1/MTBF = -\ln(0.42)/8 = 0.108438$   
 $MTBF = 9.2 \text{ hrs}$

From equation 2.1 the operational availability is obtained per equipment to give a system operational availability of 53% as shown in Table 8. Component reliabilities are also shown in Table 8 with a series system reliability of 0.42. Tables 9 and 10 contain the system failure characteristic and downtime analysis respectively. From Table 8 the least available equipment is the pre-breaker with only 34% operational availability.

**Table 8: Equipment Reliability and Operational Availability**

No	Equipment	Reliability	Availability
1	Slab cutter	0.93	0.55
2	Pre-breaker	0.90	0.34
3	Extruder 1	0.96	0.63
4	Extruder 2	0.96	0.68
5	Macerator	0.94	0.57
6	Creeper 1	0.94	0.58
7	Creeper 2	0.93	0.48
8	Creeper 3	0.92	0.45
9	Shredder	0.84	0.38
10	Dryer	0.90	0.43
11	Press	0.95	0.72
System Reliability/Availability		0.42	0.53

The low operational availability is attributed essentially to the high mean time to repair MDT of 102 hours as shown in Table 10

compared to the mean time between failure MTBF of 9.2 hours – Table 9

**Table 9: Failure Analysis**

Total test time (hr)	27048
Number of failures	284
Failure rate	0.01
System R(8)	0.42
Mean Time Between Failure MTBF (hr)	9.2

Maintainability in Table 10 is obtained from

$$M = 1 - e^{-\mu t} = 1 - e^{-t/MTTR} \quad (2.4)$$

Where  $t$  = time allowed for maintenance action

$$\mu = \text{repair rate} = 1/MTTR$$

**Table 10: System Downtime Analysis**

Total maintenance action time (hr)		30008
Number of maintenance actions		295
Meantime of maintenance action (hr)	$\phi$	102
Maintenance action rate	$\mu$	0.010
Maintainability	$M$	1.00



**Plant Operational Availability improvement options:**

Since the machine design reliability of 0.99 cannot be exceeded, the company has no other option than to work in the meantime to repair which currently stands at 102 hours. This involves reducing the MDT to 12 hours obtained as follows and distributed per component as shown in Table 3.1. The component's reliability specification of the machines is 0.99 over an 8-hour production run i.e. 90 per cent reliability for a system in series configuration [8]. The mean time between failure (MTBF) that offers a guide on preventive maintenance interval is then obtained as follows:

$$R(8) = \exp(-8/MTBF) = 0.90$$

$$1/MTBF = -\ln(0.90)/8 = 0.013170064$$

$$MTBF = 75.9 \text{ hours}$$

One of the reasons adduced for low capacity utilization includes the dearth of cup-lump. Hence the maintenance plan is based on the 4-ton per hour processing line which is one of the three 8-8-4 tons per hour processing lines. This line can reliably be fed from the 5000 hectares of rubber plantation owned by the company with an estimated production of 8,322 tons per annum. 87% of this processing line demand of 9,600 tons per annum is therefore guaranteed. The desired operation availability of the processing line is therefore put at 87% to yield a mean downtime MDT of 12 hours as follows:

$$A_o = \frac{MTBF}{MTBF + MDT}$$

$$0.87 = \frac{75.9}{75.9 + x}$$

$$0.87(75.9 + x) = 75.9$$

$$x = \frac{75.9 - 66.031}{0.87} = 12 \text{ hrs}$$

Where  $x = MDT = 12 \text{ hours}$

The high MDT of 102 hours reported by record indicates that conditional monitoring and preventive actions may not have been strictly followed thereby necessitating more breakdown maintenance than preventive actions. Hence, a 76-hour preventive maintenance strategy is recommended to achieve 87% operational system availability backed by 12-hour corrective maintenance to be based on condition monitoring and routine inspection. Corrective maintenance will be composed of repair, replacement or restore activities after the occurrence of a failure to eliminate the source of the failure or to reduce the frequency of occurrence while preventive maintenance is responsible for cleaning the equipment, lubrication to prevent wear, programmed replacement and also indirectly deals with condition monitoring, failure statistics and adjustments to limit wear. In fault elimination the steps taken can be adjusting, aligning, calibration, reworking, removing, replacing or renovation. Corrective maintenance demands effective planning of spare inventory and trained personnel. The allocation of MDT per equipment is shown in Table 11.

Table 11: Allocation of recommended MDT

Equipment	MDT	MDT Required (hr)
Slab cutter	89.6	0.9
Pre-breaker	142	1.5
Extruder 1	109	1.1
Extruder 2	102	1.1
Macerator	92	1.0
Creeper 1	91	1.0
Creeper 2	118	1.2
Creeper 3	121	1.3
Shredder	76	0.8
Dryer	100	1.1
Press	63	0.7
Total	1104	11.7





## CONCLUSION

The factory has a lot of machines and equipment found in modern rubber milling factories. The potential of the factory is huge and if well managed will be one of the leading rubber factories in Nigeria. The plant's state of health is not in doubt with minimal rehabilitation and infusion of the fund to procure and install a few missing gadgets and renew others. Both preventive and corrective maintenance, based on characteristic life curve and mean downtime respectively will ensure that the envisaged operational availability of the plant is achieved. The competitive edge of the plant, therefore, depends on the competence and diligence of the management team in implementing the maintenance strategy developed.

## RECOMMENDATIONS

Managing by best Practice Demonstrated (MPD) would improve the plant's operational performance to the global benchmark shown in Table 4. The envisaged mean time to repair is achieved by hiring additional maintenance persons, increasing machine spare inventory, relocating the inventory closer to the plant, improving condition monitoring procedures and simplifying the removal and replacement of high-failure components thereby achieving the desired equipment operational availability goal. The other two 8-tons processing lines are recommended for streaming when the raw material supply situation improves. Routine inspection, cleaning and lubrication are necessary to mitigate corrosion and stem system deterioration.

## REFERENCES

- [1] Nwachukwu J. (2000), *Introduction to Maintenance and Reliability*, Ambik Press Ltd, p. 49
- [2] Kinnison H. and Siddiqui T. (2013), *Aviation Maintenance Management*, McGraw Hill Education (India) Private Limited, p. 3
- [3] Banga T. and Sharma S. (2010), *Industrial Engineering and Management*, Khanna Publishers, p 946
- [4] Basu S, Sahu k. and Datta N. (1997), *Works Organization and Management*, Mohan Prmlani Oxford & IBH Publishing Co. Pvt. Ltd, p. 291
- [5] Benbow D and Broome H., (2009) *The Certified Reliability Engineer Handbook*, ASQ Quality Press the US, p. 191
- [6] Pandey O. and Aneja B. (2012) *Reliability Engineering*, S. K. Kataria & Sons Publishers, p. 183
- [7] Gupta A. (2015), *Reliability, Maintenance and Safety Engineering*, University Science Press, New Delhi, p. 265
- [8] Ebeling C. (2015), *An Introduction to Reliability and Maintainability Engineering*, McGraw Hill Education (India) Private Limited, p. 85