GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL 14, NO. 1, 2008: 135 - 145

 ISSN 1118-0579

SIMULATION OF A PRODUCTION LINE SYSTEM WITH MACHINE BREAKDOWNS USING PERT NETWORK MODELLING

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(Received 13 September 2006; Revision Accepted 19 June 2007)

ABSTRACT

The Mathematical analysis of production system that includes machine failure is often very complex, cumbersome and usually difficult to carry out. Therefore, it is necessary to develop a simplified and straightforward model in which machine failure is analyzed within the context of a realistic production line system, containing numerous machines with multiple lines. In this study, a model of palm oil production line owned by Risonpalm is developed and simulated, hence the data used in the analysis were obtained from a palm oil mill. The approach was to define the problem evaluating data, developing and determining relationship between variables by incorporating the Project Evaluation and Renew Technique (PERT). A modified version of the well known renewal theory model adopted by Jardine was implored for the analysis of a simulation problem is used to achieve the set goal. A demonstration of how the model can be used to determine the effect of changes in machine repair times, and failure rates is presented. The goal is to determine the best machine maintenance schedule in order to assist the Company to achieve increased productivity.

Following a detailed analysis of the machine utilization process of the Company on improved maintenance schedule enhance effective capacity utilization, which could minimize down time and enhance effective capacity utilization was proposed

KEYWORDS: Palm oil production line, machine repair times, Renewal theory, Simulation.

1.0 INTRODUCTION

Cleland and King (1978) viewed that the systems theory expresses the importance of considering objects as composed of interrelated and inter acting parts in such a manner that they form a discernable whole and tend to achieve common objectives. The processing units are analyzed individually and the effect of each on the total system considered.

Wild (1980) stated that "for a continuous production system, the emphasis is on production planning not control".

The production operations of the Oil Mill are a continuous system and therefore is well suited for this study, using planning technique such as project evaluation and review technique,(PERT).

Groff and Muth (1972) argued that the economic design for reliability requires not only information about ways in which system reliability may be increased, but also, information about the economic effects (usually cost) of such alternatives. Horst (1976) described maintenance as the activities that fight defects in existing equipment without changing the design of the equipment and this comprise lubrication, looking for defects, cleaning and repair. The focus for maintaining system reliability related to machine failure is to enhance repair facility in order to reduce machine down time. Corder (1979), stated that, "Downtime is referred to as the period during which a facility is not ready for use and this could be caused by overloading, unsuitable materials, bad machine operation, incorrect machine setting, insufficient maintenance, inferior maintenance standards, lack of spare parts, absence of adequate technical information from the manufacturer's to enable maintenance and operational adjustments to be carried out properly".

The economic life-span of oil-palm tree is 25 to 30 years and it is a source of stable food item (richest in vitamin E) to the entire black world, (Hartley, 1977). This palm oil mill sources for its raw materials locally and the raw material is basically the oil palm fruit. Nwanze (1987) stated that Nigeria needs 1.2 million metric tons of palm oil a year, but that not even half of this amount is produced yearly. Apart from being the richest source of vitamin E, numerous uses of palm oil include, ice cream, animal feed, bakery and biscuits, margarine, candles, soaps and detergents as recorded in RISONPALM news bulletin.

Ejemba (1989) observed that the distribution of oil-palm growth ranges between latitudes 4°N and 11°N, from the fresh water swamp of the coast to the fringes of Guinea savannah. There are basically two types of oil palm trees, the Tenera, which bears fruits after one or two years of cultivation and Dura, which takes seven to eleven years to produce fruits. It is obvious that where the efficiency and growth of a company whose products and by-products are so useful is improved, the desired industrialization for our country will be further enhanced.

Clayton et al (1982) developed and simulated a network model of a complex production line consisting of several assembly lines each containing several machines. According to the author, in a manufacturing system, several factors can affect the reliability of the system in producing expected output levels, such factors include resources input levels, labour rate variability, product quality and machine failures. The primary focus was the effect of machine breakdown in system output. Network modeling and simulation with Q-Gert Package were the vehicles of analysis employed. An example of how the simulation model can be used to test changes in machines repair times and breakdown rates were presented

Hess and Quigley (1963) have used simulation techniques in examining the problem of management decisions in the face of uncertainty. The system can be represented analytically or in form of a black box. Typically illustrations of the analytical model are found in the chemical-process systems described by Williams and Otto (1961) and by Guiness (1951). The later type has been discussed in detail and used in optimization by D-Bella and Stevens (1965) with a rate-of-return objective.

Case et al (1978) described simulation as the process of conducting experiments on a model of a system in lieu of either direct experimentation with the system itself or direct analytical solution of some problems associated with the system.

The purpose is to observe the behaviour of a system under varying conditions or to gain an understanding of the relationships between components of a system.

Fernandes and Johnson (1978) outlined the application of a GPSS computer simulation model to the maintenance of aircraft engines in TAP, the Portuguese

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National Airline. The author stated that "the engines pass through the cycle of: In service, maintenance, in stock, and eventual return to service. Doering and Lin (1979) developed a model which was used to simulate a complex energy plant so that more information could be provided for the dispatcher to enable a better understanding of the plant, and make more cost effective decisions under different plant conditions. The paper argued that, in most cases, operating decisions were made by a control room dispatcher on the basis of empirical data, machine efficiency calculations and or trial and error method.

Vander Henst (1978) described a computer simulation procedure for improving the efficiency of an existing multi-product transfer line. The transfer line consists of three independent stage and behind each stage, buffer stock and in-process stocks can be built up. The computer program simulates a production program for a given period of time and takes into account change over, tool change and maintenance characteristics.

Lake et al (1979) described a model for the replacement of a particular type of machine. And in order to predict the effect of this in terms of the machine's case, a simulation model is developed. The results from the replacement in terms of their sensitivity to the variability in the estimates required by the mode were presented.

Case et al (1978) simulated the performance of a machine-repair man system for a period of ten hours. Firstly, the simulation was performed with one repair man and the resulting total costs measured, then two repairmen were used and again the resulting total cost measured and so on.

Jardine (1973) suggested ways in which the concept of optimization, through the constructions and solution of mathematical models could be brought to bear on the resolution of decision making problems associated with the maintenance, replacement and reliability of equipment. To achieve this, he constructed a number of mathematical models including that of optimal preventive replacement interval, subject to breakdown with an objective to minimize down time per unit time. Simulation was conducted by applying the total downtime equation to determine the optimal downtime in order to reduce machine idle time.

Elsayed (1981) considered two repair polices for the machine interference problem where machines have two failure modes. In policy (i) priority of repair is assigned to one failure mode over the other while in policy (ii) the two failure modes have equal probability of repair.

Sculi and Suraweera (1979) determine age limits for preventive replacements and overhauls in tramcar maintenance where opportunities are provided by a failed component or an essential overhaul. Two-pair-wise sub-optimal preventive replacement policies were considered.

METHODOLOGY

A modified version of the renewal theory model as adopted by Jardine (1973) was used to conduct the simulation. Whereas Jardine applied one specific value of failure or preventive repair time in the model equation to determine the optimal down time, multiple failure or preventive repair times have been assessed by incorporating the concept of PERT into the model. PERT Stands for Project Evaluation and Review Techniques, and its criteria of optimistic time, pessimistic time and most likely time are used in the simulation. This approach better suits the system under study because of the uncertainty associated with the length of equipment repair times and it is also attractive and simple to apply in the simulation of data gathered.

According to Case et al (1978), Simulation is one of the most powerful analysis and design tools available to the Industrial Engineer in that where a mathematical problem is so complex and using strictly analytical techniques make the solution impractical, simulation could be employed to bring about possible results hence it is applied to address the equipment maintenance management problems of the company under investigation.

One major problem with simulation is that it is time consuming and the decisions as to how many "runs" should be made is difficult since it is only after a sufficiently large number of runs are made that the "steady state" is reached, hence the renewal theory is used here to offset this difficulty.

The major advantage of the renewal approach, is that, the expected number of failure in stipulated intervals could very easily be determined and used to compute the optimal preventive maintenance periods. With the determination of the expected number of failures, the number of iterations or simulation "runs" could be conceived and conducted even mutually where there are no computers due to the limited "runs". The probability of failure is incorporated in the renewal theory so there is no need to generate random numbers.

The renewal theory, even as the name implies, assumes that an ageing or broken down (failed) equipment can be restored to its about as "new state" and perform its functional duty.

The assumptions for the model are:

(1) That it is impossible to predict with certainty when a failure will occur or more generally when the transition from one state of the equipment to another will occur.

(2) That there are two possible conditions of the equipment, good and failed and that the actual condition is always known.

(3) That the replacement actions return the equipment to the *"as new condition"*, and that the failure distribution used in the analysis are always the same. The exception to this assumption will be the problem where technological improvement of equipment is taken into account in the model.

(4) That the failure rate of the equipment must be increasing.

DETERMINATION OF THE EXPECTED NUMBER OF FAILURES, (H(t), IN AN INTERVAL OF LENGTH, tp.

THE RENEWAL THEORY APPROACH AS ADOPTED BY JARDINE (1973).

In general;

$$H[T] = \sum_{i=0}^{T-1} (1 + H(T - i - 1)) \int_{i}^{i+1} f(t)dt; \quad T \geq 1 \qquad \text{Eqn. 1}$$

With H(0) = 0, the above equation is termed a recurrence relation.
H(1), (H2), (H3), and H(4) can be determined from equation (1).

The failure distribution is found to be a normal distribution because according to Jardine (1973), there is an increasing likelihood of failure as the component gets older. A failure pattern of this type indicates that the primary cause of failure is age-related and due to mechanisms such as abrasion, corrosion and fatigue. Furthermore, Jardine (1973) stated that when the shape parameter in the density function is greater than one, Weibull failure distribution pattern approximates to the normal distribution. Prenreinchi (1940) stated that for components of vegetable oil producing equipment, the Weibull beta value (shape parameter) is (3) for components that are wearing,(3) for those that are Aging, (1) for those that are loosening and (2) for components that are corroding, hence the failure distribution pattern is taken to be normal distribution. The expected number of failures can be calculated by integrating the area under the normal distribution curve and the probability density function for normal distribution as stated by Jardine (1973) as:

$$F(t) = 1/(\sigma\sqrt{2\pi})\ \exp[(-t-\mu)^2/2\sigma^2] \quad \text{..(A)}$$

Where *for normal distribution failure pattern, standard deviation, σ is one (1) and the mean of the distribution ,μ is five(5),the* distribution function is:

$$\int_0^1 f(t)\,dt = 1/(\sqrt{2\pi})\int_0^1 \exp\left[(-t-5)^2/2\right]dt \quad \text{(B)}$$

The distribution function of the standard normal distribution whose mean is 0 and standard deviation 1 as given by Jardine (1973) as:

$$\Phi(t) = 1/(\sqrt{2\pi})\int_0^1 \exp[(-t)^2/2]dt = \Phi(1-0) = \Phi(1) \quad \text{(C)}$$

The cumulative density function of the standard distribution whose mean is 5 and standard deviation 1 was given by Jardine (1973) as:

$$\Phi(t) = (1/\sqrt{2\pi})\int_0^1 \exp[-(t-5)^2/2]dt = \Phi(1-5) = \Phi(-4) \quad \text{(D)}$$

The determination of the expected number of failures in week one would be:

$$H(1) = [1+H(0)]\int_0^1 f(t)\,dt$$

Substituting the cumulative density function into the above equation gives:

$$H(1) = [1+H(0)]\ 1/(\sqrt{2\pi})\int_0^1 \exp[-t-5)^2/2]dt$$

$$= [1+H(0)]\ \Phi[1-5]$$

$$= [1+H(0)]\Phi[-4];$$

and Φ [-4] = 0 (Jardine, 1973).

H(1) = [1+H(0)] x 0

H(1) = [1 + 0] x 0

H(1) = 0

$$H(2) = [1+H(1)]\ (1/\sqrt{2\pi})\int_0^1 \exp[-(t-5)^2/2]dt + [1+H(0)](2\pi\int_1^2 \exp[-(t-5)^2/2)dt$$

H(2) = [1+0]0+[(1+0) Φ[-3] – Φ(-4)]

and

Φ[-3] = [0.0014], Jardine (1973).

So:

H[2] = [1+0]0+[1+0]0.0014

= 0.0014

F(t) = N(5.1) refers to the cumulative density function of the standard normal distribution whose mean is 5 and standard deviation 1 ,Davies et al, (1972). By applying the values of the proportic ı of the whole area corresponding to the different values of the mean into equation (1) gives the calculated values of H(3), H(4), H(5) and H(6) which are:

H(3) = 0.02418

H(4) = 0.18674

H(5) = 0.49980

H(6) = 0.84490

Applying Jardine's model equation, the total downtime per unit time, for preventive replacement at time t_p, denoted by D(tp), is given as:

$$D(t_p) = \frac{Expected\ \text{down time due to failure} + \text{Downtime due to preventive replacement.}}{\text{Cycle Length}}$$

$$= \frac{H(t)T_f + T_p}{t_p + T_p} \quad \text{.......................................Eqn 2}$$

where T_f = Downtime required to make a failure replacement

and T_p = Downtime required to make a preventive replacement.

TABLE 1: RAW MAINTENANCE REPAIR TIMES AND FAILURE INTERVALS DATA

	Down required to make a failure replacement(Tf)					Down time required to make preventive replacement(Tp)					Frequency of failures		
Process Unit	MIN	MAX	MOST LIKELY	AVE	STAN. DEV	MIN	MAX	MOST LIKELY	AVE	STAN. DEV	MIN	MAX	MOST LIKELY
1	2.00	8.00	3.42	3.947	1.000	0.16	1.30	0.75	0.743	0.190	WEEKLY	3MOHTLY	MONTHLY
2	8.00	120.00	32.00	42.667	18.667	1.00	16.0	3.00	4.833	2.500	4MONTHLY	YEARLY	8MONTHLY
3	2.00	5.00	4.00	3.833	0.500	0.50	1.30	1.00	0.966	0.133	4 MONTHLY	6MONTHLY	5 MONTHLY
4	2.00	8.00	3.42	3.947	1.000	0.16	1.30	0.75	0.743	0.190	MONTHLY	6MONTHLY	3MONTHLY
5	1.00	4.00	2.00	3.600	0.500	0.33	1.00	0.75	0.722	0.112	WEEKLY	8WEEKLY	3WEEKLY
6	0.75	32.00	6.00	0.458	5.208	0.25	1.50	0.33	0.512	0.208	6 MONTHLY	YEARLY	8 MONTHLY
7	8.00	96.00	48.00	49.333	14.667	4.00	48.0	24.00	24.66	7.333	3 MONTHLY	6 MONTHLY	4 MONTHLY
8	6.00	48.00	12.00	17.00	7.000	0.50	16.00	3.00	4.750	2.583	MONTHLY	2MONTHLY	5WEEKLY
9	1.00	4.00	2.00	2.166	0.500	0.33	1.00	0.75	0.722	0.112	WEEKLY	MONTHLY	2WEEKLY
10	1.00	4.00	2.00	2.166	0.500	0.25	1.50	0.33	0.512	0.208	WEEKLY	2MONTHLY	MONTHLY
11	0.75	32.00	6.00	9.458	5.208	0.33	8.00	0.50	1.722	1.278	WEEKLY	3MONTHLY	5WEEKLY
12	0.75	8.00	4.00	4.125	1.208	0.33	3.00	1.50	1.555	0.445	MONTHLY	3MONTHLY	2MONTHLY
13	4.00	8.00	5.00	5.333	0.667	1.25	2.50	1.50	1.625	0.208	WEEKLY	4MONTHLY	MONTHLY

KEY

NO	PROCESS UNITS	NO	PROCESS UNITS
1. -	STERILIZER	10 -	ROTATING BRUSH
2. -	BUNCH FEEDER	11 -	DECANTER
3. -	THRESHER	12 -	DESANDING
4. -	FRUIT WASH	-	CYCLONE
5. -	LOOSE FRUIT ELEVATOR	13 -	ALFA LAVAL
6. -	LOOSE FRUIT DISTRIBUTOR		
7. -	DIGESTER		
8. -	PRESS		
9. -	CRUDE OIL VIBRATING SCREEN		

The values of the repair time contained in Table 1 (in hours) have been converted from hours to weeks or months before being plowed into the D(tp) equation along with the calculated $H(t_p)$ as shown below to run the simulation for each process unit to obtain table 2. In table 3 the conversion is redone to return the values back to hours. The essence of this initial conversion from hours to weeks or months was because of the small hourly units which if not converted to weeks or months would have made it difficult to evaluate the model equation hence after the results are obtained a re-conversion to hours is done.

Sample Calculation.

Applying equation (2) to compute the failure distribution values based on minimum, maximum and most likely failure rates vis-à-vis the failure normal distribution pattern of mean equals five(5) and standard deviation equals one(1), Six iterations labeled D1,D2....D6 are calculated

Sterilizer:

MINIMUM VALUES: $D(1)= \dfrac{H(t)T_f + T_p}{t_p + T_p} = \dfrac{0X0.016+0.001333}{1+0.001333} = 0.001328$

MAXIMUM VALUES: $D(1)= \dfrac{H(t)T_f + T_p}{t_p + T_p} = \dfrac{0X0.066+0.01083}{1+0.01083} = 0.010714$

MOST LIKELY VALUES: $D(1)= \dfrac{H(t)T_f + T_p}{t_p + T_p} = \dfrac{0X0.0285+0.006}{1+0.006} = 0.006211$

$D(t_p)= \dfrac{H(t)T_f + T_p}{t_p + T_p}$	Minimum Values	Maximum Values	Most Likely Values
	0.001328	0.010714	0.006211
	0.000676	0.005432	0.003135
	0.000457	0.003651	0.002102

D(4)	=	0.001110	0.005801	0.002889
D(5)	=	0.001931	0.008804	0.004094
D(6)	=	0.014298	0.011163	0.005050

The optimal down time due to preventive maintenance values of all the process units are contained in Table 2. The pint of optimality is when t_p is 3 weeks (D3) with a corresponding optimal down time due to preventive maintenance of 0.000457, 0.003651 and 0.002102 weeks for minimum, maximum and most likely repair times respectively.
The weighted average repair times and standard deviation of each production equipment is calculated, using PERT analysis method. These are recorded in Table 1.

Sample Calculation:

Let t_o = Optimistic time (minimum time)

t_m = Most likely time

t_p = Pessimistic time (maximum time)

t_o = Expected (weighted average) time

t_e = (to + 4m + tp)/6 (Case et al, 1978) ....Eqn. 4

Applying the values of the above defined parameters on Table 1 into the t_e equation gives:

For the sterilizer,

t_oF = (8 + (4 x 3.42) + 2)/6 = 3.947

t_eP = (1.30 + (4 x 0.75) + 0.16)/6 = 0.743

where $t_{ef}F$ and $t_{ep}P$ mean expected repair times due to failure and expected repair times due to preventive respectively.

The Standard deviation which is the variability or spread of the probability density function underlying the different repair times is also determined and it is given by the equation:

S_t = $(t_o - t_p)/6$ (Case et al, 1978) .... Eqn. 5

For the sterilizer, the standard deviation due to failure replacement, S_{tf}, and the standard deviation due to preventive replacement, S_{tp}, are given below respectively:

S_{tf} = (8 – 2)/6 = 1.00

S_{tp} = (1.30 – 0.16)/6 = 0.190

The values of t_{ef}, t_{ep}, S_{tf} are also recorded in Table 1 and both the values of t_{ef} and t_{fp} are applied into the simulation model to obtain Table 2.

TABLE 2: CONVERSION OF REPAIR TIMES FROM HOURS TO WEEKS OR MONTHS AND DETERMINATION OF OPTIMAL DOWN TIME DUE TO PREVENTIVE MAINTENANCE

(A)

	UNITS CONVER.	TP MIN	TF MIN	D(tp)						OPTIMAL DOWN TIME (ODTp)	TF-ODTp
PROCESS UNITS	TO		H(tp)	0.000000	0.001400	0.024180	0.186740	0.499800	0.844900		
STERILIZER	WEEKS	0.00133	0.01666	0.001328	0.000676	0.000457	0.001110	0.001931	0.014298	0.000457	0.01620
BUNCH FEEDER	MONTHS	0.00208	0.01666	0.002076	0.001051	0.000706	0.001297	0.002080	0.014423	0.000706	0.01595
THRESHER	MONTHS	0.00104	0.00417	0.001039	0.000523	0.000350	0.000455	0.000625	0.003697	0.000350	0.00382
FRUIT WASH	WEEKS	0.00133	0.01666	0.001328	0.000676	0.00457	0.001110	0.001931	0.014298	0.000457	0.01620
LOOSE FRUIT ELEVATOR	WEEKS	0.00277	0.00833	0.002762	0.001389	0.000929	0.001081	0.001386	0.007499	0.000929	0.00740
LOOSE FRUIT DISTRIBUTOR	WEEKS	0.00208	0.00625	0.002076	0.001043	0.000698	0.000811	0.001040	0.005627	0.000698	0.00555
DIGESTER	MONTHS	0.00833	0.01660	0.008261	0.004159	0.002782	0.002852	0.003320	0.015412	0.002782	0.01382
PRESS	WEEKS	0.00416	0.06660	0.004143	0.002122	0.001438	0.004117	0.007423	0.056456	0.001438	0.064456
CRUDE OIL VIB SCREEN	WEEKS	0.00277	0.00833	0.002762	0.001389	0.000929	0.001081	0.001386	0.007499	0.000929	0.00740
ROTATING BRUSH	WEEKS	O.00208	0.00833	0.002076	0.001045	0.000700	0.000908	0.001248	0.007385	0.000700	0.00763
DECANTER	WEEKS	0.00097	0.00625	0.000969	0.000489	0.00328	0.000534	0.000819	0.005442	0.000328	0.00592
DESANDING CYCLONE	WEEKS	0.00275	0.00625	0.002742	0.001377	0.000921	0.000979	0.001174	0.005739	0.000921	0.00533
ALFA LAVAL	WEEKS	0.01041	0.03330	0.010303	0.005201	0.003485	0.004146	0.005399	0.029867	0.003485	0.2982

(B)

	UNITS CONVER.	TP MAX	TF MAX	D(tp)						OPTIMAL DOWN TIME (ODTp)	TF-ODTp
PROCESS UNITS	TO		H(tp)	0.000000	0.001400	0.024180	0.186740	0.499800	0.844900		
STERILIZER	WEEKS	0.01083	0.06660	0.010714	0.005432	0.005801	0.008804	0.011163	0.003651	0.003651	0.06295
BUNCH FEEDER	MONTHS	0.03330	0.25000	0.32227	0.016549	0.011177	0.019831	0.031441	0.040529	0.011177	0.23882
THRESHER	MONTHS	0.00313	0.01040	0.003115	0.001567	0.001049	0.001266	0.001664	0.001984	0.001049	0.00935
FRUIT WASH	WEEKS	0.01083	0.06660	0.10714	0.005432	0.003651	0.005801	0.008804	0.011163	0.003651	0.06295
LOOSE FRUIT ELEVATOR	WEEKS	0.00833	0.03330	0.008261	0.004171	0.002796	0.003630	0.004986	0.006069	0.002796	0.03050
LOOSE FRUIT DISTRIBUTOR	WEEKS	0.1250	0.26600	0.12346	0.006396	0.004363	0.015495	0.029017	0.039458	0.004363	0.26164
DIGESTER	MONTHS	0.10000	0.20000	0.090909	0.047752	0.032414	0.033500	0.039208	0.04095	0.032414	0.16759
PRESS	WEEKS	0.13300	0.40000	0.117387	0.062616	0.042760	0.050253	0.064859	0.076791	0.042760	0.35724
CRUDE OIL VIB SCREEN	WEEKS	0.00833	0.03330	0.008261	0.004171	0.002796	0.003630	0.004986	0.006069	0.002796	0.03050
ROTATING BRUSH	WEEKS	0.01250	0.03330	0.012346	0.006234	0.004176	0.004665	0.005814	0.006758	0.004176	0.02912
DECANTER	WEEKS	0.06600	0.26600	0.061914	0.032126	0.021736	0.028449	0.039271	0.047930	0.021736	0.24426
DESANDING CYCLONE	WEEKS	0.02500	0.06660	0.024390	0.012392	0.008318	0.009301	0.011599	0.013489	0.008318	0.05828
ALFA LAVAL	WEEKS	0.02080	0.06660	0.020376	0.010339	0.006939	0.008266	0.010773	0.012801	0.006939	0.05966

TABLE 2 C

	UNITS CONVER.	TP MOST LIKELY	TF MOST LIKELY	D(tp)						OPTIMAL DOWN TIME (ODTp)	TF-ODTp
PROCESS UNITS	TO		H(tp)	0.000000	0.001400	0.024180	0.186740	0.499800	0.844900	(ODTp)	
STERILIZER	WEEKS	0.00625	0.02850	0.006211	0.003135	0.002102	0.002889	0.004094	0.005050	0.002102	0.02640
BUNCH FEEDER	MONTHS	0.00625	0.06660	0.006211	0.003162	0.002133	0.004664	0.007897	0.010409	0.002133	0.06447
THRESHER	MONTHS	0.00208	0.00833	0.002076	0.001045	0.000700	0.000908	0.001248	0.001519	0.000700	0.00763
FRUIT WASH	WEEKS	0.00625	0.02850	0.006211	0.003135	0.002102	0.002889	0.004094	0.005050	0.002102	0.02640
LOOSE FRUIT ELEVATOR	WEEKS	0.00526	0.01666	0.006211	0.003127	0.002092	0.002337	0.002912	0.003384	0.002092	0.01457
LOOSE FRUIT DISTRIBUTOR	WEEKS	0.00277	0.05000	0.002762	0.001418	0.000963	0.003025	0.005549	0.007499	0.000963	0.04904
DIGESTER	MONTHS	0.05000	0.010000	0.047619	0.024459	0.016473	0.016957	0.019798	0.022230	0.016473	0.08353
PRESS	WEEKS	0.02500	0.010000	0.024390	0.012315	0.008344	0.010851	0.014921	0.018173	0.008344	0.09166
CRUDE OIL VIB SCREEN	WEEKS	0.00625	0.01666	0.006211	0.003127	0.002092	0.002337	0.002912	0.003384	0.002092	0.01457
ROTATING BRUSH	WEEKS	0.00277	0.01666	0.002762	0.001395	0.000936	0.001469	0.002218	0.002806	0.000936	0.01572
DECANTER	WEEKS	0.00417	0.05000	0.004149	0.002114	0.001427	0.003372	0.005826	0.007730	0.001427	0.04857
DESANDING CYCLONE	WEEKS	0.01250	0.003330	0.012346	0.006234	0.004176	0.004665	0.005814	0.006758	0.004176	0.02912
ALFA LAVAL	WEEKS	0.01250	0.04166	0.012346	0.006240	0.004183	0.005054	0.006648	0.007933	0.004183	0.03748

	UNITS CONVER.	TeP	teF	D(tp)						OPTIMAL DOWN TIME	teF-ODteP
PROCESS UNITS	TO		H(tp)	0.000000	0.001400	0.024180	0.186740	0.499800	0.844900	(OdteP	
STERILIZER	WEEKS	0.00619	0.03289	0.006154	0.003109	0.002086	0.003079	0.004521	0.005658	0.002086	0.03081
BUNCH FEEDER	MONTHS	0.01007	0.08889	0.009968	0.005071	0.003416	0.006650	0.010877	0.014171	0.003416	0.08547
THRESHER	MONTHS	0.00201	0.00799	0.002006	0.001011	0.000677	0.000875	0.001200	0.001459	0.000677	0.00731
FRUIT WASH	WEEKS	0.00619	0.03289	0.006154	0.003109	0.002086	0.003079	0.004521	0.005658	0.002086	0.03081
LOOSE FRUIT ELEVATOR	WEEKS	0.00602	0.02917	0.005981	0.003020	0.002025	0.002862	0.004114	0.005105	0.002025	0.02714
LOOSE FRUIT DISTRIBUTOR	WEEKS	0.00427	0.07682	0.004249	0.002184	0.001484	0.004741	0.008724	0.011801	0.001484	0.07733
DIGESTER	MONTHS	0.05139	0.10278	0.048876	0.025120	0.016922	0.017421	0.020342	0.022842	0.016922	0.08585
PRESS	WEEKS	0.03964	0.014'67	0.038130	0.019533	0.013154	0.016362	0.21916	0.026382	0.013154	0.12851
CRUDE OIL VIB SCREEN	WEEKS	0.00602	0.01805	0.005981	0.003012	0.002016	0.002343	0.003004	0.003541	0.002016	0.01603
ROTATING BRUSH	WEEKS	0.00427	0.01805	0.004249	0.002141	0.001435	0.001907	0.002655	0.003251	0.001435	0.01662
DECANTER	WEEKS	0.01435	0.07882	0.014147	0.007179	0.04824	0.007241	0.010716	0.013458	0.004824	0.07399
DESANDING CYCLONE	WEEKS	0.01296	0.03438	0.012793	0.006461	0.004328	0.004829	0.006012	0.006985	0.004328	0.03005
ALFA LAVAL	WEEKS	0.01354	0.04444	0.013361	0.006756	0.005429	0.005442	0.007131	0.008496	0.004529	0.03991

TABLE 3: CONVERSION OF THE DOWNTIME PER UNIT TIME DUE TO FAILURE MAINTENANCE MINUS OPTIMAL DOWN TIME PER UNIT TIME DUE TO PREVNETIVE MAINTENANCE FROM WEEKS OR MONTHS TO HOURS.

PROCESS	UNIT Converted from	Conversion to hours Failure – Preventive (T_r – ODTp) (hours)			Weekly Probable Number of Failures in a Year.		
		Min Likely	Max	Most	Min	Max	Most Likely
Sterilizer	Week	1.94	7.554	3.168	52	4	12
Bunch Feeder	Month	7.656	114.60	30.950	3	1	-1
Thresher	Month	1.834	4.488	3.662	3	2	-2
Fruit Wash	Week	1.944	7.944	3.168	12	2	4
Loose Fruit Elevator	Week	0.888	3.660	1.748	52	6	17
Loose Fruit Distributor	Week	2.664	31.400	5.885	2	1	-1
Digester	Month	6.634	80.443	40.094	4	2	3
Press	Week	7.747	42.900	10.999	12	10	-10
Crude Oil Vibrating Screen	Week	0.888	3.66	1.748	52	12	26
Rotating Brush	Week	0.710	29.311	5.828	52	4	10
Decanter	Week	0.710	29.311	5.828	52	4	10
Desanding Cyclone	Week	0.640	6.994	3.494	12	4	6
Alfa Laval	Week	3.578	7.160	4.498	52	3	12

Using one year as a basis, the total downtime is obtained by multiplying the individual process units optimal downtime by the number of failures in a year and this is recorded in Table 5 as total downtime from simulation results.

In order to arrive at the total downtime of the two process lines for a period of one year, it would have been necessary to calculate statistically "line 1 combination line 2", if the repair times and failure rates were different. This is not the case, hence a mere addition of the number of units of each individual production component of the two lines are used to calculate the total downtime.

TABLE 4: TOTAL DOWN TIME MINIMIZATION DUE TO PREVENTIVE AINTENANCE

(A)

UNIT	NO OF UNITS	MINIMUM FAILURES HOURS			MAXIMUM FAILURES HOURS			MOST LIKELY FAILURES		
		REP. TIME MIN. HRS	REP. TIME MAX. HRS	REP. TIME MOST LIKELY	REP. TIME MIN.	REP. TIME MAX	REP. TIME MIN. LIKELY	REP. TIME MIN. LIKELY	REP. TIME MOST HRS	REP. TIME MIN. HRS
STERILIZER	4	403.52	1571.552	658.944	13.04	120.864	50.688	93.120	152.064	13.040
BUNCH FEEDER	2	45.936	687.600	185.700	15.312	229.200	61.900	15.312	61.900	15.312
THRESHER	2	11.802	11.802	26.928	21.972	13.430	17.952	14.648	13.430	13.430
FRUIT WASH	2	46.656	380.640	76.032	7.776	30.126	12.672	15.552	25.344	7.776
LOOSE FRUIT ELEVATOR	2	92.352	380.640	181.792	10.656	43.920	20.276	30.192	59.432	10.656
LOOSE FRUIT DISTRIBUTOR	2	28.388	125.600	23.540	5.328	62.800	11.770	5.328	11.770	5.328
DIGESTER	4	106.144	1287.088	641.504	53.072	643.544	641.504	79.600	481.128	53.072
PRESS	4	371.856	2059.200	527.792	309.88	1716.000	439.968	69.976	87.992	309.88
CRUDE OIL VIBRATING SCREEN	2	92.352	2380.640	181.792	181.926	87.840	41.952	46.176	90.896	18.926
ROTATING BRUSH	2	95.624	363.376	196.144	21.312	87.842	20.952	21.984	90.792	21.312
DECANTER	4	73.84	3048.344	606.112	5.680	234.488	46.624	14.200	116.560	5.680
DESANDING CYCLONE	2	15.36	167.856	83.856	5.12	55.592	27.952	7.680	41.928	5.12
ALFA LAVAL	2	372.112	744.642	467.792	21.868	42.96	26.988	85.872	107.952	21.866

Alternatives for maintaining system reliability related to machine failure include enhancing the repair facility in order to reduce machine down time and utilization of preventive maintenance policies to avoid failure. The results of the simulation for a period of machine failures, the effect of changes in machine failure rates and repair times were analyzed unit by unit and comparison drawn between failure repair policies and preventive maintenance policies in order to reduce machine downtime.

Sterilizer Unit: An analysis of the failure repair times and preventive repair times per unit time in terms of whether such times were minimum, maximum or most likely was carried out by plugging these values into the model equation. The results show that; the downtime of this unit may be minimized per unit time by 1.9540hrs, 7.554hours and 3.168hours for minimum, maximum and most likely repair times respectively.

Bunch Feeder: A predicted preventive maintenance interval of three months was obtained from the simulation runs based on the failure repair times and preventive repair times and this is contained in Table 2. The difference in hours between down time per unit time due to failure repairs and due to preventive repairs for minimum, maximum and most likely repair times were 7.656 hours, 114.600 hours and 30.950 hours respectively as shown in Table 2.
Assuming that the bunch feeder fails three times in a year, the downtime will be reduced by 22.968 hours, 343.800 hours and 92.850 hours for minimum repair time, maximum repair time and most likely repair time.

Thresher (Stripper): A preventive maintenance interval of 3 months was assessed for the thresher, which fails after every 4 or 6 months.

Fruit Wash: The optimal downtime due to preventive maintenance are 0.01620 weeks, 0.006295 weeks and 0.02640 weeks for minimum, maximum and most likely repair times with a corresponding optimal replacement interval of every 3 weeks, Table 3.

Loose Fruit Elevator: A "3 weekly" preventive maintenance interval was determined for this unit in Table 2 with an optimal downtime per unit time of 0.888 hours, 3.660 hours and 1.748 hours for minimum, maximum and most likely repairs times in Table 4.

Press: The press which has "run hours" of 600 hours was assessed according to the maintenance data obtained and this resulted in a predicted preventive maintenance interval of every 3 weeks with total downtime reduction of 371.856 hours, 2059.200 hours, and 527.952 for a monthly failure interval and 61.976 hours, 343.200 hours and 87.992 hours for a 5 weekly failure interval with the values corresponding to minimum, maximum and most likely repair times see Table 4.

Crude Oil Vibrating Screen: The difference in repair times due to failure and preventive where this unit fails every week in one year was calculated to be 92.352 hours, 2380.640 hours, 181.792 hours and 18.926 hours, 41.952 hours where it fails monthly and these values are recorded in Table 4.

Rotating Brush: From the results of the simulation runs, a three weekly preventive maintenance period was determined for the rotating brush with corresponding total optimal downtime due to preventive maintenance of 95.264 hours, 363.376 hours and 192.144 hours for minimum, maximum and most likely repair times respectively, if a minimum number of failures occurs.

Decanter: There are two decanters, the primary and the secondary decanter. Both of them have about the same failure rates, the reduction in downtime due to preventive maintenance where the decanters for the 2 lines fail every week would be 73.84 hours, 3048.344 hours and 606.112 hours and for every 3 months failure, the reduction in down time would be 5,680 hours, 234.488 hours and 46.624 hours due to minimum, maxim um and most likely repair times respectively.

Desanding Cyclone: This is a very expensive equipment and a great deal of care has to be taken in maintaining it. This unit was assessed to fail once every month or once every three months. For an every month failure interval the difference between the downtime of failure replacement an d total optimal preventive replacement was calculated to be 15.360 hours, 167.856 hours and 83.856 hours for the two lines and 5.12 hours, 55.952 hours, and 27.952 hours (table 4) for a failure interval of every 3 months. A 3 weekly preventive maintenance schedule was determined for the desanding cyclone. If preventive maintenance policy were to be adopted as opposed to failure replacement approach, bearing in mind the failure interval of every week, an astronomical minimization of total downtime of 403.520 hours, 1571.552 hours and 658.994 hours were for minimum, maximum and most likely repair times respectively obtained as recorded in Table.... Also assuming the maximum failure interval for every three months, the downtime is minimized by 31.040 hours, 120.864 hours and 50.688 hours for the respective repair times and this is contained in Table where a preventive maintenance policy is adopted.

Alfa Laval (Centrifuge Unit): One of the major component parts of the clarification unit is the Alfa Laval, which separate the oil from the sludge. This equipment was found to breakdown either every week (minimum repair times) or every 4 months maximum interval. For every weekly failure interval, total optimal downtime would be 372.112 hours, 744.640 hours and 467.792 hours and for every four monthly failure, the reduction in downtime would be 21.868 hours, 42.960 hours and 26,988 hours for minimum, maximum and most likely repair times respectively (Table 4).

SENSITIVITY ANALYSIS OF MAINTENANCE SIMULATION RESULTS

Broadly defined, sensitivity analysis is the careful study of the responsiveness of conclusions to changes or errors in parameter values and assumptions. The usual approach is to hold all aspects of the model constant and vary each parameter while observing the influence of the changes upon the optimal decision. If the parameters may be varied over the full range of "conceivable" values with no change in optimal decision, the decision is not sensitive to that particular parameter and resources should be expended to determine a more exact value for it. In this case, all other aspects of the model are kept constant while the repair times were varied in order to determine the influence of the changes in the predicted maintenance intervals. It was observed that the changes in repair times did not affect the predicted maintenance intervals. In other words the changes in repair times are insensitive to the predicted maintenance intervals so the predictions should be upheld.

Sample Calculations

Process unit – Sterilizer

Failure repair times (T_f) minimum = 2hrs. = 0.01666 weeks

	maximum	=	8hrs. = 0.0666 weeks
	most likely	=	?.42hrs. = 0.0285 weeks
Preventive repair times (T_p)	minimum	=	10mins. = 0.16hrs = 0.001333 weeks
	maximum	=	1.30hrs. = 0.01083 wk
	most likely	=	45mins. = 0.75hrs = 0.00625wk

Down time due to preventive maintenance

$$D(t_p) = \frac{H(t)\,T_f + T_P}{t_p + T_P}$$

minimum values of T_f and T_P
for T_f = 2hrs. = 0.01666wks; TP = 10mins. = 0.001333wks

$$D(1) = \frac{0 \times 0.01666 + 0.001333}{1 \times 0.001333} = 0.0013312$$

$$D(2) = \frac{0.0014 \times 0.01666 + 0.001333}{2 \times 0.001333} = 0.0006777$$

$$D(3) = \frac{0.02418 \times 0.01666 + 0.001333}{3 \times 0.001333} = 0.0005783 \text{ optimal}$$

$$D(4) = \frac{0.18674 \times 0.01666 + 0.001333}{4 \times 0.001333} = 0.0011106$$

$$D(5) = \frac{0.49980 \times 0.01666 + 0.001333}{5 \times 0.00133} = 0.002414$$

$$D(6) = \frac{0.84490 \times 0.01666 + 0.001333}{6 \times 0.001333} = 0.002567$$

Maximum values of T_f and T_P

For T_f = 8hrs = 0.0666wks; T_P = 1.30hrs = 0.01083wks

D(1) = 0.010713
D(2) = 0.005432
D(3) = 0.0041318 optimal
D(4) = 0.0058010
D(5) = 0.0088042
D(6) = 0.011163

Most likely values of Tf and TP

T_f = 3.42hrs = .0285wks. 0285; T_P = 75hrs = .00625wks

D(1) = 0.006211
D(2) = 0.003135
D(3) = 0.0023082 optimal
D(4) = 0.0028885
D(5) = 0.0040935
D(6) = 0.00504968

From the above calculations when Tf and T_P assume minimum values the optimal replacement interval is 3 weeks. When T_f and T_P assume maximum values, the optimal down time is D3 = 0.0041318 weeks which corresponds to 3 weeks replacement interval and when Tf and TP assume likely values the optimal down time is D3 = 0.0023082 weeks corresponding to 3 weeks replacement interval. The interpretation here is that irrespective of the failure and preventive repair times, the optimal preventive replacement interval should be every three weeks, the sensitivity analysis was done for all the other units and this is contained in Table 4. The conclusion drawn here is that, the predicted preventive maintenance intervals are insensitive to the variations in repair times.

CONCLUSIONS AND RECOMMENDATIONS

This research work has been carried out on optimization of downtime of palm oil mill in order to increase productivity. The related work done was by Jardine who used hypothetical machine failure or preventive replacement time to determine the optimal downtime. Whereas Jardine applied only one specific value of failure or preventive repair time in the model to determine the optimal down, multiple failure/preventive repair times will be assessed by incorporating the concept of Project Evaluation and Review Technique (PERT) into the model.

This study has attempted to simulate an entire palm oil production line in a bid to

(i) Reduce the down time by comparing the down time due to failure and that due to preventive maintenance
(ii) Determine the effects of changes in machine repair times and failure rates on the system output

The conclusions drawn were that if better planning of the routine maintenance could be implemented, the number of time of maintenance could be reduced thereby representing a considerable saving. The failure of planning is attributed to the failure of the organization to adapt.

In this study, it has been possible to isolate some factors, which have contributed to the inability of RISONPALM to apply effectively the available materials and machines to enhance productivity. Since the company already has some computers, a system of integrated maintenance/materials management should be adopted as proposed in appendix 1. To correct these anomalies, the following recommendations are offered:

(i) In the area of maintenance, the computers will assist in:
Scheduling maintenance projects,
Maintenance cost reports,
Inventory status reports for maintenance parts and supplies Parts failure data,
Operations analysis studies which may include computer simulation,
Waiting lines (queuing theory) and other analytical programmes.

(ii) The objective of maintenance management should be to ensure that plant, facilities and equipment are kept and maintained in satisfactory conditions consistent with operational, economic and safe working requirements. This will fulfill the maintenance requirements of the mill in terms of:
Breakdown (failure) maintenance
Preventive maintenance
Predictive maintenance
Shutdown (Turn Around) maintenance.

The satisfaction of the above requirements could be considered as the service rendered by maintenance management.

(iii) The service rendered by maintenance management could be mostly influenced by the following:
Identification of equipment
Definition of spare parts
Analysis of interchange-ability
Management of work request and work orders
Efficiency of workshop and capability of personnel
Procedures for information flow
Participation of maintenance management in planning the mill activities.

It was observed that the above mentioned ingredients are lacking or not properly considered hence very poor maintenance management appear to have been installed. It is recommended that these issued which affect maintenance drastically be addressed.

(iv) It is recommended that objectives of maintenance management be defined and ways of attaining the objectives highlighted. The maintenance management objectives can be attained through the process shown in fig 1.

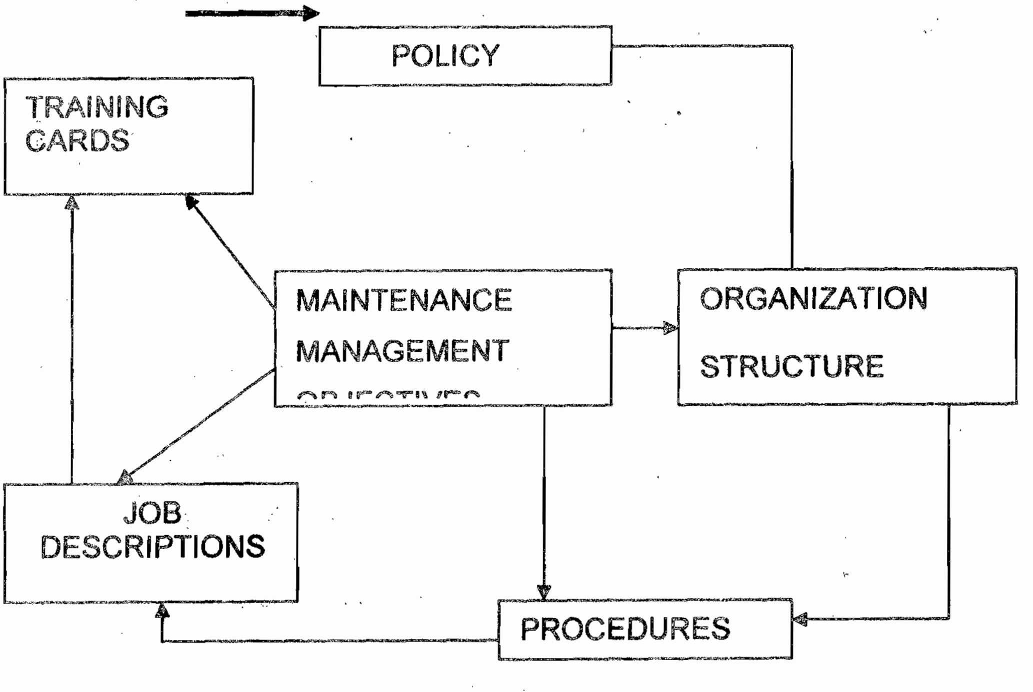

Fig. 1: Maintenance Management Scheme

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