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## A GANetXL Approach to an Optimal Maintenance Strategy in Food Manufacturing

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### Abstract

An optimal maintenance strategy for improved cost and machine reliability in food manufacturing was developed in this study. Failure time parameters and cost data were obtained from a food manufacturing firm. The data obtained were applied to the mixed integer non-linear multi-objective optimization algorithm developed in this study, and solved using GANetXL. Overall, the developed optimal maintenance strategy provided better cost savings at ₦7, 349,397 than the current maintenance cost and machine reliability of the industrial case study at ₦9, 207,979. In general, the developed optimal strategy would serve as a practical tool for adoption by food manufacturing companies and other manufacturing sectors in order to achieve optimum levels of system reliability while maintaining minimum cost expenditure through an efficient maintenance schedule.

**Keywords:** Maintenance Optimization; Maintenance Strategy; GANetXL; Maintenance Cost; Reliability

### Introduction

Globalization has increased the competitive pressure on manufacturing organizations and companies to operate in the most efficient and economical way. The resultant effect is that companies concentrate more and more on their core businesses, outsource less profitable departments and services to reduce costs [1]. Competition in manufacturing is increasing exponentially as customers are becoming more exigent and demand becomes increasingly random, this is why the development of industrial strategies (maintenance and production) has become obligatory for manufacturing firms in order to reduce their costs [2]. The

importance of maintenance is ever increasing as a result of the widespread automation of manufacturing systems and the capital expenditure allocated to it, thus making maintenance of manufacturing equipment an investment opportunity to be maximized and not to be seen as cost center [3]. However, few have the internal resources to implement such practical culture [4]. Even though every sector faces its own individual problems or issues, it can be said that the food manufacturing sector face more stringent issues than any other sector because their product is intended for human consumption, thus dealing with a

wide range of regulations regarding food safety and maintaining complex machineries and equipment so that production is not affected to the detriment of the manufacturer. In order to stay competitive, production lines are sometimes run 24 hours a day, and when manufacturing equipment is not kept in good working condition, it can be prone to microbiological and physical contamination. Debris from worn or broken parts can contaminate the production line or even enter the product directly. It is thus apparent that the maintenance team in any food manufacturing company has a lot to handle under such conditions, and to maintain these highly automated systems and keep equipment running optimally, food production and maintenance managers must stay on top of new techniques.

This study involves the development of an optimal maintenance strategy based on maintenance cost and equipment reliability in a food manufacturing company in Nigeria using GANetXL. The proposed strategy considers system's reliability, equipment failure and cost, maintenance strategies and downtime cost associated with carrying out equipment maintenance

## Material and Method

### Materials

GANetXL developed by [5] is used to solve the multi-objective optimization problem in this study. It is decision support system generator and an optimization add-in in Microsoft excel for solving spreadsheet based multi-objective optimization models. It uses genetic algorithms to solve complex optimization and search problems [6,7].

Through direct observation of the manufacturing and maintenance process, the necessary data, 26,234 hours of equipment faults and failures and equipment cost data for thirty six months as shown in the appendix was obtained from a food and beverage at Chicason Drive, Umudim, Nnewi, Anambra State, Nigeria.

## Methods

The optimal maintenance strategy uses a cost based approach to minimize total maintenance cost while assuring the desired improvement of machine reliability. The system under study is a repairable multi-component system arranged in series with each component subject to failure and follow non-homogeneous poisson process (NHPP) with an increasing rate of occurrence of failure ( $t$ ), the following notations of the optimization model are defined:

- $N$ : Number of Components:
- $T$ : Length of Planning Scope
- $J$ : Number of Periodic Intervals
- $\lambda$ : Scale Parameter
- $\beta$ : Shape Parameter
- $\mu$ : Mean
- $\sigma$ : Standard Deviation
- $\alpha_{pmi}$ : Age reduction factor of preventive maintenance on component  $i$
- $FC_i$ : cost of performing maintenance due to failure of component  $i$
- $PMC_i$ : Cost for preventive maintenance for component  $i$
- $CMC_i$ : Cost of corrective maintenance for component  $i$
- $DC$ : cost of downtime of the manufacturing system

- $R$ : Required reliability of the system of components
- $X_{i,j}$ : The effective age of component  $i$  at the start of period  $j$
- $XX_{i,j}$ : The effective age of component  $i$  at the end of period  $j$

## The Cost Function Development

Expanding on the total cost function of [8], the total maintenance cost component can be described as the summation of all the cost required to carry out maintenance and each cost component is expressed mathematically as:

Failure cost: the expected number of failures for component  $i$  in period  $j$  the expected number of failures for component  $i$  in period  $j$  is calculated and multiplied by the cost of failure for component  $i$

$$FC_i = F_i \times [N_{i,j}] \quad \text{for } i = 1, \dots, N; j = 1, \dots, T \quad (1)$$

Where

$F_i$  = cost of failure for component  $i$

$[N_{i,j}]$  = expected number of failures for component  $i$  in period  $j$

From equation 1,

$$[N_{i,j}] = \lambda_i [(XX_{i,j})^{\beta_i} - (X_{i,j})^{\beta_i}] \quad \text{for } i = 1, \dots, N; j = 1, \dots, T$$

Therefore

$$FC_i = F_i \times \lambda_i [(XX_{i,j})^{\beta_i} - (X_{i,j})^{\beta_i}] \quad \text{for } i = 1, \dots, N; j = 1 \dots T \quad (2)$$

Cost of preventive maintenance  $PMC_i$ : refers to the cost incurred while component  $i$  is maintained. It includes cost of consumables ( $CCC_i$ ), cost of condition-based

maintenance ( $CCBM_i$ ), and cost of time based maintenance ( $CTBM_i$ ). Where cost of consumables includes the cost of consumable material and equipment used while carrying out preventive maintenance activities such as cost of lubricating oil ( $CLO_{ij}$ ), cost of component wires ( $CCW_{ij}$ ), cost of replacement vital parts (screw nuts, belts etc.) ( $CRVP_{ij}$ ), cost lubricating grease ( $CLG_{ij}$ ). The cost of condition-based maintenance includes cost of inspections ( $CI_{ij}$ ), cost of diagnostic actions ( $CDA_{ij}$ ), travel cost ( $CT_{ij}$ ), labour cost ( $CL_{ij}$ ) and cost of delayed production ( $CDP_{ij}$ ). While cost of time-based maintenance includes the cost of preventive oil change ( $CPOC_{ij}$ ), cost of equipment material changes ( $CEMC_{ij}$ ).

$$\text{Thus } PMC_i = CLO_{ij} + CCW_{ij} + CRVP_{ij} + CLG_{ij} + CI_{ij} + CDA_{ij} + CT_{ij} + CL_{ij} + CDP_{ij} +$$

$$CPOC_{ij} + CEMC_{ij} \quad \text{for } i = 1 \dots N; j = 1 \dots T \quad (3)$$

$$\text{Where } CCC_{ij} = CLO_{ij} + CCW_{ij} + CRVP_{ij} + CLG_{ij}$$

$$CCBM_{ij} = CI_{ij} + CDA_{ij} + CT_{ij} + CL_{ij} + CDP_{ij}$$

$$CTBM_{ij} = CPOC_{ij} + CEMC_{ij}$$

$$\text{Thus } PMC_i = CCC_{ij} + CCBM_{ij} + CTBM_{ij} \quad \text{for } i = 1 \dots N; j = 1 \dots T \quad (4)$$

Cost of corrective maintenance of component  $i$ : is the cost incurred when component  $i$  is replaced at the end of period  $j$  with a new component  $i$ . It includes cost of diagnostic actions ( $CDA_{ij}$ ), Cost of repair actions ( $CRA_{ij}$ ), Cost of equipment hire ( $CEH_{ij}$ ) and travel expenses ( $TEC_{ij}$ ), labour cost ( $LC_{ij}$ ) and administrative cost ( $AC_{ij}$ ). Thus

$$CMC_i = CDA_{ij} + CRA_{ij} + CEH_{ij} + TEC_{ij} + LC_{ij} + AC_{ij} \quad \text{for } i = 1 \dots N; j = 1 \dots T \quad (5)$$

The cost of downtime of the manufacturing system  $DC$  is the cost lost when component  $i$  is maintained or replaced at period  $j$

$$DC = DT \times PL \quad (6)$$

Where

$DT$ : Average duration for downtime

$PL$ : estimated profit loss per hour by the company due to downtime.

Hence Total Maintenance Cost is:

$$\sum_{i=1}^N \sum_{j=1}^T \{ F_i \times \lambda_i [(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i}] + CLO_{ij} + CCW_{ij} + CRVP_{ij} + CLG_{ij} + CI_{ij} + CDA_{ij} + CT_{ij} + CL_{ij} + CDP_{ij} + CPOC_{ij} + CEMC_{ij} + CDA_{ij} + CRA_{ij} + CEH_{ij} + TEC_{ij} + LC_{ij} + AC_{ij} \} + \sum_{j=1}^T [D(1 - (PMC_{ij} + CMC_{ij}))]$$

$$\text{for } i = 1 \dots N; j = 1 \dots T \quad (7)$$

### System Reliability Function

Based on the failure time reliability distributions and system configuration, the system reliability is a function of probability of operating without failure over the planning scope. That is the probability of surviving component  $i$  to the end of period  $j$  given survival to the start of period  $j$ .

For weibull distributed failure times, the reliability of the system at the end of period  $j$  is as

$$R_j = e^{-\lambda t^{\beta}} \quad (8)$$

Where  $t = ((xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i})$

Thus  $R_{series}$  is

$$R_j = \prod_{i=1}^N e^{-[\lambda_i [(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i}]]} \quad \text{for } i = 1 \dots N; j = 1, \dots, T \quad (9)$$

Equation 7 and 9 is now presented as an optimization problem to minimize total maintenance cost and maximize system reliability as follows:

### Minimize Total maintenance cost

$$\sum_{i=1}^N \sum_{j=1}^T \{ F_i \times \lambda_i [(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i}] + CLO_{ij} + CCW_{ij} + CRVP_{ij} + CLG_{ij} + CI_{ij} + CDA_{ij} + CT_{ij} + CL_{ij} + CDP_{ij} + CPOC_{ij} + CEMC_{ij} + CDA_{ij} + CRA_{ij} + CEH_{ij} + TEC_{ij} + LC_{ij} + AC_{ij} \} + \sum_{j=1}^T [D(1 - (PMC_{ij} + CMC_{ij}))]$$

### Maximize System reliability

$$R_j = \prod_{i=1}^N e^{-[\lambda_i [(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i}]]}$$

Subject to

$$X_{i,j} = 0 \quad \text{For } i = 1, \dots, N; j = 1, \dots, T$$

$$XX_{i,j} = X_{i,j} + \frac{T}{j} \quad \text{For } i = 1, \dots, N; j = 1, \dots, T$$

$$PMC_{ij} + CMC_{ij} \leq 1 \quad \text{For } i = 1, \dots, N; j = 1, \dots, T$$

$PMC_{ij}, CMC_{ij} = 0 \text{ or } 1$  For  $i = 1, \dots, N; j = 1, \dots, T$

$$X_{ij} = (1 - PMC_{ij-1})(1 - CMC_{ij-1}) XX_{ij-1} + PMC_{ij-1} (\alpha_{pmi} \times XX_{ij-1})$$

For  $i =$

$1, \dots, N; j = 1, \dots, T$   
(10)

The first constraint indicated that the initial age of each component is zero, the second constraint accounts for the changes in age thus representing the effective age of component  $i$  at the end of period  $j$ . The third to fifth constraint specifies that if a component is replaced with another new component then  $X_{i,j} = 0$ ,  $CMC_{ij} = 1$ ,  $PMC_{ij} = 0$ . If a component is maintained then  $CMC_{ij} = 0$ ,  $PMC_{ij} = 1$ .

## Assumptions

A number of assumptions are presented and motivated in order to arrive at an optimal strategy formulation for the optimization problem in which the objective is to minimize the total cost of maintenance and to maximize the system-wide reliability. Some of these assumptions are aimed at decreasing the complexity of the problem, thereby making it possible to solve the algorithm efficiently.

1. Number of Manufacturing Components: A number of components are required to produce an end product in a manufacturing system. Failure of any one of these components typically causes the manufacturing process to be interrupted until the component has been repaired or replaced. Therefore,

a failure in one of the components of the manufacturing system typically leads to failure of the entire manufacturing system. For optimization purposes, all the components of a manufacturing system are considered as a whole in the sense that when the manufacturing system is shut down to carry out an appropriate maintenance action on one component, it may make sense to go ahead and perform preventive maintenance corrective maintenance of some other components, even if they are not at their individual optimum point where maintenance actions would have ordinarily been performed.

2. Frequency of Maintenance: A number of maintenance actions will be carried out on the manufacturing components, including complete overhaul due to corrective maintenance as opposed to just carrying out preventive maintenance. However, the duration of each maintenance activity, which will vary from one component to the other is outside the scope of this study.
3. Reliability after Maintenance: when maintenance is performed on any manufacturing components, the goal is to increase the reliability of the manufacturing component to as good as new or to the state it was operating before maintenance was performed on it. In this study it is assumed that after performing maintenance and the component is back into operation, the component's reliability will improve to as good as new or to a state it was operating before.

4. Resources required for maintenance: in a realistic manufacturing environment, many resources are required to perform effective maintenance on manufacturing component. These resources include maintenance personnel, finance, spare parts inventory, logistics etc. An optimization algorithm containing all resources is expected to be very complex, hence for the purpose of this study, it is assumed that resources such as maintenance personnel and finance is the required resources to carry out maintenance activities. This is not an unrealistic assumption as the optimization algorithm in this study is expected to produce a schedule for maintenance strategies for the period of thirty six months, meaning that it will be known beforehand that the maintenance of any particular component will occur at a certain period within the scheduling window, thus provisions can be made well in advance of each maintenance active to ensure that the spare parts and maintenance equipment required are indeed available and that all logistics are appropriately taken care of.
5. Independence of component's failure: it is assumed in this study that failures that occur in a manufacturing system are independent of one another. Hence if a component is taken out of operation due to a failure it is assumed to have little or no effect on the timing of failures of the other components in the manufacturing system.
6. Failure rates of manufacturing components: it is assumed in this study that the failure rates of

individual components follow a typical bathtub curve, hence the reliability model incorporated within the optimization algorithm is formulated for components through the different stages

### Solution Procedure

Step 1: Specify the values for the parameters  $FC_i, CLO_{ij}, CCW_{ij}, CRVP_i, CLG_{ij}, CI_{ij}, CDA_{ij}, CT_{ij}, CL_{ij}, CDP_{ij}, CPOC_{ij}, CEMC_{ij}, CDA_{ij}, CRA_{ij}, CEH_{ij}, TEC_{ij}, LC_{ij}, AC_{ij}$

Step 2: Determine the reliability distribution parameters

Step 3: From the parameters in step 1 carry out a trend analysis to determine the future forecast total maintenance cost in thirty six months

Step 4: Configure the optimization problem in GANetXL, input the parameters. Configure the proposed solution to the optimization problem in a matrix format of  $N \times T$ . With  $N$  representing the components and  $T$  representing the time periods for thirty six months, then solve the problem using the following genetic algorithm parameters.

**Table 1: Genetic algorithm parameters**

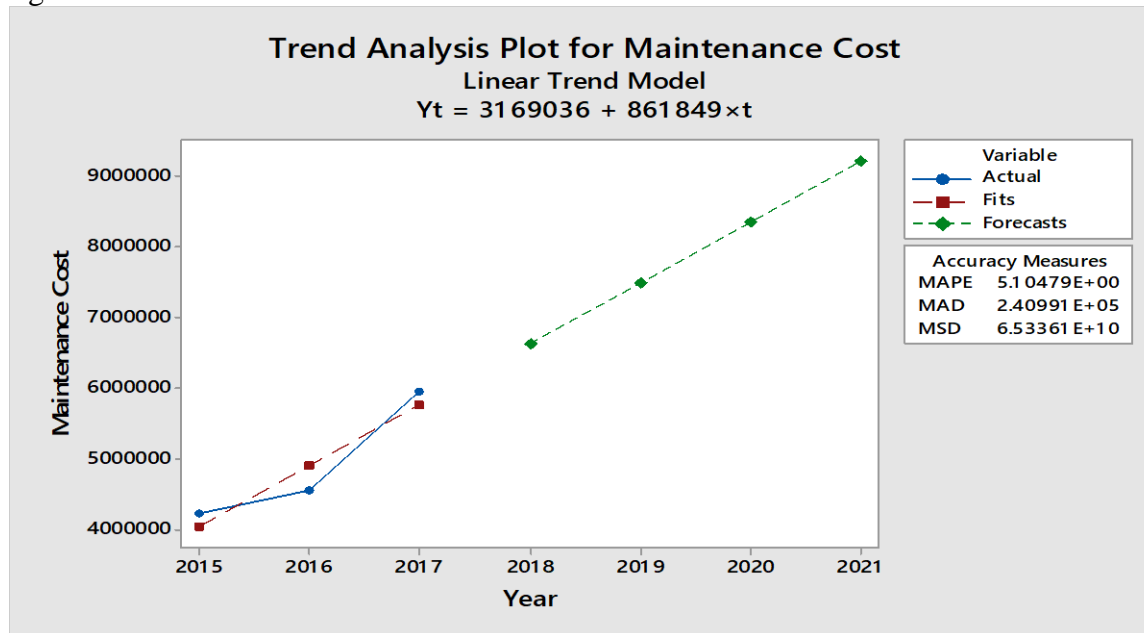
Number of Generation: 500
Population Size: 1000
Probability of Selection: 0.2
Probability of Crossover: 0.4
Probability of Mutation: 0.3

### Results and Discussion

The trend analysis results showed an increasing trend line of total maintenance cost as seen in figure 1. The trend fitted model for predicting the total maintenance



cost in a given time is expressed as shown in figure 1.



**Fig 1: Trend Plot of Total Maintenance Cost with Future Forecast**

From the analysis it was found that in the year 2021, if the current maintenance strategy is still maintained, the total cost is expected to be about ₦ 9,201,979. The main goal of this analysis is to forecasts the future cost of maintenance at a given time parameter with the current maintenance strategy of the company this will now be compared with the optimal strategy from

GANetXL. The results from the optimization model are shown in table 1. It is represented in a matrix cell of  $N \times T$ , with each cell containing 0, 1 or 2 as it corresponds to the different maintenance actions where 0 represents periodic inspections and equipment monitoring, 1, represents preventive maintenance and 2 represents corrective maintenance.



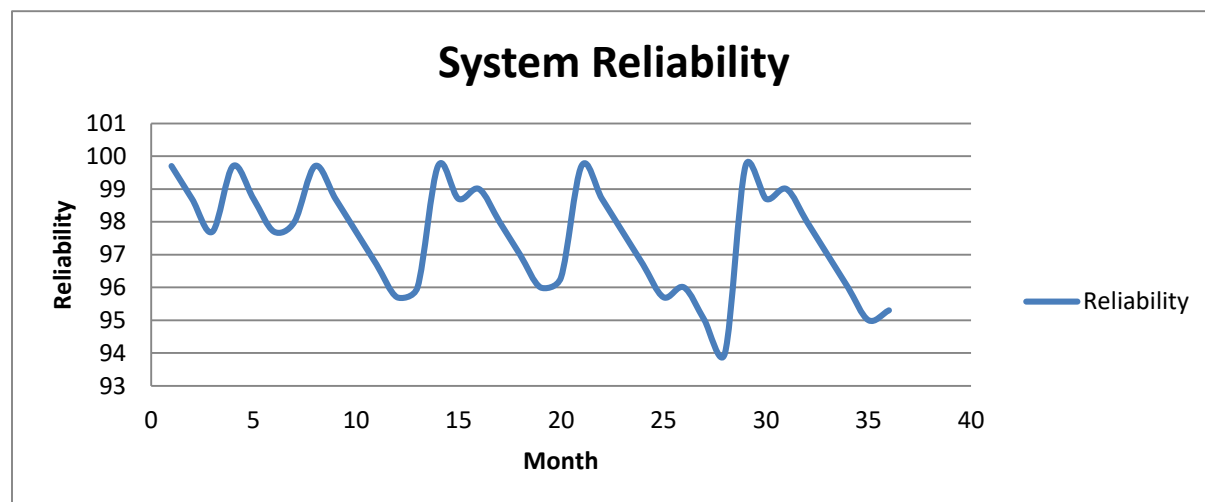
**Table 1: Optimal Maintenance Strategy**

MONTHLY SCHEDULE																																				
N	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
1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	1	0	0	1	0	0	0	1
2	0	0	0	0	0	0	1	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	1	0	0	0	1
3	0	0	0	1	0	0	0	0	0	2	0	0	1	0	0	1	0	0	0	1	0	0	2	0	0	0	0	0	2	0	0	1	0	0	0	1
4	0	0	0	2	0	0	0	0	0	2	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2
5	0	0	0	0	0	0	1	0	0	0	0	0	1	2	0	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	1	0	0	0	1

KEY: N = Number of Components; 1 = Conveyor System; 2 = Mixer System; 3 = Roller System; 4 = Slitter System; 5= Compounding Machine

The optimal maintenance strategy presented in table 1 is a combination of three maintenance strategies is presented for each component in the manufacturing system, 1) Preventive Maintenance, 2) Corrective Maintenance and 0) a period whereby nothing is done but periodic inspections and equipment monitoring is carried out. The optimal strategy provides an optimal cost solution of ₦7,349,397 in thirty six months. The system reliability in figure 2 shows that

the reliability of the system lies between 94% and 99.7%, with average reliability over the planning period being 97.2%. The significant drop at period 28 is as a result of lack of adequate maintenance action for several consecutive periods. The cost savings in the GANetXL solution can be seen as some of the components are allowed to spend longer times in service before being maintained.



**Fig 2: System Reliability**

The purpose of the optimal maintenance strategy is to find the optimal combination of maintenance actions that meets the objectives of the manufacturing firm. These can either be to maximize reliability or minimize cost. This solution when compared with the cost forecast, provided a better cost objective and improved reliability (Cost = ₦7,349,397, Reliability = 99.7%) than that the current maintenance scenario at the food manufacturing company at cost ₦9,201,979.

### Conclusion and Recommendation

The developed optimal maintenance method provides a better cost savings and improved

reliability thus Maintenance of manufacturing components can be improved using reliability parameters and cost of those components. For the method to be effective, input data needs to be as exact as possible. Therefore, there is a need for manufacturing companies to ensure that failure history and cost of maintenance/ replacement of every component are properly documented to ensure accurate reliability prediction and cost forecasting.

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## Appendix

**Table 1: Conveyor System Failure Times**

Conveyor System	Failure Times(hrs)			
	153	4772	13100	21895
	188	5122	13677	22500
	233	8260	14512	22780
	530	9205	15300	22966
	968	9810	16431	23044
	1092	10122	17000	23178
	1240	10875	18211	23361
	1778	11022	18657	23450
	2219	11554	19322	23475
	3512	11841	19900	24290
	3791	12200	20690	24850
	3899	12276	20910	24926
	4365	12407	21362	25792
				26100

**Table 2: Mixer System Failure Times**

Mixer System	Failure Times (hrs)									
	49	348	1080	2089	3654	5640	6387	6830	7440	12200
	76	420	1154	2245	3712	5689	6420	6888	7501	12276
	100	566	1280	2390	3915	5760	6475	6924	8260	12407
	124	642	1360	2421	4365	6000	6521	6970	9205	13100
	148	744	1436	2600	4772	6070	6582	6990	9810	13677
	153	810	1500	2879	5122	6136	6612	7043	10122	14512
	188	855	1675	2900	5345	6180	6656	7085	10875	15300
	200	890	1715	3122	5470	6245	6699	7134	11022	
	233	910	1856	3512	5524	6290	6744	7188	11554	
	282	988	1910	3600	5568	6328	6780	7349	11841	

**Table 3: Roller System Failure Times**

<b>Roller System</b>	<b>Failure Times (hrs)</b>													
	300	1500	2713	3565	4409	5090	5900	6790	7148	7988	8788	9589	10420	11134
	456	1612	2800	3615	4498	5134	5966	6845	7198	8045	8834	9612	10480	11190
	520	1730	2880	3682	4559	5170	6030	6882	7250	8124	8878	9680	10535	11256
	700	1800	2945	3724	4590	5245	6099	6921	7320	8200	8950	9740	10599	11289
	760	1930	3020	3795	4644	5300	6145	6990	7390	8280	8990	9829	10645	11379
	820	2060	3160	3843	4680	5378	6200	6734	7450	8300	9032	9879	10680	11400
	880	2100	3200	3899	4730	5434	6278	6780	7500	8365	9080	9900	10700	11483
	956	2090	3279	3960	4799	5500	6329	6813	7560	8432	9140	9960	10789	11500
	990	2156	3312	4048	4824	5567	6390	6877	7600	8478	9200	10030	10821	11555
	1050	2260	3190	4122	4860	5620	6457	6905	7660	8544	9280	10140	10889	11631
	1165	2320	3265	4177	4890	5700	6480	6955	7700	8590	9354	10220	10912	11689
	1280	2459	3308	4217	4930	5788	6537	6990	7843	8643	9390	10280	10987	
	1345	2534	3400	4290	4979	5831	6579	7024	7890	8689	9465	10330	11000	
	1420	2677	3488	4366	5060	5890	6722	7088	7934	8740	9522	10390	11067	

**Table 4: Slitter System Failure Times**

Slitter System	Failure Times (hrs)																
	1628	2696	3408	4280	5400	6479	7590	8390	9452	10500	12030	13239	14480	15599	16573	18048	19200
	1690	2778	3470	4303	5472	6556	7648	8459	9500	10591	12099	13290	14554	15648	16620	18120	19264
	1750	2824	3502	4360	5506	6700	7683	8499	9548	10641	12124	13360	14599	15692	16695	18196	19322
	1791	2880	3568	4390	5592	6740	7720	8544	9580	10720	12200	13483	14676	15729	16740	18255	19410
	1843	2936	3580	4468	5672	6789	7789	8580	9642	10889	12280	13548	14734	15799	16801	18300	
	1880	2990	3634	4500	5700	6834	7814	8694	9728	10949	12356	13629	14896	15876	16882	18386	
	1950	3035	3670	4580	5780	6890	7896	8720	9780	11000	12421	13680	14944	15900	16964	18421	
	2023	3077	3742	4640	5853	6943	7945	8791	9800	11180	12500	13742	14980	15965	17020	18500	
	2099	3124	3790	4681	5899	6980	7999	8869	9860	11250	12580	13800	15036	16000	17090	18575	
	2156	3160	3810	4790	5948	7024	7832	8900	9920	11320	12600	13869	15090	16035	17128	18630	
	2214	3200	3866	4865	5970	7080	7880	8970	9977	11482	12699	13920	15128	16089	17170	18684	
	2287	3255	3900	4910	6049	7145	7930	9000	10024	11500	12758	13990	15189	16154	17220	18741	
	2330	3282	3948	4990	6088	7190	7989	9048	10080	11599	12810	14066	15260	16190	17294	18828	
	2372	3358	3999	5049	6140	7260	8040	9070	10154	11634	12889	14124	15300	16240	17367	18890	
	2400	3417	4051	5124	6199	7324	8079	9148	10199	11686	12923	14191	15399	16289	17410	18934	
	2471	3460	4078	5188	6250	7380	8124	9200	10268	11730	12990	14239	15425	16342	17492	18966	
	2548	3492	4124	5244	6303	7410	8188	9288	10320	11788	13061	14300	15470	16390	17578	19006	
	2599	3530	4180	5290	6380	7486	8278	9324	10389	11830	13110	14376	15500	16444	17612	19079	
	2653	3578	4231	5369	6424	7520	8320	9399	10448	11900	13186	14432	15545	16527	17690	19148	

**Table 5: Compounding Machine Failure Times**

<b>Compounding Machine</b>	<b>Failure Times (hrs)</b>															
	76	1165	2156	3035	3670	4366	5300	6140	7198	8124	8950	9728	10420	11555	12500	13360
	148	1280	2214	3077	3742	4409	5378	6199	7250	8200	8990	9780	10480	11631	12580	13483
	200	1345	2287	3124	3790	4498	5434	6250	7320	8280	9032	9800	10500	11689	12600	13548
	282	1420	2330	3200	3810	4580	5500	6303	7390	8300	9080	9860	10591	11730	12699	13629
	300	1500	2372	3279	3866	4640	5567	6734	7450	8365	9140	9920	10641	11788	12758	13680
	456	1628	2459	3312	3900	4681	5620	6780	7520	8459	9200	9977	10720	11830	12810	13742
	520	1690	2534	3190	3948	4790	5700	6813	7590	8499	9288	10024	10889	11900	12889	13800
	700	1750	2677	3265	3999	4865	5788	6877	7660	8544	9324	10080	10949	12030	12923	13869
	760	1791	2696	3308	4051	4910	5831	6905	7700	8580	9399	10154	11000	12099	12990	13920
	820	1843	2778	3400	4078	4990	5890	6955	7843	8694	9452	10199	11180	12124	13061	13990
	880	1880	2824	3488	4124	5049	5900	6990	7890	8740	9500	10268	11250	12200	13110	14066
	956	1950	2880	3565	4180	5124	5966	7024	7934	8788	9522	10280	11320	12280	13186	
	990	2023	2936	3580	4217	5188	6030	7088	7988	8834	9589	10330	11482	12356	13239	
	1050	2099	2990	3634	4290	5245	6099	7148	8045	8878	9642	10390	11500	12421	13290	

**Table 6 Maintenance Cost Expenditure Summary for 2015**

<b>Components</b>	<b>2015 Cost Expenditures (₦)</b>							
	Diagnostic Actions	Preventive oil change	Consumable Materials	Inspections	Labour	Administrative	Travel Expenses	Equipment Hire and Transportation
Conveyor System	295,280	118,000	110,230	119,450	50,000	34,670	177,000	240,000
Mixer System	230,000	10,000	116,790	111,065	22,000	30,000	158,000	210,000
Rollers	250,000	11,225	117,000	114,680	24,000	30,000	158,000	200,000
Slitter	255,548	10,000	119,500	116,000	28,000	30,000	158,000	289,000
Compounding Machine	236,880	113,500	151,230	112,355	22,000	32,000	158,000	265,000

**Table 7 Maintenance Cost Expenditure Summary for 2016**

<b>Components</b>	<b>2016 Cost Expenditures (₦)</b>							
	Diagnostic Actions	Preventive oil change	Consumable Materials	Inspections	Labour	Administrative	Travel Expenses	Equipment Hire and Transportation
Conveyor System	273,100	129,000	100,000	122,000	29,565	33,000	160,000	300,000
Mixer System	221,000	23,400	116,000	120,000	26,670	30,000	153,000	260,000
Rollers	250,000	12,650	113,000	114,680	21,600	30,000	153,000	260,000
Slitter	200,548	11,232	122,800	115,000	22,056	30,000	153,000	235,000
Compounding Machine	265,880	100,000	117,000	115,300	9,750	13,225	153,000	347,000



**Table 8 Maintenance Cost Expenditure Summary for 2017**

<b>Components</b>	<b>2017 Cost Expenditures (₦)</b>							
	Diagnostic Actions	Preventive oil change	Consumable Materials	Inspections	Labour	Administrative	Travel Expenses	Equipment Hire and Transportation
Conveyor System	391,000	212,899	210,689	124,550	90,000	38,000	192,680	380,000
Mixer System	312,000	25,900	138,000	123,000	26,670	30,000	162,000	333,000
Rollers	324,000	12,000	134,000	124,000	21,600	30,000	164,000	212,000
Slitter	244,008	15,420	138,900	119,000	22,056	30,000	160,000	205,000
Compounding Machine	330,100	313,500	140,000	116,000	9,750	13,225	160,000	343,000