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Research Article

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Special Issue
A Themed Issue in Honour of Professor Clement Uche Atuanya on His retirement.

This themed issue pays tribute to Professor Clement Uche Atuanya in recognition of his illustrious career in Metallurgical and Materials Engineering as he retires from Nnamdi Azikiwe University, Awka. We celebrate his enduring legacy of dedication to advancing knowledge and his impact on academia and beyond through this collection of writings.

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Bi-Model-Based Multi-Criteria Optimization Decision Support System for Strategic Maintenance Scheduling in Food Manufacturing Industries

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Abstract
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 a cost center. The economic downturn continuously drives manufacturing organizations to seek for more efficient strategies to manage assets maintenance. Thus, in this study a decision support system was developed and presented in this study, of which the aim is to develop a schedule for future maintenance actions for each manufacturing component that is repairable over the period time. This is obtained through the optimization of a bi-model-based multi-criteria optimization model. The developed system was validated using an industrial case study and it proved to be highly effective and less cumbersome in obtaining the optimal maintenance strategy from any manufacturing setting.

Keywords: Maintenance Optimization; Maintenance Strategy; Decision Support System; Maintenance Cost; Reliability

1. Introduction

The pressure on businesses and organizations to function in the most productive and cost-effective manner has intensified as a result of globalization, manufacturing systems often operate at less than full capacity potential equipment breakdown thus leading production wastes and losses (Chukwutoo and Nkemakonam, 2018). They are compelled to examine internal production activities and business processes in order to gain a competitive advantage (Godwin et al., 2022). Thus making production planning and maximizing profits a difficult task for manufacturing organizations (Igbokwe et al., 2024). In all industries worldwide, maintenance optimization presents a chance for greater economic advantage and profit generation (Syan and Ramsoobag, 2019).

Through optimization efforts, savings of 20–30% of the total operational cost have been attained (Regattieri et al., 2015). This is the main focus for the food manufacturing industry which is to improve efficiency and profitability through the reduction of total manufacturing costs by optimizing operation processes and maintenance activities achieved through continuously improved machine reliability and an efficient maintenance strategy (Igbokwe and Godwin, 2022).

Achieving high dependability in the context of manufacturing systems is essential and may be sought by putting in place appropriate maintenance plans, even taking into account its substantial effects on a company's competitiveness and cost-effectiveness (Pisacane et al., 2021). Thus decisions about maintenance optimization in this modern era must solve complex problems involving various, competing criteria (Regattieri et al., 2015). When such conflicting criteria are taken into account, multi-criteria formulations are practical methods for resolving such challenging engineering optimization issues. Thus a feasible approach to a multi-criteria problem is to investigate of a group of solutions, each of which satisfies the objectives at a commensurate level without being dominated by any other criteria (Ji et al., 2019). Maximum asset performance, high dependability, and low life cycle cost are the main objectives for production managers in Nigeria, and maintenance optimization becomes essential in achieving this aim while satisfying customer and management demands.

Single criterion optimization model applicability to actual economic and business-specific maintenance optimization criteria is constrained. A cost optimization method is used in the majority of these models, which lacks any economic reason when compared to other maintenance criterion restrictions like reliability, dependability, availability, or output quality in a complex engineering problem. As a result, it doesn't adequately represent every significant feature of a real-world industrial situation. Maintenance optimization, particularly within the framework of multi-criteria decision-making (MCDM), involves determining the most effective strategies for maintaining assets or systems while considering various criteria and objectives. In industrial settings, maintenance plays a crucial role in ensuring equipment reliability, minimizing downtime, and maximizing operational efficiency. However, resources allocated to maintenance are often limited, necessitating optimization approaches to achieve the best possible outcomes. Modern-day maintenance optimization decisions are complex problems which need to satisfy multiple and conflicting criteria (Syan and Ramsoobag, 2019). Syan and Ramsoobag (2019), defines multi-criteria optimization as a situation in which two or more conflicting criteria exist for which simultaneous optimization is required.

However, few have the internal resources to implement engineering solutions to a complex problem, hence this research intends to contribute by developing a bi-model-based multi-criteria optimization decision support for strategic maintenance scheduling. The system leverages on business intelligence, multi-criteria optimization, and a strategic approach to maintenance scheduling to address the specific needs of the food manufacturing industry. It aims to enhance efficiency, reduce costs, and ensure the smooth operation of equipment and processes in the production of food products.

2.0 Material and methods

The bi-model based multi-criteria optimization model developed by Igbokwe and Godwin, (2022), is applied and implemented as a model base in the decision support system developed in this study.

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

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

Where

F_i= cost of failure for component i

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

From equation 1,

$$[\boldsymbol{N_{i,j}}] = \lambda_i[(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta i}] \qquad \text{for } \boldsymbol{i} = \boldsymbol{1}, \dots, \boldsymbol{N}; \boldsymbol{j} = \boldsymbol{1}, \dots, \boldsymbol{T}$$

Therefore

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

Cost of preventive maintenance PMC_i: refers to the cost incurred while component 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_i). 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 ($CEMC_{ij}$).

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

$CPOC_{ij} + CEMC_{ij}$ for $\boldsymbol{i} = \mathbf{1}...\boldsymbol{N}$; $\boldsymbol{j} = \mathbf{1}...\boldsymbol{T}$ (3)

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

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

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

Thus $PMC_i = CCC_{ij} + CCBM_{ij} + CTBM_{ij}$ for $\boldsymbol{i} = \mathbf{1}...\boldsymbol{N}$; $\boldsymbol{j} = \mathbf{1}...\boldsymbol{T}$ (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

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

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

$$DC = DT\ X\ PL \tag{6}$$

Where

DT: Average duration for downtime

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

Hence Total Maintenance Cost is:

$$\sum_{i=1}^{N}\sum_{j=1}^{T} \{\boldsymbol{F_i} \times \lambda_i[(xx_{i,j})^{\beta_i} - (x_{i,j})^{\beta_i}] + CLO_{ij} + CCW_{ij} + CRVP_{ij} + CLG_{ij} + CI_{ij} + CDA_{ij} + CT_{ij} + CL_{ij} + CDP_{ij} + CPOC_{ij} +$$

$$CEMC_{ij} + CDA_{ij} + CRA_{ij} + CEH_{ij} + TEC_{ij} + LC_{ij} + AC_{ij}\} + \sum_{j=1}^{T}[\ D(1 - (PMC_{ij} + CMC_{ij}))]$$

For $\boldsymbol{i} = \mathbf{1}...\boldsymbol{N}$; $\boldsymbol{j} = \mathbf{1}...\boldsymbol{T}$ (7)

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*.

The reliability of the system at the end of period *j* is given as

$R_j = e^{-\lambda t^{\beta}}$

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

Thus Ris

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

for $\boldsymbol{i} = \mathbf{1} \dots \boldsymbol{N};\ \boldsymbol{j} = \mathbf{1}, \dots, \boldsymbol{T}$ (8)

Equation 7 and 8 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

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

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

$PMC_{ij} + CMC_{ij} \leq 1$ 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 $\boldsymbol{i} = \mathbf{1}, \dots;\ \boldsymbol{j} = \mathbf{1}, \dots, \boldsymbol{T}$ (9)

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 $\boldsymbol{X}_{i,j} = \mathbf{0}$, $CMC_{ij} = 1$, $PMC_{ij} = 0$. If a component is maintained then $CMC_{ij} = 0$, $PMC_{ij} = 1$. The optimization model uses a cost based approach to minimize total maintenance cost while assuring the desired improvement of machine reliability.

2.1 Assumptions

In this section, 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. The optimization complexity is, however, decreased in such a manner so as not to generate maintenance schedules that are unrealistic or unfit for use in practice.

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 a s new or to a state it was operating before.
4. Effect of Maintenance on manufacturing component: in this study, it is assumed that any maintenance action or strategy has a positive effect on the manufacturing component. Thus based on Eygelaar (2018), any preventive maintenance actions carried out reduces the effective age of the manufacturing component by 30% while corrective maintenance results into the component to be as good as new.
5. 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.
6. 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.
7. 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 if formulated for components through the different stages.
8. Nature of manufacturing components: within the realm of reliability theory, two main systems prevail, namely repairable systems and non-repairable systems. It is assumed in this study that components in a manufacturing system are repairable system. In a scenario where the manufacturing system has both repairable and non-repairable systems, the optimization algorithm form this study is formulated for repairable systems.

3.0 Results and Discussions

A decision support system is an information system that may be employed to support employees of companies with business and organizational decision making activities. Typically, such systems compiles useful information, which is presented to the user, by analyzing raw data and documents in order to identify or solve complex problems. The decision support system developed in this study consists of three main components namely:

- The database: developed to allow input data to be stored in a structure manner.

- A graphical user interface: developed to ensure effective human-computer interaction, thus enabling the user the means of providing the required input and obtaining relevant output.

- A model base: the workhorse of the system, implementing one of the solution techniques developed in the study to provide the relevant output.

An illustration of the interaction between the three components is described in figure 2.0

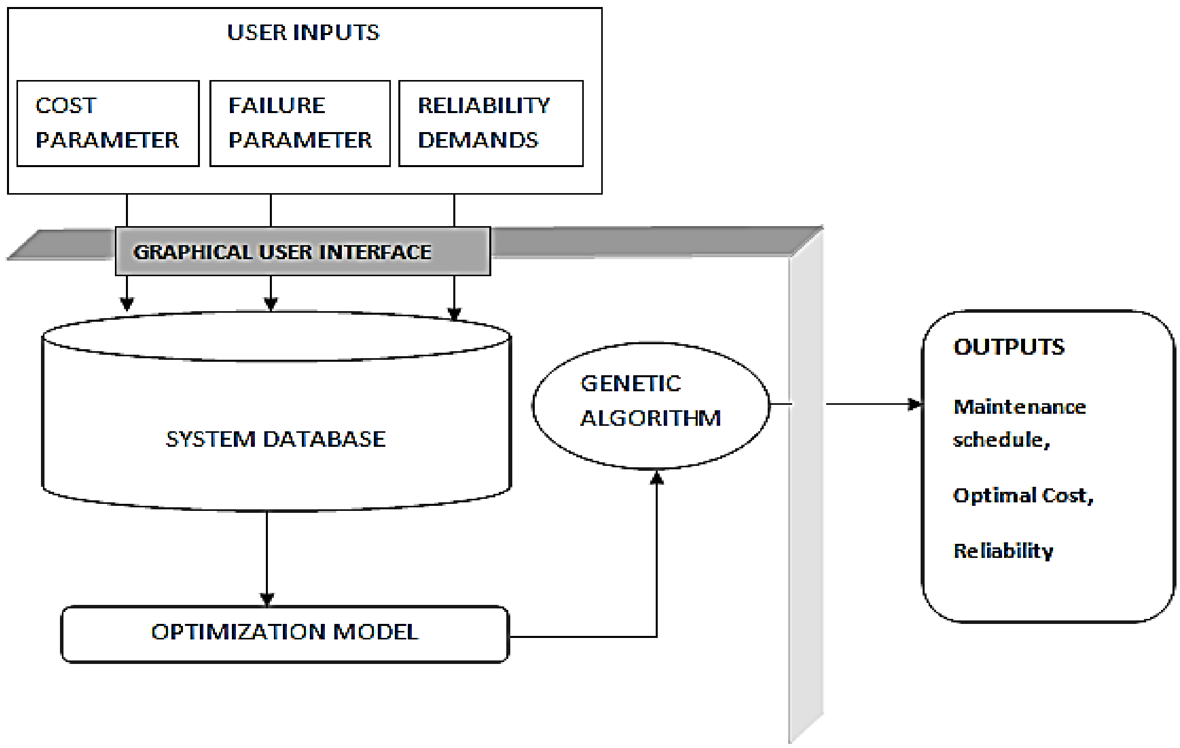

Fig 2.0: An Overview of the Decision Support System

3.1 Decision Support System Development

The software environment within which the decision support system was developed by this study is a framework supported by RStudio called Shiny. Shiny is an application framework used to construct elegant and powerful applications displaying interactive reports and data visualizations based in R. The framework Shiny was adopted in the development of the decision support system in this study due to its ability to create elegant GUIs capable of changing dynamically, based on R script files.

3.2 Data Preparation

In order to standardize the procedures of the decision support system support system, the required input data have to be prepared in a specific format before the decision support system can be utilized. The system requires one user-specified input file, containing maintenance cost information, information on the age reduction factor and information of reliability parameters. The format required of the file for the system is a comma separated values (CSV) format. An example of the exact required input data required is shown in figure 3.0.

Unit Number	Preventive Maintenance Cost	Corrective Maintenace Cost	Failure Cost	Total Maintenace Cost	Shape	Scale	Mean	Standard Deviation	Age Reduction Factor
1	387,450	496,760	884,210	1,768,421	1.5855	3316.5	2976.03	1920.25	0.7
2	93,855	272,560	366,415	732,820	1.761	3375.42	3005.13	2741.21	0.7
3	92,680	338,000	430,680	861,360	1.7397	3254.14	2899.2	1718.89	0.7
4	99,500	413,822	513,322	1,026,644	1.7123	3252.65	2900.75	17744.82	0.7
5	231,685	387,000	618,685	1,237,370	1.6852	3170.13	2830.25	1727.3	0.7

Fig 3.0: Required Input Format of the Specifications of a Manufacturing System

3.3 System Walk Through

After having prepared the required input data in the specified format, as described in the previous section, the user interface support system can be utilized to recommend optimal maintenance strategies for the manufacturing system specified. Once the user interface support system is initialized, the user is presented with the “Home screen" shown in Figure 4.0. On this screen, a short introduction to the user interface support system is provided to the user, as well as the steps to be followed in order to utilize the user interface support system to its full potential. After the instructions have been read and understood, the user can navigate to the “System specifications" window on the left-hand side of the screen, which displays the window seen in Figure 5.0. The user may, however, navigate back to the “Instructions" window at any subsequent time if some of the instructions have to be reviewed. In the “System specifications" window, the user can input the input requirement specifications in the format specified above.

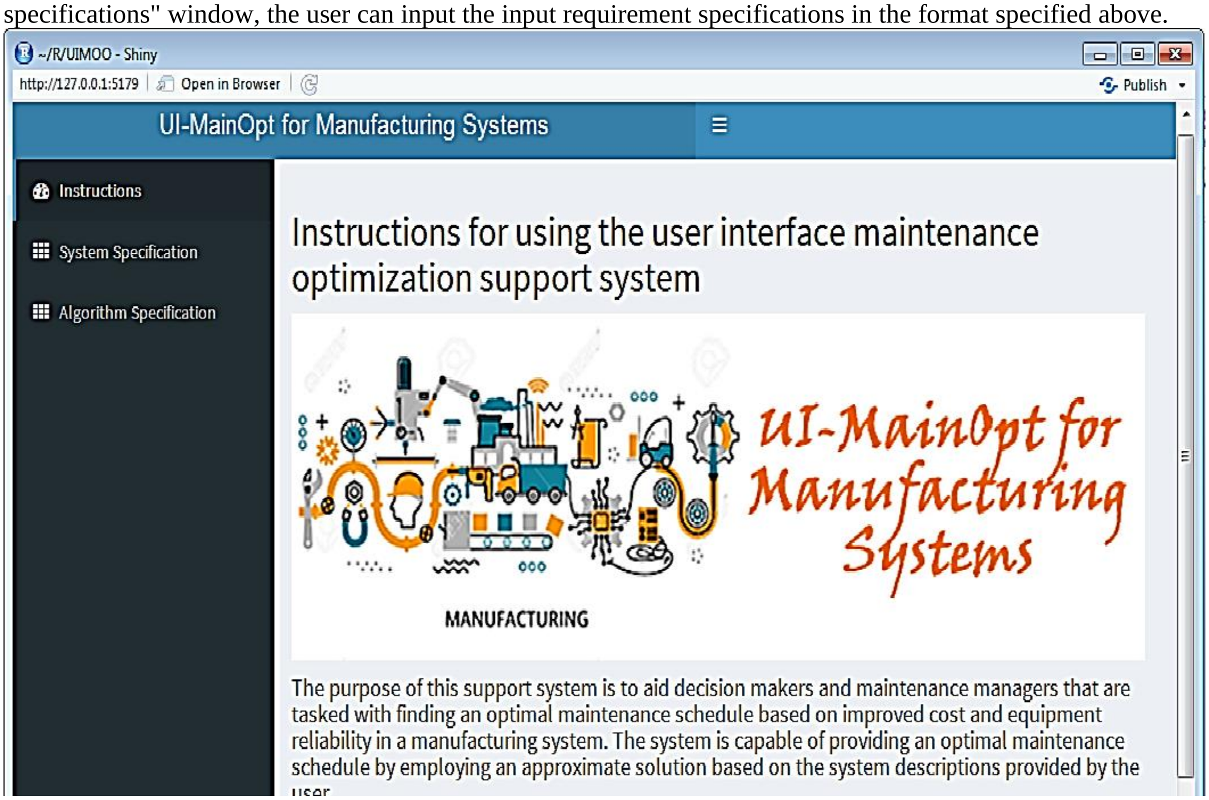

Fig 4.0: The “Home screen" presented to the user when the system is initialized

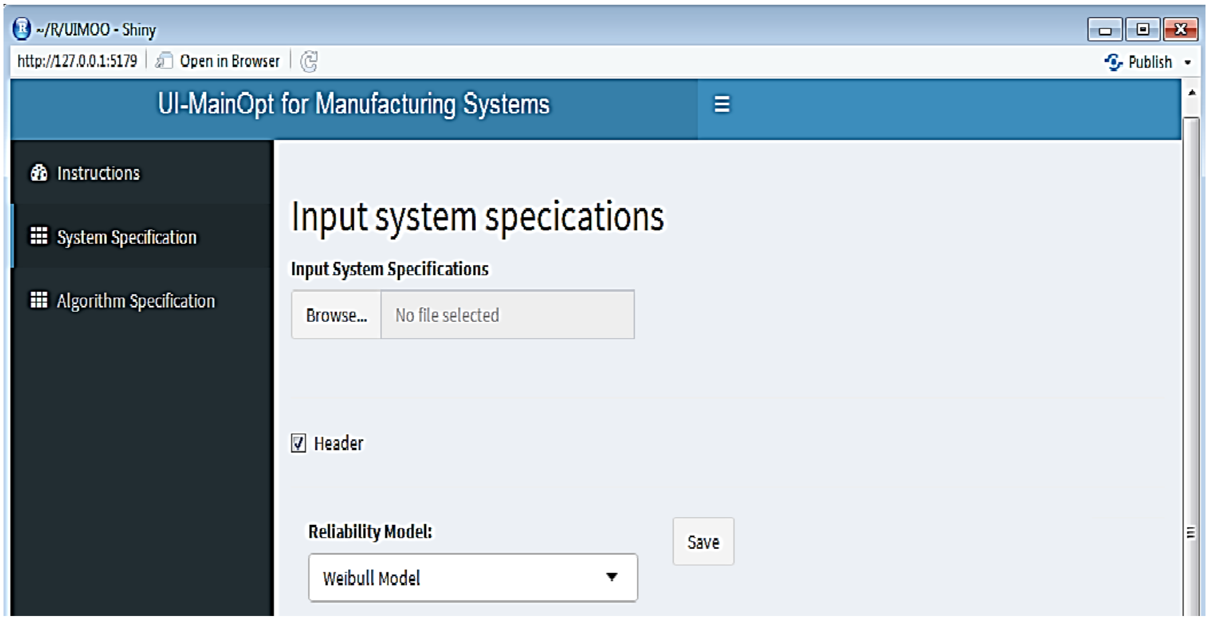

Fig 5.0: GUI through which the user can upload the input specifications

Once the user uploads the specified input data in the required format, the system generated an overview of the data uploaded, and if the user is satisfied with the data uploaded, the user can click on the “save" button which will upload the specifications to the system database. This is illustrated in figures 6.0 and 7.0.

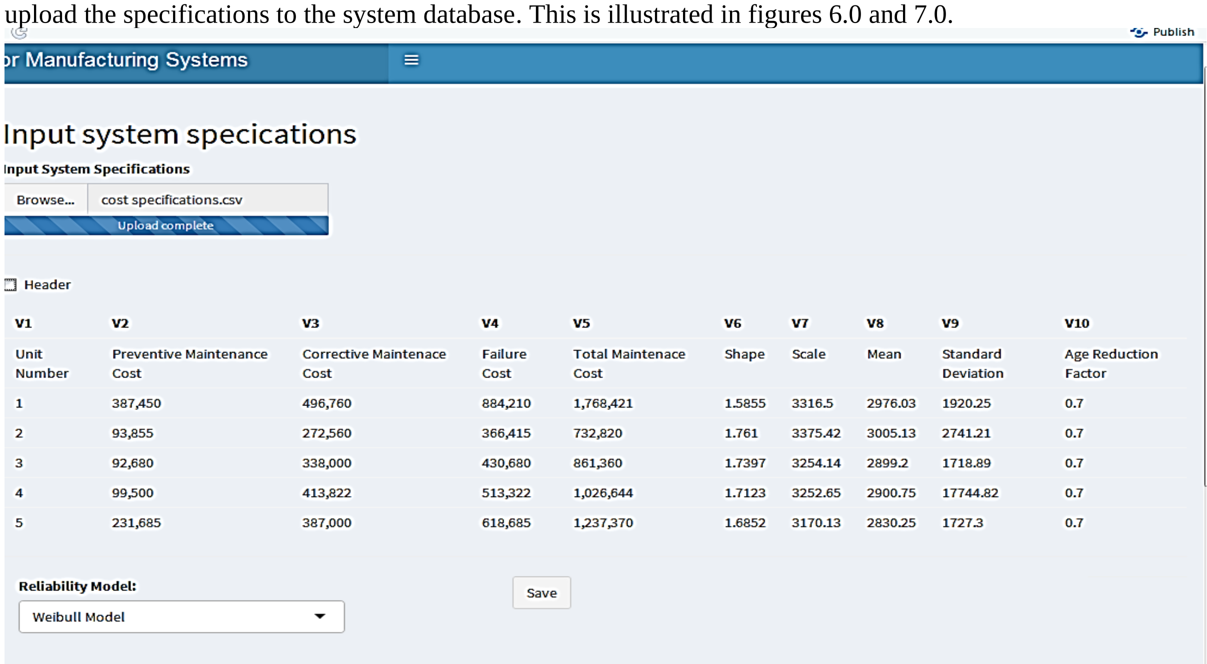

Fig 6.0: An Overview of the Specified System Specification

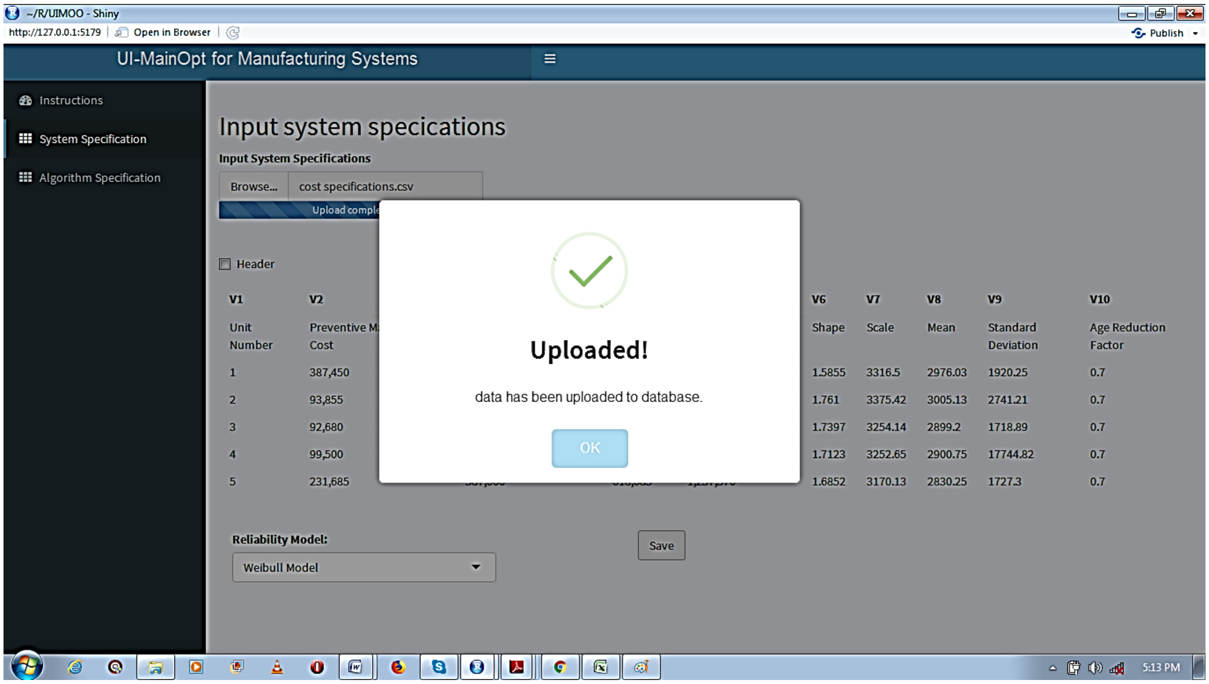

Fig 7.0: An Overview of the Specified System Specification database uploads

After the input specifications have being uploaded successfully the next step is to indicate the algorithm specifications for the model. In the algorithm specification window as shown in figure 8.0, the user is required to specify the objective functions and other requirements of the genetic algorithm. This includes the desired maintenance objective functions (selected by clicking on the radio buttons associated with the objective functions), the number of generations and population size (selected by moving the slider to the associated value), and other required parameters associated to the probability of selection, crossover and mutation (selected by choosing values from the dropdown list).

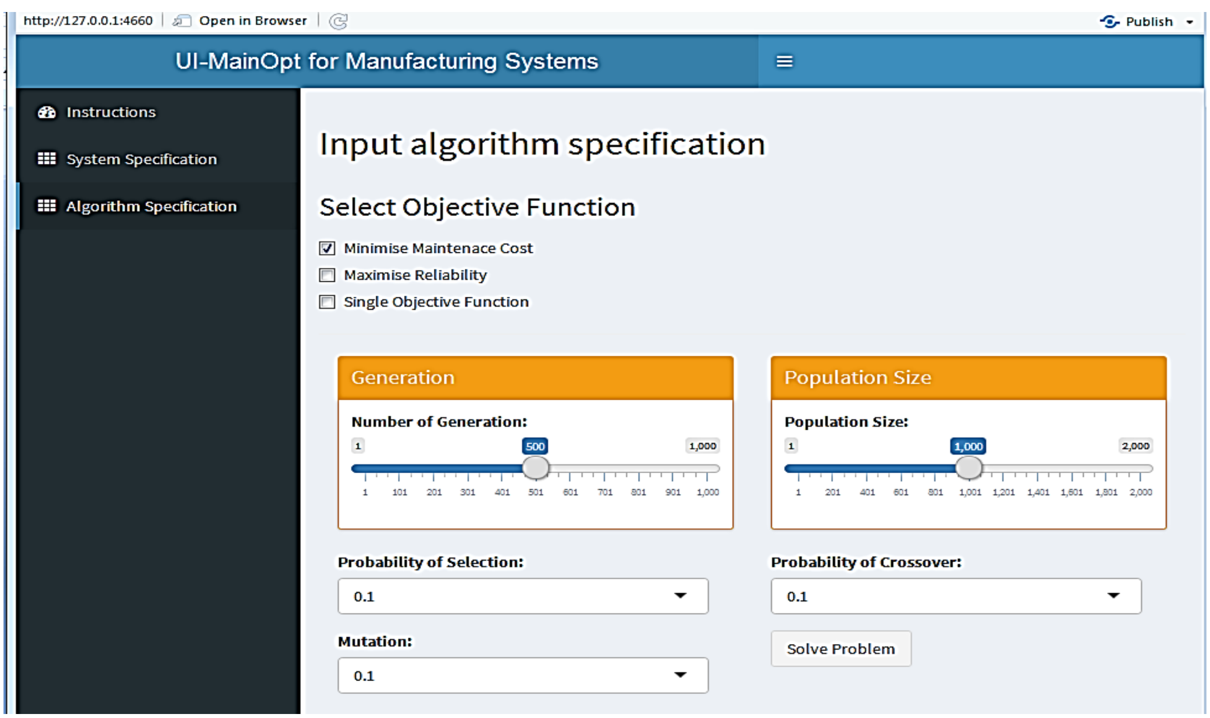

Fig 8.0: The Algorithm Specification Window

Once the user is satisfied with the selected objective function, and the genetic algorithm parameter values, he/she can click on the solve button. Clicking this button will execute the genetic algorithm and the user interface support system will subsequently be occupied, solving the model. The duration for which the user interface support system may be occupied, depends on various factors such as Central Processing Unit rating, number of generation and population size. Once the algorithm has found a solution (when the status window disappears), the solutions which includes an optimal schedule, optimal pareto fronts and system reliability will be saved in a comma separated values files through which the user can access the solutions in the user's personal computer.

3.4 Validation Case Study

The decision interface support system was used to solve a large, real-life industrial case study in a food manufacturing company in Nigeria. The industrial case study, adopts corrective maintenance as its preferred maintenance strategy only, which can be described as a reactive, firefighting strategy (Igbokwe and Godwin, 2021). The data in table 1.0 represents the summary of maintenance cost data obtain in thirty six months from the company.

Table 1.0: Summarized Optimization data from Industrial Case Study

T		36 months (3 years)							
DC		₦ 197,561							
N	Component	Shape (β)	Scale (ƛ)	Mean (μ)	Standard Deviation (σ)	α_{pmi}	Failure Cost	Preventive Maintenance Cost	Corrective Maintenance Cost
1	Conveyor System	1.5855	3396.50	2976.03	1920.25	0.7	₦ 884,210	₦387,450	₦ 496,760
2	Mixer system	1.7610	3375.42	3005.13	2741.21	0.7	₦ 366,415	₦93,855	₦ 272,560
3	Roller system	1.7397	3254.14	2899.20	1718.89	0.7	₦ 430,680	₦ 92,680	₦ 338,000
4	Slitter	1.7123	3252..65	2900.75	1744.82	0.7	₦ 513,322	₦ 99,500	₦ 413,822
5	Compounding Machine	1.6852	3170.13	2830.25	1727.30	0.7	₦ 618,685	₦ 231,685	₦ 387,000

The results from the computerized user interface support system which represents the best schedule are shown in table 2. 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 2: 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

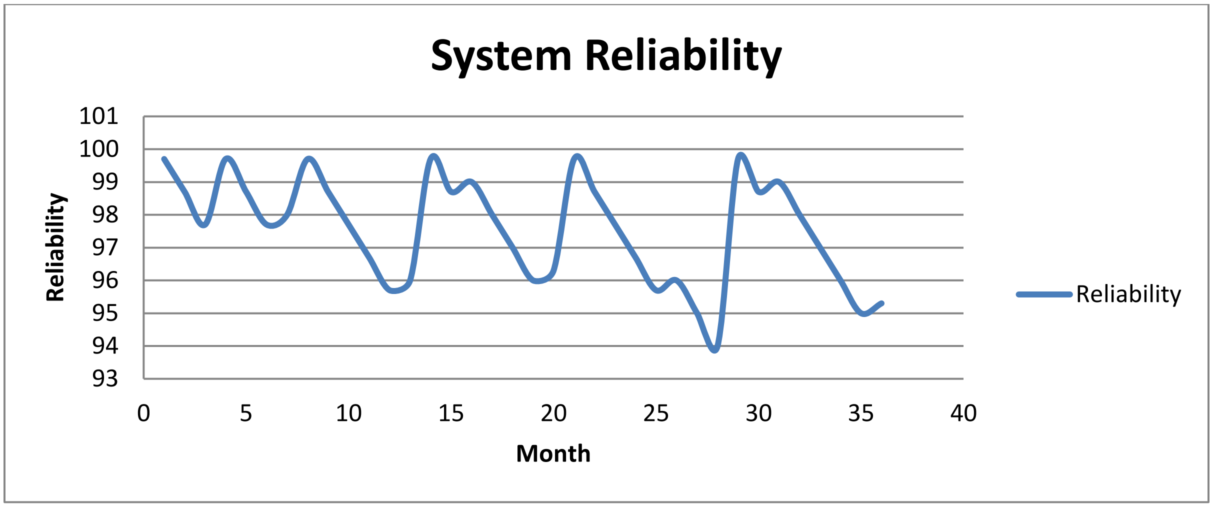

Fig 9: Reliability of the system over the period of 36 months

The optimal maintenance strategy presented in table 2 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 9 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 system solution can be seen as some of the components are allowed to spend longer times in service before being maintained. From the optimal maintenance strategy one can analyze the effective age of each component. As illustrated in Figures 11 – 15, it could be used to track the effective age of the components and then utilize the information to initiate additional monitoring activities. For example, after a component reaches a certain level of effective age, additional monitoring, tests or inspections might be warranted to assist in the detection of imminent failure.

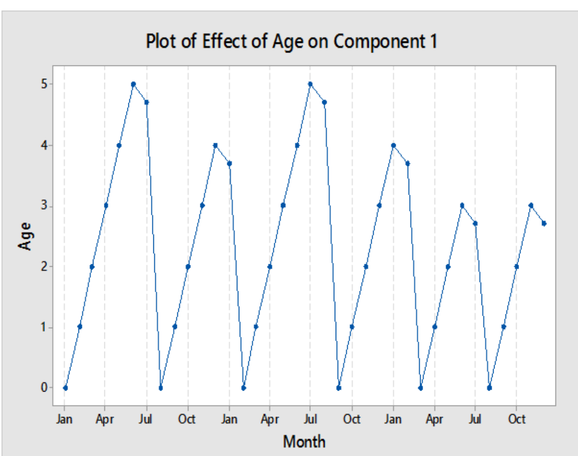

Fig 10: Optimal maintenance strategy effect on Conveyor System

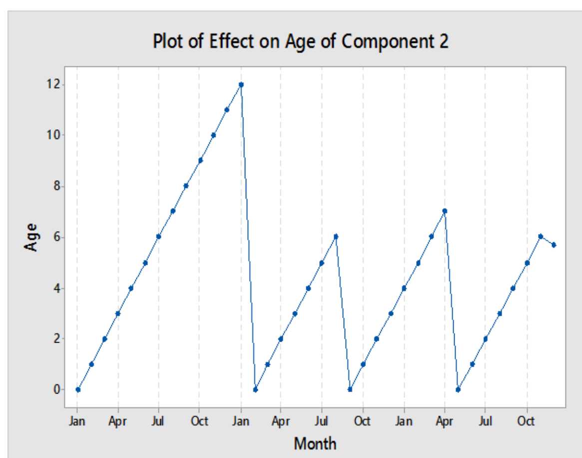

Fig 11: Optimal maintenance strategy effect on Mixer System

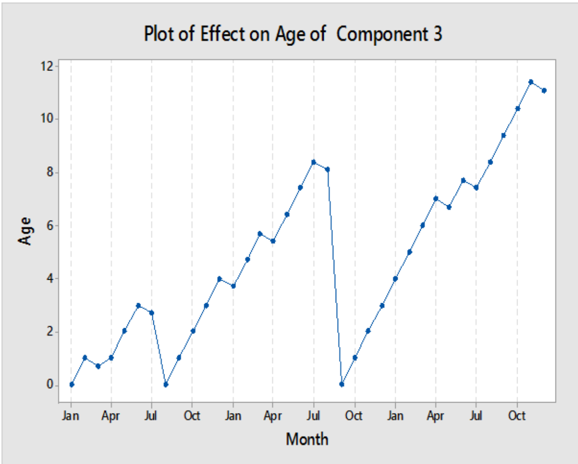

Fig 12: Optimal maintenance strategy effect on Roller System

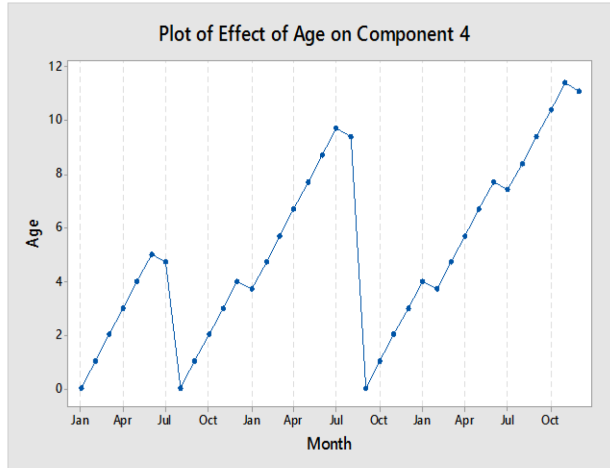

Fig 13: Optimal maintenance strategy effect on Slitter System

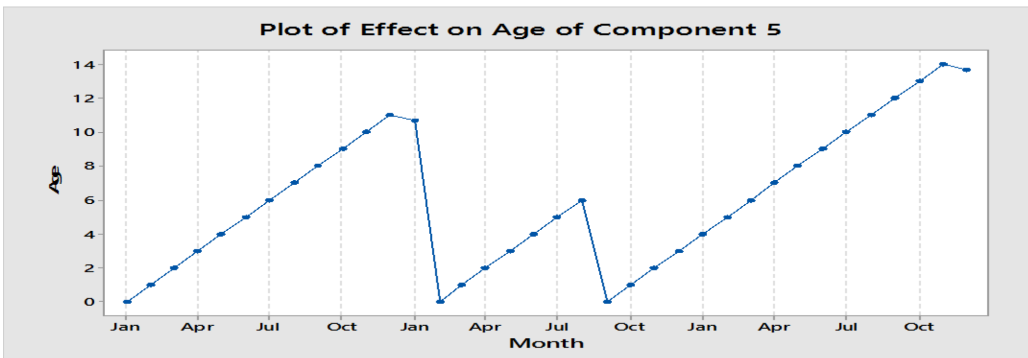

Fig 14: Optimal maintenance strategy effect on Compounding Machine

Another observation is the effect of failure rate on the number of scheduled maintenance, for example when one compares component 1 and 5, it can be observed that component 1 has more scheduled maintenance actions than component 5. This explains the variation in effective ages of the component as component one has higher failure rate than component 5. Thus, it is necessary that component 1 receives more attention.

4.0. Conclusion

A bi-model based multi-criteria optimization decision support system for strategic maintenance scheduling in food manufacturing industries was presented in this study. This system is designed to assist decision-makers in making informed and optimal maintenance decisions. It provides relevant information and analytical tools to support the decision-making process. The optimal strategy was obtained through the optimization of a mixed integer nonlinear multi-objective programming model to minimize total maintenance cost and maximize system reliability using the decision support system developed and presented in this study. The support system proved to be highly effective and less cumbersome in obtaining the optimal strategy from any manufacturing setting. For the system 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.

5.0 Recommendation

As a practical recommendation, it will be useful to apply other maintenance criteria, for example availability, inventory spare parts, maintenance time, risk, and spare parts supply logistics to develop an optimal strategy in order to achieve the same purpose of improving maintenance performance.

Nomenclature

N: Number of Components;
T: Length of Planning Scope;
J: Number of Periodic Intervals;
ƛ: Scale Parameter;
β: Shape Parameter;
μ: Mean;
σ: Standard Deviation;
Xi,j: Effective age of component i at the start of period j;
XXi,j: Effective age of component i at the end of period j;
αpmi: Age reduction factor of preventive maintenance on component i;
$\boldsymbol{Fi}$: Failure cost of component i;
PMCi: Cost of preventive maintenance on component i;
CMCi : Cost of Corrective maintenance on component i;
DC: Downtime cost;

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