Modelling and Optimization of Reliability Functions for a Gas Compressing System

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Abstracts: This study entails the optimization of a gas compressing system to maximize its reliability and subsequently cut maintenance costs. In the course of the work, an improvement of Mean Time To Failure (MTTF technique was achieved by varying different failure cost of maintenance with targeted system reliability for a gas processing system and this was done using LINGO application programming bundles which was used to run a Nonlinear Mixed Integer Programing Model (NLMIP) to effectively enhance the processing plant and the reliability of five individual systems, including air compressing system: impeller, bearings, mechanical seals, valves and cooling fan within the gas compression system. The Excel solver was utilized to process the mean time to failure (MTTF) and the evaluated MTTF was additionally used to assess and understand the system failure history. From the study outcomes, it was ascertained that the MTTF of a system can be controlled through a maintenance planned support program The study outcomes also helped to determine that an alternative way to deal with the conventional maintenance practice is developing a support program through the execution of system reliability that reviews the system framework and sub-component and key parameter index, such as repair rate and failure rate.

Keywords: Mean Time to Failure; Gas compressing system; LINGO, Repair rate, Failure rate.

1. INTRODUCTION

The oil and gas processing industry is complex and comprises equipment working under extreme conditions. When a component belonging to a critical system fails, severe accidents may occur. Vinnem (2014) explored major accidents in the oil and gas industry, one of which being Piper Alpha in 1990, when a gas leak in the compression area started an accident that claimed 166 lives. The huge loss and sanctions experienced during the 2010 Macondo oil spill due to the failure of Blow-out Preventer, the 2011 Bonga incident and a host of recent failures has sparked accelerated efforts towards improvement of reliability, risk management and asset integrity of oil and gas systems (Skogdalen *et al*., 2011; Cai *et al*., 2013; Vadachalam, 2016).

An investigation conducted by the UK Health and Safety Executive (HSE UK, 2014) indicated that nearly 80% of risk posed to oil and gas workers emanate from process related failures. These failures which often cause accidents, downtimes and serious economic losses emanate from the complex interaction between human and technical factors which cause approximately 70% and 30% of incidents respectively (Cai *et al*., 2013). With an increasing appetite for processing installations in the industry, risk exposure could even be higher due to lack of standardized reliability data and the fact that assets when deployed to some environment are exposed to additional stresses brought by dynamic influencing factors of such environment (Bai & Bai, 2012; Vedachalam, 2015). This justifies any study which seeks to understand the equipment failure behaviour to ensure maximum uptime. The highly specialized oil and gas sector is not exactly known for standardized asset life cycle reliability procedures (Antosen *et al*., 2012) because there seems to be a lope-sided focus on the technical reliability qualification at manufacturing stages of modules and systems by several scholars; whilst appearing to neglect lifecycle asset reliability especially during the operational stages where the intertwine between human, equipment, environment is more pronounced (El-ladan & Turan, 2012). Although, risks and failure cannot be completely eradicated from any system, they certainly can be controlled through enhanced reliability strategies throughout the lifecycle of the project.

The rapid development of sophisticated and industrialized equipment is a tremendous progress but the problem lies in the fact that maintaining high equipment reliability requires a well detailed maintenance approach apart from the manufacturer's recommendation. Sophisticated engineering systems like gas and nuclear power station, and other complicated industrial equipment operate under extreme high reliability and safety conditions due to the complicated nature and technology involved. Tan and Kramer (1997) highlighted the importance of moving from the regular way of carrying out maintenance to a more sophisticated approach of studying the system mechanism and developing a model for the specific system to optimize its overall maintainability. The rapid demand for quality products and services is increasing at an overwhelming rate. For those in the manufacturing industries to overcome these challenges, then an effective approach to maintenance strategy needs to be adopted. A sophisticated maintenance scheme that is reliable and trustworthy in attaining a high standard and quality control and assurance need to be implanted by manufacturing firms. Also, the significance of the compressing system, warrants a diagnostic and maintenance method capable of diagnosing the system while in operation in order to record zero downtime.

This paper investigated the maintenance approach adopted at a Petrochemical company in Port Harcourt that utilizes the refinery intermediates to produce petrochemical precursors. The paper focused on the modelling and optimization of the overall reliability functions for a gas compressing system with respect to cost function.

2. METHODOLOGY

2.1. System Architecture and Configuration

Considering the system configuration of case study, the approach to the research starts with the reliability and cost analysis of a production plant connected in a series configuration. Although the production plant comprises several complex system configurations but to achieve a reasonable outcome of this research, critical components and potentially critical components were the sole drive of this work. Hence failure data of both critical components and potentially critical components were extracted from the maintenance log book of the case study with the assistance of staff of the company. Therefore, the mechanical components from the gas compressing system of the processing plant are as follows:

1. Impeller
2. Bearings
3. Mechanical seals
4. Valves
5. Cooling fan Turbine

The methodology adopted was to analyze, evaluate and develop a model based on the gas compressing system failure history and then use the system exponential failure history to model a Weibull or normal distribution failure history for the system respectively. The gas compressing system studied as described above is made up of several independent sub-units but the focus was on the five most critical components of which the failure history was used to evaluate the Mean Time to Equipment Failure for each system respectively.

2.2. Mathematical Formulation of the Gas Compressing System

Weibull and exponential distribution were adopted in the formulation of the hazard function expression in relation to the mean time to equipment failure. For n independent components of the gas compressing system arranged in series, parallel or series-parallel connection, the reliability of the system configuration is analyzed and evaluated based on the individual component by carrying out a series analysis, parallel analysis or series-parallel analysis respectively. The individual component reliability function can be denoted as $r_1(t), r_2(t), \dots \dots \dots . r_n(t)$

where $r_1(t)$ *represent the reliability of component* 1,

W$r_2(t)$ *represents the reliability of component* 2,

W$r_3(t)$ *represent the reliability of component* 3,

for the last two terms-$r_4(t)$ and $r_5(t)$

W$r_4(t)$ *represent the reliability of component* 4 and

W$r_5(t)$ *represent the reliability of component* 5

The reliability of the entire gas compressing system can be expressed as:

$$r(t) = v(r_1(t), r_2(t) \ldots \ldots \ldots . r_n(t)) \quad (1)$$

Where v can be denoted as the reliability function of the system.

2.3. Status Functions of the Gas Compressing System

To develop a model for the gas compressing system, the status function of the compressing system must be defined. Hence, the functional status for any system or component can be expressed as:

$$\emptyset = \begin{Bmatrix} 1 \text{ if the system functions properly} \\ 0 \quad \text{if the system is failed} \end{Bmatrix}$$

The gas compressing system is comprised of the following components (Impeller, Bearing, Mechanical seals, Valve and Cooling fan Turbine) and that system status is determined by the component status. Then we represent the number of components that make up the system (gas compressing system) and express the component status variables as

$$x_1 = \begin{Bmatrix} 1 \text{ if the component is functioning} \\ 0 \text{ if the component is failed} \end{Bmatrix}$$

Hence, the number of n components that make up the system can be represented as component status vector which can be expressed as:

$$\underline{x} = (x_1, x_2, \ldots \ldots \ldots \ldots x_n) \quad (2)$$

Therefore, the dependence of the system status on the component status as a function can be expressed as

$$\emptyset = \emptyset(\underline{x}) \quad (3)$$

Equation (1) is defined as "system structure function" which defines the way each component interacts with each other to determine the system reliability function. The component status vector of the gas compressing system can be defined as vector of binary elements so that an n-number of components can be expressed as 2^n possible component status vectors. Therefore, the component status vector for the gas compressing system can be expressed as:

$$Q = 2^n \quad (4)$$

where n represent numbers of component considered. For this research, n = 5, $2^5 = 32$

A five-component system has $2^5 = 32$ component status vectors, where each component status vector field yields a corresponding value for the gas compressing system status function∅ respectively.

2.4. Series System Structure

A series system can be defined as a system in which all components in the system must function efficiently in order for the system to function properly. Therefore, for the gas compressing system to function properly we consider a series structure which means all components of the gas compressing system must function properly and it can be expressed as

$\emptyset(\underline{x})$ = min (x_1) (5)

Define all the symbols used in any equation at first appearance.

This can be expressed in a more useful way as:

$\emptyset$ $(\underline{x})$ = $\prod_{i=1}^{n} x_i$ (6)

2.5. Parallel System Structure

A parallel system can be defined as a system in which the proper function of any one component means system function Therefore, for the gas compressing system to function properly we consider a parallel architecture which can be expressed as

$\emptyset(\underline{x})$ = max (x_1) (7)

Which can be expressed in a more useful way as

$\emptyset$ $(\underline{x})$ = $\prod_{i=1}^{n} x_i$ (8)

$\emptyset$ $(\underline{x})$ = $\prod_{i=1}^{n}(1 - x_i)$ (9)

Therefore, the system status values for a series or parallel structure can be in these states

$\underline{x}_1 = \{11111\}$,$\underline{x}_2 = \{11110\}$, $\underline{x}_3 = \{11101\}$,$\underline{x}_4 = \{11100\}$ and $\underline{x}_5 = \{11011\}$

The expression above describing the system status can be expressed in a more useful form as

$P_1 = (12345)$,$P_2 = (1234)$,$P_3 = (1235)$,$P_4 = (123)$,$P_5 = (1245)$

Hence, the system status can be expressed in general term as:

$P_j(x) = \prod_{i=P_j}^{n}(x_i)$ (10)

$P_1(\underline{x}_1) = \prod_{i=P_1}^{n} x_i = x_1x_2x_3x_4x_5$ (11)

$P_2(\underline{x}_2) = \prod_{i=P_2}^{n} x_i = x_1x_2x_3x_4$ (12)

$P_3(\underline{x}_3) = \prod_{i=P_3}^{n} x_i = x_1x_2x_3x_5$ (13)

$P_4(\underline{x}_4) = \prod_{i=P_4}^{n} x_i = x_1x_2x_3$ (14)

$P_5(\underline{x}_5) = \prod_{i=P_5}^{n} x_i = x_1x_2x_4x_5$ (15)

For the gas compressing system structure, this expression expands to

$\emptyset(\lambda) = 1 - (1 - x_1x_2x_3x_4x_5)(1 - x_1x_2x_3x_4)(1 - x_1x_2x_3x_5)(1 - x_1x_2x_3)(1 - x_1x_2x_4x_5)$ (16).

2.6. Reliability of the Gas Compressing System Structure

The reliability of the gas compressing system can be represented as “system stake” and denoted with a binary variable$\emptyset$. Therefore, the reliability of the gas compressing system (R_s) can understand to be the probability that the system is functioning properly.

$$R_s = P_r[\emptyset = 1] \quad (16a)$$

Considering the system component vector which can be defined as status variables:

$$r_i = P_r[x_i = 1] \quad (17)$$

Hence, for a system comprising of n component:

$$\underline{r} = \{r_1 r_2, \dots r_n\} \quad (18)$$

Equation (16) donates vector representation of component reliability. Therefore, it is expected that component reliability determines system reliability which can be expressed as:

$$R_s(\underline{r}) = P_r[\emptyset(x) = 1] \quad (19)$$

Equation (19) represents the system reliability based on architecture of the gas compressing system, the general representation of the reliability function for the gas compressing system is expressed as:

$$R_s(\underline{r}) = P_r[\emptyset(x) = 1] \quad (19a)$$

$$R_s(\underline{r}) = P_r[\textstyle\prod_{i=1}^{n} x_i = 1] \quad (20)$$

$$R_s(\underline{r}) = \textstyle\prod_{i=1}^{n} x_i \quad (21)$$

Based on the system status and system function we can represent an equivalent structure to evaluate system reliability. Adapting the same approach for the system status, the system reliability can be evaluated in all possible system states then obtain the probability for each state and add-up the probabilities that make up the system function

Based on the expression of Equation (10) to Equation (14) the system reliability of the gas compressing system with five (5) critical components can be expressed as:

$$\underline{x}_1 = \{1\ 1\ 1\ 1\ 1\} = P_r\left[\emptyset\ (\underline{x})\right] = (r_1 r_2 r_3 r_4 r_5) \quad (22)$$

$$\underline{x}_2 = \{1\ 1\ 1\ 1\ 0\} = P_r\left[\emptyset\ (\underline{x})\right] = r_1 r_2 r_3 r_4 (1 - r_5) \quad (23)$$

$$\underline{x}_3 = \{1\ 1\ 1\ 0\ 1\} = P_r\left[\emptyset\ (\underline{x})\right] = r_1 r_2 r_3 (1 - r_4) r_5 \quad (24)$$

$$\underline{x}_4 = \{1\ 1\ 1\ 0\ 0\} = P_r\left[\emptyset\ (\underline{x})\right] = r_1 r_2 r_3 (1 - r_4)(1 - r_5) \quad (25)$$

$$\underline{x}_5 = \{1\ 1\ 0\ 1\ 1\} = P_r\left[\emptyset\ (\underline{x})\right] = r_1 r_2 (1 - r_3) r_4 r_5) \quad (26)$$

$$R_s = r_1 r_2 r_3 r_4 r_5 + r_1 r_2 r_3 r_4 (1 - r_5) + r_1 r_2 r_3 (1 - r_4) r_5 + r_1 r_2 (1 - r_3) r_4 r_5 + r_1 r_2 (1 - r_3) r_4 (1 - r_5) + r_1 r_2 (1 - r_3)(1 - r_4) r_3 + r_1 (1 - r_2) r_3 r_4 r_5 + r_1 (1 - r_2) r_3 r_4 (1 - r_5) + r_1 (1 - r_2) r_3 (1 - r_4) r_5 + r_1 (1 - r_2)(1 - r_3) r_4 r_5 + r_1 (1 - r_2)(1 - r_3) r_4 (1 - r_5) + (1 - r_1) r_2 r_3 r_4 r_5 + (1 - r_1) r_2 r_3 r_4 (1 - r_5) + (1 - r_1) r_2 r_3 (1 - r_4) r_5 + (1 - r_1) r_2 (1 - r_3) r_4 r_5 + (1 - r_1) r_2 (1 - r_3)(1 - r_4) r_5$$

(27)

$$R_s = r_1 r_4 + r_2 r_5 + r_1 r_3 r_5 + r_2 r_3 r_4 - r_2 r_3 r_4 0\backslash 8I,/$$
$$- r_1 r_2 r_3 r_4 - r_1 r_2 r_3 r_5 - r_1 r_2 r_4 r_5 - r_1 r_3 r_4 r_{5../I0} - r_2 r_3 r_4 r_5 + 2 r_1 r_2 r_3 r_4 r_5$$
(28)

The five components of the gas compressing system reliability function reduced to the polynomial

$$R_s = 2r^2 + 3r^3 - 5r^4 + 2r^5 \quad (29)$$

Equation (29) represents the overall reliability of the gas compressing system and the reliability function of the gas compressing system can be expressed as

$$R(t) = \exp\left[-\int_0^t f dt\right](t) \quad (30)$$

Since the reliability equation (function) are different based on the various stages of the bathtub curve, we introduce the reliability expression for infant mortality distribution as,

$$R(t) = \exp \boldsymbol{\lambda}\left[-\int_a^b \beta_i t^{\beta_i - 1}\right] \quad (30a)$$

β= represents the scale parameter from the Weibull age reliability relationship which scales the age value at time t. Since the system is at the infant mortality distribution which follows a Weibull distribution of 1 year (β =12 month).

λ=is the failure rate of the gas compressing system,

$a$and$b$=is the time interval between 0 to 12month.

2.7. Reliability Optimization

Based on the system configuration we can minimize the system cost of maintenance subject to a reliability constraint or maximize system reliability subject to cost constraints.

Let R_s represent the reliability of the gas compressing system.

M_i= the number of components in the system configuration

C_i = the unit cost for component (i) maintenance or replacement

2.8. Cost Function for the Gas Compressing System

The gas compressing system in focus can efficiently attain high reliability if proper resources are channeled to the most critical components of the system. Hence the cost of system maintenance is paramount in our analysis. Therefore, this paper considered the following:

i. Cost of maintenance (C_{m_i}),

ii. Cost of Replacement (C_{r_i}) as thesystem cost function, and

iii. Total cost (failure cost) that represent both replacement cost and maintenance cost.

2.9. Cost of Maintenance($\mathbf{C_{m_i}}$)

One of the key performance indicators for measuring the reliability of any system is the amount of resources invested in keeping the system in its best state. Therefore, the cost of maintaining component (i) in a in a specific period (j) can be mathematically expressed as its system cost function, hence.

$$C_{m_i} = \sum_i^n \sum_j^t M_i . m_{i,j} \quad (31)$$

$m_{i,j}$= a binary operative that shows maintenance activities have occurred during the planning horizon,

M_i = maintenance cost for a particular component in a particular period

2.10. Cost of Replacement ($\mathbf{C_{r_i}}$)

$$C_{r_i} = \sum_i^n \sum_j^t R_i r_{i,j} \quad (32)$$

$r_{i,j}$ = a binary operative that shows replacement activities have occurred during the planning horizon.

R_i = replacement cost for a particular component in a particular period

Therefore, the total cost function (failure cost) for the gas compressing system from Equations (31) and (32) can be expressed as:

$$C_{T_c} = \sum_i^n \sum_j^t M_i m_{i,j} + \sum_i^n \sum_j^t R_i r_{i,j} \quad (33)$$

where $C_{T_c} = Total\ cost$

Total Failure Cost $\mathbf{C_{f_i}}$

The cost of total failure which represents both the replacement cost and maintenance cost, can be expressed as

$$C_{f_i} = \sum_i^n \sum_j^t F[N_{i,j}] \quad (34)$$

Where MTTF can be expressed as based on Weibull distribution of the bathtub curve of early live.

$$F[N_{i,j}] = \int_{a_{i,j}}^{b_{i,j}} \boldsymbol{\lambda}_i \beta_i t^{\beta_i - 1} \quad (35)$$

$$F[N_{i,j}] = \boldsymbol{\lambda}_i {a_{i,j}}^{\beta_i} - \boldsymbol{\lambda}_i {b_{i,j}}^{\beta_i}$$

Hence, the total failure cost function can be expressed as:

$$C_{f_i} = \sum_i^n \sum_j^t \mathbf{C_{f_i}} [\boldsymbol{\lambda}_i {a_{i,j}}^{\beta_i} - \boldsymbol{\lambda}_i {b_{i,j}}^{\beta_i}] \quad . \quad (36)$$

2.11. Optimization Model: Reliability Maximization Subject to Failure Cost Constraints

Max. Reliability = $C_{f_i} = \sum_i^n \sum_j^t \mathbf{C_{f_i}} [\boldsymbol{\lambda}_i {a_{i,j}}^{\beta_i} - \boldsymbol{\lambda}_i {b_{i,j}}^{\beta_i}] \quad .$ (37)

Subject to

$$\sum_i^n \sum_j^t \mathbf{C_{f_i}}[\boldsymbol{\lambda}_i a_{i,j}{}^{\beta_i} - \boldsymbol{\lambda}_i b_{i,j}{}^{\beta_i}] \quad + \sum_i^n \sum_j^t M_i m_{i,j} + \sum_i^n \sum_j^t R_i m_{i,j} < \text{Failure Cost} \tag{38}$$

$$m_{i,j} + r_{i,j} \leq 1 \qquad for\ i = 1,2,3 \dots \dots .n; j = 1,2,3 \dots \dots .t \tag{39}$$

$$m_{i,j} \leq 1\ or\ 0 \qquad for\ i = 1,2,3 \dots \dots .n; j = 1,2,3 \dots \dots .t \tag{40}$$

$$r_{i,j} \leq 1\ or\ 0 \qquad for\ i = 1,2,3 \dots \dots .n; j = 1,2,3 \dots \dots .t \tag{41}$$

The model above expressed reliability maximization with respect to target cost of critical five components. Equation (37) represents the reliability function that is required to maximize the reliability of the system with respect to cost. The first term on the right hand of the equation represents the reliability function while the second term represents the cost function associated with maintenance and replacement of the gas compressing system respectively. Equation (38) represents the various cost constraints placed on each component respectively. Finally, Equation (39) represents a binary operative that shows either maintenance or replacement activities have occurred during the planning horizon.

2.12. Approach Adopted in Evaluating the Model (Optimization Software: LINGO)

The LINGO software was applied in solving the non-linear model. The 17.0* 64.0 LINGO software has a unique syntax code and modeling language that is built to analyze and solve complex mathematical problems in an easier way. Its features include but not limited to the following; Mixed Integer Solver, Global Solver, Multistate Solver, Stochastic Solver etc. The LINGO modeling language was used to code and optimize the developed model for the gas compressing system plant.

3. RESULTS

3.1. Computational Results and Numerical Input Data

An examination of a Gas Compressing System was upgraded taking into insight key operating parameters; failure rate (γ) and MTTF. The crucial idea adopted in this work was data taken from the Gas Compressing System. This information was gathered and analyzed utilizing LINGO programming language.

3.2. Computational Results and Numerical Input Data

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3.3. Gas Compressor Input Data

System failure rate information was extricated from the system maintenance logbook records from the gas compressing plant.

Table 1: Gas Compressor Input Data for Numerical Analysis.

System	MTTF(hr.)	λ=1/MTTF (hr.)	Replacement cost(₦)	Maintenance cost(₦)	Total Failure cost(₦)
Component 1	4440	0.00023	113000	85000	198000
Component 2	3497	0.00029	98000	65000	163000

Component 3	3984	0.00025	175500	75000	250500
Component 4	4422	0.00022	105700	56000	161700
Component 5	4607	0.00021	172200	41000	213200

Table 1 shows the input data for the analysis (evaluated value of MTTF for five (5) critical component of the gas compressing system. Failure rate of the system was estimated from the MTTF. Finally, the last column shows the estimated total failure cost (Replacement cost and Maintenance Cost).

Table 2: Global Optimal Reliability of Component 1

Global optimal solution found.	
Objective value:	**0.9997700**
Objective bound:	0.9997700
Infeasibilities:	0.000000
Extended solver steps:	3
Total solver iterations:	6
Elapsed runtime seconds:	0.08
Model Class:	MINLP
Total variables:	2
Nonlinear variables:	0
Integer variables:	2
Total constraints:	3
Nonlinear constraints:	0
Total nonzeros:	4
Nonlinear nonzeros:	0

Table 3: Global Optimal Reliability of Component 2

Global optimal solution found.	
Objective value:	**0.9714165**
Objective bound:	0.9714165
Infeasibilities:	0.000000
Extended solver steps:	3
Total solver iterations:	6
Elapsed runtime seconds:	0.08
Model Class:	MINLP
Total variables:	2
Nonlinear variables:	0
Integer variables:	2
Total constraints:	3
Nonlinear constraints:	0
Total nonzeros:	4
Nonlinear nonzeros:	0

Table 4: Global Optimal Reliability of Component 3

Global optimal solution found.	
Objective value:	**0.9753099**
Objective bound:	0.9753099
Infeasibilities:	0.000000
Extended solver steps:	3
Total solver iterations:	6
Elapsed runtime seconds:	0.08
Model Class:	MINLP
Total variables:	2
Nonlinear variables:	0
Integer variables:	2
Total constraints:	3
Nonlinear constraints:	0
Total nonzeros:	4

Nonlinear nonzeros:	0

Table 5: Global Optimal Reliability of Component 4

Global optimal solution found.	
Objective value:	**0.9782402**
Objective bound:	0.9782402
Infeasibilities:	0.000000
Extended solver steps:	3
Total solver iterations:	6
Elapsed runtime seconds:	0.08
Model Class:	MINLP
Total variables:	2
Nonlinear variables:	0
Integer variables:	2
Total constraints:	3
Nonlinear constraints:	0
Total nonzeros:	4
Nonlinear nonzeros:	0

Table 6: Global Optimal Reliability of Component 5

Global optimal solution found.	
Objective value:	**0.9979022**
Objective bound:	0.9979022
Infeasibilities:	0.000000
Extended solver steps:	3
Total solver iterations:	6
Elapsed runtime seconds:	0.08
Model Class:	MINLP
Total variables:	2
Nonlinear variables:	0
Integer variables:	2
Total constraints:	3
Nonlinear constraints:	0
Total nonzeros:	4
Nonlinear nonzeros:	0

Table 7: Global Optimal Reliability of the five (5) components for the gas compressing system

S/N	System	Reliability (%) If the unit is %, then multiply by 100
1	Component 1	0 99.98
2	Component 2	0 97.14
3	Component 3	0 97.53
4	Component 4	0 97.82
5	Component 5	0 99.79

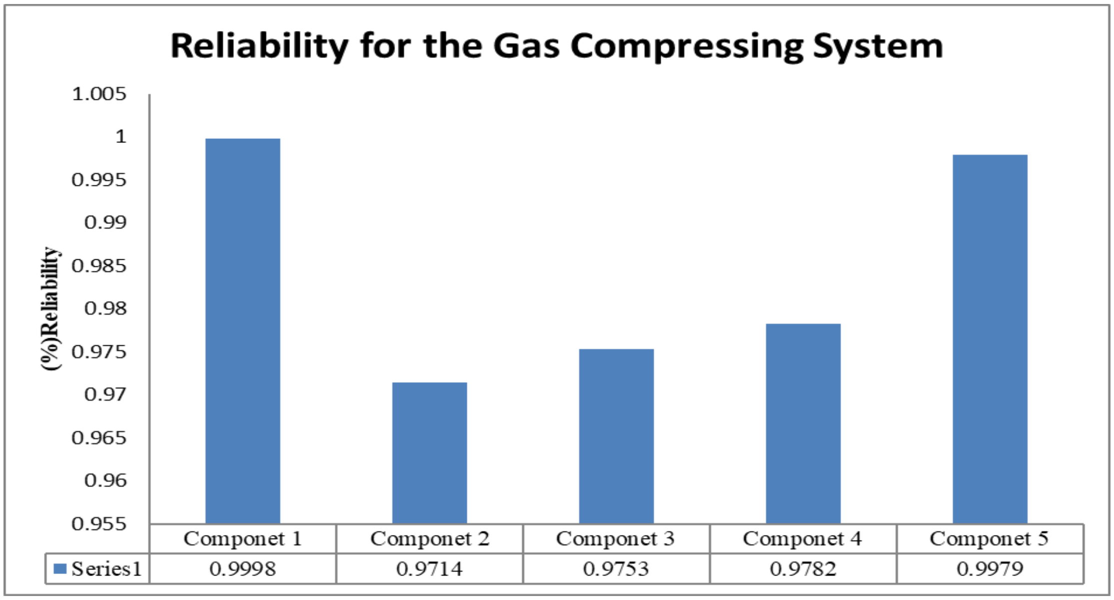

Figure 1: Graphical Representation of the Reliability for Each Component for the Gas Compressing System

DISCUSSIONS

Table 2 shows the reliability analysis results of component 1 from the Lingo software package used to solve the MINLP (Mixed Integer Non-Linear Programming). It generated an objective value of 0.9998 with objective bound using an extended solver of step three (3) and six solver iteration with an elapsed time of 0.08 seconds.

Table 3 result displayed Lingo software package used to solve the MINLP (Mixed Integer Non-Linear Programming).It was able to generate an objective value of 0.9714 with objective bound using an extended solver of step three (3) and six solver iteration with an elapsed time of 0.08 seconds.

Table 4 result displayed Lingo software package used to solve the MINLP (Mixed Integer Non-Linear Programming). It was able to generate an objective value of 0.9753 with objective bound using an extended solver of step three (3) and six solver iteration with an elapsed time of 0.08 seconds.

Table 5 result displayed Lingo software package used to solve the MINLP (Mixed Integer Non-Linear Programming). It was able to generate an objective value of 0.9782 with objective bound using an extended solver of step three (3) and six solver iteration with an elapsed time of 0.08 seconds.

Table 6 result displayed Lingo software package used to solve the MINLP (Mixed Integer Non-Linear Programming). It was able to generate an objective value of 0.9979 with objective bound using an extended solver of step three (3) and six solver iteration with an elapsed time of 0.08 seconds. Figure 1 shows a graphical representation of each component reliability.

CONCLUSION

This paper automated the usage of maintenance techniques through a NLMIP. This examination consolidated a strategy utilizing LINGO numerical programming to run a NLMIP to maximize the reliability of the system for the five (5) individual components. The Excel solver was utilized to process the MTTF, the evaluated MTTF was additionally used to assess and understand the system failure history respectively. Taking everything into account, the outcomes created from the two application programming bundles (LINGO software Packages and Micro Soft Excel Solver) were utilized to:

i. Optimize the reliability of the system with five (5) independent components utilizing NLMIP.

ii. It is additionally, comprehended that MTTF (Failure rate) can be controlled through a maintenance planned support program.

iii. Finally, an alternative way to deal with the conventional maintenance practice is developing a support program through the execution of system reliability (maximization) that reviews the system framework and sub-component and key parameter index, for example, repair rate and failure rate.

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