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Multi-Criteria Computer Aided System for Industrial Machines' Performance Assessment

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Abstract

Efforts have been made by some researchers to determine machines' economic performance, some considered engineering features, some supply conditions while some look into the productivity as well as profitability of the machine separately. Recently, [1] saw the performance assessment of machine as surrogate problem and they deviate from single strategic decision common in past researches to multi-criteria approach in their research. Considerations were given to: annual operation cost, machine effectiveness and cost effective index as strategic decisions for machine performance evaluation. The model was robust, well integrated but its application is time consuming for decision making. There is no software to address this multi-criteria surrogate problem yet. Available single strategic decision software was of high cost, hence the development of this software that is flexible and novel to proffer solution to this problem using JAVA programming language. The software performance was evaluated using the data gotten from [1]. The summary of each year performance of a case study of cocoa winnowing machine on each of the selected strategic decision from 2008 to 2017, as it affects the machine annual operating cost (MAOC), overall machine effectiveness (MEFF) and cost effective index (CEI), was shown in **Table 2**. That of the year 2008 was 226,061.365; 0.97; and 0.99 for AOC; MEFF and CEI respectively. These results were statistically analysed and the results' graphs were shown in **Figures 2-5**, and **Figure 6**, respectively. Their results were compared with the results of the software developed and the results were 100% accurate since there was no deviation from the results. Availability of this software makes the developed multi-criteria machine performance assessment model useable anywhere in the world.

Subject Areas

Industrial Engineering

Keywords

Modeling, Strategic Decision, Multi-Criteria Features, Software Development, Performance Evaluation

1. Introduction

1.1. Background

The need to explore information and computer technology to solve agricultural problem most especially in agro-oil machines in industries become so important when the trend in computer world is increasing. The development in Information Computer Technology (ICT) can be applied to material processing industries in other to improve the effectiveness, quality and productivity of the processing machinery. This study was motivated by the recent emergence and growth of the computer in our society into which our processing industries must integrate.

1.2. Literature Review

When evaluating the performance of processing machine, two separate approaches can be taken: processing machines follow established principles that describe their operating characteristics on a generic basis and calculations of power, efficiencies, etc. are easily calculated using simple equations governing those properties [2] [3] [4] [5]. In other to evaluate machine performance, a holistic approach was suggested by several studies [6] [7] [8] [9] and [10]. By collecting data from the operations of processing machines, operator behaviour and skill level [9], and economic factors related to processing industries [6] were determined on a much broader scale than with traditional theory based research.

Effective optimization model development is essential for processing equipment. This enhances the repair and maintenance of equipment at the most appropriate time [11]. It is being used in the developed world to know the salvage life of the machine, when you need to change the machine, the time to carry out certain periodic maintenance and repair. This also helps in determining the degree of utility of the equipment [12]. Important factors including types of equipment and operations are to be considered.

Optimization techniques such as linear or non-linear programming that minimize cost subject to reasonable constraints (e.g., labour availability, frost dates) can help improve profitability [12]. Over the decades, industries and their organization concentrated most of their attention upon products production thereby ignoring the “Overall Machine Effectiveness” (OEE) factors, viewing it as a necessary evil. [13] and [14] said, today, with the general operating cost rising each year, there is the potential of realizing significant savings if industrial optimization managers adhere strictly to proper OEE analysis practices. [15] said a well-structured OEE metrics practice plays a vital role in the efficiency, development and progress of manufacturing/processing industries.

A computer program is an instance, or concrete representation, for an algorithm in some programming language [16] [17]. Once we have a correct algorithm for a problem, we have to determine the efficiency of that algorithm. This view is stated very succinctly in the well-known slogan "algorithm = data structure + control" [18].

Some of the related works done so far in this area of study are hereby summarized in **Table 1**. Hundreds of high level programming languages have been developed, the most common ones were shown in **Table 2** for good comparison under ten criteria.

2. Methodology

The method applied to achieve the set objectives of this research involves: identification of the strategic decisions and their attributes; adopting the model developed by [1] as well as its logic. The computer algorithm and its software were developed, application of the developed software using data of [1], on winnowing machine of cocoa industry as case study, results of the developed software were evaluated by comparing it with the manually generated results for its performance evaluation.

2.1. Models Development for Machine Annual Operating Cost

The models developed for the strategic decisions were: machine annual operating/running cost, overall machine effectiveness and machine cost effective index.

2.1.1. Machine Annual Operating/Running Cost $\left[\ddot{O}_c\right]$

This is the financial economic consideration required to run the processing machine throughout the year. The model was as shown in Equation (1).

$$\left[\ddot{O}_c\right] = Fe\%P + H\left(RM_c + L + O + F + T\right) \tag{1}$$

2.1.2. Overall Machine Effectiveness $\left[\ddot{A}\right]$

This is the capability of producing a desired result. The three major attributes for its determination are machine availability, $\left[\tilde{A}\right]$ performance efficiency $\left[\dot{\eta}\right]$ and rate of quality product $\left[\phi_r\right]$. The mathematical model required is shown in Equation (2),

$$\left[\ddot{A}\right] = \tilde{A} \times \ddot{\eta} \times \phi_r \tag{2}$$

2.1.3. Cost Effectiveness Index (W_c)

It also shows machine's ability to fight inflation.

Table 1. Previous works on cocoa processing and machinery and software development.

S/N	Names/Years	Job Description	Contributions/Remark
[19]	Akinnuli *et al.* (2014)	Computer Aided Design for Cocoa Beans Processing Yield Prediction.	Model developed focused on cocoa beans, butter and cake yield predictions for any quantity of cocoa beans pressed.
[20]	Akinnuli *et al.* (2015)	Design concepts towards mechanization of cocoa beans winnowing process.	Design and analysis of required winnowing machine components,
[21]	Adzimah *et al.* (2010)	Design of cocoa pod splitting machine.	Cocoa pod splitting machine was fabricated.
[22]	Arai and Iwata, (1992)	Product Modeling system in conceptual design of mechanical products.	Model of mechanical products.
[23]	Audu *et al.* (2014)	Development of a concentric cylinder locust beans dehuller.	A concentric cylinder dehuller for locust was developed.
[24]	Awua, (2002)	Cocoa Processing and chocolate manufacture in Ghana.	Review of how cocoa bean is being processed in Ghana.
[25]	Bjarnemo *et al.* (1998)	Shortcomings of Computer Aided Design Systems in conceptual design.	Inadequacies of Computer Aided Design Systems in conceptual design.
[26]	Bozzo *et al.* (1998)	Application of qualitative reasoning in Engineering.	Qualitative reasoning in Engineering.
[27]	EEC (1973)	Directive 73/241 EEC by European parliament and the European Council relating to cocoa and chocolate products intended for human consumption.	Examination of cocoa and chocolate products consumed by human by European Parliament and European Council.
[28]	Faborode and Oladosu (1991)	Development of a cocoa pod processing machine.	Ccocoa pod machine was developed and performance evaluation was carried out on it.
[28]	Harrington (1998)	Development of software tools for automation and acceleration of the engineering design process.	Model developed was used for automation and acceleration of engineering design process.
[30]	http://www.worldcocoafoundation.org	Speciality crops for Pacific Island Agroforestry.	Review of some crops for Pacific Island Agroforestry.
[31]	Jurgen and Buhler (2009)	The manufacturing confectioner cocoa processing.	Cocoa beans processing in confectionary industries.
[32]	Lipp and Anklam (1998)	Review of cocoa butter and alternative fats for use in chocolate.	Cocoa butter and alternative fats for use in chocolate industries was reviewed.
[33]	Whitefield (2005)	Making chocolates in the factory.	The process of chocolate making in the factory.

*From literature there is a gap of multi-criteria model and its software to be developed for decision making on processing machines' economic, engineering and productivity performance assessment. This led to this research.

Table 2. Commonly used programming language and their comparison for selection.

Criteria/PL	Java	Scale	C++	Haskell	VB.Net
Default More Secured Programming practice.	Good secured programming feature with GC no pointers, packages and thread.	Good Default Security with features like GC. exception handling & works on JVM so uses it security Manager.	Not a secured programming language, buffer overflow is not detected.	Good secured programming features with a GC, no pointer and good type system.	Built-in secure features provided by .net and programming itself can implement secure features.
Web Application	Quite popular for web application abundant libraries and services serve this cause.	Can develop, flexible, highly scalable, secure applications with help of web development frameworks.	Used for stand alone applications, difficult to create by default.	Can develop the application with rich set libraries.	Vb.net supports web applications
Web Services design and Composition	Good for web services because of portability and large number of APIs and XML available.	RESTful services provided with help of frameworks. Provisions of other services still under construction. XML processing simple.	Supports REST, XML, WSO2 framework.	Provide service like SOAP and REST but it is still immature in terms of WSDL and UDDI.	Vb, net can implement web services such as HTTP, SOAP, XML, WSDL, UDDI and Net remoting service can implement itself.
Object-oriented base Abstraction	Primarily an object oriented language with powerful features.	Supports two types of abstractions. Alternative to functional abstraction. Mainly used for modeling families that varies covariantly.	Support Object Oriented principles but not as a default.	Object Oriented Concepts are not supported by Haskell. It requires an extension called OO Haskell	Vb.net is an object oriented language. It supports OO abstraction.
Reflection	Powerful reflection mechanism. Supplies a rich set of operations for using metadata and avoid complications.	It's a subsystem. Reflection API,. Limited scope. Modular, hence reduce foot print & be efficient.	Limited reflection capabilities.	Haskell does have libraries for dynamics, but they still do not support complete reflection.	Vb, net supports reflection using Built-in called "system reflection"
Aspect-Oriented Programming	Aspect, an extension of JAVA treats AOP concepts as first class element of the language.	Provides 2 different types. Mainly, Mixin composition stacks.	With static type of language it is difficult, Aspect C++ supports it.	Does not directly support. Has an extension called AOP Haskell.	AOP Engine in NET to implement AOP programming but it supports only at run time.
Functional Programming	No functional instead uses interfaces & inner classes it is fairly easy to mimic some features of FP	Powerful support and well suited. Light weight sytax. Support High-order, nested function, and currying.	Doesn't support to fuller extent but can be done using FC++.	This is a functional programming language.	Vb.net is not a pure functional programming but it supports Lambda Calculus.
Declarative Programming	Library like JsetL and Jsolver offer a number of facilities to support DP.	Uses a prolog interpreter called scale Logic. Emphasises on simplicity and not performance.	By default not possible but merging prolog is an alternative.	Haskell, one can use Monards to implement Declarative Logic Programming.	Doesn't implement declarative programming by itself.

Continued

Batch Scripting	Easy, involve the use of two JAVA classes. The Run time class and process class.	Support Batch/Bash/Perl scripting language.	Including libraries allows to do so. But decreases performance.	Shell scripting is possible with Haskell using HSH.	Vb.net supports batch scripting and macros.
UI protype design	Rich set of libraries for UI applications but the code is verbose and can be mysterious for stakeholders.	Support UI with basis on JAVA swing framework but hides much of its complexity.	Difficult to implement by defaults but supports some libraries.	Has rich set of libraries for GUI applications.	Vb.net supports rich UI interfaces and IDE give good support to programmers.

Source: [34] [35].

$$\text{Cost Effective Index} = \frac{\text{Productivity for Current Period}}{\text{Productivity for the base Period}}$$

$$W_c = \frac{\sum Q_2 P_2 / \sum Q_1 P_1}{\sum I_2 C_2 / \sum I_1 C_1} \tag{3}$$

It is to be noted that cost effectiveness index is product of factor productivity index and price recovery index. The developed software interface is as shown in Figure 1.

3. Results and Discussions

The data collected for the running of the models and the software developed ran through period of ten (10) years from 2008 to 2017. Application of the software using the three selected strategic decisions on windowing machine, for each year 2008 to 2017 gave the results shown in Table 3.

Table 3 shows summary of each year performance of winnowing machine on each of the selected strategic decisions from 2008 to 2017. The performance as it affects the machine annual operating cost (MAOC), overall machine effectiveness (MEFF) and cost effective index (CEI) were shown in Table 3. These results were statistically analysed and the results' graphs were shown in Figures 2-5, and Figure 6, respectively.

Figure 2 and Figure 3 show the mathematical model of the MAOC over the period of 10 years on the MAOC. The plot was modeled using a polynomial equation of one degree which gave us

$$f(x) = p1 * x + p2$$

where: $P_1 = 0.056$ and $P_2 = -112.2$. This example shows how to fit polynomials up to one **degree** to the available MAOC data for the period of 10 years on the Windowing machine figures that correspond to the error (SSE) and the adjusted R-square statistics to help **determine** the best fit.cross zero on the **p1** and **p2** coefficients for the first-degree polynomial.

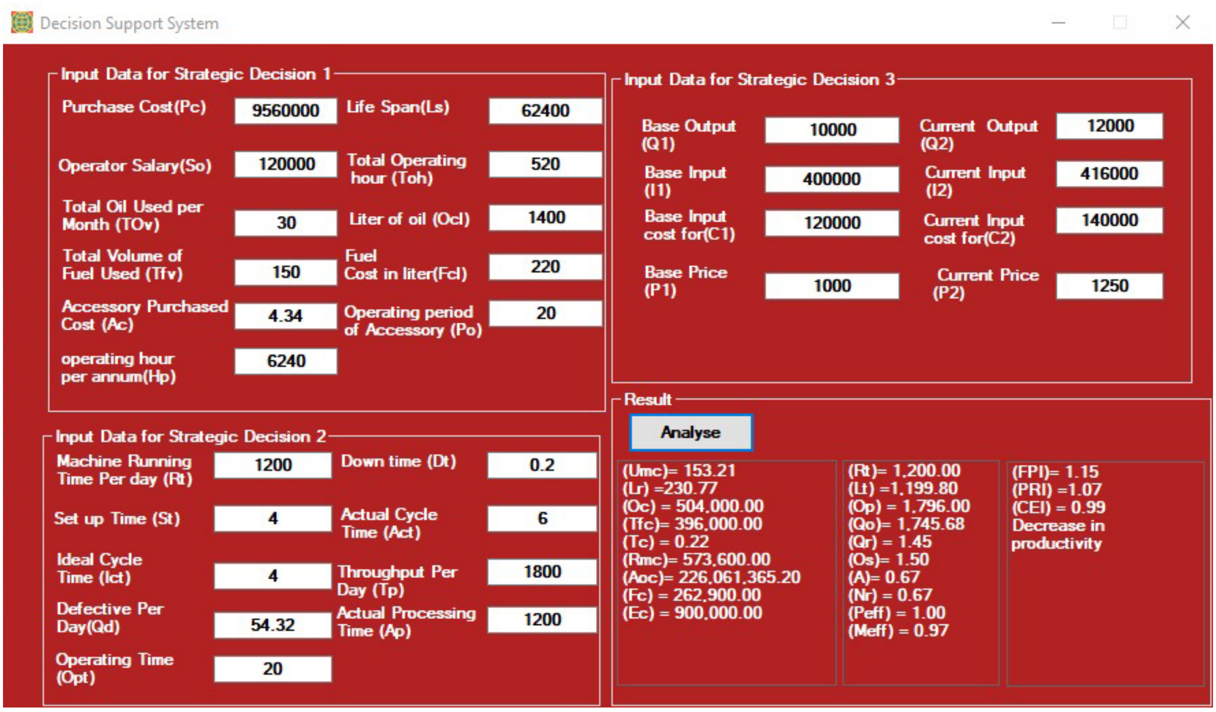

Figure 1. Interface for data collection, analysis and results generation.

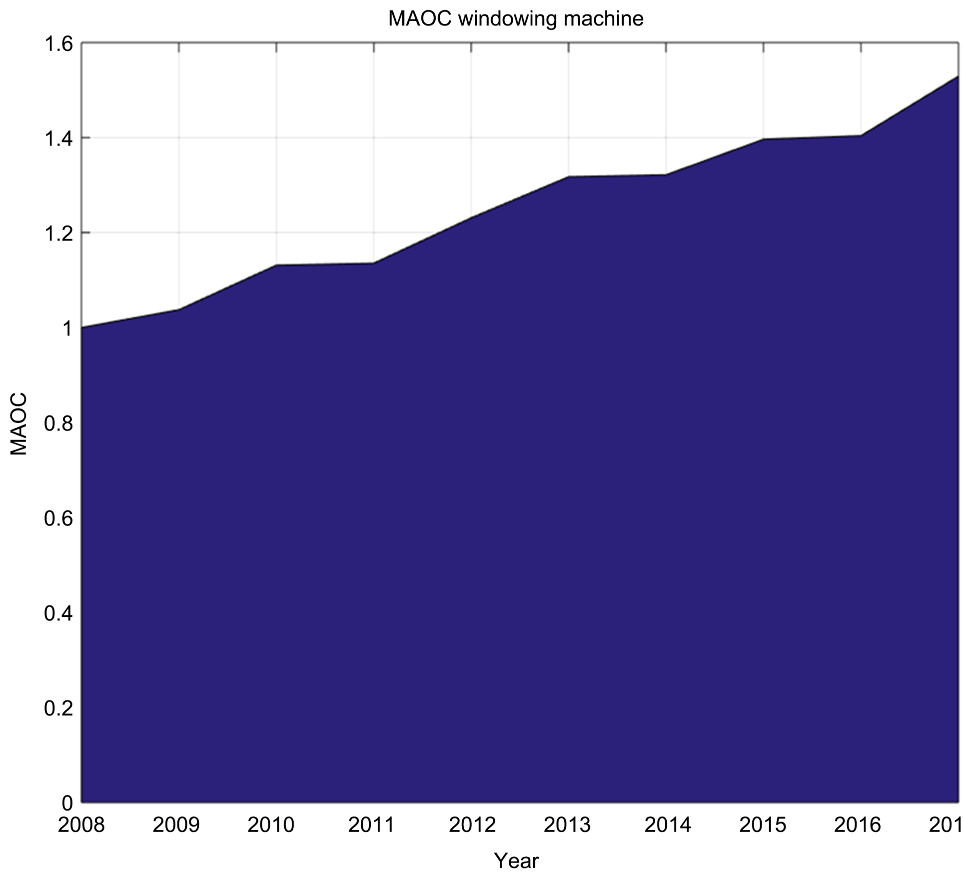

Figure 2. Statistical analysis of windowing machine performance on Machine Annual Operating Cost (MAOC) from 2008 till 2017.

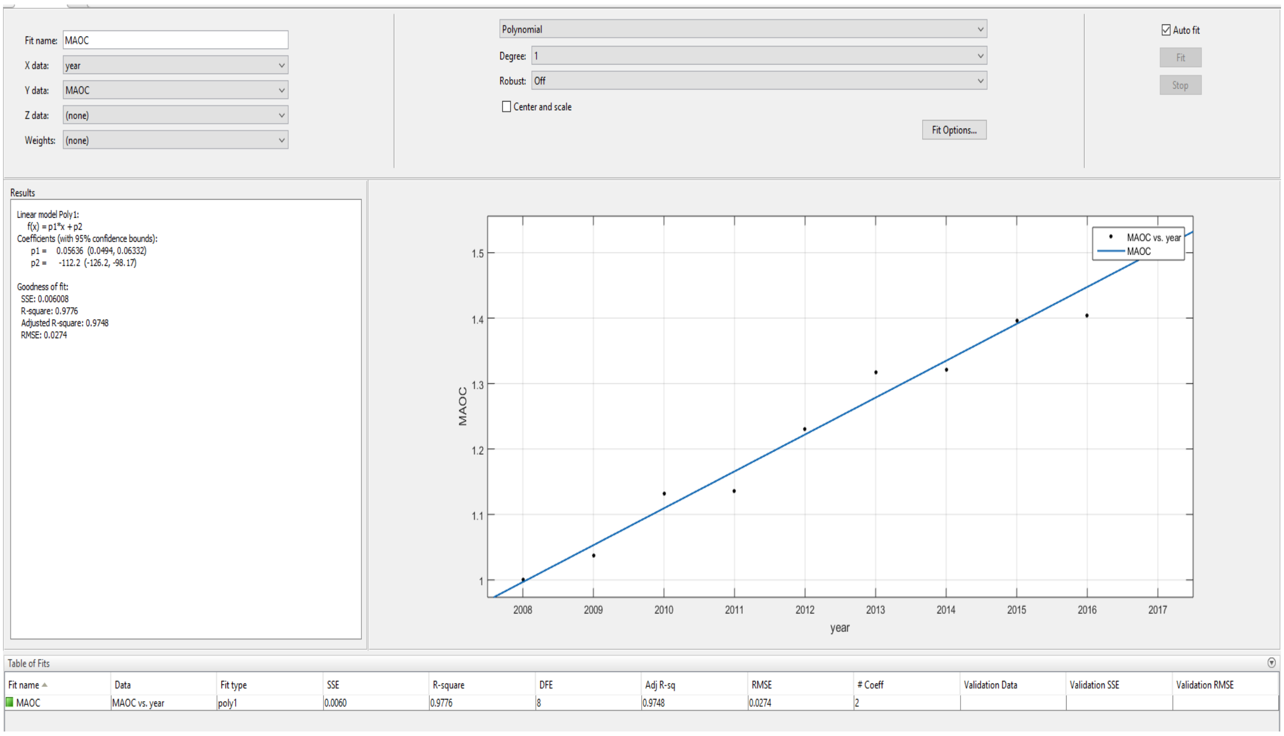

Figure 3. Determination of the model fittings Using R-Square Test.

Table 3. Yearly windowing machine's performance on each strategic decision (AOC, MEFF and CEI) from 2008 to 2017. The bolded 2008 results were seen on the computer interface developed.

	AOC	Meff	CEI
Windowing Machine			
2008	**226061365.2**	**0.97**	**0.99**
2009	234536333.2	0.89	1.09
2010	255735333.2	0.91	0.8
2011	256678487.2	0.97	0.78
2012	278272629.2	0.94	0.97
2013	297837365.2	0.92	1.14
2014	298761553.2	0.98	1.02
2015	315673833.2	0.95	1.11
2016	317365433.2	0.87	0.81
2017	345721365.2	0.86	0.96

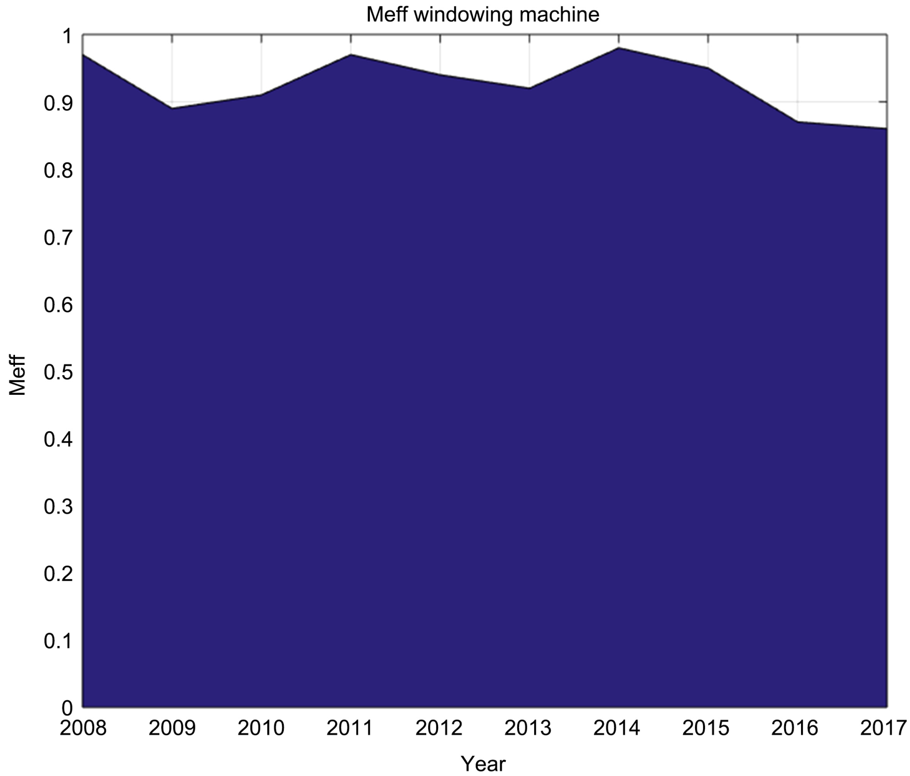

Figure 4. Statistical analysis of windowing machine performance on Machine Effectiveness (MEFF) from 2008 till 2017.

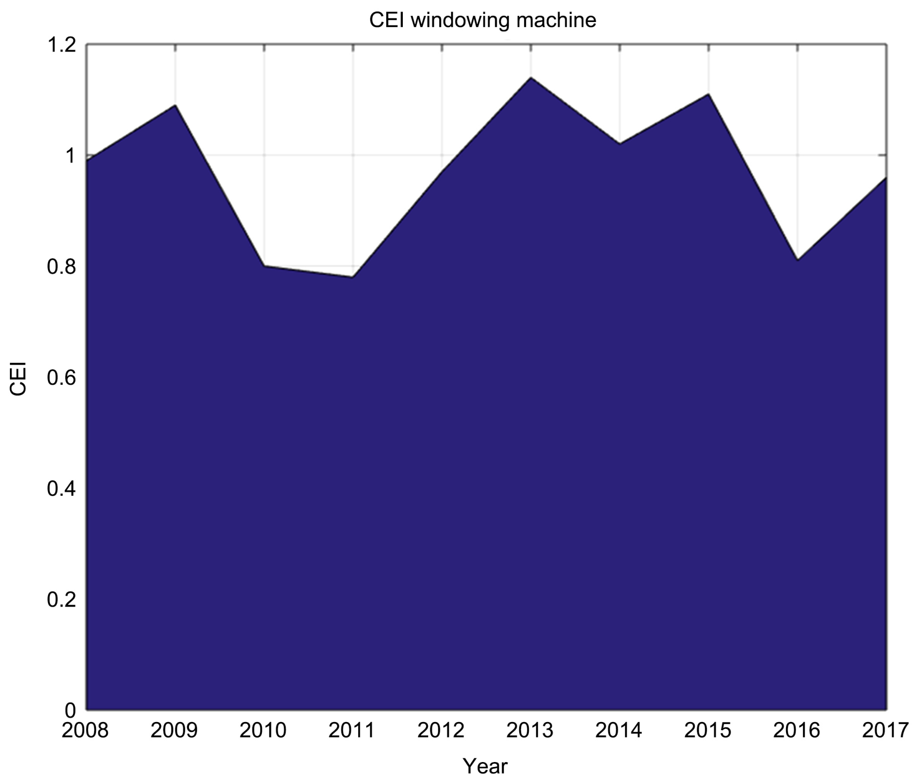

Figure 5. Statistical analysis of windowing machine performance on machine Cost Effective Index (CEI) from 2008 till 2017.

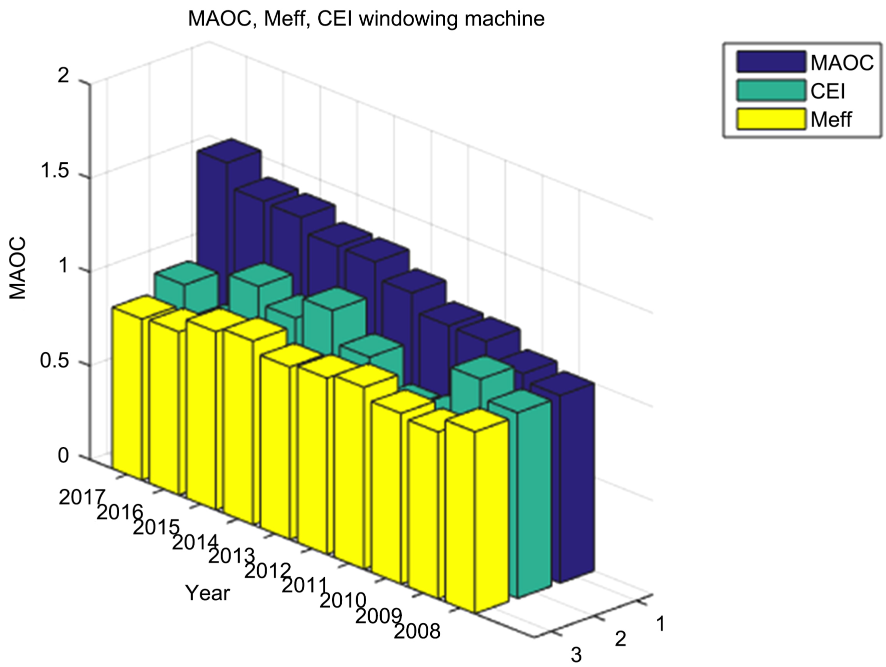

Figure 6. The 3D bar chart of MAOC, CEI and MEFF over the period of 10 years (2008-2017).

The model has a fitting of 97.76% according to R-Square test and the Sum of square error was given as 0.006 which is approximately 0. With this model we can actually predict the following year MAOC if all necessary factors are constant.

Figure 4 represents the machine operating effectiveness of the windowing machine over the period of 2008 to 2009 it has a very good flow with average effectiveness of 92.6% with variance of 0.0018. The average effectiveness of the machine varies over the years however the minimal effectiveness which is occurred in 2017 still has a very good effectiveness of 86% this is above the acceptable low limit of 85%.

Figure 5 represents the area chart of the cost effective index. Initially in 2008 the CEI is very close to 1 which means the operating cost of the windowing machine was performing well on budget. In 2009 the operating cost was performing well against budget. But 2010, 2011 and 2016 the windowing machine was over budgeted

Figure 6 represents the 3D bar chart of MAOC, CEI and Meff over the period of 10 years (2008-2017) to show the exact value of MAOC, CEI and Meff because area chart are known to show a trend over a particular period and not the exact value

Source Code For The Software Development.

```
Public Class Form1
    Private Sub Analyse_Click(sender As Object, e As EventArgs) Handles Analyse.Click
        'calculation for SD1
```

```
'FC cal
Dim FC, Um, RMs, Lr, Oc, Tfc, Tc, Ec, SD1 As Double
FC = Val(sd1_pc.Text) * 0.0275
Um = Val(sd1_pc.Text) / Val(sd1_ls.Text)
RMs = 0.06 * Val(sd1_pc.Text) '* Val(sd1_hp.Text)
Lr = Val(sd1_so.Text) / Val(sd1_toh.Text)
Oc = Val(sd1_tov.Text) * Val(sd1_ocl.Text) * 12
Tfc = Val(sd1_tfv.Text) * Val(sd1_fcl.Text) * 12
Tc = Val(sd1_ac.Text) / Val(sd1_po.Text)
Ec = Tfc + Oc
SD1 = FC + (Um * (RMs + Lr + Ec + Tc))
Console.WriteLine("FC%= " & FC.ToString)
Result1.Text = "(Umc)= " & FormatNumber(Um, 2).ToString & vbCrLf & "(Lr) =" & FormatNumber(Lr, 2).ToString & vbCrLf & "(Oc) = " & FormatNumber(Oc, 2).ToString & vbCrLf & "(Tfc)= " & FormatNumber(Tfc, 2).ToString & vbCrLf & "(Tc) = " & FormatNumber(Tc, 2).ToString & vbCrLf & "(Rmc)= " & FormatNumber(RMs, 2).ToString & vbCrLf & "(Aoc)= " & FormatNumber(SD1, 2).ToString & vbCrLf & "(Fc) = " & FormatNumber(FC, 2).ToString & vbCrLf & "(Ec) = " & FormatNumber(Ec, 2).ToString
'calculation for SD2
Dim A_bar, opt, speed, efficiency, N_bar, epsilon, SD2 As Double
Dim Rt As Double = Val(sd2_rt.Text)
Dim Lt = Rt - Val(sd2_lt.Text)
Dim Qo As Double = (Val(sd2_tp.Text) - Val(sd2_qd.Text))
opt = Val(sd2_tp.Text) - Val(sd2_st.Text)
A_bar = Val(sd2_rt.Text) / opt
speed = Val(sd2_act.Text) / Val(sd2_lct.Text)
N_bar = Val(sd2_ap.Text) / opt
efficiency = speed * N_bar
epsilon = (Val(sd2_tp.Text) - Val(sd2_qd.Text)) / Val(sd2_rt.Text)
SD2 = A_bar * efficiency * epsilon
Console.WriteLine(SD2.ToString)
If (SD2 < 0.85) Then
    If (A_bar < 0.9) Then
        Rt = 0.9 * opt
        A_bar = Rt / opt
    End If
    If (efficiency < 0.95) Then
        Dim n_constant As Double = 0.8
        efficiency = speed * (0.95 / n_constant)
    End If
    efficiency = speed * N_bar
    If (epsilon < 0.89) Then
```

```
            epsilon = (Val(sd2_tp.Text) - Val(0.89 * Val(sd2_rt.Text))) / Val(sd2_rt.Text)
        End If
        SD2 = A_bar * efficiency * epsilon
    End If
    Result2.Text = "(Rt)= " & FormatNumber(Rt, 2).ToString & vbCrLf & "(Lt) =" & FormatNumber(Lt, 2).ToString & vbCrLf & "(Op) = " & FormatNumber(opt, 2).ToString & vbCrLf & "(Qo)= " & FormatNumber(Qo, 2).ToString & vbCrLf & "(Qr) = " & FormatNumber(epsilon, 2).ToString & vbCrLf & "(Os)= " & FormatNumber(speed, 2).ToString & vbCrLf & "(A)= " & FormatNumber(A_bar, 2).ToString & vbCrLf & "(Nr) = " & FormatNumber(N_bar, 2).ToString & vbCrLf & "(Peff) = " & FormatNumber(efficiency, 2).ToString & vbCrLf & "(Meff) = " & FormatNumber(SD2, 2).ToString
    'SD3 computation
    Dim mpi, pri, cei, pf, fpi As Double
    Dim fina As String
    'mpi = (Val(sd3_a1.Text) / Val(sd3_a2.Text))
    pri = ((Val(sd3_Q2.Text) * Val(sd3_p2.Text)) / (Val(sd3_Q2.Text) * Val(sd3_p1.Text))) / ((Val(sd3_I2.Text) * Val(sd3_c2.Text)) / (Val(sd3_I2.Text) * Val(sd3_c1.Text)))
    cei = ((Val(sd3_Q2.Text) * Val(sd3_p1.Text)) / (Val(sd3_Q1.Text) * Val(sd3_p1.Text))) / ((Val(sd3_I2.Text) * Val(sd3_c2.Text)) / (Val(sd3_I1.Text) * Val(sd3_c1.Text)))
    fpi = ((Val(sd3_Q2.Text) * Val(sd3_p1.Text)) / (Val(sd3_Q1.Text) * Val(sd3_p1.Text))) / ((Val(sd3_I2.Text) * Val(sd3_c1.Text)) / (Val(sd3_I1.Text) * Val(sd3_c1.Text)))
    pf = cei / pri
    If (pf = pri) Then
        fina = "Static productivity"
    ElseIf pf > pri Then
        fina = "increase In productivity"
    Else
        fina = "Decrease in productivity"
    End If
    Result3.Text = "(FPI)= " & FormatNumber(fpi, 2).ToString & vbCrLf & "(PRI) =" & FormatNumber(pri, 2).ToString & vbCrLf & "(CEI) = " & FormatNumber(cei, 2).ToString & vbCrLf & fina
  End Sub
End Class
```

4. Conclusion

The objectives which are computer algorithm and software development for the models' implementation were achieved and source code written for the model's ease of application using JAVA programming language due to its flexibility and friendliness was also achieved. The cost benefit, was successfully determined by comparing the cost of foreign software of nearly similar functions with limitation of single criterion with this of multi-criteria cost and the software was able to make a saving cost of 40% based on the average cost of the six software collected from the internet. The tool was able to consider arms of Economic, Engineering and Productivity features, of production processes, in an attempt to reduce/eliminate all barriers that could hinder optimal performance. The outcome contributed to the existing knowledge in the field of Industrial Engineering and in particular decision making in machine operating cost, overall machine effectiveness for productivity enhancement and machine operations' cost effective index to determine the machine's ability to fight inflation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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