Machine economic life estimation based on depreciation-replacement model

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Abstract: Decision-making is considered as the cognitive process resulting in the selection of a belief or a course of act among numerous substitute possibilities. Today, decision-making helps to opt for the best assets i.e. machine tools, equipment etc. of firms under several concerns such as depreciation value, price, replacement, maintenance cost, repairmen cost, power consumptions etc. which augments the effectiveness of operations of production units. Recently, the problem of replacement is realized, when the job performing units such as men, machines, equipment, parts etc. becomes less effective, uneconomic, useless due to breakdown, sudden failure and gradual deterioration in their efficiency by the passage of time. By replacing those assets with new ones at frequent interval, maintenance and other overhead costs can be reduced. The work presented a replacement model combined with straight-line depreciation method, which can be used to determine the economic life of the productive machines and equipment. The proposed approach helps the managers and the owners of the business firms in computing the economic life of their machine. Numerical case has been presented, in order to justify the validation of the proposed model.

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PUBLIC INTEREST STATEMENT
In present scenario, the world is rapidly changing by new technologies and smart materials, as a result new machineries are launching in every fraction of second, loaded with advance technologies and easy working mechanism. It is very hardship and difficult to decide, “When to replace” existing machineries with new ones. Thus every business firm has to adopt certain policy to replace their machineries. The work suggests the policy of optimum replacement time for replacing firm assets. The work facilitates prior advance planning to the firms and tries to frame the integrated relationship between depreciation and replacement. An illustration reflecting the realistic situation is presented, to demonstrate the usefulness of the proposed work and to make it understandable by the large group of audience. The manuscript will inspire, motivate and help other researchers in developing new models in the arena of replacement, by providing an idea of dealing with replacement policy.
1. Introduction

It is of great significance to avoid the failure of a system during actual operation, when such an event is costly or dangerous (Sheu, 1998). Machines and equipment are usually used by the manufacturers to reproduce profit. These assets involve huge investments and have relatively longer useful life. To stand competitive and to earn profit in the market the manufacturers should equipped with innovative machines and equipment. The existing machines and equipment should be replaced at random intervals to remain competitive. The manuscript aids the manufacturers in deciding the optimal time for replacement. The presented work chooses weighted average cost as one of the major criterion for replacing their machines and equipment. It is a common phenomenon that the performance & efficiency of these machines or equipment deteriorates with time. The remedy is either to replace them with new one or to restore their efficiency by providing some sort of maintenance and repairs. An operating system contains a replaceable unit, whose wear (accumulated amount of damage) can be observed over time. However a stage comes, when the maintenance of existing machines or equipment becomes so expensive, thus it is more economic to replace them. When the wear reaches a certain level, the unit is no longer able to function satisfactorily and needs to be replaced (Kumar & Westberg, 1997). Machines and equipment are not merely subjected to wear and tear, which is adjusted in the form of depreciation, but they are also subjected to the risk of obsolescence. The failure characteristics of a system may depend on the total operating time, operating conditions or on the values of monitored variables (Allen & Ching, 2005). Due to technological developments, the obsolescence may occur at any time in the life cycle of a machines and equipment, even few months after the installation of the machines. The requirement for increased plant productivity, safety and reduced maintenance costs have led to a growth in popularity of various methods to aid the planning of plant preventive maintenance and operational policies (Christer, Wang, & Sharp, 1997). It should be noted that, if any existing equipment fail to meet the challenges made by the advancements of the technological developments, it must be replaced even though it is in operating conditions. Thus in such cases even though the equipment has physical value, it should be replaced, if it loses economical value means fails to withstand competition.

The presented work highlights on determining the optimal time period, up to which a manufacturer can operate his machine with minimum expenditure. The presented work focuses on a time-based replacement policy. The machine replacement is significant for maintaining the operational efficiency, effectiveness and economic. Table 1, depicts different model representing various types of replacement policies:

| Model | Description |
|-------|-------------|
| 1     | Replacement of items whose maintenance cost increases with time and the value of the money remains constant during the period |
| 2     | Replacement of items whose maintenance cost increases with time and value of money also changes with time |
| 3     | Group replacement policy |
2. State of art
Crowder and Lawless (2007) incorporated a random effect or frailty term, in the model for individual degradation. They have considered costs for observing the wear on a unit, for replacing a unit, and for allowing a unit to fail before being replaced. They suggested that when the last cost is comparatively large replacement before failure is preferable. Craig and Stephen (2010) considered life-cycle assessment (LCA), as a tool to identify the environmental impact of a product or process. They compare three replacement options for an aging Portland cement concrete (PCC) pavement with the use of an LCA process-based protocol. Their objective is to remove and replace the aging pavement with PCC pavement. Kumar and Westberg (1997) suggested a reliability based approach. They considered values of monitored variables to estimate the optimum replacement time interval for a system or threshold values under age replacement policy.

Sheu (1998) derived the expressions for the expected long-run cost per unit time and the total discounted cost for each considered policy. The optimal \( T \) which minimizes the cost rate or total discounted cost is discussed in their presented work. Alta, Pedro, and James (2015) suggested that the performance of the system is quantified in terms of operational cost savings. Oyedepo, Fagbenle, Adefila, and Mahbub (2015) worked on minimizing the cost, which comprises the cost associated with the investment, operation, maintenance, and fuel cost etc. Allen and Ching (2005) demonstrated the modeling of the machine replacement problem by renewal theory. They proposed a deterministic model to illustrate the concept of a machine cycle, followed by a stochastic model with a general cost. They compare the quantity-based replacement policy and time-based replacement policy for a single machine replacement problem. Sheu (1999) proposed a generalized replacement model, where a deteriorating system has two types of failures. Numerical example to minimize the expected cost rate is discussed in his work.

Chu, Proth, and Wolff (1998) considered predictive maintenance to decide, whether or not to maintain a system according to its state. They address the case of one-unit system. They proposes a global approach to the problem and provides a characterization of the optimal maintenance. Shey, Griffith, and Nakagawa (1995) constructed a numerically efficient algorithm to minimize the long run expected costs per unit time of the policy. Cardoso and Gomide (2007) suggested the use of predictive data mining techniques, as a systematic approach to explore newspaper company database and improve predictions. The focus of their work is to develop a prediction method that uses fuzzy clustering and fuzzy rules together with performance scores of selling points for prediction. Sahu, Sahu, and Sahu (2016, 2016b) found that uncertainty always lies in decision-making and suggested to adopt proper policy in handling and managing the case. They utilized the concept of fuzzy logic to deal with uncertainty in their work.

Christer et al. (1997) developed a replacement action decision aid for a key furnace component subjected to condition monitoring. They suggested state space model to predict the erosion condition of the inductors in an induction furnace. Kristensen and Søllested (2004) presented a sow replacement model for the methodological improvements of Bayesian updating and multi-level hierarchical Markov processes. They demonstrated the application of the model using data from two commercial Danish sow herds and concluded that the Bayesian updating technique and the hierarchical structure decrease the size of the state space dramatically. They describe the optimization model of the sow replacement model and implemented it, as a prototype for use under practical conditions.

Tan and Raghavan (2008) developed a simple practical framework for predictive maintenance (PDM)-based scheduling of multi-state systems (MSS). They derived maintenance schedules from a system-perspective using the failure times of the overall system. The results of their simulation demonstrate the significant impact of maintenance on quality and the criterion for the call for maintenance on the system reliability and mean performance characteristics. Their studies also reveal that, to reduce the frequency of maintenance actions, it is necessary to lower the minimum user demand from the system. Chien, Sheu, Zhang, and Love (2006) proposed a generalized replacement policy,
where a system is replaced at the $n$ type I failure or first type II failure or at age $T$, whichever occurs first. They obtained the expected cost rate and discussed the optimal $n$ and optimal $T$ which would minimize the cost rate. There is a need to explore new multi-level hierarchical modules and indexes, aligned with new multi decision-making criterions and methods (Sahu, Sahu, & Sahu, 2014, 2016a). Thus the field of replacement is required to be explored in terms of building multi criteria decision-making models and developing criterion. The multi criteria decision-making models are required to build in future by the insertion of the replacement criterion as the chief and vital criterion. A. K. Sahu, N. K. Sahu, and A. K. Sahu (2015), N. K. Sahu, A. K. Sahu, and A. K. Sahu (2015) discussed multi criteria decision-making models in the ambit of decision-making and found that the criterions plays an important role in exploring the system behavior.

3. Straight-line depreciation method

Generally, there are two types of cost named as fixed cost and variable cost, which are used along with numbers of units for determining the selling price of the product. Fixed costs are the amount spent on purchasing fixed assets like plant and machinery etc. These fixed assets are used throughout the operation of a business for numerous successive periods. Value of such fixed assets declined with passage of time, due to their utilization in chains of operations. These fixed assets, which are used for generating revenue, should assumed to be bring to its original position by replacing with new ones after a certain period of time. Thus the portion of earned revenue should be allocated to fulfill the capital cost of new fixed asset and is called depreciation fund or cost, which is a measure of wear, obsolescence through technology or market change etc. Cost of depreciation usually starts, when the assets are placed into operation or service. It affects the net total income that is reported by the business firm and should be taken into account for determining the net profits. The earned total revenue of the firms is required to be reduced by some amount to compute the actual profit. The reduced amount is the cost of the machinery of equipment, that is going to be spent on purchasing new machinery and equipment after passage of time. These reduced costs are not immediately consumed in the operation or activity.

Depreciation may be defined as a decrease or decline in the value of talent or assets over time due to wear and tear. The most frequent used method for depreciation is the straight-line method. This method assumes that the rate of depreciation is fixed for every year. In this method the depreciation value remains constant for every period. In this method yearly depreciation equals to a constant fraction of the initial investment. Equation (1) is used to calculate the depreciation amount by this method.

$$\text{Depreciation cost per year} = \frac{(C - S)}{N} \quad (1)$$

where $C =$ Cost of equipment/capital cost, $S =$ Scrap/salvage value of the equipment, $N =$ Equipment useful life. If the scrap value of the equipment is zero, then the Equation (1) can be written as:

$$\text{Rate of depreciation} = \frac{(C - S)}{N}$$

$$\text{Rate of depreciation} = \frac{\text{Original cost}}{\text{Useful life}}$$

This method assumes that the rate of depreciation always follows the linear relationship as the time passes. Figure 1 depicts the depreciation slope over time.
4. Replacement model
The intention of the presented work is to propose an economic replacement policy with the objective of minimizing the overall total cost. The work assists the managers and the owners of the business firms to accomplish the objective of generating more earnings via operating the machines with minimum average cost rather than operating them by higher cost. The optimal replacement policy is decided by balancing the cost of the new machine against the decrement in efficiency and the increment in cost of operation and maintenance of the old equipment. In addition with that there are several other theoretical reasons, which suggest the replacement of old assets with new one. Figure 2 depicts the variety of reasons responsible for replacement of assets.

The optimal replacement policy is determined in terms of time period \( n \), which reciprocates the minimum weighted average cost for operating/running the machine. It is assumed that the assets will be replaced at the end of year. It is very hardship and difficult to decide, at the end of which year the existing machineries should be replaced with new ones. In the presented work, the authors suggest the concept of weighted average cost (WAC) to determine the economic year for replacement of assets. Table 2, depicts the pre-requisite needed for determining the optimal replacement policy.

| Opportunity of handling extra additional operations by innovative machines | Reduction in consumption of power or fuel by the innovative machine | Percentage increase in maintenance costs, decline in product quality | Reduction in down time by new machine due to breakdown or repairs |
|---|---|---|---|
| Deduction in scrap or spoiled work by new machines | Reasons for Replacement of Assets | Reduction in rate of output, increment in labor costs. | Smoky, noisy, hazardous working conditions and pollution by old machines leading to accidents and causing workers unsafety. |
| Fall in Profit and to stay rival in the market due to changed machinery | Reasons for Replacement of Assets | | |
| Development of lesser space requirement & new reliable machines | Depreciation due to wear and tear | Spare parts unavailability | Obsolescence as a result of technological expansion |

| Table 2. Data structure for replacement policy |
|---|
| Time | 1 | 2 | 3 | 4 | 5 | 6 | 7 | \( \ldots \) | \( n \) |
| Operating/maintenance/running cost | \( R_{c}(1) \) | \( R_{c}(2) \) | \( R_{c}(3) \) | \( R_{c}(4) \) | \( R_{c}(5) \) | \( R_{c}(6) \) | \( R_{c}(7) \) | \( \ldots \) | \( R_{c}(n) \) |
5. Approach and computation

In order to determine the optimal time \( n \) to replace the machine, the authors calculated the weighted average cost by exploring Equation (3). The notations as shown in Table 3 are used for representing the various associated terms in the presented model. If the machine is used for \( n \) years, then the total cost \( TC \) incurred during this period can be calculated as:

\[
TC = \text{Capital cost} - \text{Resale value for } t \text{ period} + \sum_{t=0}^{n} \text{maintenance cost}
\]

Net present value (NPV) per rupee for \( n \)th period \( = \frac{1}{(1 + I)^n} \)

where \( I \) = rate of return (Interest rate).

Total maintenance cost incurred on the machine during \( n \) year is:

\[
\int_{t=0}^{n} R_c(t) \times R_f(t) = \sum_{t=0}^{n} R_c(t) \times R_f(t)
\]

Total cost (TC) = \( C - R_v(t) + \int_{0}^{n} R_c(t) \times R_f(t) \)

Total cost (TC) = \( C - R_v(t) + \sum_{0}^{n} R_c(t) \times R_f(t) \)  

(2)

Weighted average cost (WAC) = \( \frac{TC}{\text{Cumulative discount rate}} \)  

(3)

The time period with minimum weighted average cost will be selected for the replacement of machine. Table 4, defined various terms associated with the presented case. The replacement policy to

| Notation | Description |
|----------|-------------|
| \( C \)  | Cost of equipment/capital cost |
| \( R_v(t) \)  | Resale value for period \( t \) |
| \( R_c(t) \)  | Operating/maintenance/running cost for period \( t \) |
| \( R_f(t) \)  | Discounted rate factor for period \( t \) |
| \( C - R_v(t) \)  | Depreciation |
| \( TC \)  | Total cost |
| \( WAC \)  | Weighted average cost |
determine the economic life of the machine based on WAC is discussed by considering the following steps, shown in Figure 3.

| Table 4. Terminologies |
|------------------------|
| **1. Discount rate:**  |
| a. Rate at which a bill of exchange or an accounts receivable is paid before its maturity date |
| b. Rate by which an invoice amount is reduced when a condition is complied with such as payment on delivery |
| c. Multiplier that converts anticipated returns from an investment project to their current market value (present value) |
| d. It is always less than 1, and depends on the cost of capital and the time interval between the investment date and the date when return starts to flow |
| e. Discounted rate factor \( (R_f) = \frac{1}{(1+I)} \) where \( I \) is the required rate of return (interest rate) and \( n \) is the number of years, also called discount factor or present value factor |

| **2. Maintenance:** |
| a. All action taken to retain materiel in or to restore it to a specified condition. It includes inspection, testing, servicing, classification as to serviceability, repair, rebuilding and reclamation |
| b. All supply and repair action taken to keep force in condition to carry out its mission |
| c. The work of keeping something in proper condition |

| **3. Depreciation:** |
| a. An expense that reduces the value of an asset as a result of wear and tear, age, or obsolescence. Most assets lose their value over time |
| b. A decline in the value of a given currency in comparison with other currencies |

| **4. Economic life** |
| a. Period over which an asset (machine, property, computer system, etc.) is expected to be usable, with normal repairs and maintenance for the purpose it was acquired, rented or leased |
| b. Expressed usually in number of years, process cycles or units produced. It is usually less than the asset’s physical life |
| c. The period of time (years) that yields the minimum equivalent uniform annual cost (EUAC) of owning and operating as asset |

| **5. Net present value (NPV):** |
| a. Tomorrow is hidden in mystery. The money received today is greater in magnitude than the money received tomorrow. Net present value is the present value of net cash inflows generated by a project in future |

\[
NPV = \frac{R_1}{(1+I)} + \frac{R_2}{(1+I)^2} + \ldots + \frac{R_n}{(1+I)^n}
\]

where \( I \) = Target rate of return per period, \( R_1 \) = Net cash inflow during the first period, \( R_2 \) = Net cash inflow during the second period, \( R_n \) = Net cash inflow during the third period and so on
6. Applications and implications

The main application of the presented work lies in helping the government to draft policies, which are required to maintain ecological balance of the environment. The suggested work can act as a tool to the government authority in tackling green environmental decisions. We are aware that green concerns are significant and are drawing attention of the several social regulatory authorities to devise, choose, select and study various tools, techniques and methods, which aids in controlling environment pollution. Replacement is one of the functional area needed proper attention by the regulatory authorities in achieving a part of the goal of maintaining global green environment. The presented work illustrates the case of replacement of machinery of the business firms taking cost as an objective and thus can also be implemented by the individual. Moreover the presented work also depicts numerous reasons answerable for the replacement of assets connected to green environment concerns i.e. reduction in consumption of power or fuel by the advanced machine, Smoky, noisy, hazardous working conditions and pollution by old machines. Machine can be defines as a bunch of moving parts which moves to perform some task when electricity or fuel is given. It can be automobile vehicle. Thus the presented work apart from the business firm also helps the consumer in deciding the individual optimum replacement time of replacing their vehicle. Moreover, it will help the government regulatory authority in sketching the green replacement models by considering the parameter effecting pollution as cost parameters and computing the optimum replacement time. This will aid in drafting necessary rules and regulations to be strictly followed by every individual of the society owning productive assets, by declaring a time period to replace their vehicle or machinery assets after passing it. The economist can also be facilitated by the presented work in computing the optimum replacement period and suggesting the government to impose replacement of the owned productive assets by the peoples of the society based on their average income, which will boost the revenue generation (tax) and national economy by increasing the cash flow in the market.
7. Course of action

The considered case reflects the policy of Replacement of items whose maintenance cost increases with time and value of money also changes with time. The quantitative solution of the presented case is shown in Table 5, by considering the following course of action:

• The purchasing cost along with the installation charges should be considered as capital cost, represented by $C$, in second column in the presented case.
• Rate of depreciation is constant, calculated by straight line method and depicted in third column.
• Resale value, $R_v(t)$ of the machine, depicted in fourth column and can be calculated by:

$$C - \sum_{0}^{n} \text{Rate of depreciation}$$

• Operating/maintenance/running cost as $R_c(t)$ should be determine as per the expected expenditure on the machine in future, depicted in fifth column.
• Discounted rate factor, $R_f(t)$ is represented in sixth column and can be calculated by:

$$\frac{1}{(1 + I)^n}$$

• Net present value of the operating/maintenance cost that ought to be spend on the successive years, represented in seventh column and can be calculated as:

$$R_c(t) \times R_f(t)$$

• Calculate the cumulative maintenance/operating cost, shown in the eighth column by:

$$\sum R_c(t) \times R_f(t)$$

• Total cost of the machine, shown in ninth column can be determine by:

$$C - R_v(t) + \sum R_c(t) \times R_f(t)$$

• Calculate the cumulative discounted factor, shown in tenth column.
• Weighted average cost (WAC) should be compute, shown in eleventh column by dividing the total cost by the cumulative discount factor.

The time period $n$ representing the minimum WAC should be considered for replacing the machine.
| Service year (N) | Cost of the equipment/capital cost (C) | Depreciation cost per year by straight line method | Resale value \( R_v(t) \) | Operating/maintenance running cost \( R_i(t) \) | Discounted rate factor \( R_f(t) \) | \( \Sigma R_i(t) \times R_f(t) \) | Total cost \( (TC) = C - R_v(t) + \Sigma R_i(t) \times R_f(t) \) | Cumulative discount rate | Weighted average cost (WAC) |
|----------------|----------------------------------------|-----------------------------------------------|-------------------------|--------------------------|-----------------|-------------------|----------------------------|--------------------------|--------------------------|
| 1              | 800,000                                | 50,000                                        | 750,000                 | 16,000                   | 1.000           | 16,000            | 66,000                   | 1                         | 66,000                   |
| 2              | 800,000                                | 50,000                                        | 700,000                 | 24,000                   | 0.9091          | 21,818            | 137,818                  | 1.9091                   | 72,190.48                |
| 3              | 800,000                                | 50,000                                        | 650,000                 | 32,000                   | 0.8264          | 26,446            | 214,264                  | 2.7355                   | 78,326.28                |
| 4              | 800,000                                | 50,000                                        | 600,000                 | 40,000                   | 0.7513          | 30,053            | 297,049                  | 3.4869                   | 85,191.2                 |
| 5              | 800,000                                | 50,000                                        | 550,000                 | 48,000                   | 0.6830          | 32,785            | 379,834                  | 4.1699                   | 91,090.17                |
| 6              | 800,000                                | 50,000                                        | 500,000                 | 56,000                   | 0.6209          | 34,772            | 464,605                  | 4.7908                   | 96,978.92                |
| 7              | 800,000                                | 50,000                                        | 450,000                 | 64,000                   | 0.5645          | 36,126            | 550,732                  | 5.3553                   | 102,839.4                |
| 8              | 800,000                                | 50,000                                        | 400,000                 | 72,000                   | 0.5132          | 36,947            | 637,679                  | 5.8684                   | 108,662.8                |
| 9              | 800,000                                | 50,000                                        | 350,000                 | 80,000                   | 0.4665          | 37,321            | 725,000                  | 6.3349                   | 114,444.8                |
| 10             | 800,000                                | 50,000                                        | 300,000                 | 88,000                   | 0.4241          | 37,321            | 812,320                  | 6.7950                   | 120,183.1                |
| 11             | 800,000                                | 50,000                                        | 250,000                 | 96,000                   | 0.3855          | 37,012            | 899,332                  | 7.1446                   | 125,876.4                |
| 12             | 800,000                                | 50,000                                        | 200,000                 | 104,000                  | 0.3505          | 36,451            | 985,784                  | 7.4951                   | 131,524.4                |
| 13             | 800,000                                | 50,000                                        | 150,000                 | 112,000                  | 0.3186          | 35,687            | 1,071,470                | 7.8137                   | 137,127.3                |
| 14             | 800,000                                | 50,000                                        | 100,000                 | 120,000                  | 0.2897          | 34,760            | 1,156,230                | 8.1034                   | 142,685.3                |
| 15             | 800,000                                | 50,000                                        | 500,000                 | 128,000                  | 0.2633          | 33,706            | 789,937                  | 8.3667                   | 94,414.49                |
| 16             | 800,000                                | 50,000                                        | 000,000                 | 136,000                  | 0.2394          | 32,557            | 1,322,494                | 8.6061                   | 153,669.7                |
8. Problem statement

Today, in the race of generating more earnings and to remain competitive amongst rival, the decision-making is important and should be optimize. It is the task of the managers of business firms to explore and consider various branches of science and departments of their hierarchical structure in decision-making. Replacement of machineries and assets is a common concern in the mind of the owner of the business firms. In the presented work, the authors considered the case of replacement of mechanical equipment (lathe machine) with a purchase price of Rs. 800,000 and worked to accomplish the objective of generating more income by the way of operating the machine with minimum average cost rather than running by higher yearly cost. The authors considered running costs per year and resale values for shaping economic time period of lathe machine, So that prior advance planning can be done by the operating firm to replace their machine.

Based on the expert assessment and market survey the authors found that the operating cost which includes maintenance costs and running costs are found as Rs. 16,000 for the first year, which increases by Rs. 8,000 every year. The authors also considered depreciation of machine as criteria for modeling the replacement problem along with other parameter i.e. capital cost, operating cost, resale value and the concept of value of money in contrast to future (particularly known as net present value). The authors considered the discounted rate factor of 10% for computing the net present value of cash in future.

The authors try to frame the integrated relationship between depreciation and replacement and adopt straight line method of depreciation, assuming the life of the machine as 16 years. The resale value is calculated based on the computed depreciated value. Table 6 furnished the objective information explored by proposed mathematical model. Replacement is common problem in engineering applications and can be defined as a type of uncertain maintenance given to run a system efficiently and effectively. Figure 4 depicts the importance of replacement action in the field of management activities.

| Service year (N) | Cost of the equipment/capital cost (C) | Depreciation cost per year by straight line method | Resale value Rv(t) | Operating/maintenance/running cost Rc(t) | Discounted rate (I) (%) |
|------------------|--------------------------------------|-----------------------------------------------|-------------------|---------------------------------------|-----------------------|
| 1                | 800,000                              | 50,000                                        | 750,000           | 16,000                                | 10                    |
| 2                | 800,000                              | 50,000                                        | 700,000           | 24,000                                | 10                    |
| 3                | 800,000                              | 50,000                                        | 650,000           | 32,000                                | 10                    |
| 4                | 800,000                              | 50,000                                        | 600,000           | 40,000                                | 10                    |
| 5                | 800,000                              | 50,000                                        | 550,000           | 48,000                                | 10                    |
| 6                | 800,000                              | 50,000                                        | 500,000           | 56,000                                | 10                    |
| 7                | 800,000                              | 50,000                                        | 450,000           | 64,000                                | 10                    |
| 8                | 800,000                              | 50,000                                        | 400,000           | 72,000                                | 10                    |
| 9                | 800,000                              | 50,000                                        | 350,000           | 80,000                                | 10                    |
| 10               | 800,000                              | 50,000                                        | 300,000           | 88,000                                | 10                    |
| 11               | 800,000                              | 50,000                                        | 250,000           | 96,000                                | 10                    |
| 12               | 800,000                              | 50,000                                        | 200,000           | 104,000                               | 10                    |
| 13               | 800,000                              | 50,000                                        | 150,000           | 112,000                               | 10                    |
| 14               | 800,000                              | 50,000                                        | 100,000           | 120,000                               | 10                    |
| 15               | 800,000                              | 50,000                                        | 500,000           | 128,000                               | 10                    |
| 16               | 800,000                              | 50,000                                        | 0000000           | 136,000                               | 10                    |
9. Replacement and disposal
The presented work strikes on highlighting the role and importance of replacement policy by the way of determining the most favorable replacement instant of machines. The work proposes the economic worth of machines to firms via determining the minimum average cost of operating, but by replacing the old machines with new one, the former have to be properly disposed, which can be the difficult problem to be tackle in this rapidly changing world. In order to control the disposal problem and avail benefits of smart production via replacing old machineries, the research work in the domain of effective and effectual disposal strategies are required to be conducted. The government various policies of reduce–reuse-recycle-recover–dispose during various phases of the life cycle of the equipment or machineries must be utilized. These policies are required to be strictly compelled towards the manufacturing firms, which will help to diagnose the disposal problem up to some extent. The manufacturer and operating firms should be guided and the administrative rules are required to be stringently functional to every manufacturer, consumer or bulk consumer implicated in manufacturing, sales, and purchase as well as involved with scrap materials, collection centers, dismantlers and recyclers etc.

10. Limitations
The work shaped the economic time to replace assets and assists the business firms to accomplish the objective of generating more earnings via operating the machines with minimum average cost rather than operating by higher cost. The suggested replacement model is unfeasible in terms of green issues, when deploy to select electronics equipment and machineries. Since the owner of the firm preserve more earnings by replacing these electronics equipment and machineries with new one at optimum time period, but this will generate E-waste, which is an emerging problem encountered by numerous countries, as E-waste contains heavy metals or chemicals such as cadmium, chromium, lead, antimony, magnetic properties and mercury etc. Therefore it is suggested to address and diagnose the problem of E-waste by the forthcoming researchers via developing biodegradable materials for the manufacturing of electronics assets or the replacement of the electronics assets should be carried out by favoring the last usage of it until the equipment malfunction and unattainable to repair or maintain.

11. Conclusions
In today’s competitive environment, due to fast technological development and globalization, replacement of machines and equipment is a permanent and complex problem, which is common concern in the mind of the owner of the almost every business firms. The decision pertaining to replace machines and equipment helps in determining their economic life, so that prior advance
planning can be done to replace their machine and can also consider the spent cost in computing the variable cost per unit and the selling price of the produced product. The presented case favored to replace the lathe machine at the end of first year with the minimum average operating cost of Rs. 66,000. If the manufacturer does not replaces the considered lathe machine after completing the first year of his operation and proceeds for the second year, third year and so on, in that case the firm operates his machine with high average cost in spite of minimum average cost, which can be easily computed by the presented work, shown by scatter diagram in Figure 5. Scatter diagram depicts the average yearly cost corresponding to time (years), that the business firms have to spend in subsequent years. Figure 6 depicts the histogram, which shows the comparison between average yearly cost to be spent in future and the minimum yearly cost that can be achieved by the presented work. It also depicts that how much extra amount has to be paid by the business firms in other years. The authors would like to conclude that based on the presented work, merely due to small calculation, it is possible by the business firms to operate the purchased machinery via determining the economic replacement time with the minimum cost as compared with other years.

The proposed case depicts that it can be possible for a manufacturer to run their machines with minimum cost per year by replacement analysis and can also be helpful to a manufacturer to get rid from obsolescence due to technological developments or change that may occur at any time. Separately from obsolescence and minimum yearly cost equipment replacement also facilitates in producing better quality products and provides the competitor to earn more profit, increased

Figure 5. Scatter diagram.

![Scatter diagram](image1)

**Figure 6. Histogram.**

![Histogram](image2)
production, introduction of new products, safety etc. and helps in remaining competitive due to new machines replaced. Replacement decision is not an easy job, it requires special consideration as it involves large capital investment. A wrong decision may adversely affect the profitability of the organization, therefore a scientific approach is essential to solve these types of problems.

12. Future work

Replacement is a common concern to every business firms. The assets that an individual possess, need replacement due to wear and tear. It is apparent that uncertainty constantly exists in practical and real life problems. The class of researchers is concentrating on developing the methodology related to replacement and depreciation based on objective information. Work is required to be conducted in developing new methods and techniques in the direction of replacement and precise computation of depreciation cost by incorporating inconsistence, vagueness, imperfect, imprecise and uncertain information because it is not easy to obtain consistence, certain, true and precise information from the real system in the domain of replacement and depreciation. New methods and techniques via incorporating subjective as well as subjective cum objective information need to be developed. Work is also required to be done in the ambit of replacement by introducing new methods and developing merge concepts between breakeven analysis and replacement, queuing theory and replacement, linear programming models and replacement, qualitative group replacement policies, simulated modeling in replacement etc.

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References

Allen, H. T., & Ching, W. K. (2005). On the use of renewal theory in machine replacement models. International Journal of Applied Mathematical Sciences, 2, 240–247.

Alta, K., Pedro, J. M., & James, T. (2015). Evaluation of the operational cost savings potential from a D-CHP system, based on a monthly power-to-heat ratio analysis. Cogent Engineering, 2, 1–13.

Cardoso, G., & Gomide, F. (2007). Newspaper demand prediction and replacement model based on fuzzy clustering and rules. Information Sciences, 177, 4799–4809. http://dx.doi.org/10.1016/j.ins.2007.05.009

Chen, Y. H., Sheu, S. H., Zhang, Z. G., & Love, E. (2006). An extended optimal replacement model of systems subject to shocks. European Journal of Operational Research, 175, 399–412. http://dx.doi.org/10.1016/j.ejor.2005.04.042

Cherster, A. H., Wang, W. J., & Sharp, J. M. (1997). A state space condition monitoring model for furnace erosion prediction and replacement. European Journal of Operational Research, 101, 1–14. http://dx.doi.org/10.1016/S0377-2217(97)00132-X

Chu, C., Proth, J. M., & Wolff, P. (1998). Predictive maintenance: The one-unit replacement model. International Journal of Production Economics, 54, 285–295. http://dx.doi.org/10.1016/S0925-5273(98)00004-8

Craig, W., & Stephen, T. M. (2010). Life-cycle assessment of reconstruction options for interstate highway pavement in Seattle, Washington. Journal of the Transportation Research Board, 2170, 18–27.

Crowder, M., & Lowless, J. (2007). On a scheme for predictive maintenance. European Journal of Operational Research, 176, 1713–1722. http://dx.doi.org/10.1016/j.ejor.2005.10.051

Kristensen, A. R., & Søllested, T. A. (2004). A sow replacement model using Bayesian updating in a three-level hierarchical Markov process II. Optimization model. Livestock Production Science, 87, 25–36. http://dx.doi.org/10.1016/j.livprodsci.2003.07.005

Kumar, D., & Westberg, U. (1997). Maintenance scheduling under age replacement policy using proportional hazards model and TT–Plotting. European Journal of Operational Research, 99, 507–515. http://dx.doi.org/10.1016/S0377-2217(96)00317-7

Oyedepo, S. O., Fagbenle, R. O., Adefila, S. S., & Mahbub, A. M. (2015). Exergy costing analysis and performance evaluation of selected gas turbine power plant. Cogent Engineering, 2, 1–21.

Sahu, A. K., Sahu, A. K., & Sahu, N. K. (2016). Appraisal of partner enterprises under GTFNS environment: Agile supply chain. International Journal of Decision Support System Technology, 8(3), 1–19. http://dx.doi.org/10.4018/IJDST

Sahu, A. K., Sahu, N. K., & Sahu, A. K. (2014). Appraisal of CNC machine tool by integrated MULTI MOORA-IVGVN circumstances: An empirical study. International Journal of Grey Systems: Theory and Application, 4, 104–123.

Sahu, A. K., Sahu, N. K., & Sahu, A. K. (2015). Benchmarking CNC machine tool using hybrid fuzzy methodology a multi indices decision making approach. International Journal of Fuzzy System Applications, 4, 32–50.
Sahu, A. K., Sahu, N. K., & Sahu, A. K. (2016a). Application of integrated TOPSIS in ASC index: Partners benchmarking perspective. Benchmarking: An International Journal, 23, 540-563. http://dx.doi.org/10.1108/BJI-03-2014-0021

Sahu, A. K., Sahu, N. K., & Sahu, A. K. (2016b). Application of modified MULTI-MOORA for CNC machine tool evaluation in IVGTFS environment: An empirical study. International Journal of Computer Aided Engineering and Technology, 8, 234-259. http://dx.doi.org/10.1504/IJCAET.2016.077603

Sahu, N. K., Sahu, A. K., & Sahu, A. K. (2015). Appraisal and benchmarking of third party logistic service provider by exploration of risk based approach. Cogent business and Management, 2, 1-21.

Sheu, S. H. (1998). A generalized age and block replacement of a system subject to shocks. European Journal of Operational Research, 108, 345-362. http://dx.doi.org/10.1016/S0377-2217(97)00051-9

Sheu, S. H. (1999). Extended optimal replacement model for deteriorating systems. European Journal of Operational Research, 112, 503-516. http://dx.doi.org/10.1016/S0377-2217(97)00400-1

Shey, S. H., Griffith, W. S., & Nakagawa, T. (1995). Extended optimal replacement model with random minimal repair costs. European Journal of Operational Research, 85, 636-649. http://dx.doi.org/10.1016/0377-2217(93)E0364-4

Tan, C. M., & Raghavan, N. A. (2008). Framework to practical predictive maintenance modeling for multi-state systems. Reliability Engineering and System Safety, 93, 1138-1150.