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Full Length Article

Analyzing the impact of opportunistic maintenance optimization on manufacturing industries in Bangladesh: An empirical study

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ABSTRACT

The study investigates the impact of opportunistic maintenance (OM) optimization on manufacturing industries, especially in Bangladesh, to reduce maintenance costs. To that end, OM strategies have been proposed and optimized for multi-unit manufacturing systems, whereas most of the existing research is for single- or two-unit systems. OM strategies in this research cover one of the three policies: preventive replacement, preventive repair, and a two-level maintenance approach. The proposed two-level maintenance approach is a combination of lower-level maintenance, known as preventive repair, and higher-level maintenance, known as preventive replacement. Simulation optimization (SO) techniques using Python were utilized to evaluate the strategies. Historical data from two of Bangladesh's most promising and significant sectors, the footwear and railway industries, was used as the case study. Compared to the currently utilized corrective maintenance approach, the two-level maintenance approach is the most effective for both case studies, demonstrating cost savings of 16.9 % and 22.4 % for the footwear and railway industries, respectively. This study reveals that manufacturing industries can achieve significant cost savings by implementing the proposed OM strategies, a concept that has yet to be explored in developing countries like Bangladesh. However, the study considered the proposed approaches for major components of the system, and more significant benefits can be achieved if it is possible to apply them to all critical components of the system.

1. Introduction

Maintenance is the set of decisions and actions required by management, technical experts, and administrators to keep a system or asset functioning properly or bring it back to its previous state [1]. Maintenance has been treated as a neglected business function for many years, especially in manufacturing and engineering [2]. Two main reasons may have initiated this situation about maintenance: the first reason is thinking of the maintenance department as a support activity that has no direct relation with production processes; the second reason relates to the complexities of measuring maintenance contribution to firm profits. Thus, maintenance is usually considered a cost rather than an investment. Therefore, it can be concluded that such earlier views of negligence regarding maintenance are among the leading causes of low maintenance efficiency in industries [3]. Adequate and proper maintenance not only improves the company's essential performance, including product quality, reliability, and productivity, but also reduces monetary losses by increasing manufacturing system availability, keeping the standard of products, and maintaining workplace safety [4]. Also, a proper maintenance approach enhances system reliability, improves overall effectiveness, and minimizes long-term costs [5].

Over several decades, researchers have gathered a wealth of data on maintenance. According to them, maintenance can be broadly classified into two primary categories: preventative maintenance (PM) and corrective maintenance (CM). Preventive maintenance (PM) can be described as planned actions to enhance the anticipated lifespan of operational systems. In contrast, corrective maintenance (CM) addresses unforeseen component or system failures to restore operational functionality [6]. Researchers have emphasized on PM more than CM [7]. However, the existing maintenance practices in the manufacturing industries, especially in Bangladesh, are mainly failure-based, i.e., corrective maintenance. Sudden failures in a manufacturing system results in a great deal of production loss for the company here. However,

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Notations

θ	component scale parameter for the Weibull distribution
β	component shape parameter for the Weibull distribution
N	number of machines in the system
Z	number of parts in a machine
C_A	estimated daily average cost of maintenance of a machine
p	component age percentage
r	age restoration factor
C_{PV}	cost of preventative replacement
C_{PF}	fixed cost of preventive maintenance
C_P	cost of preventive maintenance
C_R	replacement cost of failed component
C_{PD}	predetermined labor cost rate for maintenance action (in Tk./hour)
C_{TR}	total replacement cost of failed component
$C_{support}$	supportive cost for preventive maintenance in a machine in the system
R_L	cost of lost production (per unit)
TC	total cost of maintenance
$Tk.$	Tk. is a Bangladeshi currency. At the time of the study, the exchange rate was 1 USD = 117.09 Tk.
$MTTCA$	mean time to corrective action
$MTTPM$	mean time to preventive maintenance
$MTTPRA$	mean time to preventive replacement action
$MTTPrA$	mean time to preventive repair action
P_R	production rate (units per hour)
$LF_{z,n}$	lifetime that is generated for component z in machine n.
$FA_{z,n}$	actual age of failure of part z in machine n
$IR_{z,n}$	indicator value for failure replacement
$IP_{z,n}$	preventive maintenance action value
IS_n	an indicator value that signifies whether the system has undergone any maintenance.
t_I	the total length of the iteration

other kinds of maintenance, like scheduled preventive maintenance (PM) and condition-based maintenance (CBM), are practiced in some industries to avoid such failures. Due to time and resource constraints, this kind of maintenance is not always possible to fully implement in practical situations. Moreover, the cost of preventive maintenance (PM) activities in industries is rising due to the growing intricacy of industrial systems and the broader implementation of PM [8]. So, most researchers are now attempting to optimize PM actions to save expenses. Sudden breakdowns of machines can be taken as an opportunity to implement maintenance on other parts or machines in the system. This kind of maintenance is known as opportunistic maintenance (OM). OM does not occur at a predetermined time or condition. Instead, it occurs when an "opportunity" arises [9]. Thus, OM saves time and money. The repairs of failures in different system components are widely acknowledged as potential opportunities to perform preventive maintenance on specific components within the systems under consideration [10,11].

OM has mainly been followed in the industries of developed countries, especially in the power sectors [12–15], gas [16], and railway sectors [17,18]. In South Asia, Bangladesh is one of the few emerging countries that has made such an exciting promise of economic growth [19]. Like all other developing countries, Bangladesh needs to industrialize more and more for its economy and society to grow quickly and steadily. However, the large and significant investment in the industrial and manufacturing sectors exposes many difficulties in achieving the lowest maintenance and operational costs. To lower these expenses to the greatest extent, exploring and implementing more intelligent and affordable maintenance strategies is essential for ensuring the country's sustained development. So, the industries of developing countries like Bangladesh can benefit significantly from adopting such OM strategies. The subsequent steps advance by answering the following research questions (RQ):

RQ1: Can opportunistic maintenance strategies reduce costs in manufacturing industries compared to corrective maintenance?

RQ2: Which OM strategy (replacement, repair, two-level) is the most cost-effective for manufacturing industries, especially Bangladesh's footwear and railway industries?

This paper offers a novel contribution by proposing and evaluating opportunistic maintenance strategies for multi-unit manufacturing industries, whereas most of the existing research is for single or two-unit systems. Moreover, the concept has yet to be explored for manufacturing industries in developing countries like Bangladesh and OM has many challenges here due to resource constraints and lack of advanced predictive maintenance technologies. Three OM strategies (preventive replacement, preventive repair, and a two-level maintenance approach) are proposed as solutions to optimize maintenance practices and reduce costs. The proposed two-level approach is a unique maintenance approach that distinguishes between a lower-level approach called preventive repair and a higher-level approach called preventive replacement. These two maintenance levels are intended to be carried out at distinct stages of the equipment's lifespan. Two case studies, (i) the footwear and (ii) the railway industries, are employed to verify the proposed OM strategies and demonstrate the potential impact of OM on cost savings. The feasibility of implementing OM strategies has been checked by comparing them to the currently used corrective maintenance approach and doing a sensitivity analysis. The study identifies the two-level maintenance approach as the most cost-effective option in the footwear and railway industries, providing valuable insights for decision-makers.

The rest of the paper is divided into subsequent sections. Section 2 comprehensively analyzes the contemporary literature on maintenance and opportunistic maintenance. Problem description and proposed opportunistic maintenance policy formulation are covered in Sections 3 and 4, respectively. Solution methodologies to assess the costs associated with suggested OM policies are presented in Section 5. Section 6 validates the proposed strategies through two different Bangladeshi manufacturing industry case studies, a comparative study, and a sensitivity analysis. Section 7 encompasses a summary of the research's findings, an evaluation of its limitations, and recommendations for potential areas of future research.

2. Literature review

Opportunistic maintenance offers numerous benefits that significantly boost the efficiency and cost-effectiveness of maintenance operations. Simultaneously maintaining several components, companies can reduce labor and material costs while minimizing total downtime, thus enhancing operational availability. This method ensures the optimal use of resources such as tools, spare parts, and personnel and facilitates better planning and scheduling. Regular maintenance based on opportunity helps to prevent unexpected failures, extending the lifespan of equipment and improving reliability, thereby decreasing the chances of sudden breakdowns [20]. Additionally, routine checks and maintenance ensure equipment meets safety standards, enhancing worker protection. Predictable maintenance activities also enable better financial planning and budget allocation, and well-maintained equipment operates more efficiently, leading to energy savings. Regular maintenance helps ensure compliance with industry regulations and standards, and data-driven insights from maintenance activities can inform future strategies [21]. Reliable operations resulting from consistent maintenance led to better service delivery and higher customer satisfaction. Maintenance intervals provide opportunities to integrate new technologies or improvements into existing systems, fostering innovation. Properly maintained equipment is less likely to leak or emit harmful substances, benefiting the environment. Finally, regular maintenance builds a more resilient operation capable of handling unexpected disruptions [20,21].

Manufacturing-based industrial sectors in Bangladesh typically struggle to make a proper profit due to higher maintenance and operational costs. Consequently, most industries view maintenance as a cost rather than an investment. However, maintenance significantly impacts multiple operational aspects such as production quantity, expenses, asset reliability, equipment availability, quality of the finished products, environmental sustainability, worker and end-user health and safety, and social welfare [22]. Due to limited time and resources, many industries in developing countries like Bangladesh cannot fully realize these benefits. A more adaptable and less expensive maintenance system is needed to address these issues. Opportunistic maintenance (OM) is one approach to achieve this, particularly for multi-component systems [23]. Implementing opportunistic maintenance in multi-stage manufacturing systems can yield substantial benefits [24].

The paper [12] presented an opportunistic maintenance strategy for wind turbines, addressing challenges posed by stochastic weather conditions and spare parts management. Using a Markov chain model to simulate wind speed time series, the study calculated maintenance wait times due to weather constraints. The economic benefits are demonstrated through numerical examples, showing a reduction in life cycle operation and maintenance costs by 10.92 % and 18.30 % compared to static-opportunistic and non-opportunistic maintenance strategies, respectively. According to Wang et al. [25], the maintenance policy that includes OM activities is the most effective, resulting in significantly lower average costs compared to other policies. Adopting a policy that incorporates condition-based and age-based OM measures can decrease maintenance expenses and enhance efficiency of a two-unit system. The model has potential for expansion to systems with more than two units [25]. Another study showed that employing a condition-based opportunistic maintenance strategy in offshore wind farms saves 32.46 % of costs compared to corrective and preventive maintenance strategies (CPM). However, this study did not consider maintenance time, which significantly impacts average maintenance costs [26]. In another study, Wang et al. [27] showed that a strategy utilizing the downtime of a unit to opportunistically repair other components resulted in savings of £130.0 per month and £25.2 per month compared to two policies where OM is not followed. In a comparative analysis, Li et al. [28] demonstrated that age-based OM can reduce the annual cost by 2.6 % and 1.5 %, respectively, when compared to two traditional opportunistic maintenance strategies. Bakhtiary et al. [17] introduced a novel approach to scheduling tamping interventions to minimize total maintenance costs. The proposed policy establishes an Opportunistic Maintenance Threshold (OMT) for preventive tamping on railway segments, leveraging a steady-state genetic algorithm to find the optimal OMT and tamping schedule. Using data from a railway line in Sweden, the study demonstrates that implementing an OMT can reduce machine preparation costs by approximately 46 %.

The paper [29] presented an advanced OM strategy tailored for multi-component systems in wind turbines, considering seasonal variations. It analyzed the impact of minimal repair, imperfect repair, and replacement on a component's effective age. A dynamic maintenance threshold is established to minimize the life-cycle maintenance cost of wind turbines. The strategy used a genetic algorithm for optimization and was validated through a case study, suggesting that higher component reliability and maintainability reduce the frequency of repairs and replacements. Research [30] concluded that opportunistic production-maintenance synchronization offers a viable solution for optimizing PM scheduling. Companies can achieve substantial cost savings and operational improvements by using production breaks for maintenance activities. The proposed model and algorithm provided a robust framework for future research and practical applications in various industrial settings. A study highlights the trade-offs between different maintenance approaches, noting the fixed costs of planned maintenance, the benefits of OM, and the expenses related to premature part replacements. When the cost of replacing premature parts is very high, OM may not be advantageous [31]. The timeframe of OM is often set to a constant value [28,32]. However, since different components are maintained in different OM windows, the total time required for maintenance varies. Thus, a static maintenance window is unrealistic [28,32]. Table 1 displays the literature review summary and a comparison with the current work.

2.1. Research gaps, novelty, and contributions

Table 1 provides a summary of the most recent literature that has investigated OM. Only a handful of studies dealt with manufacturing industries; only one dealt with multi-component and multi-unit manufacturing systems. To fill this research gap, our paper makes the following contributions:

- Our study incorporated three strategies to determine the best cost optimization method. The application of OM in Bangladesh presents unique challenges and opportunities compared to other countries. Bangladesh's manufacturing industries often face resource constraints and a lack of advanced maintenance infrastructure, hindering the implementation of sophisticated OM strategies. However, the potential for cost savings is significant due to the high failure rates and maintenance costs in these industries. Unlike in developed countries where OM strategies are supported by advanced predictive maintenance technologies, in Bangladesh, the focus is on optimizing existing resources and processes to achieve similar benefits. Our study shows that, with appropriate adaptation, OM strategies can be highly effective even in resource-limited settings.
- Most existing studies have proposed and implemented OM for single- or two-unit systems. Our study deals with more than two units as well as multi-component systems.
- Unlike most previous studies that avoided or ignored the consideration of maintenance duration [25,26], our study considers maintenance duration. In real life, the average maintenance cost is primarily impacted by maintenance duration, regardless of the maintenance crew's experience and expertise, which also indirectly reflects production loss.
- Our simulation-optimization approach has been implemented for two different types of manufacturing industries with uncertain OM time windows, whereas most literature studies considered deterministic OM time windows.

3. Problem description

Techniques for maintenance based on opportunity are distinguished by the component age percentage values where a decision on the component's maintenance can be made. Typically, the proposed policy is displayed in Fig. 1. Imagine that there has been a failure in a manufacturing system. The maintenance team is sent out to replace the malfunctioning component, and they take advantage of the situation to do preventative maintenance on the remaining components of the machine that will meet the condition. Assume that component i failed and

Table 1
A comparison of the present work with the most relevant papers in the literature.

Refs.	Types of System			Types of components			Types of Industries			Objective function		OM time Window		Maintenance duration		Solution Approach			
	Single unit	Two unit	More than two unit	Single	Two	More than two	Manufacturing	Power	Other	Cost	Reliability	Deterministic	Stochastic	Considered	Avoided	SO	Exact Methods	Metaheuristic	Approximate method
[12]	✓					✓		✓		✓	✓			✓					✓
[25]		✓			✓			✓		✓		✓			✓				✓
[26]	✓					✓		✓		✓		✓			✓	✓			
[29]	✓					✓		✓		✓								✓	
[17]			✓						✓	✓		✓			✓			✓	
[30]			✓				✓							✓				✓	
[27]		✓			✓			✓		✓		✓			✓				✓
[28]		✓				✓		✓		✓					✓	✓			
[32]			✓			✓	✓			✓		✓			✓	✓			
[31]	✓					✓		✓			✓				✓	✓			
Present work			✓			✓	✓			✓			✓	✓		✓			

component x will have to go through a preventative maintenance operation since its age is greater than the limit, which is now $p \times MTTF_x$. Where p is the component age percentage and *MTTF* stands for the mean time to failure.

On the other hand, because the age of the component y is smaller than the $p \times MTTF_y$, there will be no maintenance work done on it, and it will continue to function either until the next opportunity arises or it may break down first.

The following presumptions provide the foundation for the suggested policies:

- The rate of failure for each individual component in a manufacturing system follows a Weibull distribution.
- Each component in a machine degrades independently.
- Failure of the machine results from any component failure.
- Assume that there are N number of machines in the system and each machine has Z important components.
- Any machine downtime due to a failure or maintenance action will result in production losses for the manufacturing plant.

4. Proposed Opportunistic Maintenance (OM) optimization strategies

The following section presents the methods followed in this study and details of the proposed OM optimization strategies.

4.1. Preventive repair and age restoration factor

The preventive repair approach is a novel maintenance methodology that has gained popularity in recent decades as an alternative to the conventional categorization of maintenance [33]. It will not make components as good as new. It will reduce the starting age of the component with a probability represented by *r,* where *r* is the age restoration factor. The age restoration factor represents the degree of improvement a component will experience following a repair action, specifically a decrease in age. It is used to find the component's age following a preventive repair. Here, $0 \leq r \leq 1$.

$$Component' s\,age\,after\,maintenance,\ Age_{new} = Age_{old} - Age_{old} \times r \tag{1}$$

$$Failure\,age\,after\,maintenance = r \times LF_{new} + (1 - r) \times LF_{Old} \tag{2}$$

Assume, for instance, that the age restoration factor, r=*0.6,* a hydraulic pipe's lifetime is 10 months (LF_{Old}) and that it has an age of 4 months (Age_{old}) before maintenance. And if it is replaced by a new one with a lifespan of 12 months (LF_{new}). As a result, according to Eq. (1), this hydraulic pipe will have a new age of 4-4 × 0.6=1.6 months after preventive repair, whereas, according to Eq. (2), maintenance activity with a preventive repair approach renews its failure age to 12 × 0.6+ 10 × 0.4=11.2 years.

4.2. Maintenance cost functions

In this study, the cost models include the various maintenance costs along with production losses during downtime. The detailed cost functions used in this paper are given in the following subsections:

4.2.1. Failure replacement and cost of corrective maintenance

When a failure occurs in the manufacturing system, a failure replacement action must be performed. If an industry follows only a failure replacement strategy, it will be regarded as a corrective maintenance action. The costs of Corrective maintenance are as follows:

$$TC = C_R \times IR_{z,n} + (C_{PD} + P_R \times R_L) \times MTTCA_z \tag{3}$$

Here, $IR_{z,n}$ is the indicator of failure. Due to failure, other costs, such as labor costs and production loss, also occured, which will be described in the next sections.

$$\text{Similarly, cost of lost production } C_{LP} = P_R \times R_L \times \sum_{Z=1}^{Z} MTTCA \text{ when } \sum_{Z=1}^{Z} MTTCA \geq MTTPM \tag{9}$$

4.2.2. Opportunistic preventive maintenance costs

If preventive maintenance is performed at an opportunity, the cost will be updated as follows:

$$C_{PM} = \sum\nolimits_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N \tag{4}$$

For the preventive replacement approach, the cost of opportunistic preventive maintenance will be updated as follows:

$$C_{P,Z} = C_{PV} + C_{PF} \tag{5}$$

For preventive repair approach, the total cost of opportunistic preventive maintenance will be updated by assuming that the cost of preventive repair is dependent on the variable r, as in the following equation:

$$C_{P,Z} = r^2 C_{PV} + C_{PF} \quad \textit{where} \quad 0 \leq r \leq 1 \tag{6}$$

In this context, C_{PV} represents the preventive replacement cost, while C_{PF} stands for the fixed cost for preventive maintenance. The entire preventative cost is $C_{PV+}C_{PF}$ will occur when the age restoration factor is 1 i.e., 100 % age restoration which is practically impossible.

4.2.3. Labor cost

Total labor costs depend on the total maintenance time and the predetermined labor cost rate i.e.,

$$C_L = C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPM \right) \tag{7}$$

Here, *MTTPM* will be *MTTPRA* for preventive replacement and *MTTPrA* for preventive repair action.

4.2.4. Cost of lost production

Production losses may occur for several reasons. It will occur in two ways at a time. Production loss will be calculated due to failure replacement action and opportunistic preventive maintenance action. As opportunistic maintenance in the model will be implemented at the same time of corrective maintenance, calculating production loss has some considerations in this case. When, the total mean time to preventive maintenance *(MTTPM)* will be larger than *MTTCA*, considering *MTTPM* is enough to calculate the cost of lost production and vice versa.

So, the cost of lost production,

$$C_{LP} = P_R \times R_L \times \sum_{Z=1}^{Z} MTTPM \text{ when } \sum_{Z=1}^{Z} MTTPM \geq MTTCA \tag{8}$$

Here, *MTTPM* will be *MTTPRA* for preventive replacement and *MTTPrA* for preventive repair action.

4.2.5. Total maintenance cost

The total cost due to failure replacement and opportunistic maintenance will be the sum of all maintenance-related costs, which is given as:

$$TC = C_R + C_{PM} + C_L + C_{LP} \tag{10}$$

So, the total cost of maintenance will be as follows:

$$\begin{aligned} TC = {} & C_R \times IR_{z,n} + \sum_{n=1}^{N} \left(\sum\nolimits_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N \right) + C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPM \right) \\ & + P_R \times R_L \times \sum_{Z=1}^{Z} MTTPM \end{aligned} \tag{11}$$

Here, *MTTPM* is used to calculate the cost of lost production as in most of the cases, total *MTTPM* is larger than *MTTCA*. However, *MTTCA* can also be used if it becomes larger according to Section 4.2.4. To simplify the model representation, this approach of using *MTTPM* is followed in the whole study but real scenario has been considered in the simulation process.

The average maintenance cost per machine per day will be:

$$C_A = \frac{TC}{t_I \times N} \tag{12}$$

4.3. Opportunistic maintenance strategies

Opportunistic maintenance procedures are covered in three ways, as described in the following subsections.

4.3.1. Strategy 1: maintenance based on opportunities with a preventive replacement approach

The maintenance policy includes the implementation of corrective replacements as necessary. Additionally, this provides an opportunity to perform preventative replacements on various components within the same machine and other machines in the system. Replacement action will bring the component as good as new. Maintenance selection is dependent upon the component's age at the moment of failure. As soon as a failure occurs in machine n (n=1,..., N), do preventive replacement of component z (z=1,..., Z) if $agek_{z,n} \geq MTTF_z \times p$. Without preventative replacement, the component will continue to function until the machine fails again.

The objective function is

$$MinC_A(p) = \frac{\left[\begin{array}{l} C_R \times IR_{z,n} + \sum_{n=1}^{N} \left(\sum\nolimits_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N \right) + \\ C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPRA \right) + P_R \times R_L \times \sum_{Z=1}^{Z} MTTPRA \end{array} \right]}{t_I \times N} \tag{13}$$

subject to

$0 \le p \le 1$

Where variable p is the component age percentage, C_A represents the estimated daily average cost of machine maintenance. Other notations are described earlier. The goal is to obtain the optimum age percentage, p in order to lower the anticipated daily average cost of maintenance.

4.3.2. Strategy 2: maintenance based on opportunities with a preventive repair approach

In this action, corrective replacements are carried out when needed, and we use the occasion as an opportunity to carry out preventive repair on other parts of the same machine and other machines in the system. The age of the machine part at the time of failure dictates the maintenance strategy used. If $age_{z,n} \ge MTTF_z \times p$, then preventive repair should be conducted at the moment of failure by decreasing the age of the component by r on component z (z = 1,...,Z) in machine n (n = 1,...,N). The preventive repair techniques described in section (4.1) are put into reality. In the event that the component does not meet the condition, it will be utilized until a subsequent breakdown occurs.

The objective function in this regard is

$$MinC_A(p,r) = \frac{\left[\begin{array}{l} C_R \times IR_{z,n} + \sum_{n=1}^{N}\left(\sum_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N\right) + \\ C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPrA\right) + P_R \times R_L \times \sum_{Z=1}^{Z} MTTPrA \end{array}\right]}{t_I \times N} \quad (14)$$

subject to

$0 \le p \le 1$
$0 \le r \le 1$

Where p and r are design variables. p represents the age percentage for a component, and r represents the age restoration factor and other notations are the same as before. It is crucial to identify the optimum p and r to achieve the minimum daily maintenance cost per machine.

4.3.3. Strategy 3: maintenance based on opportunities with a two-level approach

In this model, corrective replacements are carried out as needed under this maintenance strategy, and we use the occasion to carry out two-level preventive maintenance procedures on other parts of the same machine and other machines of the system. Two age thresholds, $MTTF \times p_L$ and $MTTF \times p_H$ where $p_H > p_L$, define preventive repair and preventive replacement actions, respectively. The choice of maintenance is based on the component's age at the time of failure. If $MTTF_z \times p_H \ge age_{z,n} \ge MTTF_z \times p_L$, then preventive repair should be conducted at the moment of failure by decreasing the age of the component by r on component z (z = 1,...,Z) in machine n (n = 1,...,N). And if $age_{z,n} \ge MTTF_z \times p_H$, replace this component preventively. It is assumed here that older components are replaced more frequently than younger ones. If the component is not subjected to preventative maintenance, it will continue to function until the system experiences its subsequent breakdown.

The objective function in this regard is

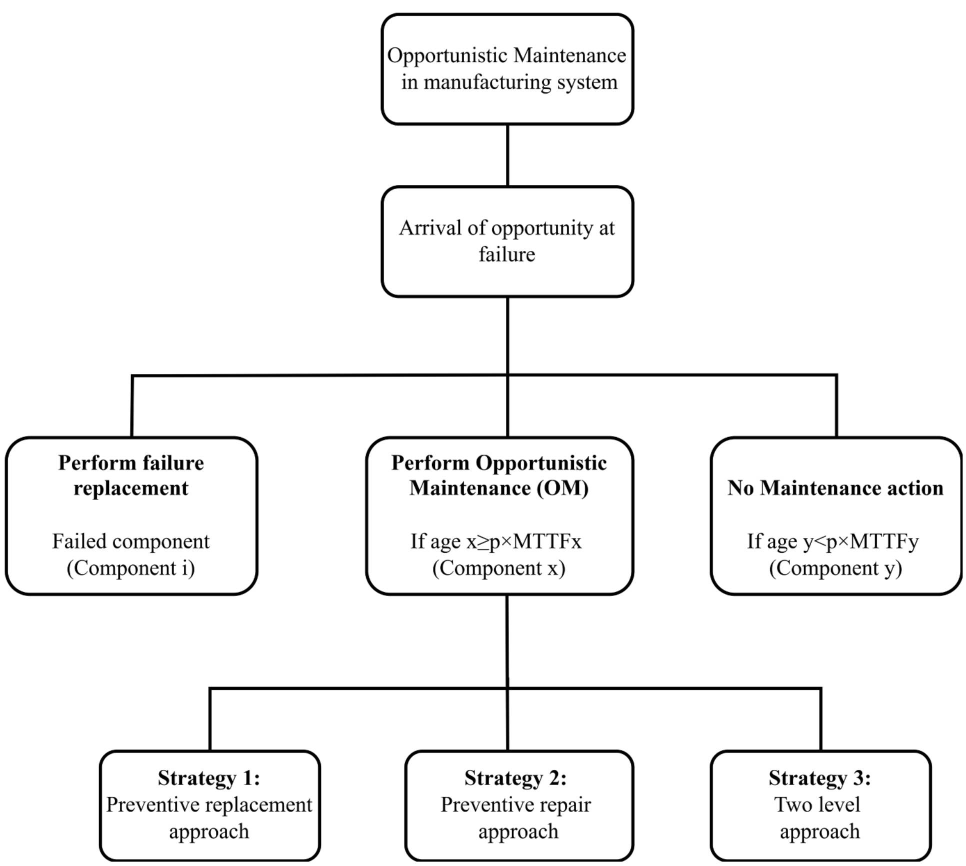

Fig. 1. The idea of opportunistic maintenance.

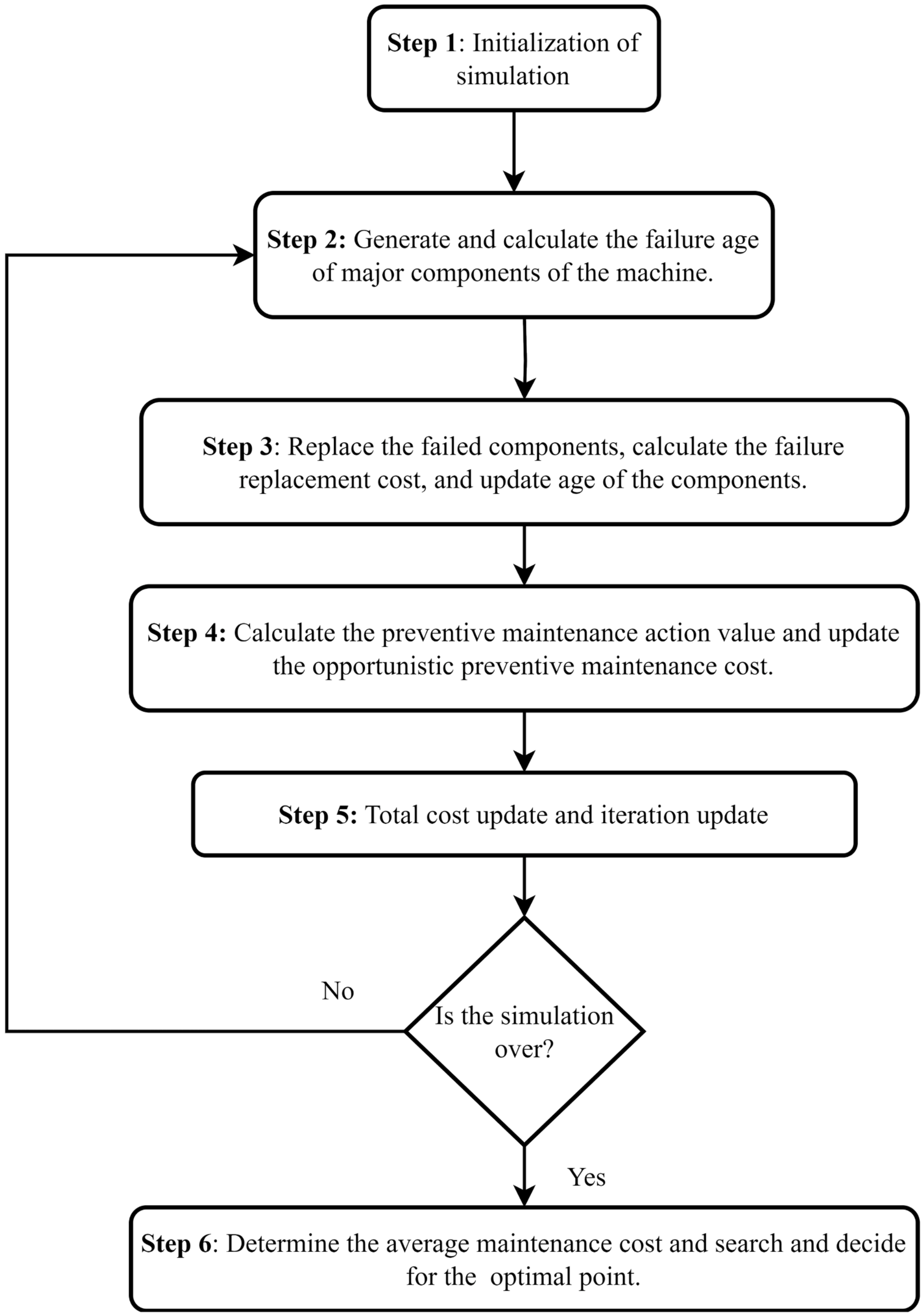

Fig. 2. Flow chart of the simulation process

$$MinC_A(p_L, p_H) = \frac{\left[\begin{array}{l} C_R \times IR_{z,n} + \sum_{n=1}^{N}\left(\sum_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N\right) + \\ C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPM\right) + P_R \times R_L \times \sum_{Z=1}^{Z} MTTPM \end{array}\right]}{t_I \times N} \tag{15}$$

subject to

$0 < p_L < p_H < 1$

where the design parameters are p_L, p_H, correspond to component age percentage at two levels. The goal is to identify optimal age percentage to reduce the overall anticipated maintenance expense per machine per day. In case of preventive replacement and preventive repair, *MTTPRA and MTTPrA* will be used, respectively, in place of *MTTPM* in Eq. (15). The optimal value of *r,* found in strategy 2, will be used in this action to simplify the simulation process.

5. Solution methodologies

Simulation approaches have been developed to determine the average cost for all three models to evaluate the OM model. Assume that failure distributions of components are known, and it is possible to determine the ages of each component at the time of failure. The following steps have been performed for the simulation process, as shown in Fig. 2.

Step 1: Initialize the simulation. Define the total number of iterations, *I*. The total number of machines in the system (*N)* and the number of parts in the machine (*Z)* also have to be specified. Set the limits and values of the design variables p, r, p_L *and* p_H. Define the cost values for each component, encompassing failure replacement cost (C_R), variable replacement cost due to preventive maintenance (C_{PV}), fixed cost due to preventive maintenance (C_{PF}), predetermined labor cost rate (C_{PD}), and supportive cost for preventive maintenance in a machine in the system ($C_{Support}$). The total cost (*TC*), initially set to zero and will be revised throughout the simulation. Define the θ_z and β_z values for the Weibull distribution for each part. Determine *MTTF* from Eq. (16), stated by Ebeling, which is regulated by the Weibull distribution [34].

$$MTTF_z = \theta_z \Gamma\left(1 + \frac{1}{\beta_z}\right) \tag{16}$$

Generate component lifetimes (LF_z) by sampling the Weibull distribution parameters, θ_z and β_z. Initially, set the age values (Age_z) for all components to zero as all are new. Set initially the iteration time interval value $t_i = 0$. After i^{th} iteration, the time interval $t_i = min\ (LF_z)$. At that time, the other active component's age will also be equal to $min\ (LF_z)$ because first failure will be occurred then.

Step 2: Calculating the failure age of the components, *FA*. At the beginning, the failure age of component *z*, FA_z is set to the value of LF_z. This means that initially, the failure age, i.e., real lifetime of the component (FA_z) is assumed to be equal to the generated lifetime (LF_z).

- For failure replacement:

If failure replacement occurs to component *z*, the new failure age of this component after replacement is updated as:

$$FA_z = LF_z \tag{17}$$

For strategy 1, preventive replacement approach:

If preventive replacement is applied to component *z*, the new failure age of this component after maintenance is updated in the same way as Eq. (17).

For strategy 2, preventive repair approach:

If preventive repair is applied to component z, the failure age of this component is updated as described in Section 4.1 as follows:

$$FA_z = r \times LF_z + (1 - r) \times FA_z \tag{18}$$

Eq. (18) is similar to Eq. (2). Here, FA_z in the right side is equal to the old lifetime of the component and component's new lifetime, LF_z will be generated at the time of preventive repair action.

For strategy 3, two-level approach:

Failure age will be updated according to Eqs. (17) and (18) depending on maintenance action. However, age restoration factor *r* is an optimal fixed value obtained in strategy 2.

Step 3: Updating the component age and iteration length, t_I. Firstly, the minimum lifetime will be searched from the list of LF_z. A component with a minimum lifetime will fail first. Then, the failure replacement cost, C_R will be calculated. The indicator value, IR_z indicates failure.

$$TC = TC + C_R \times IR_{z,n} \tag{19}$$

The minimum LF_z will be the updated age for the other components. These ages will be used to check the condition of opportunistic preventive maintenance.

$$Age_z = min(LF_z) \tag{20}$$

$$t_i = t_i + Age_z \tag{21}$$

Age after opportunistic maintenance will be updated as follows:

For strategy 1, preventive replacement approach:

As in preventive replacement, the component will be replaced, and its age after maintenance will be zero.

$$Age_z = 0 \tag{22}$$

The component that will not fulfill the condition will have no preventive maintenance and will wait for the next failure. The lifetime will be updated as follows. It is applicable to all those components that will not undergo preventive maintenance for all strategies.

$$LF = LF_{old} - Age_z \tag{23}$$

For strategy 2, preventive repair approach:

The age of the components and failure age after maintenance will be updated as described in Section 4.1, which is actually Eqs. (1) and (2), respectively.

For strategy 3, two-level approach:

Depending on maintenance action, component age will also be updated according to Eqs. (1) and (22) for preventive repair and preventive replacement approaches.

Step 4: The preventive maintenance action value, *IPz*, will be determined by checking the condition described in section 4.3. This value determines whether preventive maintenance should be performed on a machine component or not. Set IP_z to 1 if the conditions are fulfilled, indicating that preventive maintenance is required for this component. Otherwise, set IP_z to 0 (indicating no preventive maintenance is required).

After finding the preventive maintenance action value, IP_z, the cost of opportunistic preventive maintenance (C_{PM}), labor cost (C_L), and cost of lost production (C_{LP}) have to be determined as described in Section 4.2. These costs are added to the total cost (*TC*), and the overall total cost (*TC*) is found in the next step.

Step 5: Calculating total cost, TC. The total cost due to opportunistic maintenance can be found by summing failure replacement costs and all kind of maintenance costs as described in Section 4.2.5. These total costs will be calculated until Ith iteration occurs, and the updated costs will be as follows.

$$TC_I = \sum_{i=1}^{I} \left[\begin{array}{l} C_R \times IR_{z,n} + \sum_{n=1}^{N} \left(\sum_{z=1}^{Z} C_{P,Z} \times IP_z + C_{Support} \times IS_N \right) \\ + C_{PD} \times \left(MTTCA_z + \sum_{z=1}^{Z} MTTPM \right) + P_R \times R_L \times \sum_{Z=1}^{Z} MTTPM \end{array} \right] \tag{24}$$

After completing opportunistic preventative maintenance on all of the parts in each iteration, set I=i+1. Repeat steps 2 through 5 if the value of *I* is less than the highest number of iterations allowed by the simulation. In our case studies, I=100000 was used.

Step 6: Calculating the average maintenance cost, C_A. Maintenance

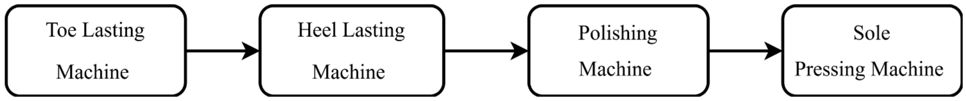

Fig. 3. Series system of machines in a FWLF in Bangladesh.

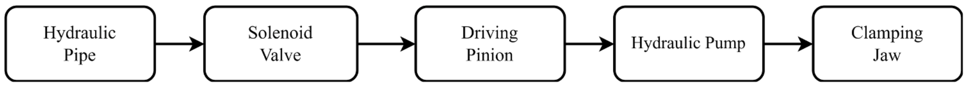

Fig. 4. Series system of components of wheel lathe in a railway industry.

cost per machine per day (C_A) is calculated as follows.

$$C_A = \frac{TC_I}{t_I \times N} \tag{25}$$

In case study I, N=4, and in case study II, N=1. In the case of study I, all similar machines are from the same brand and connected in series. In case study II, all machines are similar of the same brand and connected in parallel. Look for the optimum variables at which the related estimated maintenance cost per machine per day, $C_{A,}$ can be reduced to its lowest possible value. The optimal maintenance techniques are found when the ideal values of the variables p, r, p_L, and p_H have been discovered.

6. Case study

This section provides two different case studies to validate the proposed OM strategies for Bangladeshi manufacturing industries.

6.1. Data source

Case Study I: A Footwear and Leather Industry in Bangladesh

A renowned state-owned footwear and leather factory (FWLF) in Bangladesh has been selected for the first case study. As a developing country, Bangladesh has a huge opportunity to benefit from this sector, as raw leather is cheap here. So, if it is possible to lower the maintenance cost of this sector, it will be more profitable for the country. In this case study, a production line consisting of four distinct machines is considered, which makes a series system, as shown in Fig. 3. Only the major components of each machine are considered to simplify the simulation procedure. There are five (05) similar production lines. Similar machines are from the same brand. Maintenance costs can vary slightly depending on brand variations. But it is very negligible. Historical data from the last three years (2021–2023) was used in the case study.

Case Study II: A railway industry in Bangladesh

A state-owned railway company, which is also the largest railway industry in Bangladesh, has been selected as the second study area. The railway industry mainly manufactures and repairs railway parts. The industry's busiest C&W shop is filled with 10 similar wheel lathe machines from the same brand. Historical data from the last five years (2019–2023) was used in the case study. Maintenance costs vary very slightly for brand variations. It has a very low impact on average maintenance costs. Only five important components named hydraulic pipe, solenoid valve, driving pinion, hydraulic pump, and clamping jaw are considered for the simulation process.

In this case study, all machines are connected in parallel, and the failure of any machine will not affect the production of other machines. Thus, the value of N is one in this case. As failure of any component will stop the whole machine, the components can be considered a series system, as shown in Fig. 4.

6.1.1. Data collection of the case study

The data was collected from a footwear and leather factory (FWLF) and a railway industry in Bangladesh. The Weibull parameters of failure distribution were set based on the historical failure data of the machines with the consultancy of the industry's specialists. The data tables include information regarding the costs of the individual components. The costs include the replacement cost of the failed component (C_R), the variable cost of preventative replacement (C_{PV}), the fixed cost of preventive maintenance (C_{PF}), the predetermined cost rate for a maintenance team (C_{PD}), and the supportive cost for preventive maintenance for each component in a machine in the system ($C_{Support}$). Data on lost revenue due to downtime (R_L), production rate (P_R), and mean time of corrective and opportunistic maintenance action has also been collected to measure the cost of lost production and total labor costs.

6.1.2. Data for case study I

Data for various costs of major components of the machines of a FWLF in Bangladesh are presented in Table 2, Table 3, Table 4, Table 5.

6.1.3. Data for case study II

Data for various costs of major components of the wheel lathe in the railway industry are presented in Table 6.

6.2. Results of applying opportunistic maintenance in the manufacturing industry in Bangladesh

In this part, numerical examples are used to represent the benefit and comparison of the suggested maintenance optimization model incorporating opportunistic maintenance. A Python 3.9 code was written for the simulation procedure and was run on a Windows machine with an AMD Ryzen 7 5700U processor having a frequency of 2.20 GHz and 16GB of RAM. Optimization results are presented graphically, and comparisons among suggested maintenance optimization models are discussed.

6.2.1. Case study I

Strategy 1. With preventive replacement approach

As Fig. 5 shows, the ideal age percentage for a component in strategy

Table 2
Costs and parameters for failure distributions of major components of the Toe Lasting Machine (Tk.).

Machine Part	θ (Day)	β (Day)	C_R	C_{PV}	C_{PF}	C_{PD}	$C_{Support}$	MTTCA (hrs)	MTTPRA (hrs)	MTTPrA (hrs)	P_R (/hr)	R_L
Toe Band	120	2	8000	4000	1000	500	1000	0.5	0.5	0.3	100	150
Pincher	150	2	65000	32500	4000			0.5	0.5	0.16		
Timer	400	3	4000	2000	500			0.2	0.20	0.20		
Wiper Plate	220	3	16000	8000	800			0.5	0.5	0.33		

Table 3
Costs and parameters for failure distributions of major components of the **Heel Lasting** Machine (Tk.).

Machine Part	θ (Day)	β (Day)	C_R	C_{PV}	C_{PF}	C_{PD}	$C_{Support}$	MTTCA (hrs)	MTTPRA (hrs)	MTTPrA (hrs)	P_R (/hr)	R_L
Wiper Plate	220	2	8000	4000	1000	500	1000	0.5	0.5	0.20	100	150
Heel Band	220	2	3500	1750	500			0.25	0.25	0.33		
Relay	220	3	300	150	100			0.2	0.2	0.33		
Hydraulic Solenoid Bulb	400	3	6000	3000	1000			1	1	0.16		

Table 4
Costs and parameters for failure distributions of major components of the **Polishing** Machine (Tk.).

Machine Part	θ (Day)	β (Day)	C_R	C_{PV}	C_{PF}	C_{PD}	$C_{Support}$	MTTCA (hrs)	MTTPRA (hrs)	MTTPrA (hrs)	P_R (/hr)	R_L
Electrical Motor	220	2	16000	8000	1000	500	1000	1	1	0.5	100	150
Brush	52	3	1050	525	200			0.25	0.25	0.16		
Switch	220	2	1200	600	200			0.33	0.33	0.20		
Magnetic Conductor	220	3	2000	1000	400			0.33	0.33	0.33		

Table 5
Costs and parameters for failure distributions of major components of the **Sole Pressing** Machine (Tk.).

Machine Part	θ (Day)	β (Day)	C_R	C_{PV}	C_{PF}	C_{PD}	$C_{Support}$	MTTCA (hrs)	MTTPRA (hrs)	MTTPrA (hrs)	P_R (/hr)	R_L
Rubber Pad	66	3	1300	750	200	500	1000	0.5	0.5	0.20	100	150
Sensor	85	3	1200	600	200			0.33	0.33	0.33		
Selector Switch	130	3	650	325	100			0.5	0.5	0.33		
Air Regulator	400	2	5000	2500	500			1	1	0.2		
Limit Switch	220	2	600	300	50			0.33	0.33	0.33		

Table 6
Costs and parameters for failure distributions of major components of a wheel lathe in a railway industry in Bangladesh (Tk.).

Machine Part	θ (Day)	β (Day)	C_R	C_{PV}	C_{PF}	C_{PD}	$C_{Support}$	MTTCA (hrs)	MTTPRA (hrs)	MTTPrA (hrs)	P_R (/hr)	R_L
Hydraulic Pipe	400	2	10000	5000	1000		2000	1	1	0.5	0.625	30000
Solenoid Valve	280	3	10000	5000	1000			1	1	0.5		
Driving Pinion	950	3	10000	5000	1000	1000		2	2	1		
Hydraulic Pump	1500	2	137000	68500	5000			4	4	2		
Clamping Jaw	180	3	30000	15000	1000			1	1	0.5		

1 is 30 %, and the minimum cost is Tk. 411.4 per day per machine. So, according to this strategy, preventive replacement will be performed at 30 % and above of the age of the components. It is noted that OM will not be beneficial if the pre-mature equipment replacement cost is significantly high. But, in this study, the replacement costs of various machine parts are relatively low, which is usual for such kinds of manufacturing industries. Rather, the best strategy is the two-level maintenance approach for both of the case studies, where preventive replacements have been done from 110 % and 100 % or above of the component's age for case studies I and II, respectively, which will be discussed in the upcoming sections.

Strategy 2. With **a** preventive repair approach

As represented in Figs. 6, 7, and 8, the optimal point for maintenance entails conducting maintenance with a preventive repair approach on the part when its age becomes p=20 % of its lifetime, while the age restoration factor, r = 35 %. So, according to this strategy, preventive repair will be performed from 20 % and above of the components' lifespan or age. It is noted that opportunistic preventive repair at the early ages of the components is not impractical. For example, preventive repairs are usually done after buying a machine to increase the lifetime of the components regularly or at an opportunity.

Using a preventive repair approach, the study finds the minimum daily maintenance cost to be Tk. 376 per machine, according to these graphs.

Strategy 3. With two-level approach

Figs. 9 and 10 demonstrate that implementing the two-level approach results in a minimal cost of Tk. 366.5 per machine per day. This is the most cost-effective strategy among the three OM strategies.

Given the requirement $p_H > p_L$ in this proposed policy, it is essential to highlight that the costs associated with an area where $p_H < p_L$ in Figs. 9 and 10 are set to zero and need not require any consideration in this study. The age restoration factor of 35 % is used in this strategy as a fixed value, which was found to be the optimal value in strategy 2. The proposed two-level approach in the footwear and leather industry implements preventative repair for components aged from 20 % to 110 % of their lifespan, replacing them if they are aged from 110 % and above.

6.2.2. *Case study II*

Strategy 1. With a preventive replacement approach

Fig. 11 illustrates that the optimal age percentage for a component is 40 %, and the minimal cost is Tk. 610.1 per day per machine for preventive replacement approach. So, according to this strategy, preventive replacement will be performed from 40 % and above of the lifespan or age of the components.

Strategy 2. With a preventive repair approach

As depicted in Figs. 12, 13, and 14, optimal maintenance occurs at p=20 % of the part's lifespan with an age restoration factor of r=55 % in the preventive repair approach. So, according to this strategy, preventive repair will be performed from 20 % and above of the components' lifespan.

Using a preventive repair approach, the study finds the minimum daily maintenance cost to be Tk. 572.8 per machine as illustrated in the plots.

Strategy 3. With two-level approach

As illustrated in Figs. 15, 16 and 17 that employing the two-level approach achieves a minimal daily cost of Tk. 569.6 per machine, which is the minimum among the three strategies.

In this proposed policy, as $p_H > p_L$ is the optimization constraint, areas with $p_H < p_L$ in Figs. 15–17 are set to null. A fixed age restoration factor of 55 % from strategy 2 is used here. The two-level approach

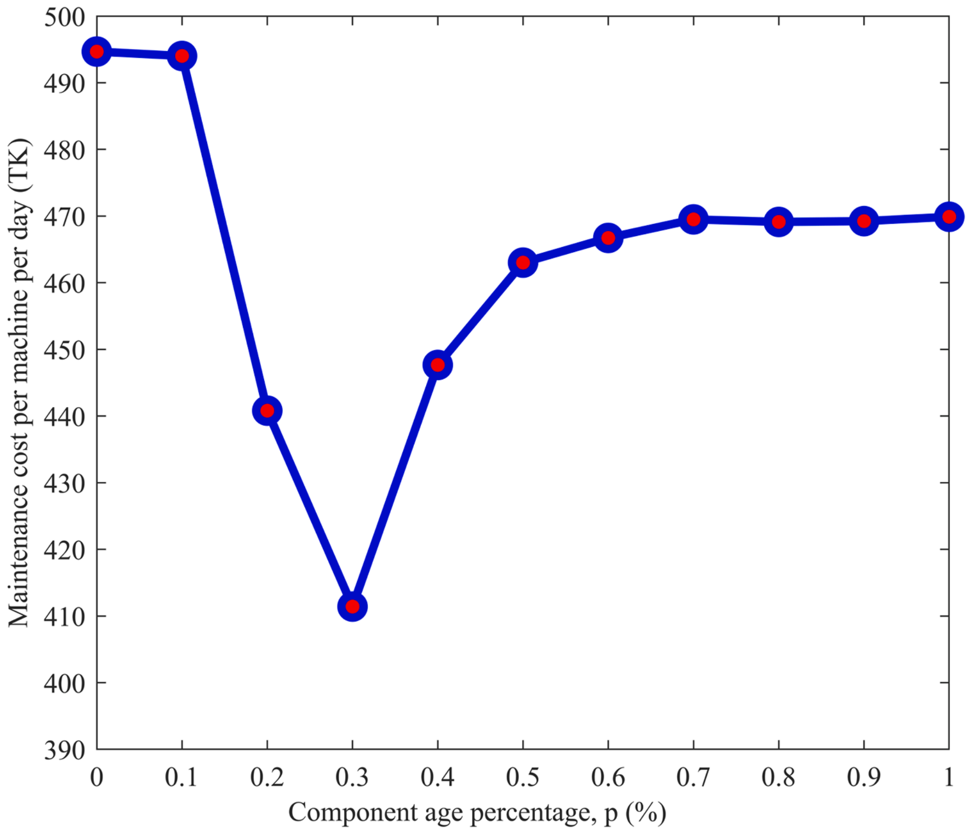

Fig. 5. Maintenance cost versus component age threshold value, p (%).

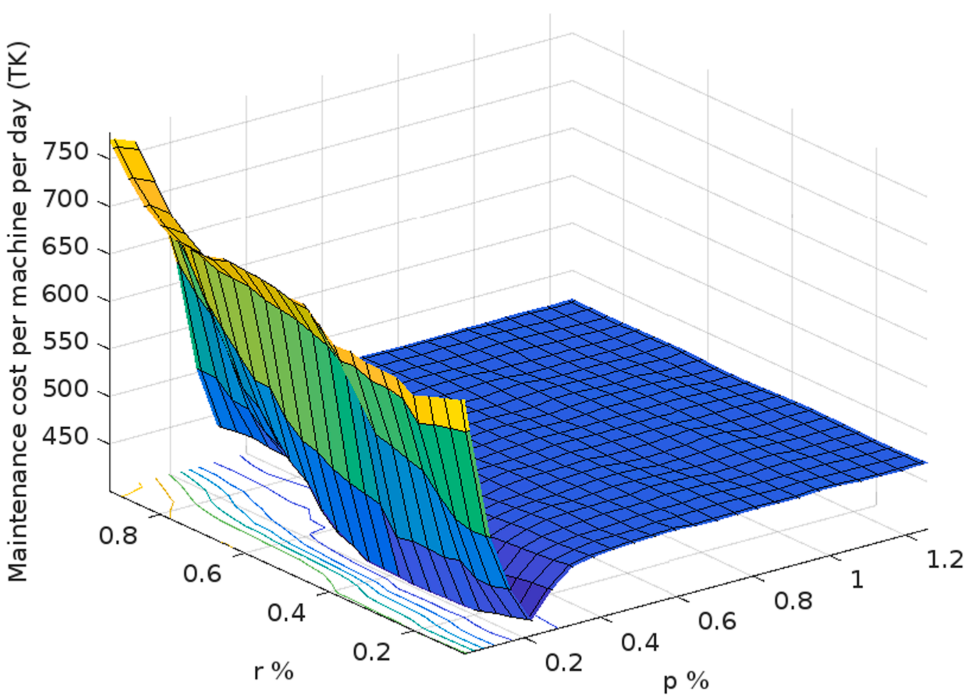

Fig. 6. Maintenance cost versus component age percentage (p) and age restoration factor (r).

employs preventive repair for components aged between 30 % and 100 % of their lifespan, with replacement from and beyond 100 %.

6.3. *Comparative study*

The proposed approaches are also examined in comparison to the currently followed corrective maintenance policy, which involves replacing a component only when it fails.

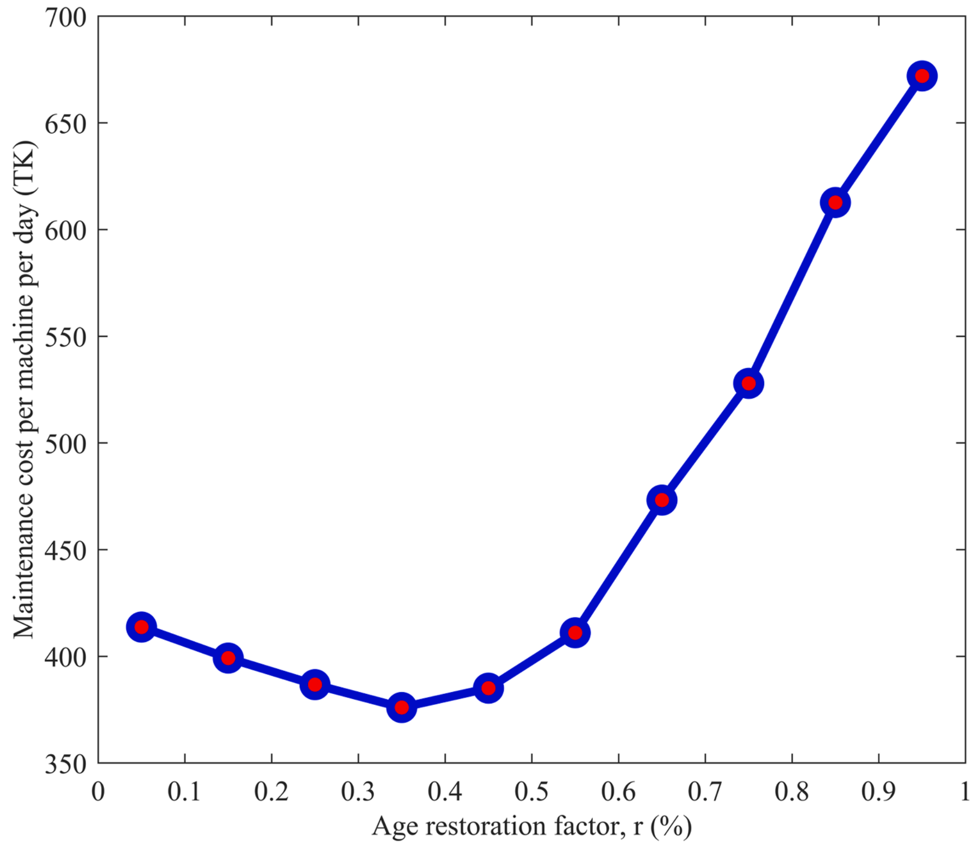

Fig. 7. Cost versus age restoration factor (r) plot at $p = 20$ %.

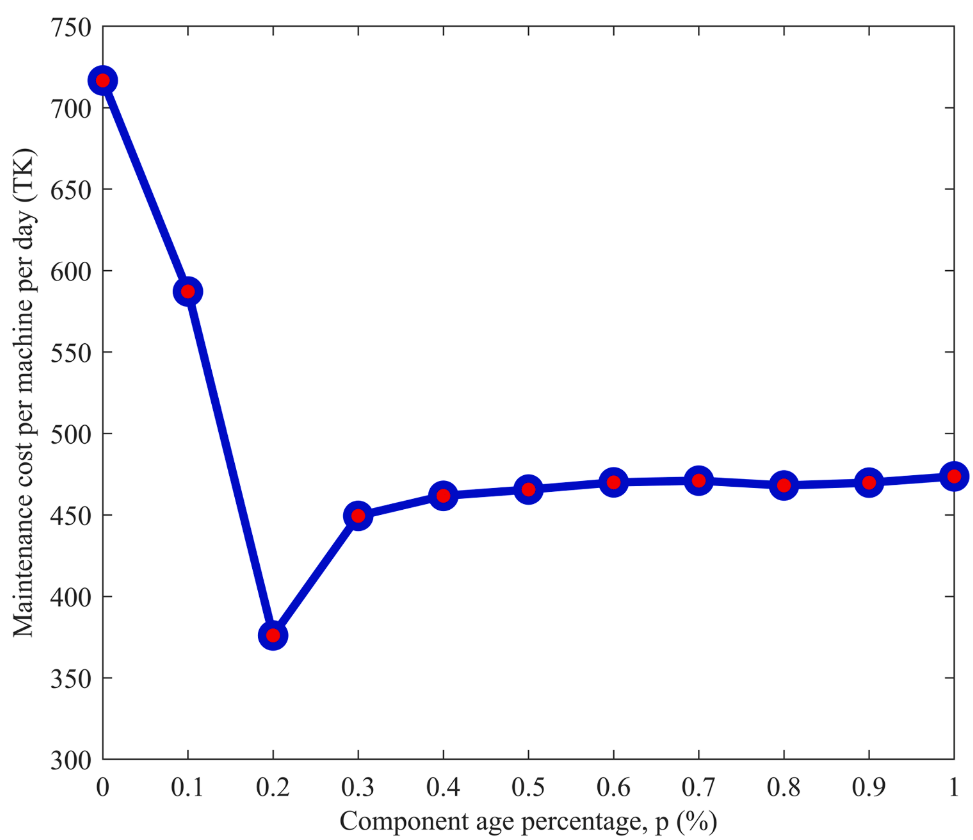

Fig. 8. Maintenance cost versus component age percentage (p) plot at $r = 35$ %.

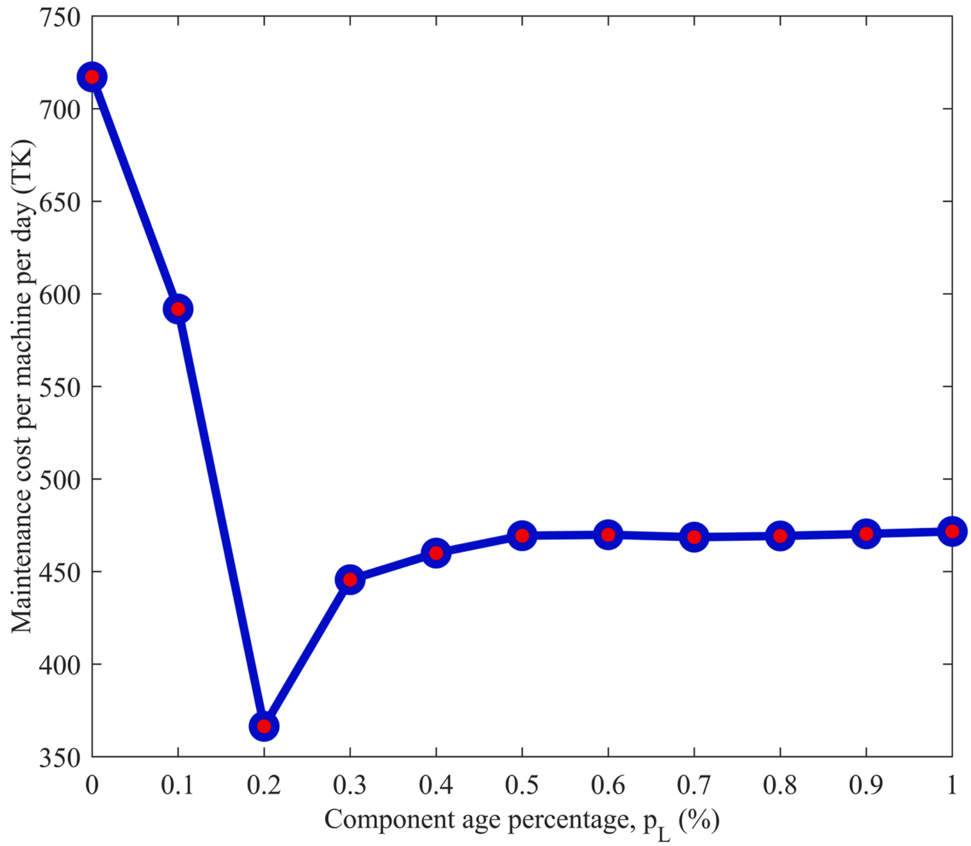

Fig. 9. Maintenance cost versus component age percentage, p_L (p_H = 110 %).

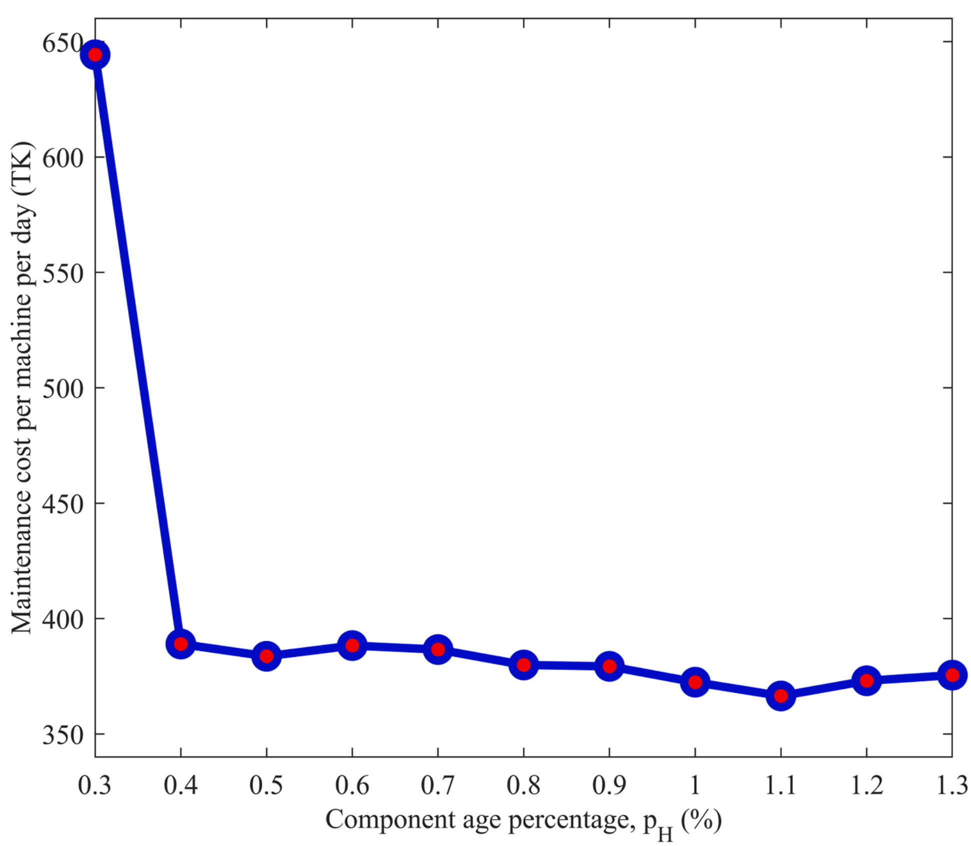

Fig. 10. Maintenance cost versus component age percentage, p_H (p_L=20 %).

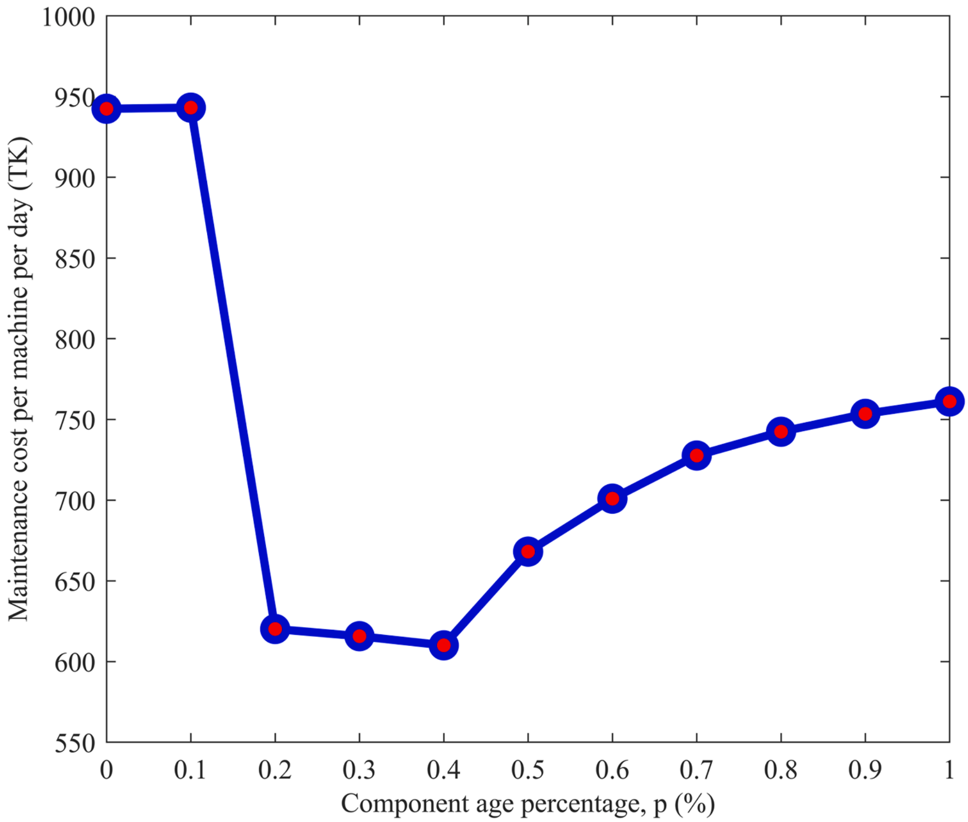

Fig. 11. Maintenance cost versus component age threshold value, p (%).

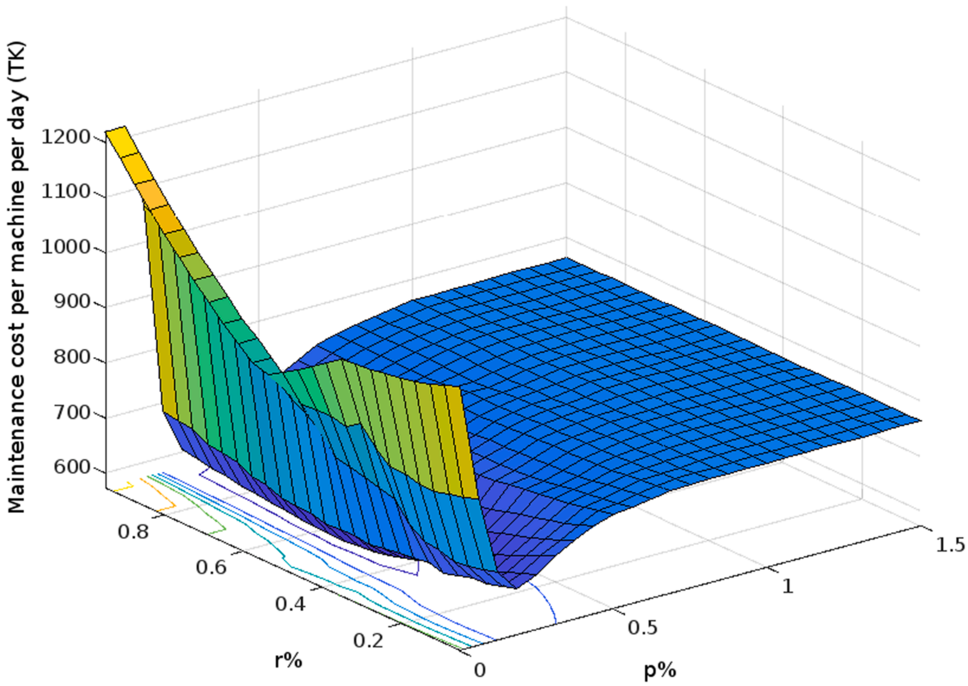

Fig. 12. Maintenance cost versus component age percentage (p) and age restoration factor (r).

6.3.1. *Cost of corrective maintenance*

The overall mean cost of implementing corrective action only for both case studies is calculated using the data from Tables 2 through 6. Employing corrective maintenance only, the maintenance cost per machine per day was found to be Tk. 440.92 and Tk. 733.97 for case studies I and II, respectively.

6.3.2. *Comparison results*

Table 7 summarizes the results and compares them with the industries' existing maintenance approaches (corrective maintenance).

In Section 6.2.1, the optimization findings demonstrate that the proposed techniques yield an ideal average cost of Tk. 411.4 per day, Tk. 376 per day, and Tk. 366.5 per day for preventive replacement,

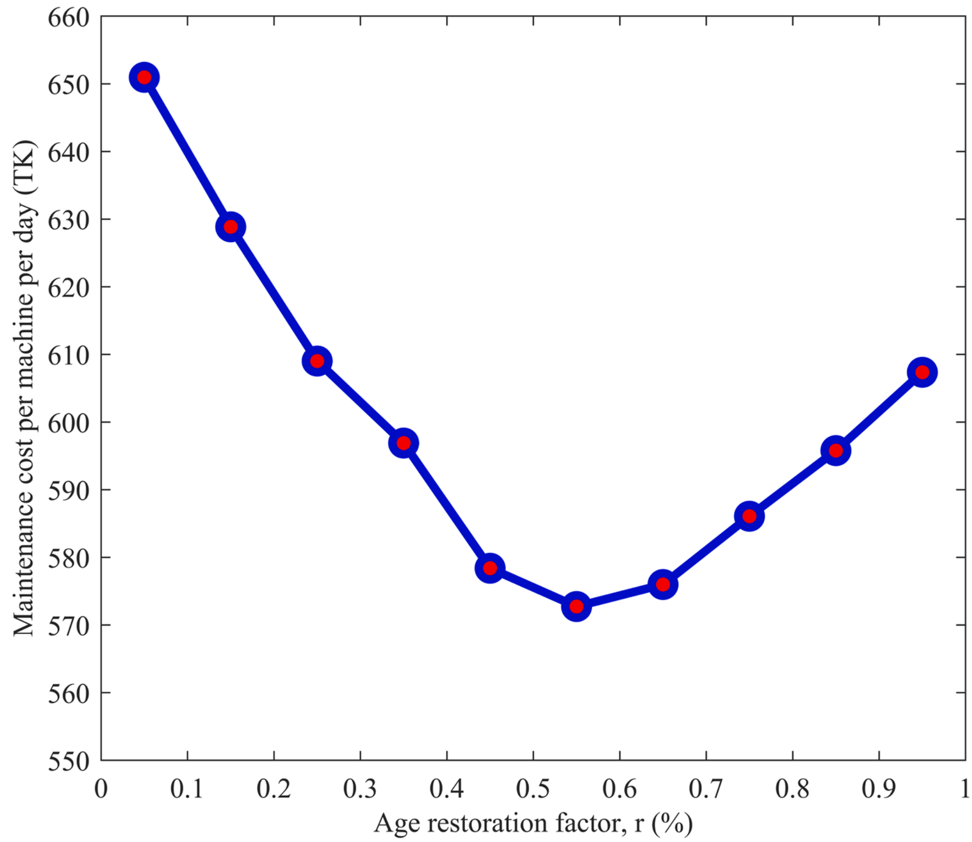

Fig. 13. Cost versus age restoration factor (r) plot at p=20 %.

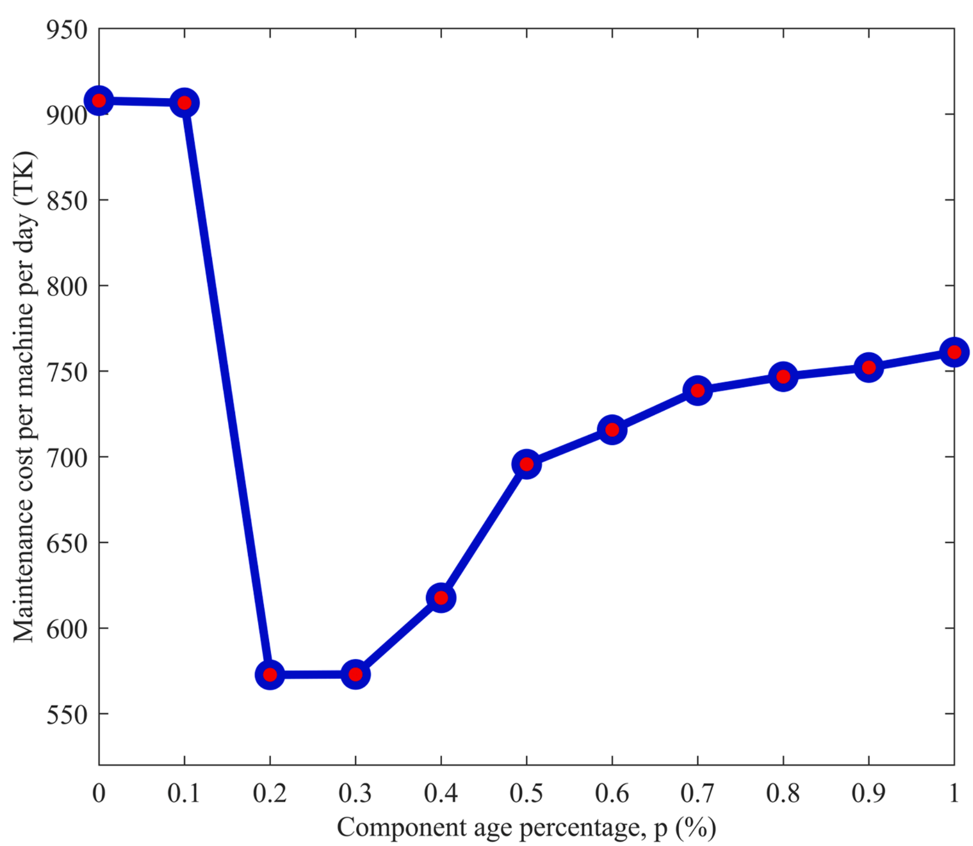

Fig. 14. Maintenance cost versus component age percentage (p) plot at r=55 %.

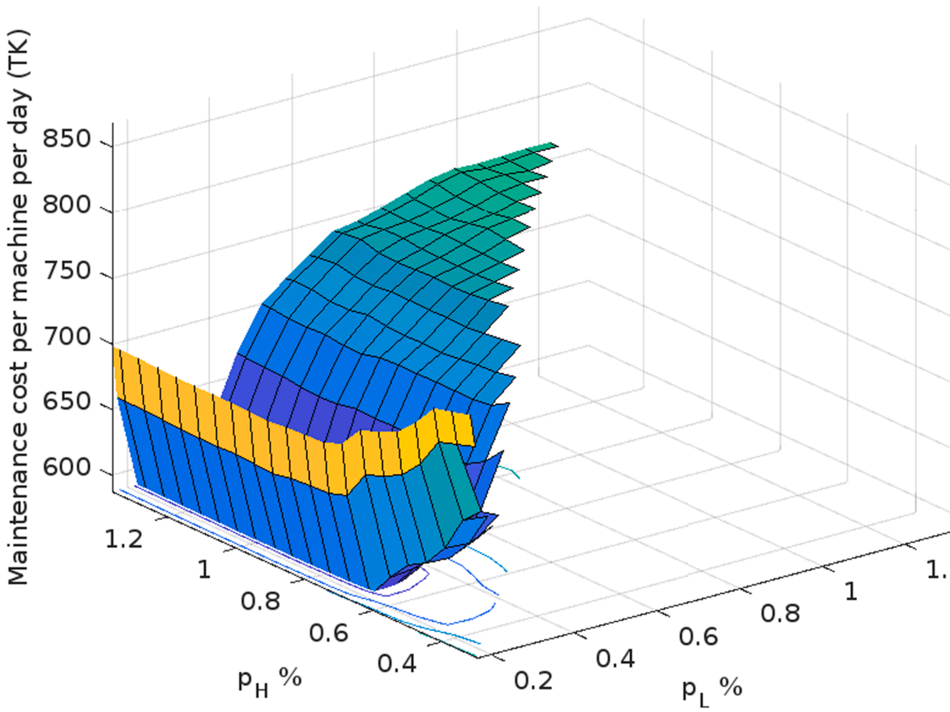

Fig. 15. Maintenance cost versus component age percentage, p_L and p_H.

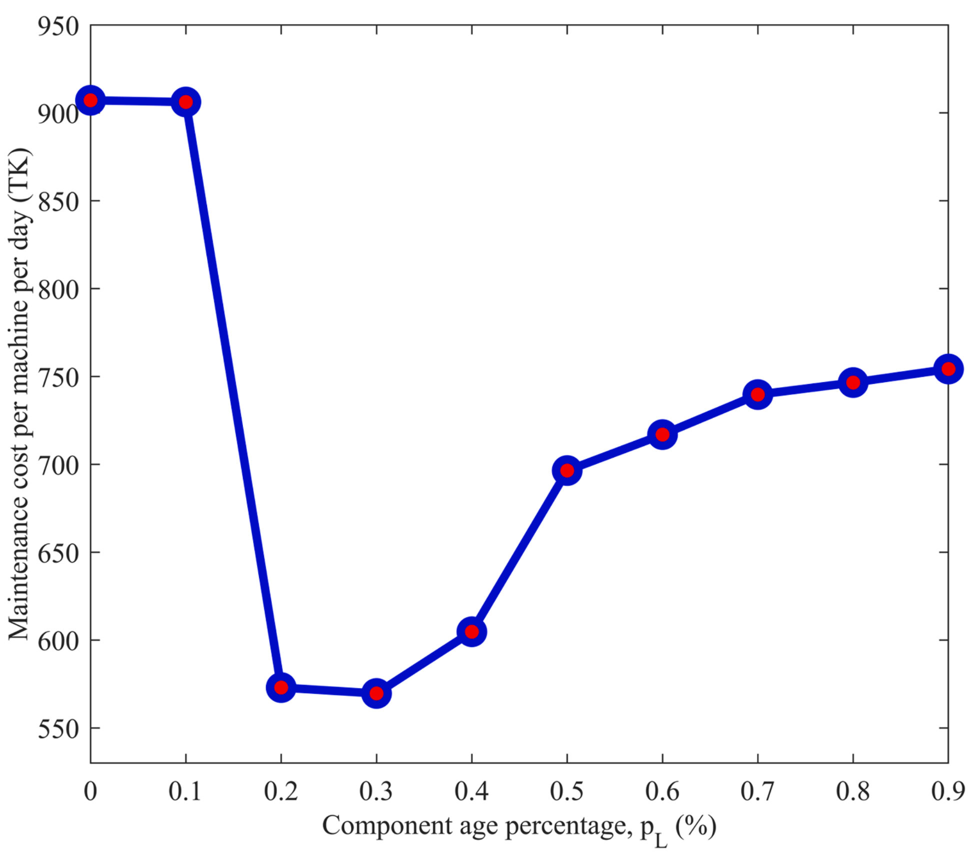

Fig. 16. Maintenance cost versus component age percentage, p_L (p_H=100 %)

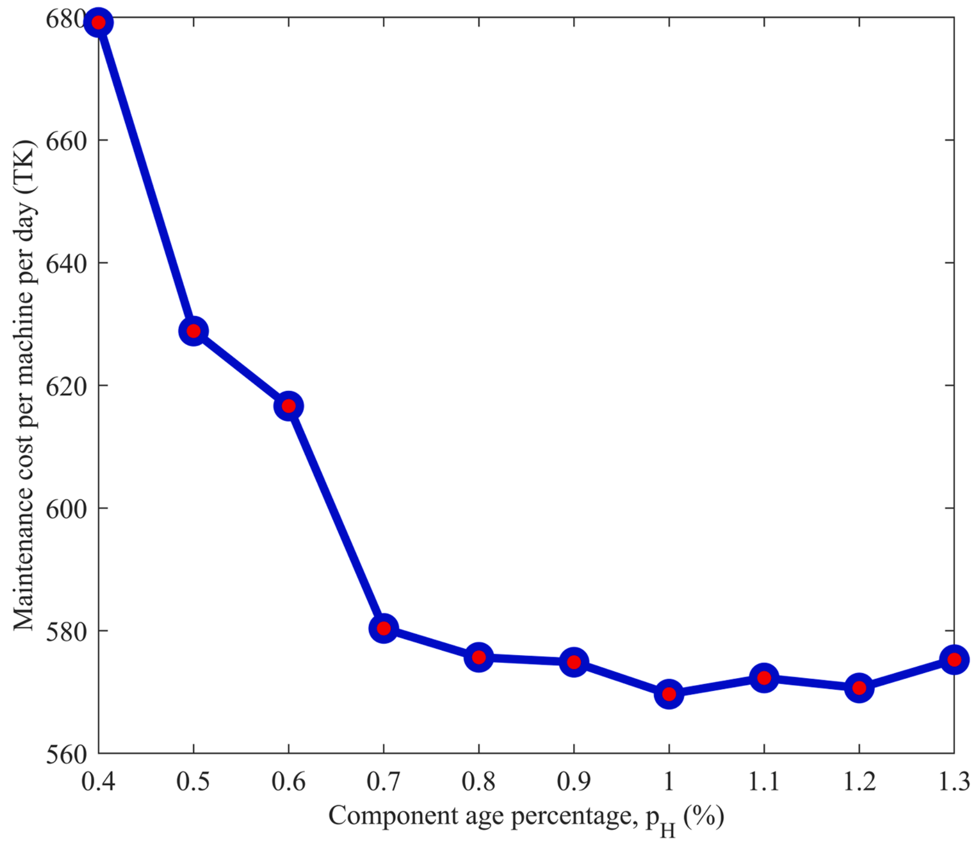

Fig. 17. Maintenance cost versus component age percentage, p_H (p_L=30 %)

Table 7
Comparison of optimal maintenance costs with corrective maintenance strategy.

Proposed opportunistic Maintenance strategy	Case study I: A FWLF in BD		Case study II: Railway industry of BD	
	Optimal cost	Cost savings	Optimal cost	Cost savings
Preventive replacement approach	Tk. 411.4	6.7 %	Tk.610.1	16.9 %
Preventive repair approach	Tk. 376	14.7 %	Tk. 572.8	21.9 %
Two level approach	Tk. 366.5	16.9 %	Tk. 569.6	22.4 %

preventive repair, and two-level approach, respectively, for case study I. The two-level approach seems the best, showing 16.9 % cost savings compared to the current corrective maintenance approach. However, the preventive repair approach, which is simpler than two-level action, also showed a good result, with 14.7 % cost savings. In contrast, the preventive replacement approach indicates only 6.7 % cost savings compared to corrective action.

However, Case Study II showed better performance than Case Study I. The optimization results in Section 6.2.2 show that the proposed strategies achieve an optimal average cost of Tk. 610.1 per day, Tk. 572.8 per day, and Tk. 569.6 per day for preventative replacement, preventive repair, and the two-level approach, respectively, in case study II. The two-level technique appears superior, demonstrating a 22.4 % reduction in costs compared to the existing corrective maintenance approach. Nevertheless, implementing preventive repair, which is less complex than two-level action, also yielded a favorable outcome with a 21.9 % cost reduction. However, compared to corrective maintenance, the preventive replacement approach demonstrates a cost savings of 16.9 %.

The reason for the better performance of Case Study II is the long lifetime of its components. The components of the leather industry experience more frequent breakdowns compared to the railway industry. Thus, opportunistic preventive maintenance reduced less costs in the leather industry than in the railway industry. In spite of that, both of the case studies showed significant cost reductions per machine per day, which will be a very large amount for the whole industry annually. Moreover, OM strategies were applied only for major components. If it is possible to implement it for all components, more cost savings will be possible.

So, the evaluation results of the model for both of the case studies show significant cost savings in compared with corrective maintenance (CM). Thus, the proposed OM strategies will be beneficial for the manufacturing industries, especially in developing countries like Bangladesh.

6.4. Sensitivity analysis considering the effect of varying C_{PV} on the average maintenance cost

This section conducts a sensitivity analysis to clearly identify the impact of the OM strategies on the average maintenance cost and to achieve more validated evaluation results for the proposed OM strategies.

- **Case Study I:**

As shown in Fig. 18, when the cost of preventive replacement (C_{PV}) is between 50 % and 75 % of C_R (cost of replacement), strategy 3, i.e., the two-level maintenance approach, is the best of all three strategies. But when the C_{PV} decreases to 25 % of C_R, strategy 1, i.e., preventive replacement, has the lowest maintenance cost. Although such a level of decreasing of C_{PV} is not possible, this is happening because preventive replacement is advantageous for low replacement costs as well as the shorter lifetime of the components, as is happening in case study I.

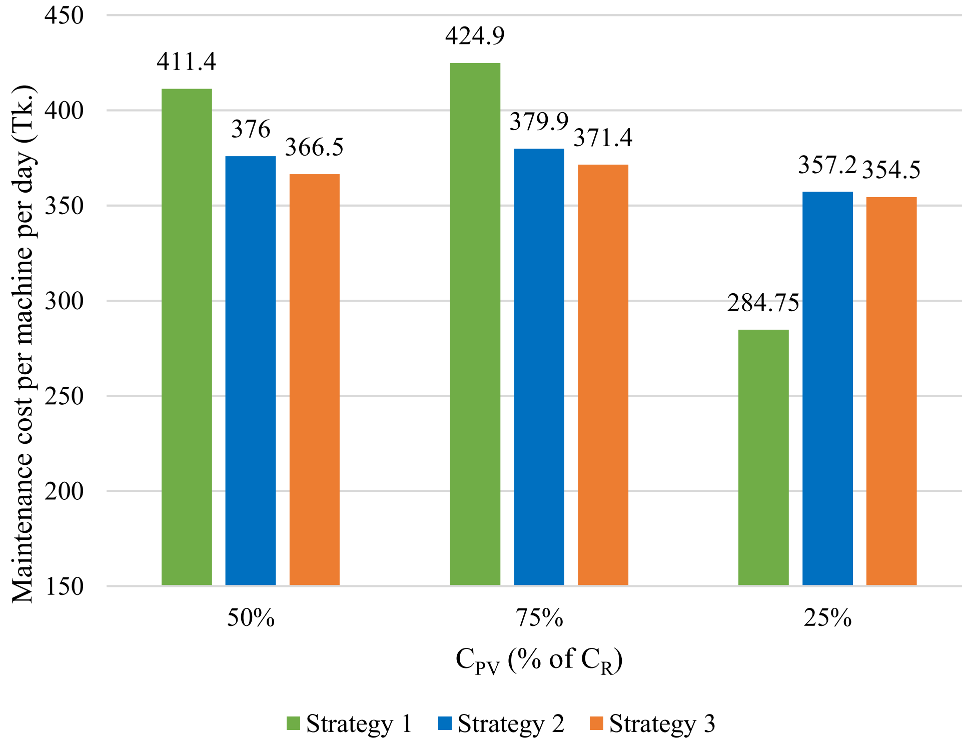

Fig. 18. Sensitivity analysis of maintenance costs for case study I with varying C_{PV}.

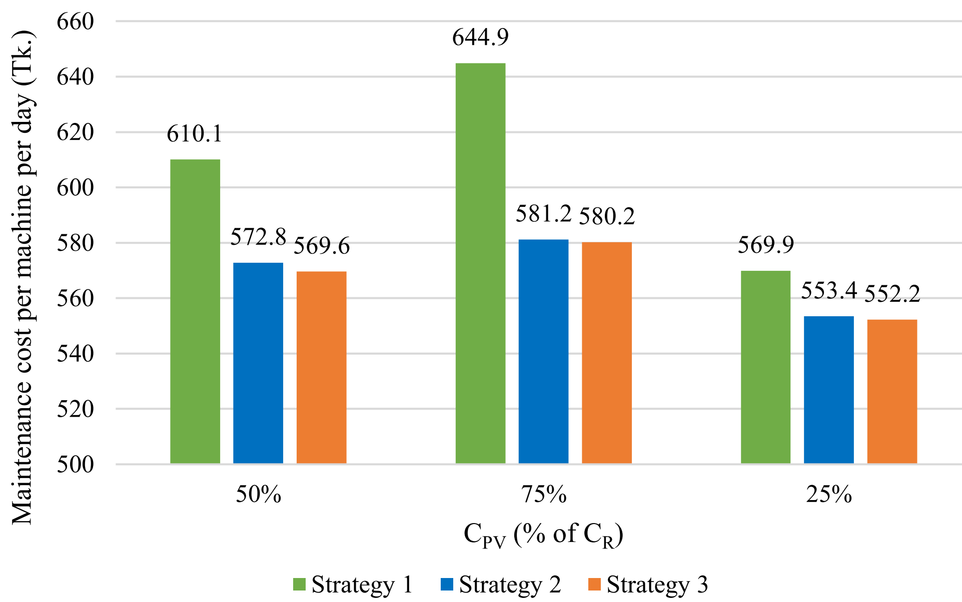

Fig. 19. Sensitivity analysis of maintenance costs for case study II with varying C_{PV}.

- **Case Stuy II:**

As shown in Fig. 19, strategy 3, the two-level maintenance approach remains the best strategy at all varying C_{PV}. Here, strategy 2, i.e., preventive repair, is very close and next better OM strategy. This is occurring due to the high replacement costs of the wheel lathes' components, which is a practical consideration.

7. Conclusions and future work

In this empirical study, the impact of opportunistic maintenance (OM) optimization has been analyzed for manufacturing-based industries in developing countries like Bangladesh. For this purpose, three OM strategies have been proposed for multi-unit manufacturing systems, where preventative maintenance is viewed as replacement, repair, and a two-level approach. The significance of the proposed OM strategies has been assessed by applying those strategies to two important industrial sectors: leather and railways in Bangladesh. The costs associated with the suggested strategies are evaluated using simulation optimization (SO) techniques. Graphical results illustrate the significance of OM strategies in lowering the average cost of maintenance. The proposed two-level maintenance approach is the best option among the three proposed OM strategies for both case studies, which show cost savings of 16.9 % and 22.4 % compared with the current CM approach for the footwear and railway industries, respectively. However, these approaches are universal and can be implemented at any opportunity due to failures or stoppages of the machines because of any other reasons. Also, the main things that matter to the industry when making maintenance decisions are the cost and availability of the system. This study presents a simulation optimization approach that will help decision makers to implement the best strategy for maintenance at the right time. It is anticipated that the leather and railway industries as well as other manufacturing industries will benefit from the proposed OM strategies.

A multi-component multi-unit manufacturing system has many important components, but to avoid complexity of the simulation process, the study only focused on the major components of each unit or machines. For future research, implementing OM strategies for almost all significant components can bring more cost savings. The research adopted a simulation optimization technique to evaluate the OM strategies. So, future research can be done via analytical techniques to assess costs and expenses more precisely. It would also be interesting to consider alternative maintenance policies with distinct reliability implications and investigate the impact of those policies on cost, availability, or any other decision parameters.

CRediT authorship contribution statement

Md. Ariful Alam: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Md. Rafiquzzaman:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Md. Hasan Ali:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis. **Gazi Faysal Jubayer:** Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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