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Production Machinery Maintenance Cost Optimization: A Review

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Abstract: This paper aims to review the literatures on production machinery maintenance in order to reveal the potential cost components and information on cost optimization of maintenance. We start with reviewing contemporary and past literatures on production machinery maintenance. We studied more than 100 scientific publication including journal papers, books, case studies in the relevant field. Study plan focused on the concepts, cost elements, and strategies of maintenance. A special attention was given to collect mathematical models for estimating maintenance cost with evaluation of the challenges and opportunities. This study developed a model for evaluating maintenance cost for achieving economic sustainability. Findings reveal the components of maintenance cost include maintenance management, spare parts related cost and skill level of maintenance personnel are indeed significant ($p<0.05$) for achieving cost optimization. The findings of literature also indicate in the past, major emphasis was given on maintenance management, and less emphasis was given to maintenance cost issue and cost optimization. In this aspect, this study is designed to fill this gap. Model developed from this study would contribute to industrial policy makers to formulate strategies in cost optimization in the aspect of machinery maintenance. The findings of this study would serve as foundation for future study on maintenance cost optimization to contribute to achieve economic sustainability. The core value of this paper is providing the important findings on significant contribution of maintenance cost elements and cost optimization which previously did not get the right attention.

Keywords: Cost Optimization, Cost Component, Machinery Maintenance, Production Performance, Manufacturing Sustainability

I. INTRODUCTION

This paper presents a literature review on machinery maintenance management and cost associated with machinery maintenance; indeed, we attempt to identify the potential significant cost factors. This study aims to develop a framework by using potential cost factors to be applied in formulating maintenance strategy. In particular, our interest is to make the outcomes of this study useful for the technical staffs involved in day-to-day machinery maintenance activities. We begin with reviewing the productions, operations management and maintenance research papers for collecting data on relevant issues including opportunities and challenges of maintenance management.

The machinery maintenance history is quite old; but the age of maintenance management theory is contemporary, and maintenance cost concept is developed recently to meet competitive challenges. The maintenance cost optimization has recently been adapted by production economists and operations management specialists in order to identify non-value-added production cost. However, this work is not the first attempt to reveal the potential cost components of maintenance. Bamber et al. (1999) stated that in the past, maintenance was only considered as supportive and non-productive activities, and adding little value to the industrial manufacturing business. Patrik (1997) described that maintenance is an important issue since firms tend to downsize organizational structures, optimizing inventory levels, and changing toward flexible and time-based manufacturing systems. A number of researchers and practitioners have acknowledged the importance of maintenance as a major contributory factor to the production performance (Maggard and Rhyne, 1992; Pehanich, 1995). Basically, studies focused on the significance of maintenance. However, EUREKA (1993) reveals a lack in the relationship between maintenance and quality improvement strategy. Kutucuoglu et al. (2001) have proposed a maintenance performance measurement framework for two-way communications between the organizations; and they suggested for top-down and bottom-up communication for ensuring higher performance in maintenance activities. Atkinson et al. (1997) and Nakajima (1988) have introduced maintenance performance measurement concepts. Nakajima proposed the Overall Equipment Effectiveness (OEE) tool for measuring maintenance performance. It is evident that all these studies have focused on maintenance management and ignored the cost optimization.

Nowadays, maintenance performance appears as a significant factor to production and operations managers of manufacturing firms. Since few decades, manufacturing industry has experienced drastic changes in management, technologies, customer demands, suppliers, and competitive behaviours (Ahuja *et al.*, 2006). In the perspective of globalization, the architecture of manufacturing performance reshaped in line with economic efficiency and cost effectiveness of product (Yamashina, 1995). However, cost optimization in maintenance has always being overlooked (Wireman, 1990). Based on the above statement, it can be summarized that previously right attention was not given to cost optimization in maintenance; rather it focused on maintenance management. The fact is that, adding any expenditure in the production process, it appears as an added cost to the finished products and ultimately it contributes to reduce competitiveness. It means, manufacturing firms must pay attention to cost optimization process for sustaining in the manufacturing business. It demands an in-depth study to develop a cost optimization model; and this study attempts to get this challenge.

The review findings start to present by explaining the maintenance strategy concepts, costs, and its optimization. The paper is divided into four main sections. In the next section, we present the existing definitions of maintenance, cost concept, and cost optimization model. Section three presents the review findings. Finally, section four contains closing comments and recommendations for future study.

II. LITERATURE REVIEW

A) Concept of Maintenance

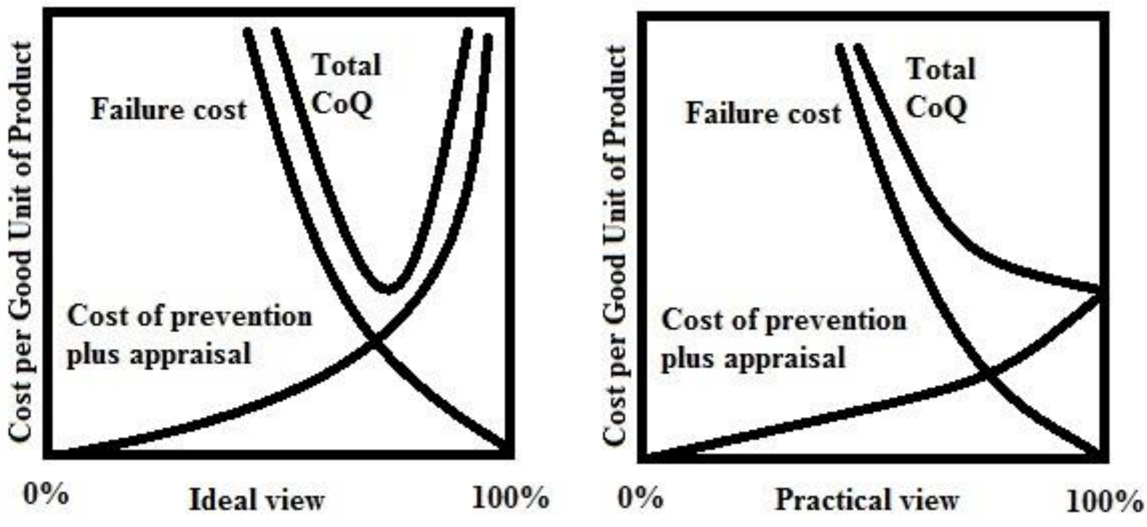
In a manufacturing plant, mainly two types of maintenance strategies are being used namely planned and unplanned. These strategies are also known as proactive and reactive maintenance respectively. Proactive maintenance activity is planned by manufacturing maintenance department; which is developed based on schedules and conditions (Bigdeli and Safi, 2005). But, reactive maintenance is carried out when a machine fails to operate.

B) Concept of Maintenance Cost

The maintenance cost is the money usually spent to repair the machinery for smooth running. The cost components of maintenance are the replaced parts, consumables, salaried labour, wage-based labour, site maintenance activities, and equipment (Poore and Walford, 2008). The cost is also associated with options such as extreme weather operation and condition monitoring of machinery. Alsyouf (2004) mentioned that the machinery maintenance costs are negatively associated with machinery quality. Besides, Blanchard (1986) and Husband (1986) argued that the best way of reducing machinery maintenance cost is to pay attention for improving design and manufacturing quality. Maintenance cost optimization is an important factor for achieving higher machinery operating performance.

C) Concept of Maintenance Cost Optimization

The maintenance is evolving rapidly as major contributors to the performance and profitability of manufacturing systems (Bill and David, 1992). It is estimated that maintenance is representing about 10%-40% of production costs (Baldwin, 1990). Khalil et al. (2009) have developed an integrated cost optimization model for industrial machinery maintenance based on the balance between preventive and corrective maintenance costs; this model contributed to improve operational reliability and failure rate of machinery. Lofsten (1999) has built a model to optimize preventive maintenance cost. However, maintenance quality and its cost are inversely related (Goulden and Rawlins, 1995) which are presented in Figure 1 below.



(a) (b)

Figure 1: Ideal and practical cost optimization

D) Basic Component of Maintenance

i. Unplanned Maintenance

The reactive maintenance is performed after an occurrence of machinery failure; usually, no maintenance action is taken before the failure. This type of maintenance is being implemented with the following conditions:

- (i) Failure is unpredictable
- (ii) Repair cost is lower than other types of maintenance
- (iii) Maintenance of the component is not getting priority

However, there are disadvantages in this maintenance strategy. For instance the reactive maintenance cost, failure of one component will lead to another; thus increases the replacement cost. Unplanned maintenance strategy is also contributing to decrease the availability of machinery in production.

ii. Emergency Maintenance

The emergency maintenance is carried out immediately after the breakdown of machineries in order to restore its operations. This type of maintenance is usually applied to critical machineries such as power generators, explosive gas tanks, and cooling systems in nuclear power plant. Failure of performing emergency maintenance usually leads to catastrophic disaster. For example, Japan nuclear crisis in 2011 is caused by failure of power supply to the cooling system. In that case, emergency maintenance failed to restore the power supply, which contributed to the meltdown of core parts of the plant (Medicine and Global Survival, 2011). This case reveals the value of emergency maintenance.

iii. Breakdown Maintenance

The breakdown maintenance is the oldest method of maintenance in the world. (Geert and Liliane, 2002); and it is only being performed when a breakdown occurs. More particularly, breakdown maintenance activities are those works associated with the repair services of infrastructure, building, plant machineries, and equipment when it fails to operate (Government of South Australia, n.d.). The philosophy "run it till it breaks" is the base of this type of maintenance; and no actions or efforts will be taken to maintain.

Breakdown maintenance is still the predominant type of maintenance in many countries including the United States. (Sullivan *et al.*, 2010). It is to be said as the most expensive management method (Bigdeli and Safi, 2005). It allows component to fail but to be repaired as early as possible as the failure may cause serious collateral damage to the facility, personnel, environment, and production. It deems to be the most suitable maintenance for small factories where down times are less critical to production performance and the repair costs are less compared to other types. This type of maintenance contributes to reduce cost and to improve production performance.

E) Planned Maintenance or Proactive Maintenance

The planned maintenance or proactive maintenance is a scheduled activity in order to eliminate the sources of failure and to minimize machinery downtime. This type of maintenance includes systematic resource management through planning, scheduling of work, improvement of parts and inventory control (Dale, 1997).

i. Predictive Maintenance

The meaning of predictive maintenance is to predict problems of the machinery and take corrective actions. Basically, it identifies the root cause of problems and eliminates before further deterioration (Sullivan *et al.*, 2010). It is highly relying on operations condition monitoring, efficiency, heat distribution, vibration, and other indicators to determine the actual mean-time-to-failure (MTTF). Predictive maintenance provides actual data of machinery condition for maintenance department for scheduling maintenance activities effectively. The advantages of preventive maintenance are minimum failure rate, higher machinery availability, minimum labour cost, higher product quality and reliability, and finally low production cost (Herbaty, 1990; Sullivan *et al.*, 2010). However, the main disadvantages are the high investment for maintaining the laboratory and operators' training costs. This cost makes people reluctant to adopt predictive maintenance strategy.

ii. Preventive Maintenance

The preventive maintenance concept was introduced in 1951; it is described as a scheduled downtime where well-managed set of tasks is performed periodically (Ebeling, 1997). It is comprised of maintenance activities that are undertaken after a specified period of time or amount of machine use (Herbaty, 1990). Preventive maintenance works include inspection of manufacturing machinery, repair, replacement, cleaning, lubrication, adjustment and alignment. Furthermore, it reduces machinery failure rate while increase operation time of machinery (Das *et al.,* 2006). However, preventive maintenance is justified only when it is cost effective; therefore, it is not effective when machinery in the stage of constant failure rate. Reliability of machinery will be the same in both with or without preventive maintenance. A research done by David (2008) has stated that preventive maintenance has a negligible effect on machinery availability of long-term effect. His research shows that both with and without preventive maintenance have similar machinery availability values. Rosmaini et al. (2006) also described that unnecessary preventive maintenance causes additional downtime and contributes to higher maintenance and production cost. Despite the constraints, preventive maintenance still plays an important role in achieving sustainable manufacturing process.

iii. Corrective Maintenance

The corrective maintenance uses the concept of machinery failure prevention to improve machinery reliability. Shahid et al. (2009) has described it as a reactionary modification works of a system are performed to eliminate discovered faults. Steinbacher and Steinbacher (1993) also agreed that machinery system reliability is improved through corrective maintenance. The purpose of this maintenance is to improve machinery reliability by minimizing or eliminating the root cause of failure. Proper records of corrective maintenance can be used to improve future design of machinery and improvement of existing manufacturing facilities.

iv. Reliability Centred Maintenance (RCM)

Reliability Centred Maintenance is a process that aids to determine maintenance requirements of production machinery and helps to conduct analysis in order to ensure continuous operations. It was invented and used in the 1960s by aircraft manufacturers and airline companies for maintaining aircrafts (Dekker, 1996). Basically, RCM is a systematic method that contributes to optimize preventive maintenance cost (Ben, 2000). Samanta et al. (2001) described that seven logical steps are required in RCM implementation for achieving higher performance in maintenance. Various tools such as failure mode and effect analysis (FMEA), and physical hazard analysis (PHA) are being used to improve RCM performance in order to improve maintenance efficiency (Smith, 1993). Thus RCM contributes to improve maintenance performance which achieve lower production cost.

v. Total Productive Maintenance (TPM)

TPM is known as an innovative approach to maintenance that optimizes machine effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through daily activity involving total workforce (Bhadury, 2000). The total productive maintenance (TPM) is an American style of productive maintenance which has been modified and improved to fit into the Japanese industrial environment. It is similar to just-in-time (JIT) management and total quality management (TQM), and it is also an extension of preventive maintenance. The TPM implementation involves relevant employees, and focuses on failure prevention activities (Almeanazel, 2010). TPM is a maintenance strategy developed to meet the new maintenance needs. Bamber (1998) described that TPM has two approaches such as the Western and Japanese. The Japanese TPM approach has five main points:

(i) Use machine efficiently

(ii) Establishes total preventive maintenance system

(iii) Requires participation from all departments

(iv) Involves all employees and employers

(v) Promotes and implements preventive based maintenance

Nowadays, TPM is popular in Japanese industries as well as in the Western countries (Muhammad, 2007). It is closely related to JIT and TQM where the machinery works at a high productivity and efficiency. In this way, TPM contributes to optimize effectiveness of the machinery and reduce production cost.

F) Maintenance Cost Components

In manufacturing process input costs are integrated in order to estimate product cost. In that perspective, maintenance activities is an input to the production process; and its cost is an input factor to the production cost. Thus, higher maintenance cost contributes to increase production cost. With this regards, maintenance cost components have to be identified and optimized in order to reduce production cost. In the past, huge studies have been conducted on the manufacturing maintenance methods, philosophies, and strategies. Many models are discussed in books such as Wang and Pham (2006), and review papers by Wang (2002). Similar models developed by Shum and Gong (2006) and Saranga (2004) in order to minimize the cost of maintenance and to increase machinery availability in production. However, maintenance cost components are rarely discussed in previous studies. Mohamed (2001) also mentioned that costing and cost efficiency issues of planned maintenance have received less attention. In this paper, four maintenance cost components are discussed.

Schiffauerova and Thomsom (2006) have stated that manufacturing industry nowadays is highly competing in the perspective of high product quality and low production cost. They also pointed out that high product quality and low production cost can only be achieved if each cost components is optimized. In regards to preventive maintenance, Wessels (1998) emphasised on the relationship between the maintenance cost with spare part cost, labour cost and maintenance time duration. Equation (1) is used to estimate preventive maintenance cost by using relevant time elements of maintenance.

$$C_{prevention} = \sum_i^n C_{sp} + \sum_j^m S_{mh} + \sum_k^l t_{lp} \quad (1)$$

Where,

c_{sp} = cost of spare parts

s_{mh} = maintenance personnel hourly rate

t_{lp} = time spent by maintenance personnel in carrying out a preventive action

Equation (1) represents the preventive maintenance cost including spare part, labour, and maintenance time. These components can be used to optimize maintenance cost.

i. Spare Parts Management Cost for Maintenance

Spare parts are the new components of machinery that are being used to replace the broken parts to keep machinery operating in healthy condition. Reports show that unavailability of spare parts contributes to as much as 50% of total down time of a manufacturing cycle. Moreover, it is responsible for more than 50% of the total maintenance cost, which represents a significant value in production cost. In 2009, Bernt (2009) has developed a spare parts optimization model which contributes to reduce spare parts investment and also contributes to make available of machinery spare parts. Conceptually, spare parts management is very similar to other inventory systems such as the real cost of the spare parts, expenditure for storage and finally, the cost of order for purchasing spare parts from vendors. This model can be presented by equation (2) (Wessels, 1998):

$$C_{sp} = \sum_i^n C_{parts} + \sum_j^m C_{inv} + \sum_k^l C_{ord} \quad (2)$$

Where,

C_{sp} = cost of spare parts

C_{parts} = cost of parts to be replaced

C_{inv} = cost of inventory

C_{ord} = ordering cost

Equation (2) represents the cost of spare parts including its cost components such as cost of machinery parts, inventory cost, and ordering cost. The inventory cost is discussed in the next section.

ii. Maintenance Inventory Cost

Elif et al. (1997) developed a model for managing parts inventories in a semiconmductor wafer fabrication industry; the model developed has significantly contributed inventory performance. Ruhul and Amanul (1999) studied in spare parts management and found out that industries have a tendency of maintaining overstock of a spare part in order to reduce downtime of machinery. They are suggesting that maintenance programs should be designed to reduce both maintenance and inventory costs. Jointly optimized policies are better than separately or sequentially policies. The just-in-time (JIT) strategy has been implemented first by Toyota in the 1970s (Timothy and Vidyaranya, 2002) where the ultimate goal was to completely eliminate all waiting time so that inventory cost can be minimized, and improve other performances (Cem *et al.*, 2000). Marc (2001) has developed a new model to demonstrate the impact of joint deployment of economic order quantity (EOQ) and just-in-time (JIT) purchasing plans to further optimize inventory costs.

Conceptually, this inventory management is also very similar to other inventory management systems. In maintenance inventory management, there are three major cost components namely consumable, logistic, and facility costs. Consumable cost includes grease, welding materials, lubricants, etc. Logistic cost includes caretaker, loading and unloading facilities, record keeping and ICT. Facility cost includes electricity, water, security services, fork lift, rent of premises, etc. This model can be presented by the following equation (3) (Wessels, 1998):

$$C_{T_{int}} = \sum_i^n C_{con} + \sum_j^m C_{log} + \sum_k^l C_{fac} \quad (3)$$

Where,

$C_{T_{int}}$ = total inventory cost

C_{con} = cost of consumable items

C_{log} = logistic cost

C_{fac} = cost of facility

Equation (3) represents the cost of inventory including the cost of logistic and facility. In the next section, maintenance labour cost is discussed.

iii. Maintenance Labour Cost

Mohamed (2001) has proposed a framework to generate reliable, relevant, and timely information on actual maintenance cost; and this model is suitable to measure the direct labour cost of maintenance. According to the proposed model, direct labour information should base on the job and work flow sheet (JWFS). JWFS provides information about maintenance works to be performed and labour time to be utilized under normal conditions. Labour cost of maintenance is about 8% of the total maintenance cost, which is similar to the production labour cost.

$$C_l = s_{mh} \times t_{mt} \times l_{sk} \quad (4)$$

Where,

c_l = labour cost

s_{mh} = maintenance personnel hourly rate

t_{mt} = time spent on maintenance

l_{sk} = skill level (skilled, semi – skilled, unskilled)

Taguchi figured out those low quality products due to the poor-skill level of man and machineries increases the cost of maintenance significantly (We *et al.*, 2004; Ross, *et al.*, 1989). In machinery maintenance program, labour skill level is an important issue which needs to get attention properly (Shamson & Zhan, 2004). Of course, to improve the skill level of workforce, training is needed which contributes to increase production cost. A few models have been developed by researchers in order to optimize labour cost of machinery maintenance; the models demonstrated that maintenance cost and labour quality is positively associated (Prashang *et al.* 2012; Gerald and Milind, 1998). It implies that the expenditure of maintenance with high quality labour tends to increase maintenance cost. (Khalil *et al.* 2009; Shamsuzzaman and Zhang, 2004). The labour cost of maintenance depends on several factors such as level of educations, years of experience, and degree of technology of machinery with safety level. However, practice showed that maintenance labour cost is ranging from 5% - 15% of the total maintenance cost which is similar to production operations.

iv. Maintenance Management Cost

Maintenance management is a series of activities aim to develop strategies, planning, scheduling, spare parts inventory, training of labour in order to keep machinery operating condition for improving manufacturing performance. Maintenance management is always active for implementing maintenance schedule supervision maintenance works in order to reduce maintenance cost (Adolfo and Jatinder, 2006). Maintenance management cost is usually categorized as an indirect cost of maintenance, which includes monitoring costs. A model of maintenance management cost is described in equation (5):-

$$C_{mgt} = \sum_i^n s_{mh} \times t_m \times l_{sk} + \sum_j^m c_m \qquad (5)$$

Where,

s_{mh} = management personnel hourly rate

t_m = time spent in management

c_m = cost used for materials management

l_{sk} = skill level (manager, assistant manager, operation managers, etc.)

c_m = ICT equipment

Maintenance management indeed is used to manage maintenance in order to reduce maintenance cost. Equation (5) represents the cost model of maintenance management including cost of ICT equipment. Maintenance cost matrix is discussed in the next section.

G) Maintenance Cost Matrix

This section presents the maintenance cost matrix which includes human resources and different cost components (Salonen and Deleryd, 2011).

Table I demonstrates the evaluation of each maintenance activity. From the table, total cost for each component is calculated by the summation of each human resource level. By the aid of Table I, model for estimating the cost of each activity is developed and presented by equation (6):-

$$C_i = X_i + Y_i + Z_i + W_i \qquad (where\ i = 1, 2, 3, \dots, 10) \qquad (6)$$

Equation (6) is a model used to calculate the total cost for each component of maintenance.

Table I. Matrix of cost components and human resource

		Person Involved			
	Cost Components (C)	Direct labour,hr (X)	Manager, hr (Y)	Operator, hr (Z)	Others, hr (W)
1	Man-hours for maintenance (including administration)	X1	Y1	Z1	W1
2	Exchange parts	X2	Y2	Z2	W2
3	Lubricants	X3	Y3	Z3	W3
4	Other material for maintenance, e.g. rags, cleaning solvents, etc.	X4	Y4	Z4	W4
5	Lost production time	X5	Y5	Z5	W5
6	Logistics, e.g. for spare parts or entrepreneurs	X6	Y6	Z6	W6
7	Breakdown related scrap and/or re-work	X7	Y7	Z7	W7
8	Scrap and/or re-work due to poor maintenance	X8	Y8	Z8	W8
9	Breakdown related over-time for recovery production	X9	Y9	Z9	W9
10	Speed losses due to poor maintenance	X10	Y10	Z10	W10

H) Cost of Quality (CoQ)

Ben-Daya and Duffua (1995) mentioned that maintenance and quality are not properly linked previously where 'lack of quality' got higher priority than 'cost of quality'. Therefore, the cost of poor quality should get higher priority than quality cost. Presently, quality management is not only an inspection and control at a production shop floor; but as a process where customer demand is the ultimate goal and products are assured to meet their demands. Schiffauerova and Thomson (2006) developed a few models to evaluate the cost of quality, which are as follows:

$$RoQ = \frac{\Delta P}{C_{QIP}} \qquad (7)$$

$$\frac{dQ}{dt} = \frac{X - (d_Q + d_S + R)}{X} \qquad (8)$$

$$Q_P = \frac{t_A - t_R}{t_A} \qquad (9)$$

Where,

$\mathrm{RoQ} = \text{return of quality}$

$\Delta\mathrm{P} = \text{increase in profit}$

$\mathrm{C_{QIP}} = \text{cost of quality improvement program}$

$\mathrm{t_A} = \text{available time}$

$\frac{\mathrm{dQ}}{\mathrm{dt}} = \text{quality rate}$

$\mathrm{X} = \text{input}$

$\mathrm{d_Q} = \text{quality defects}$

$\mathrm{t_R} = \text{rework time}$

$\mathrm{d_S} = \text{startup defects}$

$\mathrm{R} = \text{rework}$

$\mathrm{Q_P} = \text{procless quality}$

According to Schiffauerova and Thomson (2006), the real situation is always different from theoretical models. However, many researches and surveys have stated that CoQ is not a widely used concept (Shah and Fitzroy, 1998; Wheldon and Ross, 1998); Crosby (1983) also agreed with this opinion.

III. SUMMARY AND SCENARIO ANALYSIS OF FINDINGS

This paper has attempted to review the contemporary and past literature on potential maintenance cost components of machinery. We have focused on the concept of machinery maintenance, relevant cost components, and cost optimization. We studied relevant publications which include 72 literatures, 12 books, and 5 case studies. The attributes of this review with references are listed in Table II.

Most of the previous publications were focusing on maintenance management with little emphasis on the cost. The summary of the findings is stated below:-

- Maintenance is divided into two parts such as planned and unplanned maintenance; subdivided into emergency, breakdown, predictive, preventive, and corrective maintenances. The strategies for deploying the maintenance strategies are also described.
- The cost components of maintenance such as spare part, inventory, labour, and management are described in quantitative form.
- Various cost optimization models were proposed by researchers; however, these models were not tested in industries.

The findings above reveal that research on maintenance cost optimization is highly ignored the in contemporary and past literature; but the developed general consensus is that the expenditure of maintenance is a potential issue of manufacturing sustainability. Excess expenditure contributes to increase the production cost of goods; thus, it implies that excess cost is a non-value-added expenditure to manufacturing system. In this perspective, cost optimization is an essential part of achieving sustainability and competitiveness in the manufacturing business. However, the conclusion is that right attention was not given in the previous studies to optimize maintenance cost. It is obvious that a gap is exists in the literature of maintenance costing domain which demands an in-depth study. This study attempts to address this issue in order to fill the gap to identify and to eliminate non-value-added expenditure of maintenance.

Table II. Summary of findings

Attributes of Maintenance and its Effects	*References*
Concept of maintenance • It describes about the classification of maintenance	Bigdeli and Safi, 2005
Concept of maintenance cost • It gives an idea about cost component	Poore and Walford, 2008; Alsyouf, 2004; Blanchard, 1986; Husband, 1986; Adolfo and Jatinder, 2006
Concept of cost optimization • A few mathematical models are described	Bill and David, 1992; Baldwin, 1990; Khalil *et al.*, 2009; Lofsten, 1999; Goulden and Rawlins,1995
Emergency maintenance • Emergency maintenance is very important. Failure of performing emergency maintenance leads to catastrophe.	Medicine and Global Survival, 2011
Breakdown maintenance • Still the major maintenance strategy in the U.S. • It is said to be the most expensive maintenance strategy.	Geert and Liliane, 2002; Government of South Australia, n.d.; Sullivan *et al.*, 2010; Bigdeli and Safi, 2005
Predictive maintenance • Is highly dependent on monitoring tools to detect the source of failure; monitoring tools are expensive and require high skill operators.	Sullivan *et al.*, 2010; Ruyle Corp, n.d.; Herbaty, 1990
Preventive maintenance • It reduces failure frequency and increase machinery short-term availability; excess performed increases cost	Ebeling, 1997; Herbaty, 1990; Das *et al.*, 2006; David, 2008; Rosmaini, 2006
Corrective maintenance • Performs repair and modification works to eliminate the root causes of failure, aims towards zero-maintenance goal.	Shahid *et al.*, 2009; Steinbacher and Steinbacher, 1993
Reliability centred maintenance • Uses seven logical steps. • Different preventive maintenance tasks are performed to ensure optimum cost effectiveness of maintenance.	Dekker, 1996; Ben, 2000; Samanta *et al*., 2001; Smith, 1993
Total productive maintenance • Similar to JIT and TQM; an extension of preventive maintenance, involves all employees and focuses of failure prevention	Almeanazel, 2010; Bamber, 1998; Bhadury, 2000; Muhammad, 2007

Table II: Continued…

Table II: Continued…

Maintenance cost components • Spare part cost • Inventory cost • Labour cost • Management cost	Wang and Pham, 2006; Wang, 2002; Shum and Gong, 2006; Saranga, 2004; Mohamed, 2001; Schiffauerova and Thomsom, 2006; Wessels, 1998
Spare part cost • Unavailability of spare parts contributes to 50% of total maintenance costs and downtime. • Highly potential in cost reduction and performance improvement	Sandeep, n.d.; Bernt, 2009
Inventory cost • Cause: overstocked spare parts • EOQ and JIT management strategies are implemented to minimize inventory cost	Elif *et al.*, 1997; Ruhul and Amanul, 1999; Timothy and Vidyaranya, 2002; Cem *et al.*, 2000; Marc, 2001
Labour cost The range of expenditure on labour has described	Mohamed, 2001; We *et al.*, 2004; Ross, *et al.*, 1989; Shamson & Zhan, 2004; Prashang *et al.* 2012; Gerald and Milind, 1998; Salonen and Deleryd, 2011
Cost of Quality Cost and quality relationship has been established	Ben-Daya and Duffua, 1995; Schiffauerova and Thomson, 2006; Shah and Fitzroy, 1998; Wheldon and Ross, 1998; Crosby, 1983

IV. CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

The objective of this paper was to study the past and contemporary literature in cost components associated with production machinery maintenance to contribute to achieve economic sustainability; an emphasis was given to reveal the latest development in cost optimization. The findings reveal the present stock of knowledge in maintenance management and its cost. A few models of cost optimization were also found in the literature but the available models were not tested and validated in manufacturing industries. Therefore, this study suggests further study to test the empirical model developed from this study to validate the model.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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