Investigation of various maintenance parameters for auxiliaries in a coal-handling plant aided by a Visual Basic 6.0–based scheduled program

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Schedule maintenance programs rely on the analysis of collected data during running and shut down time. In a preventive maintenance program, it is difficult to a priori determine the time limit or set an alarm indicating the failure time of a specific component. To this end, a Visual Basic 6.0–based software program is here proposed for a comprehensive running and maintenance database management. The developed software is capable of storing all relevant data related to parts, equipment, personnel, spares, failures, costs, etc, and displays a warning message when the expected life of a particular component has been reached. An unscheduled outage heavily impacts on the production cycle costs, depending on the nature of the failure and the damaged part. Since the variation of the used parts and equipment is high, it is not possible to have an all-encompassing maintenance guide, which is applicable to all equipment. A successful program of preventive and routine maintenance may hence decrease equipment failures rates, extend equipment life, and drastically reduce the overall operating costs. Therefore, the present work can help in preventing unscheduled breakdown of operating systems due to a failure in a component.

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1 INTRODUCTION

Coal is a prominent source of energy being largely used to run thermal power plants. Developing countries mainly use coal as a fuel for thermal power plants due to its low price. Therefore, the supply of good quality coal in useable form is one of the crucial operations in a thermal power plant. This can be achieved in a coal-handling plant (CHP), which processes coal and supplies it in the required size and quality using its several auxiliaries.1 Wagons are used for carrying coals from mines to the coal plants where it is further processed for specific applications. The coal loaded on wagons is unloaded with the help of wagon tippler and transferred by means of conveyor belt towards primary and secondary crusher units and then transferred for further operation.2-4 In this section, the various auxiliaries and related problems typical of a CHP are discussed.
1.1 Various auxiliaries in a CHP

A CHP consists of several auxiliaries that are used for handling coal from a supply point to its final use. These auxiliaries help in transport, storage, movement, crushing/sizing of the coal, etc. Various auxiliaries of a CHP are as follows.

- **Wagon tippler**: A giant machine comprising gear boxes and a motor assembly which is used to unload the coal wagons into coal hoppers in a reasonable time (e.g., 20 wagons/hr. or more). It is a compact machine that discharges coal from top rail wagons by inverting the wagon over a track side hopper. The machine construction mainly comprises a cradle structure with a pair of heavy welded steel plate sectors, rigidly connected by a large torsion box girder fitted at each end to a pivot shaft. The whole cradle is carried on the pivot shaft mounted on antifriction bearings, which are, in turn, carried on a fabricated steel pedestal.

- **Conveyor belt**: Synthetic rubber belts which move on metallic rollers called idlers. The principle of a belt conveyor appears rather simple. The conveyor belt is an endless band guided around two drums. Its purpose is to convey material from the feeding station to the discharge point. However, improper use of conveyer belts viz. larger belt size and inadequate use are the major issues that can potentially affect the cost-efficient production capability of the plant.

- **Primary crusher**: Unit crushing coal up to 5 cm in size. The primary crusher assembly consists of a drum, motor, gear box, and fluid coupling. The drum consists of a large number of teeth where the coal is fed from the top which falls into a steel cage. The coal is trapped between the teeth and cage while being crushed. The combination of the conveyor belt and crusher is an essential feature for a CHP.

- **Secondary crusher**: A crusher consisting of a granulator powered by a motor. The granulator has screen bars with hammers. The efficiency of the granulator depends on the number of hammers, speed of granulator, and feeding method. This device can crush coal up to 2 cm in size.

1.2 Problems in a CHP

This section highlights some major problems faced in the maintenance process of auxiliaries in a CHP.

- **Parts fail suddenly**: Every part has its working life depending on its material, application and design technique. After exceeding their lifetime, the parts may fail at any time. Such sudden failures cause a breakdown leading to halt in production.

- **Difficult to conduct regular preventive maintenance**: Preventive maintenance should be done at regular intervals of working hours of a machine. In the maintenance process of a CHP, it is difficult to conduct proper preventive maintenance manually because no data/information is available on how many hours the machine or spare part have been running.

- **Difficult to obtain run hours of parts**: Suppose any part in the system fails, and then it is difficult to know how many hours it has worked and how many hours of its life are remaining. Hence, it is difficult for the maintenance engineer to analyze whether the problem is in the quality of the part or in auxiliary condition.

- **Difficulty in finding failure rate**: If the total working hours of spare parts and auxiliaries are not known, computing the failure rate is not possible. If failure rate is not known, then it is difficult to decide whether there is a need for a design modification or requirement of retrofitting for auxiliaries.

- **More time consumed in record keeping**: Keeping records of all spares and failure is one of the responsibilities of the maintenance department. In manual record keeping, calculation of the numbers of spares used and the numbers of spares left is a time-consuming process. Moreover, machine failure calculation is very complex and difficult to determine manually as the chances of error are high.

- **Unable to know the current status of a part**: Maintenance technicians are unable to understand how much life of a spare part is over and how much is left. Due to this, a part may be replaced before its expected lifetime which clearly results in an unnecessary cost to the plant. Moreover, if a part is replaced at the very last stage of its life, it could have already deteriorated its adjacent parts by that time. In such cases, the department sustains unnecessary loss of adjacent parts. Therefore, the knowledge of the current status also helps to order material at the right time to avoid excess shortage cost. An investigation on the current status of parts is sufficient to ascertain right quantity of parts to be ordered.

- **Difficult to sort maintenance history**: It is difficult to sort previous maintenance task records, failure records, new stock records, labor overtime record, machine failure records, etc. Such tasks of sorting records are time consuming that can cost several man hours to the plant.
Maintenance is a collection of scheduled or unplanned repairs performed to extend a system's useful life. It can also be described as a set of operations that help to ensure a correct functioning of the system. The main structure of the maintenance philosophy is either reactive or proactive. In reactive maintenance, repairs are carried out after the system has failed. Conversely, in proactive maintenance, actions are carried out to detect flaws that may cause a malfunction in the system; it thus attempts to prevent future failures.

Maintenance of multicomponent systems is more difficult than their single-unit counterparts. Complex systems in industry include many components with or without interdependencies. It is vital to define which kinds of dependencies are present among parts to reduce the cost and time of maintenance. In general, three kinds of maintenance dependencies are encountered, ie, structural, stochastic, and monetary. Structural dependence means that the associated parts are not possible to replace or maintain independently. Structural dependence is therefore dependence on repair and not on failure. Stochastic dependence occurs when one component's degradation impacts the other's failure distribution. Monetary dependence leads to either cost savings or additional costs due to component group maintenance. Gupta reported that to achieve the goal of maximum power generation from coal-based power plant it is required to run the various subsystem of the concerned system of plant, failure-free for a long duration. Özgür-Ünlüak formulated corrective maintenance methodology through dynamic Bayesian network to address regenerative air heating systems in thermal energy plants. Using Lagrangian relaxation techniques integrated in dynamic programming, Faddoula and Chateauneuf suggested minimization approach for the maintenance costs of reliability-bound series systems. Panchal and Kumar reported integrated framework of a real industrial system in coal-handling system for qualitative and quantitative approaches in North India. Qualitative analysis has been done using root cause analysis approach and the failure causes listed under root cause analysis approach were used to carry system's failure mode effect analysis. Various reliability parameters such as failure rate, repair rate, mean time between failure (MTBF), expected number of failures, and availability were calculated at different spreads, and the failure dynamics were studied. Zhao et al studied the fatigue lifetime assessment on a high-pressure heater during transient processes. The dynamic data of the thermal parameters during the transient regulating processes were obtained on the basis of the dynamic models of a coal fired power plant via the GSE software. Subsequently, the thermo mechanical stresses were calculated and analyzed using the finite element analysis method in the ANSYS software. Finally, the fatigue lifetimes of the heater were quantitatively estimated and compared. Panchal and Kumar reported stochastic behavior of a power-generating unit of a medium size coal fired thermal power plant using fuzzy methodology. Failure rate, repair time, MTBF, expected number of failures, availability, and reliability of the system were studied to enable better decision-making regarding criticality of components. Malik and Tewari designed the performance modeling and maintenance priorities for water flow system of a coal-based thermal power plant. Chapman-Kolmogorov equations were generated on the basis of transition diagram and further solved recursively to obtain the performance modeling with the help of normalizing condition using Markov approach. The adopted method resulted in enhancement of system availability and reduction in maintenance cost. Adhikary et al investigated characteristics reliability study of a coal-fired boiler using the Weibull proportional hazard model. Parameter like percentage of ash content in the coal, surrounding temperature, pH factor of inside fluid, maintenance personnel skill, and operators' skill were considered in the study. They found from the goodness-of-fit test that the proportional hazard model assumption of the failure data holds good for coal-fired boiler tubes.

Several works exist on maintenance optimization for fault diagnosis in various process plants in the literature. Most optimization studies are observed to be based on mathematical modeling, which are time consuming and complicated, and well suited for large process plants. Therefore, this software has been developed to address such issues for CHP department in thermal power station. It has a major advantage over existing models due to its applicability to large and small-scale process plants.

2 OBJECTIVES

A CHP consists of several critical components. A routine inspection of these elements is necessary to ensure their functionality and integrity. Such an inspection is performed in order to provide a timely warning by identifying any degradation in the integrity before an actual failure occurs. The component condition evaluation is essential for optimization of CHP's inspection and maintenance schedules. It also helps in more accurate decision making that ultimately reduces or avoids unplanned outages. The improvement of equipment efficiency, as well as operation efficiency in the CHP is an
important parameter, which is mainly decided by the equipment retrofitting. Therefore, the objectives of the current work are manifold.

i. To reduce breakdown - The main objective of the proposed software is to avoid auxiliary breakdown. In order to do so, knowledge of the maximum working life of a part is necessary. The maximum working life sheet of spare parts (prepared on precedent 10-year data) is available.

ii. To reduce downtime - The second objective is to reduce the downtime. In case of breakdown due to reasons, such as overload, voltage variation, poor quality material, etc, the software provides all information regarding the breakdown maintenance. The information includes symptoms, causes, remedy, type of wear, spare part required, and tools required for that particular zone of the breakdown. Such detailed information is helpful for taking immediate action and reduce downtime.

iii. Keeping maintenance record - The proposed software stores all the records of previous failures. Any information of past breakdown, shutdown, or preventive maintenance can easily be collected. It is possible to determine the tasks performed in a particular interval from the stored records.

iv. Inventory control - Inventory control is also one of the important objectives of the software. The software is able to maintain all the transaction record of each part. The transaction may be from shop to store and from store to auxiliary. This information is helpful in determining shortage of any part.

v. Find plant performance for future work - Report form of the software provides all performance reports within an interval. It can also provide information about failure between two intervals. Hence, planning for future modification and changes becomes easier.

vi. Increase availability of spares - The software provides information about current status of parts, indicating how many hours are still remaining for parts’ life to be over; so, the required quantity of that spare can be ordered in time.

3 | METHODOLOGY

This section discusses how the software program works. Every component has its own maximum working life (expressed in hours). This life is guaranteed by the manufacturer (company) of that component. The maximum life indicates that the part will function properly up to that given limit of time. After the given period, there is an uncertainty for proper functioning of the component and may fail at any time. Therefore, the main aim of the software program is to protect the part from failure when its life is over.

As an example, let a component bearing be assumed to have a maximum life of 100 hours. At first, these maximum life hours are entered in the software format, which thereafter gets stored in the database. Then, let the warning time be set at 90 hours. When this warning hour is crossed, the software alerts the operator with a warning message about the part. Here, the maximum hours indicate the expected or design life of the component, warning hours are entered by user for notifying warning limit, and the actual run hours are the summation of daily machine working hours.

Consider Figure 1; every day, when any auxiliary starts, the start date and start time are entered in the appropriate boxes. Let the assumed start date be 01/01/04 and the time be 10.00. Then, this record is started by clicking the Save button. When the machine is shutdown, the date and time are entered (assume 01/01/04 at 20.00). It means in the 1st of January the machine works for 10 hours. These 10 hours are the actual running hours of the machine. Each time the machine is run; the software compares the actual running hours (10 hours here) with the warning hours (90 hours) for all components.

If on the next day the machine works for 12 hours, those hours are added to the previous 10 hours. Therefore, the total life used becomes 22 hours. Similarly, if the machine works 11 and 10 hours on the following days, the total actual run hours of the machine is $10 + 12 + 11 + 10 = 43$ hours. These 43 hours are compared with warning hours; it is less than 90 hours, ie, component is OK. However, when the machine crosses 90 hours limit (in actual running) an alert massage is then immediately given by the software.

When any part crosses warning hours, its name is transferred in the grid table, as shown in Figure 2. The grid table shows name of auxiliary, part name, part code, suggested spares, run and working hours, etc.

Part code is used for uniquely identifying every part used in the plant. It is also possible that a part with limiting life of 100 hours can work for 120 hours (say) with proper lubrication under good environmental condition and constant loading. In such cases, department may suffer loss of 20 hours if the part is replaced in 100 hours (specified lifetime). The problem can be solved through examination of the part by an expert on receiving the warning massage from computer. On recommendation by the expert, modification can be made in the software by entering the suggested lifetime (say,
20 hours) and setting the corresponding warning hours (say, 15 hours). On crossing 15 hours, the software issues an alert to change the part after which it can be replaced.

3.1 | Preventive maintenance

To avoid system breakdown and prolong its lifetime, regular preventive maintenance on component or equipment is necessary. Under existing system CHP is unable to plan regular preventive maintenance, which leads to wastage of parts. This software is helpful to conduct regular preventive maintenance after fixed intervals as it contains records of all previous maintenance.

Consider Figure 2; the following sequence of operation has to be followed for preventive maintenance. First, the Auxiliary No. or Name is selected. The part name followed by its Code No. is selected in the subsequent step. Then, the preventive maintenance task, eg, Lubrication is entered along with its frequency or schedule time. If 300 hours is set as frequency, the computer will display “Caution Notice” or “Alert message” after 300 hours of working time. This massage strip will appear as in Figure 1 form of machine hour record. After displaying the massage strip, the grid shows name of parts that require preventive maintenance (Figure 2).

3.2 | Machine failure record

When any breakdown or failure occurs on site, the user must enter all details regarding failures in the form (Figure 3) after restoring it.

First, the auxiliary, which has failed and has been restored, is selected followed by the duration of failure in Dates form. The details of tasks undertaken are entered as follows:

Detection of fault = 2 hrs.
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Collection of labor = 1 hrs.
Disassembly of M/c = 2 hrs.
Repair time = 3 hrs.
Assembling = 2 hrs.
Testing = 1 hrs.

Then, remark (e.g., “machine OK”) and other details as per Figure 3 are entered for future reference.

This form is very important to calculate all maintenance performance factor and results with reports. Hence, it is necessary to understand how the data of that form is stored in database.

Consider Table 1; when user saved the failure data in software, the status becomes False; otherwise, it is True. Status = False means no daily machine working hours added in actual run column and vice versa.

Consider first column of Actual run; first row indicates that machine failed after 300 hours. Hence, its status changes from True to False. Now, daily working hours of machine is added in fourth row instead of first row. The fourth row indicates that currently the machine is working properly. If PC1 auxiliary fails again in future, then the user has to enter all data in fourth row and Save it. Consequently, its status converts into False and new record appears in next row.

3.3 | Performance reports

This section discusses various performance reports of software, mathematical calculations, maintenance history, and graphs.

(a) Reliability Calculation - Reliability is the probability of a device performing its purpose adequately for the period intended under given operating conditions.

To calculate reliability, the following equation is formula used:

\[ R = e^{-t/\text{MTTF}} \]  

(1)

\[  

**FIGURE 3** Form for machine failure record

**TABLE 1** Failure record of auxiliary (primary crusher)

| Sr. No. | Auxiliary | From       | To          | MDT | Remark                  | Cost | Actual Run | Status |
|---------|-----------|------------|-------------|-----|-------------------------|------|------------|--------|
| 1       | PC 1      | 09/01/04   | 10/01/04    | 12  | Fluid coupling Repair   | 1500 | 300        | False  |
| 2       | PC 1      | 22/03/04   | 22/03/04    | 10  | Gear box Repair         | 2300 | 500        | False  |
| 3       | PC 1      | 14/04/04   | 15/04/04    | 17  | Motor Repaired          | 1800 | 280        | False  |
| 4       | PC 1      |            |             |     |                         | 150  |            | True   |
where \( t \) is probabilistic time in hours and MTTF is the mean time to failure, calculated as

\[
\text{MTTF} = \frac{\text{total no. of operating hours}}{\text{total no. of failure from reference time}}
\]

\[
\text{MTTF from Ref.Tim} = \frac{250 + 180 + 310 + \cdots \text{the time to the 10th failure}}{10} \approx 196.33.
\] (3)

Now, any probabilistic time for which reliability is required may be entered to check its value as follows (as shown in Figure 4):

- Putting \( t = 200 \) to 300 at interval of 10.
- Reliability \( R = 36.16\% \) at 200 hours.
- \( R = 34.30\% \) at 210 hours.
- \( R = 32.89\% \) at 220 hours.
- \( R = 32.10\% \) at 230 hours.

(b) Mean corrective down time (MCDT) - This is also known as mean time to repair. It is the expected time that a system will be restored to operational effectiveness when the maintenance action is performed in accordance with prescribed procedures. It is calculated by the software in following way.

The equipment failure data is available to the software from the values entered, as shown in Figure 3. This data is used to calculate the MCDT and plot on graph. A typical data of MCDT appears as given in Table 2.

The formula for MCDT is

\[
\log M_{\text{max}} = \left( \frac{\log M_i}{n} \right) + 1.645 \sqrt{\frac{\sum (\log M_i^2) + (\sum \log M_i^2)}{n - 1}}.
\] (4)
By using appropriate values for the parameters in the aforementioned equation,

\[
\text{Log } (M_{\text{max}}) = 0.5426.
\]

By taking inverse log,

\[
M_{\text{CDT}} = M_{\text{max}} = 3.48. \quad (5)
\]

The MCDT is therefore 3.48 hours.

Figure 5 shows the graph of MCDT against months of a year. If two failures occur in same month, the software takes mean of those values and plot on graph.

(c) Availability - The availability of a system is the probability that it is operating satisfactorily at any point of time when used under stated conditions.

Availability is given by

\[
A = \frac{\text{MTBF}}{\text{MTBF} + \text{MDT}} \times 100, \quad (6)
\]

where MDT is the mean down time in hours and MTBF is the mean time between failure.

The MTBF is the expected time between successive failure events over the service life of the component. In other words, the MTBF is the same as mean time to first failure.

Suppose an auxiliary restored on 24/01/2004 fails after 200 hours of working on 03/03/2004, and then its MTBF is 200 hours. Then, the availability is obtained as

\[
A = \frac{200}{200 + 11} \times 100\% = 94\%. \quad (7)
\]

Thus, the availability of the said auxiliary is 94%.

Figure 6 shows the plot of availability against months of a year.

(d) Failure rate - It is the ratio of number of failures to the total number of operating hours from a reference time. It is obtained by the following formula:

\[
Fr = \frac{\text{No. of failure}}{\text{Total no. of operating hours}}. \quad (8)
\]

Figure 7 shows the failure rate of a component during different months of a year. This graph is important because if failure intensity increases for an auxiliary some modification may be incorporated in it.

(e) Other performance graphs - Two more graphs, viz, cost spent graph and machine working hours are important to the CHP because they provide details about the economics and performance for the auxiliary.
Cost spent graph (Figure 8) shows how much cost has been incurred by maintenance department in a particular month. The cost shown in graph is the total cost including cost of spares.

Machine working hours (Figure 9) show total actual machine run hours in a particular month. The performance of the machine can be judged from the graph and necessary modification can be suggested for its improvement.

4 | DISCUSSION

Scheduling in broad sense is usually concerned with the provided allocation of several tasks or jobs to one resource or more than one resources with limited capacity machine-finding solution in single interval or more than one interval. The proposed software program has several positive applications that could potentially improve the reliability and productivity of a CHP. Reliability and availability are the driving force for efficient performance of industrial systems. Accurate and reliable data on each auxiliary, its lifetime, cost, repairs/retrofitting, inventory, etc, make the software a valuable asset to the plant. Some of the major advantages that can be achieved through its use are discussed in the following section.

1) Accuracy and time saving - The software handles large complex transactions in the store room like incoming stock, outgoing stock, balanced stock, purchase order, etc. Due to computerization, all the processes and transaction are easily possible within a minute.
2) Minimizes people travel - In preventive maintenance (Figure 2) software shows suggested spares for the task at hand such as pares including spanner number, wrench number, type of oil, etc. This information reduces the trips of worker from site to store room. In other words, it reduces time and effort of manpower.

3) Flexibility - The software offers flexibility for making any changes. In preventive maintenance and shutdown program, user can easily change the frequency, ie, scheduled time. Moreover, any data can be deleted or edited as per requirements.

4) Increases equipment life - With the help of preventive maintenance program, the department conducts regular preventive maintenance. Certainly, proper checkup and lubrication at proper time increases equipment life.

5) Reduces breakdown - The software issues Caution Notice to user when parts cross the warning life, which ultimately reduces breakdown.

6) Reduces wastage of parts - The software shows current state of parts in report form. Current state includes hours used by parts and remaining hours of life. In absence of such monitoring system the parts are replaced on the basis of visual inspection, where unnecessary wastage of the parts may occur.

7) Help to decide the need for retrofitting - Software provides all maintenance history reports like machine failure reports, part failure reports, reason of part failure, and failure intensity. By studying all reports, the design engineer can easily judge what has happened to which component and with what frequency. Where frequent failures occur, more frequent retrofitting may be necessary. Sometimes, instead of retrofitting, standby equipment may be applied.
8) Password system - This software can be secured with a password so that no person in the department can make any changes in database through unauthorized access.

The software is easy to use and is graphical user interface based. Data entry, manipulation, and retrieval are easy and can be done by an average operator. It offers following flexibilities and advantages.

(a) Easily sort the maintenance history records according to requirements, eg, by day, by month, by year, and by dates.
(b) Provide an easy way for single person to sort work orders and is also secured by password.
(c) Print up-to-date lockout procedures and report of all work orders, failure tasks, spare parts, etc, automatically.
(d) Provide current status of outstanding work order.
(e) Record all service call (who, what, when, where, and how) that can be printed in a log format with outdated time/date stamping.

(g) Provide reports for budgets, staffing, evaluation, and performance.
(h) It has the ability to generate equipment history from birth (installation/construction) with all major repairs and summaries of small repairs.
(i) Provide reports of charging back maintenance cost to department/cost center.
(j) It generates report of MTBF, which show how often the unit has been worked on, how many hours have lapsed between failures, and duration of each repair.
(k) This system is compatible with local area network and can be integrated to purchasing, engineering, payroll group and accounting.
(l) It draws immediate attention to problems before any major incident happens.
(m) It is able to display work load for preventive maintenance for a future period such as a year, week, or month by trade.

5 | CONCLUSION

In the present article, the parameters concerned with maintenance optimization of various auxiliaries in a CHP have been analyzed using Visual Basic 6.0–based scheduled program. A software program has been developed for effective maintenance of a CHP that can reduce the breakdown time by predicting the faults which may occur in near future. This paper also discusses the utility of the software to examine important parameters such as preventive maintenance, machine failure record, and performance reports in a CHP. The performance reports give its outcomes by evaluating the mathematical calculations, maintenance history, and graphs. The findings of the performance report are presented in the form of reliability calculation, MCDT, availability, failure rate, etc. Therefore, the use of this software can reduce the breakdown time and thus increases the productivity of the firm. Furthermore, wastage of parts is reduced because they are replaced only when their life is over. Keeping a costly machine idle for long time due to sudden breakdown can be a great loss to the firm.

The developed program helps in preventive maintenance, shutdown, and part replacement at the right time; hence, the following parameters are improved.

- Overall plant effectiveness,
- Reliability and availability,
- Improved safety/lesser accidents,
- Energy saving,
- Higher production volume,
- Time saving, and
- Improved productivity.

The developed scheduling program is versatile in nature since it can be used in any type of plant and does not depend on the plant size or number of components in the plant. Therefore, this type of methodology can be applied on a larger scale for effective scheduling of the whole industrial unit. Further research can be done on the application of computing tools like genetic algorithm, fuzzy logic, artificial neural network, etc, which can use the outcomes of the current program to better predict future failures.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.
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