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An Expert System to Measure the Effectiveness of the Performance of Maintenance and Operations in Industrial Projects to Treat Water Units

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Abstract: ***The aim of this study is to seek and identify the role of an expert system to measure the effectiveness of the performance of maintenance and operation operations in industrial projects to treat water units in order to carry out maintenance operations, improve production efficiency and ensure the continuity of the work of devices by reducing the interruptions resulting from holidays and at the lowest possible cost in addition to ensuring the quality and quantity of production At the level that the administration aims at, and the interest in the field of operations research increased through the design and development of some systems and scientific methods for maintenance and replacement, which included building methods for maintenance and replacement policies, as well as interest in the examination and control method, building methods for planned maintenance and replacement methods, as well as working on building information systems for maintenance management equipped The administration provides information about the assets of devices and equipment, control of the stock of spare materials, determination of the period of planned maintenance programmes, information about vacations and the time of their occurrence, and information about the cost of maintenance. These methods and systems have contributed to assisting the administration in solving the problems it faces, especially the problems of scheduling, manpower planning in maintenance, controlling inventory, designing a work manual for maintenance systems, and it then choose the appropriate policy for maintenance and replacement. And through the application of the program on the computer using the Foxpro program and using the Prolog language and from during the windows used in the program, it was tested according to the standards set, and it was found that there is a feasibility of using it the expert system in maintaining and replacing water units and calculating the cost through virtual data.***

Keywords: Expert System, Effectiveness, Performance of Maintenance, operations, industrial projects, treat water

1. Introduction

The maintenance programmes of devices and equipment have a significant impact on the sustainability of the production process. The objective of performing maintenance operations is to enhance production efficiency and guarantee the availability and continuity of device operations by minimising interruptions arising from holidays, while keeping costs at a minimum. Furthermore, it is imperative to ensure that the quality and quantity of production align with the administration's objectives. There has been a growing interest among researchers and industrial management professionals, particularly those specialising in operations research, to create and implement various systems and scientific methodologies for maintenance and replacement. These efforts have included:

The study aims to develop methodologies for maintenance and replacement policies. This includes the development of a methodology for selecting the most suitable maintenance and replacement policy (Taher, 1994), a methodology for inspection and monitoring, (Christer & Waller, 1984; Christer, 1982), methodologies for planned maintenance (Christer & Waller, 1984), and methodologies for the replacement process. Maintenance activities do not encompass it. Nevertheless, in numerous instances, the determination to substitute is made on the grounds of an evaluation of maintenance expenditures (Murthy & Nguyen, 1983; Phelps, 1985), (Nakagawa, 1985; Woodman, 1967; Al-Najjar, 2021). The development of information systems for maintenance management is a crucial area of focus, encompassing various aspects such as asset management, spare material inventory control, scheduling of planned maintenance programmes, tracking of employee vacations, and cost analysis of maintenance activities. These systems aim to provide the administration with comprehensive and accurate information pertaining to the devices and equipment under their purview.

The utilisation of various methods and systems has facilitated the resolution of administrative issues, particularly those related to the scheduling of manpower planning in maintenance, inventory control, development of workshop manuals and systems for maintenance, as well as the selection of suitable maintenance and replacement policies (Taher, 1994; Christer, 1983; Sobeih, 1992).

2. The Problem and Objectives of the Study

Although there are researchers who are interested in developing programmes and systems for maintenance, it is imperative for the administration to have an integrated and user-friendly system that can evaluate the performance of maintenance and operation operations in a scientifically realistic manner. This is due to the challenges associated with utilising complex mathematical methods in maintenance. The maintenance and operation of devices and equipment are crucial for their sustained functionality and uninterrupted workflow. These two processes are interdependent, and the efficacy of one process directly impacts the other. In industrial settings, the maintenance department is typically integrated within the production operations department, with the responsibility of ensuring the optimal operation of devices and equipment. Developing a system for evaluating the efficacy of maintenance and operational activities can aid management in formulating

suitable policies for these functions, with the aim of minimising downtime and enhancing equipment availability and workflow continuity.

The swift advancement of computer technology was concomitant with the utilisation of said technology in the creation of operations research methodologies, which encompassed the development of intelligent software and decision-support systems. The objective of this study is to develop a computer-based system for assessing and appraising the efficacy of maintenance and operation activities. This will be achieved by gauging the performance of the fundamental components that impact the efficiency of these two operations. To facilitate decision-making for the maintenance department. The system is comprised of two components:

A system for measuring performance deviation. This section employs a multi-criteria approach to assess the performance deviation of various factors that impact maintenance and operation.

The framework for generating reports and analysing deviations. This section involves the preparation of essential reports in a tabular format for the purpose of facilitating the identification of performance deviations. The analysis of deviations is also conducted to assist system users in identifying the underlying causes of such deviations and determining appropriate remedial measures.

First: Building a system of maintenance and auxiliary operation

The life cycle of devices and equipment consists of three important periods (Sobeih, 1992):

a) The period of study and establishment of the project and its components of devices and equipment.
b) Operation period.
c) The replacement period.

Where the maintenance period starts from the operating period and ends with the period of replacing devices and equipment, so the maintenance and operation processes are two inseparable and important processes for managing operations. In addition, bad operation will inevitably affect the performance and effectiveness of maintenance, and bad maintenance affects the operation of devices and equipment, as well as the opinions of some of those responsible for managing production operations in industrial establishments that it is not possible to study or evaluate operating performance, and for this the main idea in this research was to build a system An integrated system for evaluating each of the maintenance and operation performance by evaluating deviations in the performance of the factors or elements that affect the performance of these two operations, and relying in the evaluation on the experience of system users, who are often engineers with experience in the field of maintenance and operation.

The system consists of two parts, the first part is building standards for measuring performance deviations, while the second part will build the preparation of reports necessary for decision-making.

1) Build a performance deviation measurement system

The efficacy of a given process is contingent upon various factors or elements that can exert a direct or indirect influence upon it. The efficiency of the production process is influenced by various factors such as technological aspects, workforce proficiency, administrative structure, equipment quality and durability, work methodology and labor-management relations, environmental conditions, financial resources, and other relevant factors. Taher (1994) utilised various factors, including cost, environment, natural conditions, devices, and equipment, to identify and assess the challenges that distribution networks of an electric power institution encounter during holidays. Pintelon and Wassenhove (2013) utilised various factors, including work, financial allocations, devices, equipment, and labour, to evaluate maintenance performance within their system. However, certain factors, such as natural conditions, are beyond control, while others can be managed by the administration. As a result, officials from an electric power production facility were consulted to identify the factors and elements that impact the performance of maintenance and operation currencies in this study. The significance of scientific expertise in this domain is paramount. The performance of maintenance and operation is directly influenced by several factors, including industrial safety, cost, inventory of materials, raw materials utilised in production, produced materials, as well as devices and equipment.

a) The workforce

The human resources constitute a crucial element that exerts a significant impact on the efficiency of maintenance and operation. The proficient expertise and comprehensive training of the workforce facilitate the efficient functioning of maintenance operations, thereby ensuring the uninterrupted operation of devices and equipment. The allocation of personnel is frequently based on their respective technical specialisations. Certain individuals may be situated in the maintenance teams, while others may be situated in the operation and control teams. Production To evaluate the efficacy of the workforce and its influence on the overall performance of maintenance and operation, contemporary benchmarks are employed. Consequently, a set of standards has been devised that aligns with the current scientific landscape.

1) Criteria for the level of instruction. The assessment of workforce proficiency encompasses the cumulative number of employees in both the maintenance and operation teams, with the computation of the variance between the observed and anticipated levels of training.

The approach employed to determine the authentic degree of training involves calculating the proportion of the aggregate number of hours expended in executing or upholding a process within a monthly timeframe, to the total number of hours projected for accomplishing the identical process during that same period. Regarding the anticipated standard, it is computed using the identical methodology, albeit based on preceding years.

The standard level of workforce attrition. This criterion pertains to the depletion of human resources resulting from factors such as resignation, retirement, absenteeism, and other similar causes. The approach employed to determine the factual magnitude entails dividing the aggregate number of employees who departed from the water treatment facility within a given month by the total number of employees who were present during that same month. The anticipated level is determined based on data from previous years.

The criterion for determining overtime hours. The approach employed to determine the factual magnitude entails adding the number of extra working hours performed by maintenance or operation personnel in a given month to the aggregate number of working hours executed during that same month. The anticipated level is derived from previous years' data.

The criterion for evaluating the extent of lost working hours. The lost working hours during a given month, for various reasons, are taken into account. The actual and anticipated levels for the month are determined using the same methodology as previously described, which involves calculating the proportion of lost working hours to the total working hours for both maintenance and operation.

b) Industrial safety

Industrial enterprises adhere to a specific system of industrial safety to ensure the preservation of the safety of personnel, machinery, and apparatus. The management endeavours to minimise workplace injuries to the utmost degree. The impact of the industrial safety factor on maintenance and operation performance is significant. An evaluation was conducted to determine the influence of safety on the aforementioned operations, based on the following set of criteria:

- The standard level of work injury rate refers to the established benchmark for the frequency of occupational injuries that occur within a given population of workers.
- The typical level of equipment downtime resulting from work-related injuries.

The anticipated frequency of work stoppages and injuries in maintenance and operation is determined by analysing historical data and calculating the mean on a monthly basis. Regarding the level in question, it refers to the monthly rate that has been attained.

c) Inventory materials

The efficacy of maintenance and operation is contingent upon the accessibility of certain spare materials. Consequently, a set of criteria has been devised to assess the warehouse material factor and its influence on these two operations.

- The degree of accessibility of essential reserve materials.
- The degree of depletion of reserve materials.
- The extent of spare materials lost.

The anticipated degree of these criteria is determined through the utilisation of monthly averages and historical data.

d) Devices and equipment

The consideration of hardware and equipment is a crucial factor in the decision-making process for maintenance and replacement. Simultaneously, documenting the condition of the devices is regarded as a surveillance mechanism for anomalies and their mitigation by identifying their origins and remedial measures. device functionality can be determined. These criteria serve as a means of evaluating the condition of the devices and gauging their operational efficiency. The efficacy and standards thereof are:

- The mean quantity of stops that did not result in a decrease in production.
- The mean value of the quantity of stoppages that resulted in a decrease in production.
- The mean duration of system unavailability.
- The mean value of the period preceding the malfunction.
- The aforementioned methodology was employed to compute both the anticipated and realised levels on a monthly basis.

e) Raw materials used in production

Certain raw materials, such as acids and raw water, can have an impact on the functionality of water treatment systems within electric power plants. The aforementioned criteria have been employed to assess the aforementioned factor and its influence on the operational process.

- The impact of raw material quality on production loss rate.
- The rate of spent raw materials utilisation.

The degree of accessibility of primary resources.

Furthermore, the expense. The investigators employed ((Taher, 1994), (Christer & Waller, 1984), (Christer, 1982)) the cost element as a metric for selecting the suitable maintenance policy, and cost is one of the parameters that an engineer can employ to assess the effectiveness of maintenance and operational performance. In prior research, the assessment of anticipated and realised levels was conducted.

- The mean level of expenses associated with the upkeep and functioning of a system or equipment.
- The mean value of the cost incurred by overtime hours.
- The extent to which holidays impact the average cost of production loss.
- The mean expenditure on raw materials cost.
- The mean cost of the manufactured materials.
- The mean expenditure incurred on residual materials.

2) Produced materials

The factor of produced materials may serve as a means of assessing the effectiveness of maintenance or operation, based on the subsequent criteria:

- The rate of production level.
- The rate of loss in production.

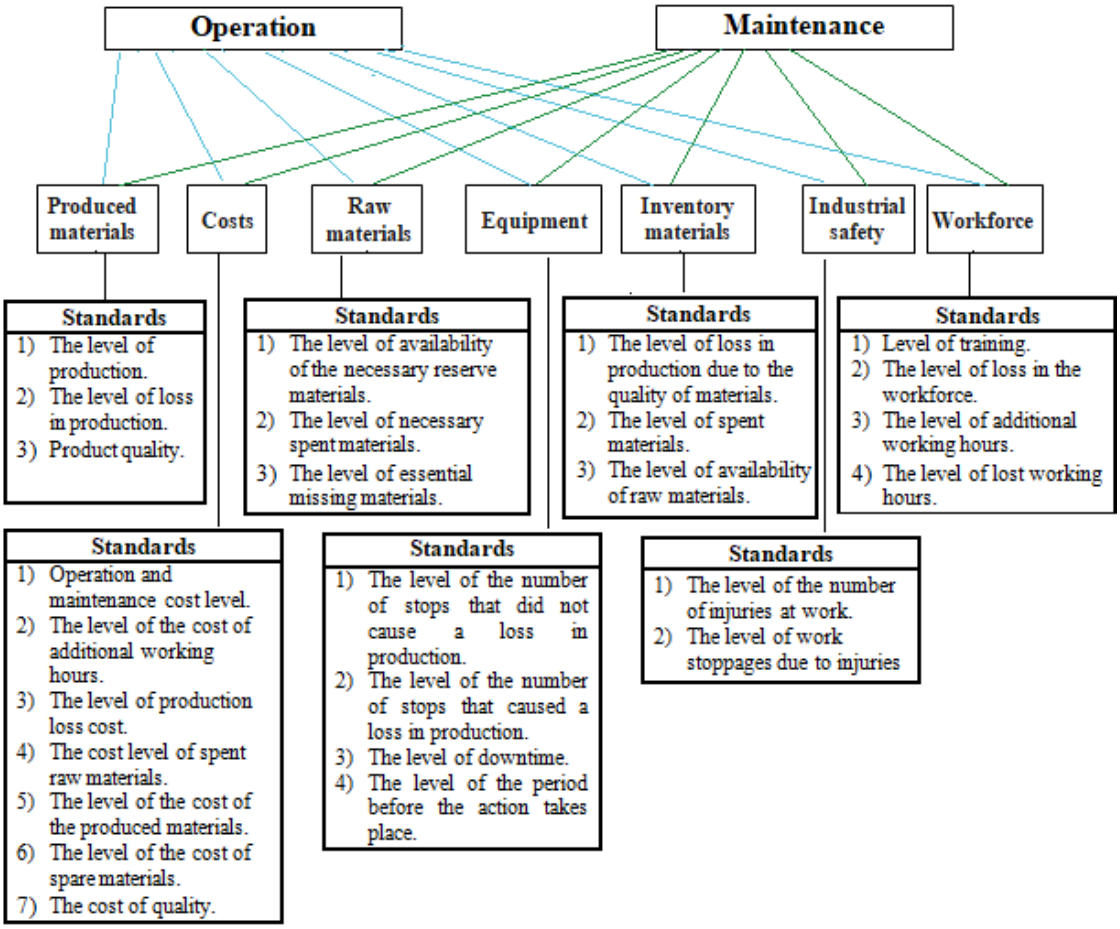

Figure 1: Shows an illustrative chart of the previous factors and criteria and their relationship to maintenance and operation

Following Figure No. (1) shows an illustrative chart of the previous factors and criteria and their relationship to maintenance and operation

Constructing a reporting mechanism and evaluating variances.

3) Compiling and generating reports

The purview of operations research extends beyond the model design and result extraction phase. The phase of scrutinising the outcomes and devising remedies is a crucial aspect of resolving the challenges encountered by the management. Hence, the phase of report preparation and deviation analysis holds significant importance in accomplishing the research objective. The procedure of compiling reports for relevant parties involved in a particular project or organisation. Administrative decisions are typically made using established protocols, with a focus on ensuring that any deviations from these protocols can be readily identified. Hence, tabular and report formats have been utilised to present the actual and anticipated levels for all preceding benchmarks in the reports. The table displays the deviation value of each standard, which is calculated by subtracting the expected level from the actual level.

Table 1: Displays several factors that impact the efficiency of maintenance and operation procedures

Factor	Standard	Maintenance			Operation		
		Actual Level	Expected	Deviation	Actual Level	Expected	Deviation
A-workforce	1) Level of training. 2) Loss in the workforce. 3) Additional working hours. 4) Lost working hours.						
B-Industrial safety	1) The number of injuries. 2) Number of stops.						
c. Equipment and tools	1) Stops that caused a loss. 2) Stops that did not cause a loss. 3) Downtime. 4) Average period before the occurrence of the malfunction.						

4) Analysis and Evaluation of Deviations

Through the value of the deviation between the actual level and the expected level of the performance criteria, it is possible to identify whether there is any problem or defect in the maintenance and operation processes. Therefore, the researcher recommended (Christer, 1983) to monitor the downtime and determine the type of malfunction in order to redesign the maintenance and replacement methods for the perpetuation of the work of devices and equipment. In this research, the researchers followed a system of analyzing and evaluating the deviations resulting from the value of the standards for the performance of the maintenance and operation processes to help the administration control the condition of the devices and take the appropriate decision in the continuity of their work. And addressing them before they affect the durability of the devices. On this basis, the process of analyzing and evaluating deviations is an essential part of the system of maintenance and auxiliary operation, as this process includes identifying unacceptable deviations, as the degree of acceptance depends on:

a) The experience of the engineer or technical officer.
b) Comparing the deviations with what was achieved in the previous period.
c) Comparing deviations with what has been achieved in other institutions.

As for the process of determining the causes of deviations and determining the appropriate treatment, it was formulated by involving a group of experienced people in the industrial sector, as shown in Table No. (2).

Factors	Deviation	Reasons	Treatments and proposals
Workforce	1) An increase in the level of work injuries 2) An increase in the level of overtime 3) An increase in the level of actual working hours to complete a job 4) An increase in the level of lost working hours	1) Failure to follow industrial safety requirements 2) Not being careful in dealing with chemicals 1) Due to work requirements and an increase in production 2) The inability of the staff to perform the work on time 1) The need for water production, shortage of water consumption 2) Incompetence of the functional staff 3) Lack of staff 1) Due to an increase in work injuries 2) Lack of coordination between operation and maintenance groups 3) Bad communication and not reporting the defect on time 4) Bad observation	1) Training workers on industrial safety conditions 2) Raise the efficiency of the job cadre through training 1) Opening training courses for employees 2) Increasing the number of workers in maintenance groups 1) Develop a monitoring program on the devices 2) Follow industrial safety requirements 3) Coordination between the different working groups
Cost	1) High operating and maintenance costs 2) A high level of hardware downtime costs 3) An increase in the level of overtime costs 4) A rise in the cost of the raw materials used 5) An increase in the cost of spent spare materials	1) An increase in the purchase price of raw and reserve materials 2) Bad operation 3) Poor maintenance 1) Poor maintenance 2) The poor quality of the spare materials used 3) Bad operation 1) Incorrect planning of maintenance teams and their tasks 2) Incompetence of the functional staff 3) An increase in the purchase price of raw materials 4) High costs of transportation and stock keeping 5) Waste in consumption 1) Poor performance of maintenance and operation operations 2) Poor quality of backup materials	1) Opening training courses for operation and maintenance workers 2) Reprogram maintenance and follow the appropriate policy 3) Maintenance reprogramming 4) Attention to control the quality of used spare materials 5) Training of employees on operations 1) Reducing the number of maintenance and operation teams 2) Retraining of employees 1) Controlling purchasing, storage and transportation operations 2) Monitoring and planning for the consumption of the necessary raw materials 1) Opening training courses for employees 2) Control the quality of purchased materials
Inventory materials	1) A decrease in the level of spent inventory materials 2) An increase in the level of spent inventory materials 3) A decrease in the level of materials manufactured by the establishment	1) Not using inventory control methods 2) Inability to meet maintenance and operation requirements 1) Inaccuracy of maintenance and operation 2) The inability of workers to perform manufacturing operations	1) Adhering to the appropriate policy in stock control operations 2) Follow the safety limits policy in purchasing and storage operations 1) Reprogramming maintenance operations 2) Training of functional staff

			1) Training of job cadres in the field of manufacturing 2) Material encouragement
Industrial safety	1) High level of work injuries	1) Failure to follow industrial safety requirements 2) Lack of industrial safety equipment 3) Failure to supervise the maintenance and operation operations	1) Opening training courses in the field of industrial safety 2) Providing the necessary equipment to reduce work injuries
Equipment	1) High level of hardware failures 2) An increase in the downtime for necessary maintenance or re-operation 3) A decrease in the continuity of the devices in work 4) High maintenance period	1) Poor maintenance 2) Bad playback 3) Impedance of devices and equipment 4) A change in the specifications of the raw water feeding the unit 5) Resist the films 1) Incompetence of workers in the maintenance and operation teams 2) Lack of technical staff 3) Poor maintenance policy 1) Poor maintenance 2) Bad operation 3) Resist the hardware timeline 1) Not properly attaching parts of the membranes and their accessories 2) Incompetence of the technical staff 3) Failure to complete maintenance on time	1) Convenient maintenance reprogramming 2) Training workers and supervising operations 3) Follow a convenient exchange policy 4) Take appropriate measures to control water specifications 1) Opening training courses 2) Maintenance reprogramming 1) Follow the appropriate exchange policy 2) Reprogram maintenance and operations 1) Training of employees 2) Reuse the appropriate policy for maintenance
Raw materials used in production	1) An increase in the level of discontinuations due to the quality of the raw materials used 2) High production loss 3) Decrease in the availability of raw materials 4) An increase in the amount of raw materials used	1) The poor quality of the raw materials used 2) Disbursement of raw materials in quantities exceeding the specified specifications 1) Unavailability of materials in stock 2) Failure to follow an appropriate policy in purchases 1 1) Bad operation 2) Wastage of raw materials	1) Controlling the quality of raw materials used 2) Auditing of exchange operations 1) Re-plan your purchases 2) Using inventory-controlled methods 1) Training of employees 2) Controlling the disbursement of raw materials
produced materials	1) A decrease in the level of production 2) Decrease in production quality	1) Rise in hardware downtime 2) Unavailability of raw materials 3) High operating and maintenance periods 4) Incompetence of the technical staff 1) Poor operation and maintenance 2) Poor quality of raw materials used and operation	1) Reprogram maintenance and operation 2) Use inventory control methods 3) Training of employees 1) Control the quality of materials used 2) Training of employees 3) Planning maintenance and operation programs

Second: Programming the system using a computer

The maintenance and operation system was programmed on the computer using the program FOXPRO and the PROLOG language, where the necessary database was designed consisting of an arranged list of data in a way that the user of the system can deal with the information easily and quickly, especially when updating or retrieving data when it is in large quantities to make it easier for him to take appropriate decision.

1) The aim of the system

The system aims to assist decision-makers and management in measuring the performance of each of the maintenance and operation processes, where performance is measured by measuring deviations in the performance standards of the elements of the workforce, industrial safety, devices and equipment, raw materials, inventory materials, costs, and produced materials, which are considered the main elements To measure maintenance and operation performance.

2) Turn on the system

For the purpose of operating the system, the Arab window nafitha program is loaded, and then the program is executed. At that point, the main system options screen appears, which is

Operation and Maintenance System
1. System input 2. System reports 3. Exit

When you press the first option using the arrows available on the keyboard and press the back key, a screen appears

showing the types of inputs to be entered into the system, which are:

System Input
1. Manpower Standards Input
2. Industrial safety standards inputs
3. Input standards for inventory materials
4. Input of hardware and equipment standards
5. Inputs of raw materials standards
6. Input standards for the produced materials
7. Exit.

As for when you click on the second option from the main system screen, which is choosing system reports, a screen appears next to the main screen, which is

System Reports
1. Performance measurement report
2. Deviation analysis and evaluation report
3. Exit

As for the performance measurement report, it is shown in Table No. (1), and the deviation analysis and evaluation report is shown in Table No. (2).

Third: scientific application

The maintenance and auxiliary operation system was tested using some unreal data in order to correct some errors and for the system to be easy to use and user-friendly by decision makers, and then the system was applied in one of the water treatment units in one of the electric power production facilities, due to the importance of these units in all industrial establishments. Some engineers and technical officials were involved in the application process, and it included the following axes:

1) Studying and evaluating the database used in the institution
2) Problems collecting and entering data into the system
3) Problems of the process of analyzing and evaluating the results
4) The pros and cons of the system

The process of using the system by the engineers and technicians in this institution did not constitute any obstacle, but the researchers faced some problems in the data collection process if all the data necessary to measure all the standards were not obtained. The data collected from the records of this unit for the period from 1/1/1993 until 31/6/1994 included:

1) The realized monthly costs, which are the costs of maintenance, operation, raw materials, spare parts, production loss costs, and manpower costs.
2) The raw materials spent monthly.
3) Manpower data, including the number of manpower in the maintenance and operation teams.
4) Maintenance operations, including the type of maintenance, date, time taken to complete the work, production loss, and number of additional working hours.
5) Hardware downtime, stop type, downtime, processing.
6) Operations.

This data has been organized in a way that suits the data needed for the system, and the values of the standards have also been predicted based on the data achieved during the data collection period. Through continuous discussions to apply the system, the researchers concluded that some standards are important and others are not important, and that the degree of acceptance of deviations varies from one engineer to another. The system will help them in the decision-making process, fix the defects, and restore the maintenance programs used, due to the large number of problems they face.

Fourth: Conclusions and suggestions

1) The system of maintenance and auxiliary operation is one of the systems that help in administrative decision-making, as it was concluded through field visits to some industrial facilities the extent of their needs for such a system. The reason for the acceptance of engineers and technical officials to use the system is the ease of use and dealing with it does not require much experience in the use of computers.
2) The researchers faced the problem of the lack of some data entered in the system because the database was not available at the time it was not designed for such a system.
3) All possible standards have been formulated and used in this system that affect the operations of maintenance and operation performance, but through application it was concluded that some of these standards are very important to some engineers and technical officials, which are the standards for the condition of devices and equipment, standards for cost and standards for manpower, and there are some less standards It is important and the degree of importance differs from one person to another, so the involvement of most of those responsible for the decision-making process is important in reaching appropriate solutions in case of deviation of performance and the type of maintenance and operation.
4) The majority of the opinions of the participants in the scientific application agreed that the type of equipment outage is important, and therefore it is possible to re-change the stop criterion to include the type of hardware outage to identify the causes of outages that occur to devices and equipment.
5) The researchers suggest redesigning each of the information systems, maintenance, cost, inventory control and manpower system in the industrial establishments in order to ensure the effective use of the maintenance and auxiliary operation system in an integrated manner, as Figure (2) shows the basic components of this integration, provided that the systems include the following matters:
   a) The cost system includes the cost of maintenance according to the type of maintenance, the cost of spare materials used in all types of maintenance and operation.
   b) The inventory control system includes the control of raw materials and spare materials used in all types of maintenance and operation.
   c) The information base system includes maintenance scheduling, maintenance plans, hardware and equipment record, stoppage record, maintenance period, waiting period until repair or restart, lost production time due to maintenance or restart.

d) The manpower system includes manpower scheduling and planning.

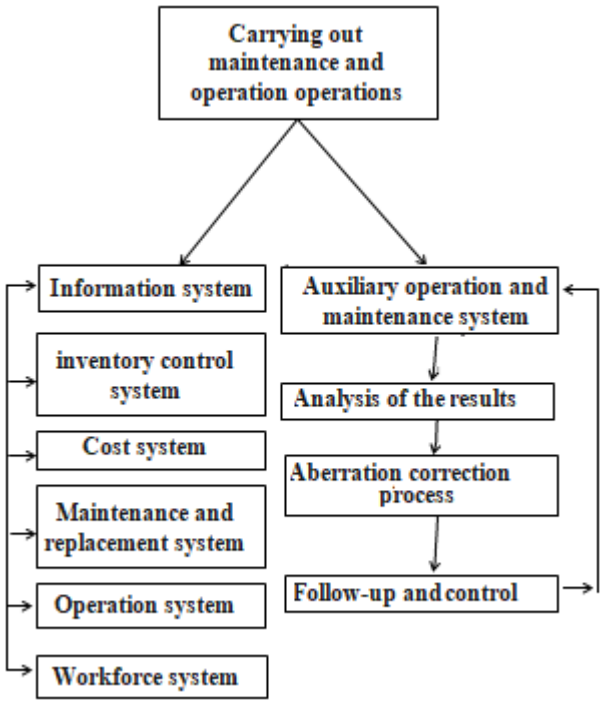

Figure 2

Information system, maintenance and auxiliary operation system

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