Chapter

A Modern Approach for Maintenance Prioritization of Medical Equipment

Călin Corciovă, Doru Andrițoi and Cătălina Luca

Abstract

Maintenance is a crucial topic in the life cycle management of medical equipment. Evidence-based maintenance consists of continuous monitoring of equipment performance, starting from evidence—the current state from the point of view of fault history—and improving its efficiency through the necessary modifications. This process is very important for optimizing the use and allocation of the resources available by the clinical engineering departments. Maintenance of medical equipment consists of two basic activities: scheduled maintenance and corrective maintenance. The purpose of this chapter is to present document-based methods to evaluate every aspect of the medical equipment maintenance process and to provide a correct, objective and standardized approach that supports clinical engineering activities. Following the analysis, the results show that the combination of the use of the two methods provides an overview, in a periodic manner, of maintenance performance that indicates the use of the most appropriate procedures.

Keywords: medical equipment, maintenance strategies, life cycle, health technology management, prioritization

1. Introduction

Within the large and modern hospitals, an increasingly common problem is the efficient management of the maintenance of the medical equipment, the quality of the assistance and the profitability. If effective management of medical equipment maintenance is to be applied, the management structure should apply appropriate planning, management and implementation processes. This is essential for providing quality health services while saving resources. Medical equipment management includes inspection and preventive and corrective maintenance operations [1].

The efficient management of maintenance and repair work must be planned and implemented using appropriate maintenance strategies to keep the devices safe and functional in accordance with the basic functional specifications. In addition to the high initial investments, medical equipment requires continuous and costly maintenance during its useful life. The issue of maintenance is the main point of discussion of the management of medical devices. Studies have shown that the most frequent cause of stopping of medical equipment is poor maintenance, planning and management. To solve this problem, it is necessary to establish and regulate an adequate system for the proper maintenance and use of medical equipment. Perfect maintenance is the equation of performance, risk, resources and costs to achieve this goal [2, 3].

The first maintenance policies developed consist of interventions on equipment, which run until it stops accidentally (breakdown) in place due to wear or because of defects. The intervention is considered satisfactory as long as the equipment/system is operating at a minimum acceptable level (reactive maintenance). The development and increase of the complexity of medical equipment and devices have led to modernizing and updating maintenance techniques and policies. Depending on the costs related to the spare parts and materials, respectively to the losses due to the time spent in repair, several types of maintenance policies have been developed [4].

Due to the way the health services are organized, the technical staff in the health units should not only perform maintenance and repair work but also be actively involved in the acquisition and management of the equipment. For example, they can plan equipment services and manage stocks; they can provide technical consultancy for procurement and can develop technical cost estimates. I can also make budget forecasts regarding the maintenance costs of medical equipment.

2. Maintenance organization: objectives and responsibility for medical equipment

In providing high-quality health services, medical equipment plays an essential role, because when the equipment is not used or properly maintained human damage can occur. In many situations, noncalibration, modification or repair of medical equipment by unqualified personnel can result in injury to the patient or loss of medical record. Preuse testing, preventative maintenance, malfunction reports (and incident reports) and repair procedures are just a few of the necessary actions prior to performing the medical act, to avoid injury caused by the use of medical equipment.

Even if the medical equipment used in the hospital is purchased, rented or borrowed, the commitment to safety is an essential element of any process related to the use of medical equipment. Proper maintenance and proper use of medical equipment ensures maximum efficiency and increased availability of equipment, at optimal costs and under satisfactory conditions of quality, safety and environmental protection [5].

In order to make the process of maintenance of the medical equipment more efficient, it is necessary to consider the use of a maintenance program of the equipment that takes into account its characteristics and the defects that appear to the medical equipment. The application of such a program of maintenance of medical equipment could be effective in applying correct maintenance strategies for the management of the older technological devices and the new high-tech devices, due to their different characteristics.

Maintenance was long considered as a subordinate function, entailing an inevitable waste of money. There was a tendency to lump it together with troubleshooting and repairing machinery that was subject to wear and obsolescence. However, hospitals today are realizing that maintenance is not merely a 'partner' in medical services: it is an indispensable requirement for quality medical services [6]. Its relation with equipment performance is a question of integrated strategy at senior management level. As such, the maintenance function becomes a management responsibility.

The structure that determines the goals and objectives of maintaining medical equipment is very important. If the goals and objectives are progressive, then the maintenance structure is recognized as a contributor to the hospital's foundation line, and thus, variations can be used on some of the more conventional organizational structures.

Objectives of maintenance management: the more specific objectives of maintenance management are as follows [7]:

- To optimize the reliability of equipment and infrastructure
- To ensure that equipment and infrastructure are always in good condition
- To carry out prompt emergency repair of equipment and infrastructure so as to secure the best possible availability for medical use
- To improve operational safety
- To train medical personnel in specific maintenance skills
- To advise on the acquisition, installation and operation of medical devices
- To ensure medical environmental protection

Within the clinical engineering department of any hospital, a crucial aspect of the activities is the activity of maintenance and preventive maintenance of the medical equipment, because it involves significant human and financial resources. Therefore, the optimization of the use of the resources available in the clinical engineering departments is done by evaluating the efficiency of the preventive maintenance programs of the medical equipment [8].

Forms of maintenance:

Maintenance has three major forms:

a. Design-out maintenance

b. Preventive maintenance, which includes systematic (periodic) maintenance and condition-based maintenance

c. Corrective maintenance

These are illustrated in **Figure 1**.

Maintenance can also be divided into planned and unplanned maintenance (or scheduled and unscheduled) (**Figure 2**). The following chart highlights the relation to the previous chart.

Table 1 briefly explains the terms used in the two charts.

The seven forms of maintenance distinguished above are the main types currently used in practice. Although preventive and predictive maintenance strategies differ in many ways, a maintenance program comprising both strategies yielded positive results. The maintenance strategy evaluation demonstrated that strategies based on performance verification and safety testing results and the manufacturers' recommendations led to a significant reduction in equipment failures and a significant increase in corrective maintenance.

An efficient strategy in the correct application of the maintenance of medical devices consists of the use of a maintenance strategy for older devices and another strategy for high-tech devices. We must keep in mind that older medical devices to which only corrective maintenance has been applied cannot be included in

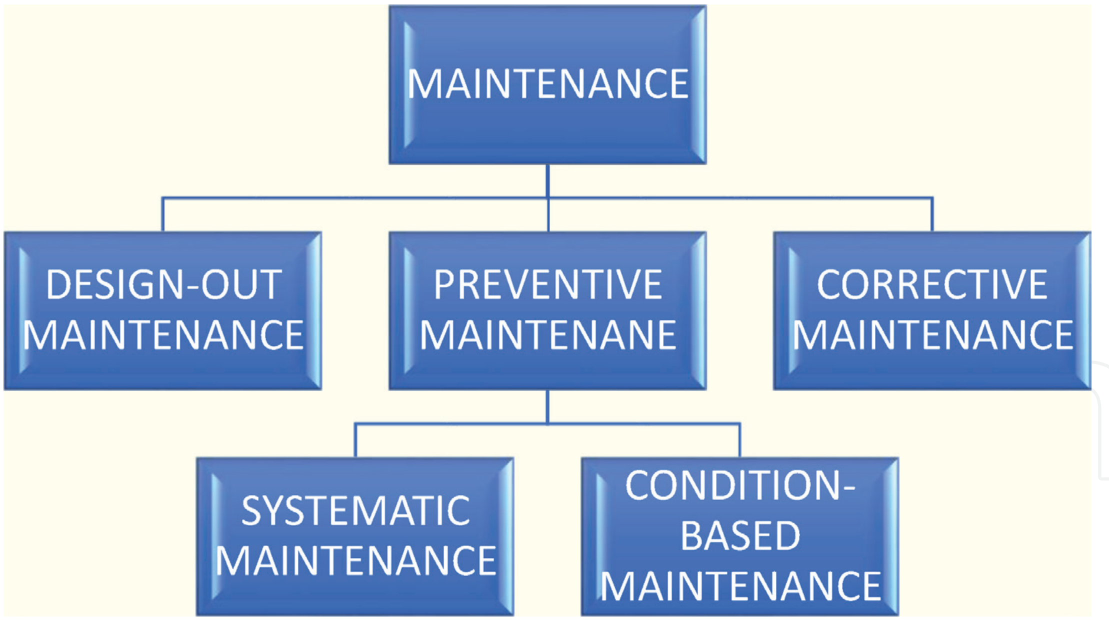

Figure 1.
The forms of maintenance.

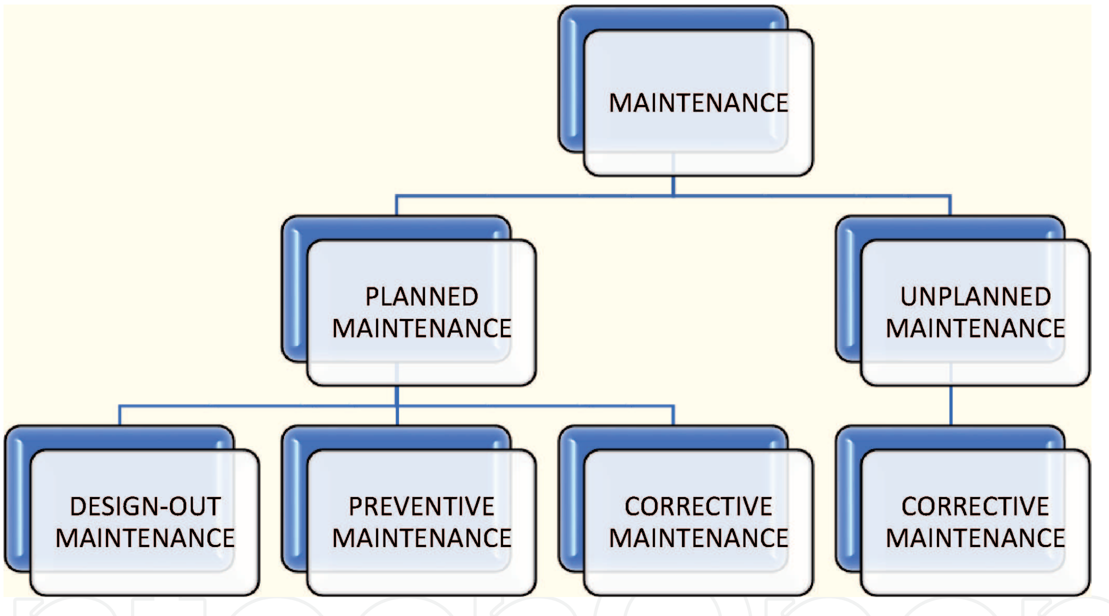

Figure 2.
Planned and unplanned forms of maintenance.

Maintenance	Maintenance is the function whose objective is to ensure the fullest availability of production equipment, utilities and related facilities at optimal cost and under satisfactory conditions of quality, safety and protection of the environment.
Design-out maintenance	This is also known as plant improvement maintenance, and its object is to improve the operation, reliability or capacity of the equipment in place. This sort of work usually involves studies, construction, installation, start-up and tuning.
Preventive maintenance	The principle of preventive maintenance is anticipation. It is put into practice in two forms: systematic (periodic) maintenance and condition-based maintenance.
Corrective maintenance	This is also called breakdown maintenance, palliative or curative maintenance. This form of maintenance consists of the following: • Troubleshooting machines whose poor condition results in stoppage or in operation under intolerable conditions • Repairs

Systematic maintenance	This consists of servicing equipment at regular intervals, either according to a time schedule or on the basis of predetermined units of use (hours of operation or distance traveled). The aim is to detect failure or premature wear and to correct this before a breakdown occurs. The servicing schedule is usually based on manufacturers' forecasts, revised and adjusted according to experience of previous servicing; this information is recorded in the machine's file. This type of maintenance is also called periodic maintenance.
Condition-based maintenance	This type of maintenance of the medical equipment is easy to apply because it does not require the disassembly of the equipment, the same technique based on the inspection by listening to the equipment involved. Predictive maintenance requires continuous observation of equipment to detect possible faults or to monitor its condition.
Planned maintenance	This is maintenance that is known to be necessary sufficiently in advance for normal planning and preparation procedures to be followed.
Unplanned maintenance	This is maintenance that is not carried out regularly as the need for it is not predictable; it is sometimes called unscheduled maintenance.

Table 1.
Short description of the terms of maintenance.

preventive maintenance strategies, such as new high-tech devices. Maintenance costs would increase greatly if we also reported old devices in the maintenance process [9, 10].

The access today is put on performance verification and safety testing in the use of medical equipment, which leads to a change in the maintenance strategies of the devices without necessarily taking into account the manufacturer's recommendations. Also, the decision-making in the management of medical equipment should be based on all the results of medical equipment malfunctions and the existence of a detailed history for each medical device.

3. Performance measurement and maintenance productivity in medical equipment

Performance measurement is a key management tool. In terms of maintenance management, an essential issue is to ensure that the planned and executed maintenance activities have given the expected results. Efficient use of indicators can facilitate this fact. Such an indicator, represented by key performance indicators (Kpi) is able to evaluate important aspects of the maintenance function. To this end, it has been shown that the measurement of maintenance performance is dominated by delay indicators (equipment, maintenance costs and safety performance).

The reduced use of the peak indicators in the maintenance process can also be observed. The obtained results did not show direct correlations between the maintenance objectives pursued and the Kpi used. Subsequent analyzes revealed that only a small part of the companies involved have a high percentage of decisions and changes caused by the use of Kpi and only a few are satisfied with their performance measurement systems. By analyzing the correlation, a strong positive linear relationship was identified between the degree of satisfaction and the changes/decisions of the process that are triggered by the use of Kpi, the people least satisfied with the least decisions and changes triggered by the use of Kpi. These observations indicate some inefficiency of performance measurement systems in improving driving performance [11].

The components of a system, such as pumps, electric or hydraulic motors, transmission systems, etc. as integral parts of it, must operate at optimal parameters to ensure that the overall performance of the device is achieved. Addressing the maintenance problems and establishing the procedures and the maintenance strategy for equipment must therefore take into account both monitoring and diagnosing at the level of each component, but also the influence of the system variables. Most of the time, the cause of a defect is found in the variations of the process parameters, and a nonintegrative approach to monitoring and diagnosing the system can lead to inefficient actions. Thus, in addition to the most popular techniques of monitoring and diagnosis (vibration monitoring, thermography and tribology), other parameters of a system such as flow rates, voltages, currents, temperatures, etc. must be considered.

In systems equipped with computer control or semiautomatic control, most of these parameters are purchased and used in the command and control process. Their type and number vary from system to system, but the algorithm for applying the monitoring and diagnostic procedure is similar. The collection of these parameters, together with the application of the traditional technologies of predictive maintenance, will provide all the necessary data for the analysis of the state and the performances of the system [12].

Since a large part of the equipment used in the medical field belongs to the category of electromechanical systems, the analysis of the maintenance technologies will focus on these, from the simplest (examples: electric motor-pump type drive systems) to complex devices.

It should be kept in mind that, in any system, the maintenance program will focus on its critical components. A critical component is defined as the element directly involved in the proper functioning of the device, on which the entire system depends, its efficiency and, last but not least, the quality of the product.

Some of the technologies for monitoring and diagnosing the state of a system are set out in the following. Vibration analysis is one of the most widely used detection methods to diagnose defects in electromechanical systems. This method measures the vibrations of the system, usually with an accelerometer, and then examines the frequency spectrum generated to identify significant frequencies from the point of view of the state of the equipment. Certain frequencies are typical of the system in normal operation. Changing the amplitude of certain harmonics, for example, can mean the presence of a defect. The data can be collected periodically, using a portable system, or continuously, by installing a continuous monitoring system. A major advantage is that the measurements are fast and noninvasive, and the functioning of the tested system is not disturbed [13].

Another key parameter that can provide information about one's status of equipment/system is temperature. This is an important indicator of the mechanical, electrical or load conditions applied to a component. Thermography is a predictive maintenance technique that uses instruments that can monitor infrared energy emission to determine operating conditions.

Infrared scanning is recommended as a regular maintenance procedure in many situations, extracting solid results as quickly as possible and without interrupting process flow, a key benefit to the industry, regardless of the age of the equipment. As an advantage of scanning a large area in a very short time, the ease with which data can be stored and processed for further analysis of images, the high mobility of the thermography camera that can be positioned at any time and place, the thermographic evaluation that is done uninterrupted and equipment inspection staff who are out of danger are emphasized.

Lubrication fluid analysis can be used to determine mechanical wear, lubrication or fluid condition. The presence of metallic particles in the lubricating fluid suggests the existence of a wear, their analysis providing information on the part subjected to wear. For fluid analysis, it uses complex equipment, which is why this method is not so often used in practice.

This strategy prioritizes the training of technicians to maintain an optimal number of actions, very important for essential medical equipment frequently used in medical institutions.

4. Classification and prioritization of medical equipment for maintenance activities

Prioritization of medical equipment maintenance should be performed for each new type of device during the inspection received when the device is added to the inventory. The device will then be assigned a test frequency. Subsequently, the maintenance history of the device will be monitored to evaluate the effectiveness of the maintenance program.

The end point of providing an organizational tool to the biomedical or clinical engineer would ensure the safe and efficient performance of medical equipment. The system must be evaluated on criteria such as:

- Data management for medical devices, manufacturers and suppliers
- Acquisition conditions
- Implementation and management of quality and safety protocols and procedures, including necessary documentation and data
- Carrying out corrective maintenance activities
- Routine procedure planning, such as acceptance testing, preventive maintenance, quality and safety inspections
- Management and monitoring of training provided by manufacturers or technical staff including biomedical engineer or clinical engineer [14]

The risk assessment was divided into four main areas: clinical function, failure avoidance probability, history of incidents and regulatory or manufacturer requirements. Devices would be evaluated on the aforementioned criteria and be assigned a score. The values would be added and a cumulative score is given for each device type. The total score would act as a quantifiable indicator for the maintenance policy. A total score of 12 or more would indicate a semiannual testing, a score between 9 and 11 would require annual testing, whereas a score of 8 or less would suggest a lesser necessity for annual testing, either biannual or no schedule, depending on clinical use. The end result would be an increase in the cost-effectiveness of the test program, less equipment downtime leading to improved patient care and a higher financial return to direct patient care activities.

To illustrate the applicability of risk assessment criteria, we evaluated two types of devices extensively used in healthcare: the defibrillator and the enteral feeding pump. Defibrillators are devices that correct or prevent arrhythmias (e.g., ventricular fibrillation and ventricular tachycardia) by sending an electrical impulse to the heart. External defibrillators, in particular, send high electrical impulses through the thoracic wall, stopping the independent action of the individual myofibers, so that the intrinsic pacemaker can take over. A set charge, between 0 and 360 J, is generated and delivered through paddles or disposable electrodes through the chest wall to the heart, determining a global contraction. Most defibrillators include an electrocardiograph to monitor the patient's rhythm, while others even include the pacer function. The clinical use is typically for emergency heart pacing such as severe bradycardia, asystole, pacemaker failure or ventricular fibrillation.

For this particular type of device, the assessment should include electrical safety evaluation—ground wire resistance, chassis and lead leakage—and inspection of parameters' performance, which includes measuring the energy output of the defibrillator throughout its range. This would include determining the value output at the lowest, midlevel and highest settings. The range of error should be with 15% of the set energy level (for 360 J, the output should be ranging from 206 to 414 J). Other performance tests would be determining the output levels at maximum setting for 10 charge cycles. The final output should still be within 15% of the recommended setting and charge time should not exceed 15 seconds. The appraisal for functional assessment frequency would be twice a year (**Table 2**) [15].

Enteral feeding pumps are used in patients who have gastrointestinal complications and who cannot consume adequate nutrients for certain reasons. The feeding solutions are transmitted to the patient through temporary feeding tubes or surgically implanted. These pumps can precisely control the flow of liquid supply solutions that are administered entirely through the digestive tract. These pumps are based on a pump mechanism such as a rotary peristaltic pump, a linear peristaltic pump or a volumetric pump. Most pumps record the dose frequency, dose settings and volume infused into memory. Audible and visual alarms alert the user to flow changes or malfunctions.

The quantity of volume delivered must be within 10% of the established volume. Thus, for a set volume of 10 ml, the measured volume must be between

Criteria	Risk	Score
Clinical function		
No patient contact	1	
Device may make contact with the patient who is noncritical	2	
Device is used for patient diagnosis or direct monitoring	3	
Device is used to deliver direct treatment to the patient	4	
Device is used for a life support	5	**5**
Problem avoidance probability		
Maintenance would not impact reliability of the device	1	
Common device failure modes are unpredictable	2	
Common device failure is predictable and can be avoided by preventive maintenance	3	
Specific regulatory requirements dictate preventive maintenance or testing	4	**4**
Incident history		
No history	1	
A significant history of incidents exists	2	**2**
Manufacturers/regulatory requirements for specific schedules		
No requirements	1	
There are requirements for testing	2	**2**
Total		**13**
Times per year tested	**2 (hight level)**	

Table 2.
Sample risk assessment for defibrillator.

Criteria	Risk	Score
Clinical function		
No patient contact	1	
Device is in contact with the patient who is not critical	2	
Device is used for patient diagnosis or direct monitoring	3	
Device is used to deliver direct treatment to the patient	4	**4**
Device is used for a life support	5	
Problem avoidance probability		
Maintenance would not impact reliability of the device	1	
Common device failure modes are unpredictable	2	**2**
Common device failure is predictable and can be avoided by preventive maintenance	3	
Specific regulatory requirements dictate preventive maintenance or testing	4	
Incident history		
No history	1	**1**
A significant history of incidents exists	2	
Manufacturers/regulatory requirements for specific schedules		
No requirements	1	**1**
There are requirements for testing	2	
Total		**8**
Times per year tested	**1 (normal)**	

Table 3.
Sample risk assessment for enteral feeding pump.

9 and 11 ml. The measured occlusion pressure must be within 1 psi of the pump occlusion pressure. For an occlusion pressure of 20 psi, the measured pressure must be between 19 and 21 psi. The recommended frequency of the functional test is annually (**Table 3**).

Before returning the equipment to medical personnel, it must be ensured that it has been adjusted to the original specific settings. Make sure that the volume of the audible alarms is loud enough to be heard under normal operating conditions [15].

5. Maintenance optimization models

Maintenance costs represent a large part of total cost functioning of health systems. Depending on the specifics of each device, the costs of maintenance can represent from 15 to 60% of the value of the expenses. For the situation in which the equipment works in safe conditions until a certain level of wear or a defect in the initial state has been established, we discuss about preventive and predictive maintenance. In such cases, the equipment will be stopped at an early date, and the repair will only be done where needed. This type of maintenance allows the early detection, localization and identification of the defect or the worn part, as well as the calculation of the operating life in safe conditions of the device. The activity of preventive and predictive type makes possible the planning of the stop, the preparation of the intervention team, the provision of the necessary spare parts and respectively the minimization of the parking time for repair [16].

Predictive maintenance represents a superior qualitative leap in a modern maintenance system, regardless of the domain or the specific production, because it offers all the information needed for the following:

- Early detection of the defects
- Location
- Diagnosis of defects
- Calculation of the operating life in safe conditions of the medical equipment

The common premise from which the predictive maintenance starts is that the periodic or continuous monitoring of the mechanical, electrical or other indicators of the functioning of the systems or processes can provide the data necessary to ensure the maximum interval between the repair and maintenance works, respectively, to minimize the cost of interruptions of maintenance. Unplanned maintenance can be the cause of possible failures, sometimes major. However, predictive maintenance is more than that. It is in fact the means of improving and increasing the productivity, product quality and overall efficiency of the systems in question. Predictive maintenance is actually a philosophy or attitude that, based on operating conditions, allows the optimization of the entire medical system. A comprehensive management of predictive maintenance uses the best methods to obtain the operating parameters of the component subsystems of a medical system, on the basis of which it will schedule maintenance and repair activities. Including predictive maintenance in the general maintenance program optimizes the availability of devices and equipment and greatly reduces maintenance costs. By using the records of the entire care of historical repair components and maintained maintenance, we can make a mathematical prediction model for the entire world.

Classifications of different types of failures and the establishment of policies for analysis involve three different levels: system level, failure peak and component level. Results analyzed can be set for a model for optimizing maintenance/inspection.

5.1 Rejects detection model

It is considered a continuous process so that it can be put into operation or rejected (scrap). The way of monitoring the functionality is as follows: first, check each product; continue checking until the consecutive k linear products are reached (full inspection). From this point, the inspection of the equipment is no longer deterministic, "piece by piece"; they will be chosen randomly, independently of the other, with probability α. Continue random monitoring (partially verified) until a defect is discovered, and then revert to previous monitoring and so on. Suppose the probability of a product being defective is q. It is understood that if a problem is found, the item is removed temporarily or permanently.

$$\frac{\left(\frac{1}{p}\right)^k - 1}{q}, \text{ where } p = 1 - q \tag{1}$$

Average of all relevant product cycle is equal to:

$$P_1 = \frac{\left(\frac{1}{p}\right)^k - 1}{q} + \frac{1}{\alpha q} \tag{2}$$

It can be shown that the proportion of undetected defective items is given by:

$$P_2 = \frac{q(1 - P_1)}{(1 - qP_1)} \quad (3)$$

Another model that offers good results when used in this field is known as "replacing a durable good." This is based on the assumption, for example, that the service life of the equipment is represented by a continuous random variable with the distribution function H and the density h and that a policy to replace the good says that it will happen if it has a major failure or if it is still in operation, it is acceptable to reach a certain "age," say the T years. We assume that the price of similar new equipment is C1, and when the equipment fails, we seriously consider a C2 amount, corresponding to the provision of the equipment.

The average length of a life cycle of equipment can be expressed as:

$$\int_0^T xh(x)dx + T[1 - H(T)] \quad (4)$$

Depending on the distribution of H, which is usually uniform $(0, T_0)$, where T_0 is a standard period, depending on the case, for example 10 years and costs C_1 and C_2, one can estimate the value of T, which will reduce to a minimum the cost of having an older, optimizing device. As in the field of health care, failure prevention is more effective than focusing on remedying them. Repairs are almost always expensive, requiring overspecialized personnel and often expensive parts. However, corrective maintenance is a permanent component of medical technology management.

Corrective maintenance allows a device to maintain its full performance of functions, through effective interventions at the time of a problem. However, this action must be well planned, because it acts not only on the level of symptoms, but also on the level of finding and solving the cause of the defect itself.

6. Life cycle of medical equipment

Users and technical staff have the obligation to maintain medical equipment at a level of safety as high as possible, compared to other types of usual equipment. Most complex medical equipment works, for example, in the intensive care unit. They have an electrical connection that in certain situations of first defect can create injuries or even death of the patient by electric shock. Patients connected to such medical equipment are not able to respond to dangerous conditions or pain. Other types of medical equipment work to support life, and a problem, sometimes even minor in some respects, can lead to the death of the patient when the equipment is used incorrectly or is poorly maintained. The life cycle of medical equipment, from the point of view of media technology management, comprises 4 stages and 9 themes according to current standards (**Figure 3**) [17–20].

An important stage in the life of medical equipment is that of maintenance and repairs that involve certain assumptions and challenges.

Some assumptions are as follows:

- Maintenance culture exists and is respected by the technicians, users and other staff.
- Technical staff are present, trained and know how to maintain and repair the equipment.

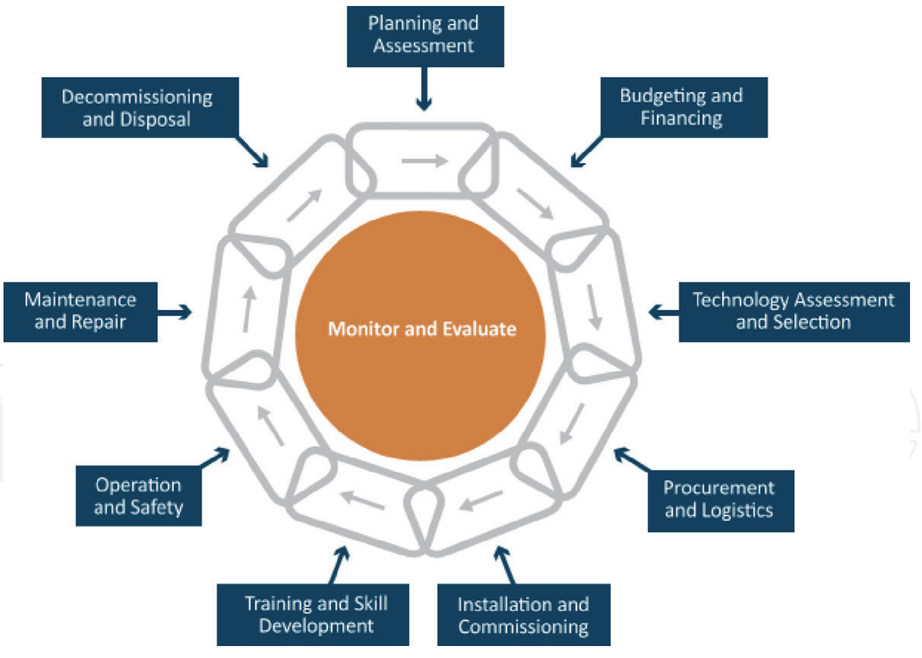

Figure 3.
Life cycle of the medical equipment.

- Preventive maintenance schedules exist and they are performed regularly.
- Technicians have access to spare parts, on stock in the hospital or ordered in and spare parts are delivered within 24 hours if necessary.
- Technicians have access to and know how to use test equipment to calibrate and test medical equipment.

7. Maintenance control system

A maintenance system of medical equipment should be considered as a simple system with inputs/outputs. Inputs to the system are data of defective equipment, materials and spare parts, consumables, data and information on its use, local and global policies and procedures. The result is reliable and well-configured medical equipment that can be achieved only by efficient planning of maintenance and service. The system to be functional has a set of rules that must be implemented. These activities include planning, scheduling, executing and controlling.

The control is performed having as objective the organization and functioning of the maintenance system. The objectives coincide with the organization's objectives and include equipment availability, costs and quality. An important role is played by the feedback that is used to improve the performance of the medical system/equipment [21].

The existence of an effective maintenance control system improves the reliability of the equipment and increases its service life without having unscheduled shutdowns. Maintenance control contains a set of activities, tools and procedures used to coordinate and allocate maintenance resources, including those for specialized personnel, to achieve the objectives of the system, including the following:

1. Work control
2. Quality control and processes
3. Cost control

8. An efficient reporting and feedback system

An essential element of maintenance control is the work order system used for planning, executing and controlling maintenance work. The work order system consists of the necessary documents and the well-defined workflow process. The documents provide means for planning and collecting the information needed to monitor and report maintenance work.

Currently, the process of controlling the maintenance of medical equipment involves four stages:

1. Concrete and coherent setting of objectives and standards: the control process begins with planning; the objectives and performance standards to be pursued are established. Performance objectives must be clear results that must be achieved.

2. Methods of measuring effective performance: the purpose is to accurately determine the results of performance (output standards) and/or performance efforts (input standards). Quantification must be accurate to identify significant differences between what was actually achieved and what was originally planned at the beginning of the process [22, 23].

3. An important role is played by the comparison of the results obtained following the measurements with imposed objectives and standards. This stage is expressed by the control equation: Need for action = Desired performance – Actual performance. Sometimes, a comparison with data from the history of equipment use, data collected from the medical device file, can be taken into account for an evaluation of current performance. Or you can use a relative comparison that tracks the performance of other equipment in the same model, meeting the same standard, used by people with similar training. In comparison, maintenance standards are scientifically established by methods such as time and motion studies. Preventive maintenance routines, for example, are measured in terms of expected time in each routine performed, depending on operating hours or time intervals.

4. Carrying out corrective actions: the last step in the control process is to take all necessary measures to correct problems, nonconformities or improvements. Effective management is one that pays attention to situations that show the greatest need for correction. It saves time, energy and other valuable resources, focusing on critical and priority areas. Maintenance managers must pay special attention to two types of situations: a problematic situation in which the real performance is below the imposed standard and a second situation, of opportunity, in which the real performance is above the standard.

9. Maintenance strategies

The oldest and most common maintenance and repair strategy is "fix it when it breaks." The appeal of this approach is that no analysis or planning is required. The problems with this approach include the occurrence of unscheduled downtime at times that may be inconvenient, perhaps preventing accomplishment of committed production schedules. These problems provide motivation to perform maintenance and repair before the problem arises. The simplest approach is to perform maintenance and repair at preestablished intervals, defined in terms of elapsed or operating hours. This strategy can provide relatively high equipment reliability, but it tends to do so at excessive cost (higher scheduled downtimes) [24]. A further problem with time-based approaches is that failures are assumed to occur at specific intervals. The only way to minimize both maintenance and repair costs and probability of failure is to perform ongoing assessment of machine health and ongoing prediction of future failures based on current health and operating and maintenance history [25–27].

This is the motivation for prognostics: minimize repair and maintenance costs and associated operational disruptions, while also minimizing risk of unscheduled downtime. Preventive maintenance is the strategy organized to perform maintenance at predetermined intervals to reduce the probability of failure or performance degradation. It can be classified into constant interval, age-based or imperfect maintenance:

1. Constant interval maintenance: as the name suggests, it is done at fixed intervals (in addition to any maintenance prompted by failure that is performed when it manifests). Intervals are selected to balance high risk of failure with long intervals and high preventive maintenance costs with short intervals.

2. Age-based maintenance: in this strategy, preventive maintenance at fixed intervals is carried out only after the system has reached a specific age.

3. Imperfect maintenance: in the above to be restored to its original condition after a preventive maintenance. However, it may be the case that the condition of the system is in between good (original) and bad (failure). This is the premise of imperfect maintenance strategies, which take into consideration the uncertainty of the current state of the equipment while scheduling future activities [28–29].

10. Conclusions

Providing quality medical services involves correct and efficient resource management and planning. An important element in achieving this is a balance between costs involved in the investment of new equipment and its maintenance. Proper use and proper maintenance of medical equipment must be supported by a clear policy in the field, technical guidance and practical tools for maintaining the functional parameters of media equipment. By using functional medical equipment, it will be possible to significantly improve the quality of the medical act and the efficiency of such a service. Consistent management practices in this area will help increase efficiency in the field of health.

An analysis of the maintenance of medical equipment is made to assess the lifespan of that equipment, which can be extended or shortened depending on the actions taken. Equipment maintenance is crucial for its lifespan. If maintenance periods are not met, on time and on a regular basis, medical equipment will be damaged to the point where it will cost more to repair than to replace. If no decisions are made at all in the maintenance of medical equipment, it will degrade irreparably. The importance of maintenance activities consists in the efficient management of the equipment; this task requires extensive information about the medical device. Thus, it is necessary to know the history of the equipment, how it has been exploited in the past, to say if the situation is improving and to learn from previous situations.

Finally, records provide staff with valuable technical information and evidence that they can use when they need arguments or need help or additional resources. The maintenance of the database system helps to keep track of repair services and other actions for optimal operation of medical equipment.

Conflict of interest

The authors declare no conflict of interest.

Author details

Călin Corciovă*, Doru Andrițoi and Cătălina Luca
Medical Bioengineering Faculty, University of Medicine and Pharmacy "Grigore T. Popa", Iasi, Romania

*Address all correspondence to: calin.corciova@bioinginerie.ro

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