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Maintenance and Modelling Strategies of Biomedical Equipment's in Hospitals: A Review

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Abstract
This article analyzes recent developments in the derivation of bio-medical equipment's maintenance management strategies, and proposes chary points to consider and affeer to perform during their operation. Medical technology is by now an integral part of health care according to consisting general accepted standards. Purchase and operation thereby represent an important economic position and both are subject of everyday optimization attempts. For this purpose by now exists a huge number of tools which conduce more likely to a complexness of the problem by a comprehensive implementation. In the future, we envision that new paradigms will be structured to overcome the present strategies, and in the longer term, provide an alternative source for maintenance and management of medical devices at hospitals.
Keywords: Biomedical equipment's, Hospitals, Maintenance, Medical Devices, Medical Technology

1. Introduction

In a modern hospital, most diagnostic, therapeutic, and rehabilitation activity is based on the extensive use of medical technologies. The management tools to make strategic decisions depend on the quality of information. One of the equipment manager's most critical duties is determining whether to repair or replace a piece of equipment [1]. Hospital is an integral part of a social and medical organization, the function of which is to provide for the population complete health care, both curative and preventive; the hospital is also a center for the training of health workers and bio-social research (World Health Organization). Hospital is much more complex than other manufacturing organizations, for it undertakes medical and health responsibilities that deal with the lives of people, and it must also account for health economics which is different from economic production in important respects [2].The documentation of equipment maintenance and risk ranking is an extremely important duty relating to these activities [3], [4]. A good maintenance system is required for almost all equipment in order to guarantee its performance, prevent failures and to extend its life expectancy [5].

Medical devices maintenance is an integral aspect of an efficient health system. Preventive maintenance policies have been studied for decades. These policies consider the timing of two types of maintenances: preventive maintenance and corrective maintenances. Corrective maintenance is more costly and time intensive than preventive maintenance, but only occurs when a ma-chine fails. A good preventive maintenance policy considers the trade-offs between more frequent preventive maintenances and the more expensive corrective maintenances [6].

On the one hand, the importance of medical equipment, effective management of such equipment, and advances of this technology in prevention, diagnosis, and treatment of diseases is evident. Without medical equipment, diagnosis and treatment will be done at very basic, insufficient levels. On the other hand, for years extortionate costs have been paid for procurement and maintenance of hospital equipment in the health and medical centers of India and the equipment has been largely supplied by foreign countries. This certainly has had negative consequences for the country and necessitates attention, care, maintenance, and proper use of hospital equipment.

Moreover, incorrect use of medical equipment leads to detrimental consequences for the safety and health of the patient, and malfunctioning equipment due to inappropriate maintenance can affect the health of patients and the performance of hospitals.

The breakdown of medical equipment in service is of particular concern because of its possible use in critical conditions. The signs of equipment failure may not always be apparent to the clinical staff. Therefore scheduled inspections help ensure the safety and efficacy of the medical equipment [7]. Time series forecasting is an important area of forecasting in which past observations of the same variable are collected and analyzed to develop a model describing the underlying relationship. The model is then used to extrapolate the time series into the future, with a promising application in the area of maintenance of medical equipment.

This paper maps out the situation of service management as well as facility management of medical technology and demonstrates a new integrative approach to optimize consisting downtime service maintenance. The concept arose against the backdrop of foreseeable social and technical developments. As a result of social change acting, hospitals and medical technology (equipment and services) providers have to rise to new challenges at the healthcare market.

In this paper different maintenance models are analysed to predict the future status of medical equipment to support decision making. The models are based on real data observation to determine some key parameters of the medical equipment such as Availability, Reliability and Performance Efficiency.

2. Methodology

The medical equipment's are preserved and utilized by using different types of methods and there maintenance is an essential requirement for their lifetime utilization. The few techniques/methods of maintenance of biomedical equipment's are discussed below:

2.1 Data Preprocessing

The past events of maintenance and failure that occurs with medical equipment's for years are observed and scheduled. Job sheets recorded for the case study hospital are analyzed to determine the loading time, uptime, downtime, operating time, standby time and deficiency time, assuming that they were the primary parameters used to extract the main parameters which are availability, reliability, and performance efficiency.

Six signals defined as sequences of data points, measured at specific time intervals are the output of this stage, each representing a main parameter (Availability, Reliability and Performance Efficiency) for an equipment; these signals are the input for the next stage.

2.2 Model Construction

To generate the final model two steps are required which are type selection and order selection. In this work two time series models are selected which are the Autoregressive Moving Average (ARMA) model [8], and the Linear Prediction Coefficient (LPC) model [9]. The commonly used procedure to select the correct order of models is to increase the order of models and calculate the Mean Square Error (MSE) where:

$$\text{MSE} = \frac{1}{N} \sum_{i=1}^{N} (e_i)^2$$

Where:
ei = true value – estimated value (9)
N = the no. of input signal points.
The order with the minimum MSE (MMSE), i.e. when error change is below 0.001, is selected as a valid order of the model [10].

2.3 Machine Parameter Estimation

In this stage, the data obtained in the first stage are presented to the selected models obtained in the second stage. The outputs of this procedure are the estimated values of the machine main parameters. To check model validation, the MSE is calculated between the true value of the machine parameter and the estimated (predicted) value.

3. Methodology for Supporting Workflow Monitoring

Current advances in medical devices allow us to think in a scenario in which all medical equipment's involved in a hospital will be connected to a communication infrastructure. The maintenance operations related to all this devices can then be approached in an automated way taking advantage of the current hospital information applications, as for example, planning tools, data bases of human resources (technicians), etc. Thus, instead of dealing with a burden workflow execution based on manual interaction, the maintenance workflow can be controlled with a computer program.

Monitoring workflow applications have been already deployed in many enterprises related to manufacturing process. But maintenance of medical equipment's has some particularities that require a special infrastructure.

At this point, it is important to distinguish between device monitoring and device maintenance workflow monitoring. On the one hand, device monitoring consists on the design of appropriate strategies for fault detection and diagnosis of a device (or a class of devices), while device maintenance workflow monitoring is related to track the real-time status of flow progress in a maintenance plan. Table 1 shows the main differences between both approaches.

Thus, while monitoring a device, a failure means that the device does not work; while monitoring a maintenance workflow, a failure means that some maintenance task should be finished, but it is not. This

situation will incur in a delay on the maintenance workflow and thus in the device availability. Similarly, a preventive event, while monitoring a device, means this device is subject to some maintenance tasks according to manufacturer's recommendations (consumable replacement for example); while a preventive issue in workflow monitoring is related to periodical or scheduled revision (for example when adjusting maintenance plans for new equipment or when use cases have been altered) so the overall maintenance process can be improved and optimized. Finally, prediction events are related to anticipative actions. In the case of device monitoring several techniques can be used to predict a trend on the equipment status (as for example, "low battery level") that will probably lead to a device failure. Data mining tools are used for this purpose when historical registers are available. Similarly, data mining tools can also be used to analyze workflow execution and recognize similar and past situations in which some deadlines where not accomplished. Based on that information, the maintenance responsibilities can review its maintenance workflow or resources assigned to it, to avoid bottlenecks and to improve the equipment usage. Thus, a monitoring process consists on the following steps:
1) acquire the data required for monitoring; 2) data processing to obtain monitoring parameters; 3) condition monitoring, i.e. evaluation of parameters of condition and determination of their status with respect to their nominal operation conditions; 4) perform a reactive action in case of failure; and 5) perform a proactive action to improve the maintenance workflow. In addition to that, the startup of the monitoring process should be also considered.

3.1 Data Acquisition

The required data to track maintenance workflows is related to actors, events and steps, as stated above. Thus, data acquisition is related to obtain these data, as for example,
- a device status information,
- a spare part has arrived,
- an in-house technician is absent or ill.

This data should be acquired directly from the medical equipment and the hospital information services. Thus, the key issue here is to build an appropriate interface to connect medical equipment and hospital information services in a common infrastructure that enables the maintenance workflow monitoring.

3.2 Data Processing

This step consists on processing the acquired data so that the appropriate maintenance events can be generated. That is, data acquisition is related to raw data sent by different applications/ interfaces. This data should then be interpreted as maintenance events to be handled in the maintenance infrastructure. For example,
- from a device code a failure maintenance event is generated, and thus a maintenance workflow instance should be initiated,
- from a spare part arrival, a maintenance task should be either continued or started,
- from the information about the sick leave the maintenance escalation event should be activated and the maintenance task reassigned to another technician.

3.3 Condition Monitoring

Conditioning monitoring is related to determine the current status of a maintenance workflow instance. Three condition states can be detected:
- Start, when a workflow maintenance instance should be initiated due to a device failure or a device preventive maintenance operation (scheduled maintenance).
- Failure, if a delay is incurred.
- Predictive, when, for example, an overload due to an increase on maintenance operations can be detected and a possible delay on non-priority maintenance tasks can be predicted.

Each condition monitoring state requires a different actuation on the maintenance workflow. First, starting a maintenance workflow instance involves the initiation of a new monitoring process. Second, a failure should be corrected as soon as possible in what it is called the reactive maintenance. And third, a predictive state requires a proactive maintenance.

3.4 Monitoring Start up

For each maintenance workflow running a monitoring process should be started. Since several workflows should be controlled at a time, concurrent approaches should be followed when implementing the workflow monitoring. In this line, agent technology offers, for example, the possibility of organizing the different workflow instances according to several criteria, as the in-house technician responsible of the maintenances and the kind of medical equipment, among other. An additional agent should also assume the role of coordinator, dealing with possible preventive and predictive issues.

3.5 Reactive Action

When a failure occurs, there is a delay in the workflow progress. For this purpose the escalation procedure involved in the workflow should be activated. As a result, the workflow would be dynamically adapted to the new circumstances This includes the actuation on the current patient scheduling so that the delays should be informed to the medical staff.

3.6 Proactive Action

When some information in the system predicts that there could be a failure in the current maintenance workflow instances, several actuations are possible among them, to dedicate more resources to the current maintenance operations, to give priority to some of them, and so on.

4. Limitations

The work and methodology require precise data to get absolute results, which is not possible as the data found is manual/hand written, printed or in other formats. So, it is important for the researcher to get correct data and the hospital authorities to preserve the equipment's.

5. Conclusion and Future Work

Review of several available methods reveals that there are multiple paths that lead from management of medical equipment's to at least an maintenance of medical equipment's that more closely resembles lack of biomedical-clinical support in the hospital's. This apparent incomplete differentiation state likely results from our poor understanding of the mechanisms underlying the developmental shift from support staff to biomedical engineering wing. Moreover, the existing lack of standardization of specification, structure, and functional operations of medical device's has made comparisons between published papers challenging, if not impossible. In this review, we have illustrated the importance of extensive structural and functional operations and we encourage the community to apply various standards during in use medical equipment's. In addition, the use of well-documented and functional biomedical equipment's reference controls is key to the future improvement of maintenance and management strategy generation. This advance will lead to the rapid adoption of ecumenical paradigm and their use in a variety of applications including the study of the mechanisms of human disease and development, and, perhaps in the longer term, as a platform for clinical engineering and to evaluate the efficiency and effectiveness of biomedical equipment's.

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TABLE I

DEVICE MONITORING VS. DEVICE MAINTENANCE WORKFLOW MONITORING

	Device Monitoring		Device Maintenance Workflow Monitoring	
	Event	Action	Event	Action
Failure	The equipment does not work	Repair the equipment	The deadline has expired with no success on the maintenance task	Change the deadline/ scale the problem
Preventive	The equipment will be revised periodically	The equipment is revised periodically	The maintenance workflow is revised periodically	Change workflow parameters relating to statistics on equipment use and downtimes
Predictive	The equipment will fail (it has decreased the quality in its output)	Anticipate equipment maintenance operation	The deadlines will not be satisfied because of an overload in the maintenance service	Re-schedule maintenance workflow