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# Determination of Preventive Maintenance Electrocardiogram Using the Analytical Hierarchy Process (AHP) Method

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***Abstract:*** *Electrocardiogram is a medium-tech diagnostic electromedical device that is widely available in healthcare facilities. Electrocardiogram maintenance is very important to maintain the performance and accuracy of reliable results for medical diagnosis. Suboptimal Electrocardiogram maintenance can be caused by various factors, including user negligence, improper use, component damage, and lack of preventive maintenance. Therefore, this study aims to determine the selection of preventive maintenance strategies on electrocardiograms that are right on target in order to minimize damage, maintain the reliability of the electrocardiogram, and provide optimal maintenance. The research method used is the Analytical Hierarchy Process (AHP). The results obtained from the AHP method are the Warehouse Backup criteria have the highest priority weight of 0.184 and the alternative with the highest priority weight is Periodic Maintenance of 0.3744, then followed by Repair Maintenance (Schedule Overhaul) of 0.3184 and the last is Condition Based Maintenance of 0.3072. The periodic maintenance strategy has the greatest weight, so it is chosen as the most appropriate strategy to be used as optimal maintenance and is expected to be an effective solution so that it can successfully reduce damage and maintain the reliability of the Electrocardiogram.*

***Keywords****: Analytical Hierarchy Process (AHP); Equipment Reliability; Maintenance Strategy; Maintenance; Preventive Maintenance*

## 1. BACKGROUND

Medical equipment is a crucial factor in the provision of healthcare services, both in hospitals and other healthcare facilities. To ensure the equipment is in good condition and functioning properly and to support healthcare services, integrated medical equipment management is necessary (Ministry of Health of the Republic of Indonesia, 2015). Medical equipment is also a significant investment in healthcare facilities and requires significant maintenance costs. It is crucial for healthcare facilities to have a planned maintenance program to ensure the safety, quality, and usability of medical equipment. Regular maintenance is also expected to extend the lifespan of medical equipment.

One piece of medical equipment that requires regular maintenance is the electrocardiogram. An electrocardiogram is a mid-range diagnostic electromedical device commonly found in healthcare facilities. Electrocardiogram maintenance is crucial for maintaining reliable performance and accuracy of results for medical diagnosis.(Siregar et al., 2022). Less than optimal electrocardiogram maintenance can be caused by various factors, including user negligence, improper use, component damage, and lack of preventive maintenance. From the above problems, a preventive maintenance strategy is needed to ensure that medical equipment is safe, high quality, and suitable for use and is also expected to extend

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the service life of the medical equipment, namely by determining the preventive maintenance of electrocardiograms using the Analytical Hierarchy Process (AHP) method.

Previous research related to preventive maintenance strategies, by Wirson, Iwan Krisnadi, compiled Electronic Preventive Maintenance Management Strategy with the SWOT Method (Wirson & Krisnadi, 2019). Research by Arierta Pujitresnani, Mulyatno compiled an Analysis of the Preventive Maintenance Index of Intensive Care Unit Medical Equipment Using the Kano Model and Quality Function Deployment (Pujitresnani & Mulyatno, 2021). Research by Sulaiman Metere, Yasinta Dewi Kristianti, Okta Zenita Siti Fatimah compiled Performance In House Maintenance of Medical Equipment Towards Satisfaction of Medical Equipment Users using Kano's Model and Quality Function Development Importan (Metere et al., 2023). Research by Hülya GÜÇDEMİR, Mehmet Ali ILGIN with the research A Clustering-based Approach for Maintenance Prioritization of Medical Devices in a New Hospital. This research determines group-based maintenance priorities in maintenance planning (GÜÇDEMİR & ILGIN, 2023). Next, Research by Futry Rejeky Sitinjak, Fitriani Tupa R. Silalahi compiled an Analysis of Excavator Preventive Maintenance Strategy Using the Analytical Hierarchy Process (AHP) Approach and Sensitivity Analysis (Sitinjak & Silalahi, 2023). As far as the author has observed, research on implementing appropriate maintenance strategies for electrocardiograms using the AHP method is still limited. This research is novel. This study uses the Analytical Hierarchy Process (AHP) method to select appropriate electrocardiogram maintenance strategies.

## 2. THEORETICAL STUDY

### *Maintenance*

Maintenance is an activity necessary to maintain or preserve the quality of equipment so that it continues to function properly and is always optimally ready for use. Maintenance is a preventive measure to maintain equipment performance under certain conditions, namely the best condition according to its intended use/manufacturer's specifications, which is carried out periodically. Electromedical equipment maintenance can be divided into several categories, including:

Planned maintenance is a preventive measure to restore the performance of a tool to a certain condition, namely the best condition according to its intended use/manufacturer's specifications, which is carried out periodically (daily, weekly, monthly, quarterly, semesterly, and annually). Planned maintenance refers to activities scheduled to be carried out to extend

the life of the device and prevent damage, namely by calibrating, replacing spare parts, lubricating and cleaning the equipment (Minister of Health of the Republic of Indonesia, 2016).

***Periodic Maintenance***

Periodic maintenance, also known as time-based maintenance, is a type of maintenance performed on an object or system on a scheduled or regular basis to maintain its performance, prevent damage, and ensure optimal operation. Periodic maintenance can also be defined as a maintenance process performed at specific intervals after the equipment has been used for operation.

***Repair Maintenance (Schedule Overhaul)***

Overhaul maintenance is maintenance performed at specific intervals, meeting the overhaul standards for each component on the equipment. Overhaul maintenance can also be defined as a type of maintenance performed on an object or system by performing more comprehensive maintenance or even replacing certain components or parts on a scheduled or periodic basis. Scheduled overhauls are performed to restore a unit or component to its standard operating condition.

***Condition-Based Maintenance***

Condition-based maintenance, also known as predictive maintenance, is a maintenance technique based on information gathered through monitoring. Some maintenance systems used include vibration monitoring, sound or acoustic monitoring, and oil analysis or lubricant monitoring. Additionally, other condition-based maintenance techniques include electrical monitoring, temperature monitoring, and the physical condition of equipment.

***Electrocardiogram (ECG)***

An electrocardiogram (ECG) is a recording of the electrical potentials that arise as a result of cardiac activity (Susi Herminingsih, dr., Sp.JP(K), FIHA, 2021). What can be recorded are the electrical potentials that arise when the heart muscles contract, while the action potentials in the heart's conduction system cannot be measured externally because they are too small. Although the electrical potential that arises from the depolarization of a single heart muscle cell is very small, the depolarization of a large group of heart muscles in a parallel position simultaneously can produce an electrical potential that can be measured from

outside the body in millivolts. ECG recordings are usually made on paper that runs at a standard speed of 25 mm/second and a deflection of 10 mm corresponds to a potential of 1 mV.

***Analytical Hierarchy Process (AHP)***

*Analytical Hierarchy Process* (AHP) is a decision support model developed by Thomas L. Saaty (Sitinjak & Silalahi, 2023)This model will decompose complex multi-criteria problems into a hierarchical structure (Hussain et al., 2015), with a hierarchy being a representation of complex problems in a multi-level structure. A hierarchy is a representation of complex problems with several levels, with the first level being the objective, then the level of factors, criteria, sub-criteria, and the final level being alternatives. Some of the advantages of using the AHP method in decision-making (Hillier et al., nd).

a. Helps solve complex problems that are irregular in structure;
b. The decision-making process is not affected by incomplete quantitative data because the assessment is the result of the respondent's point of view;
c. Assessment and measurement of elements is easier because this method is adapted to the basic human ability to assess something.

Steps and procedures for solving problems using the Analytical Hierarchy Process (AHP) method (Ifwadh Hakim, 2023). The steps are as follows:

a. Defining the problem and determining objectives.
b. Creating a hierarchy, problems are arranged in a hierarchy that begins with the general objective, followed by sub-objectives, criteria and possible alternatives at the lowest level of criteria.
c. Conducting pairwise comparisons. Comparisons are made based on the decision maker's judgment, assessing the importance of one element relative to another.
d. Determine the priority for each problem element at each hierarchical level. This process will produce a weight or contribution of the criteria to achieving the goal. Priority is determined by the criterion with the highest weight. The weights sought are expressed in the vector W = (W1, W2,…, Wn). The value of Wn indicates the relative weight of criterion An to the overall set of criteria in the subsystem.
e. Determining the level of consistency, in actual circumstances there will be inconsistencies in a person's preferences.

How to calculate the consistency index (CI) using the following formula:

$$CI = \frac{\lambda \max - n}{n-1} \quad \text{..... (2.1)}$$

Calculating the consistency ratio (CR) is done using the following formula:

$$CR = \frac{CI}{RI} \quad \text{..... (2.2)}$$

*Random Consistency Index*or also called RI is not calculated mathematically from the assessment data, but RI values are already available in tables for various matrix sizes (number of criteria)(Taherdoost, 2017). As in table 2.3 below:

Table 2.1 Random Consistency Index Value

| *N* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

## 3. RESEARCH METHODS

In the initial stage of designing and developing a strategy in determining Preventive Maintenance Electrocardiogram using Analytical Hierarchy Process (AHP). Data collection in this study will be carried out by collecting data on the object being studied, then determining criteria, subcriteria and making alternative decisions, conducting pairwise comparisons by calculating priority weights, calculating consistency ratio values, and calculating alternative weights for decision making. Briefly, the research design can be explained in Figure 3.1 as follows:

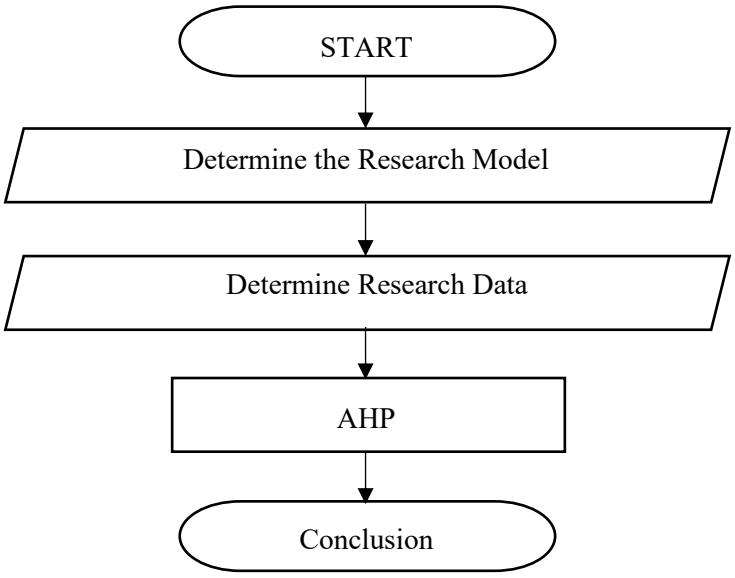


**Figure 1** Research Design.

The data processing carried out is as follows:

a. Determination of Criteria and Subcriteria

   The criteria and sub-criteria used to determine preventive maintenance in electrocardiograms were compiled by collecting criteria and sub-criteria from previous studies. In addition to collecting data from previous studies, discussions and questions and answers were also conducted.

b. Creating a Hierarchical Structure

   Once the criteria and alternatives have been determined, the next step is to create a hierarchical structure consisting of four levels: objectives, criteria, sub-criteria, and the collected alternatives. The purpose of creating a hierarchical structure is to clearly describe the problem and facilitate the determination of preventive maintenance.

c. Creating a Level of Interest Questionnaire

   This section will develop a questionnaire for electrocardiogram users at community health centers. The goal is to determine the weighting of each criterion by comparing criteria and subcriteria. Furthermore, the value of each alternative is determined by pairwise comparisons of each alternative with its subcriteria.

d. Consistency Testing

   At this stage, consistency testing is conducted to verify the validity of the data used in the questionnaire. If the consistency test results are inconsistent, the questionnaire is considered invalid and must be re-evaluated.

## 4. RESULTS AND DISCUSSION

### Identification of Criteria and Subcriteria

In determining the selection of maintenance, criteria are needed that can reflect a good maintenance strategy. The criteria used to select maintenance refer to those listed in Table 4.1.(Justin, 2021).

**Table 1** Maintenance criteria.

| No | Criteria |
|---|---|
| 1 | *Safety* |
| 2 | *Implementation cost* |
| 3 | *Added Value* |
| 4 | *Implantation capability* |
| 5 | *Maintenance performance* |
| 6 | *Stock and material management* |
| 7 | *Support system integration* |

*Source: (Justin, 2021)*

After conducting discussions with competent parties, the criteria of implementation cost, safety, added value, stock and material management are the criteria that are considered important to be considered in selecting a preventive maintenance strategy for Electrocardiograms. For the implementation cost criterion, respondents suggested that it be the cost criterion and stock and material management criteria be warehouse backup. And there are additional criteria that respondents think need to be considered when selecting a maintenance strategy, namely quality criteria, troubleshooting duration and implementation of maintenance procedures. So after identifying the criteria and subcriteria that are considered important in determining the maintenance strategy, the author sets the criteria of quality, cost, added value, troubleshooting duration, safety, warehouse backup and implementation of maintenance procedures as the criteria in selecting a preventive maintenance strategy for Electrocardiograms. The maintenance criteria and subcriteria can be seen in Table 4.2 below. Meanwhile, the hierarchical structure in the problem of selecting a preventive maintenance strategy for Electrocardiograms is shown in Figure 4.1 as follows:

**Table 1** Maintenance criteria and subcriteria.

| ***Criteria*** | ***Subcriteria*** | ***Criteria*** | ***Subcriteria*** |
|---|---|---|---|
| *Quality* | *Conformity of maintenance results* | *Safety* | *Maintenance safety guarantee* |
| | *Ability to provideconsistent improvement* | | *Minimum risk of harm* |
| *Cost* | *Spare part cost compatibility* | *Warehouse Backup* | *Ease of getting spare parts* |
| | *Labor cost compatibility* | | *Spare part management organized* |
| *Added Value* | *Minimum frequency of failure* | *Implementation of maintenance procedures* | *Ease of implementationmaintenance procedures* |
| | *Minimum duration of downtime* | | *Complexity of maintenance procedures* |
| *DurationTrouble shooting* | *Ease of repair* | | |
| | *Speed of repair time* | | |

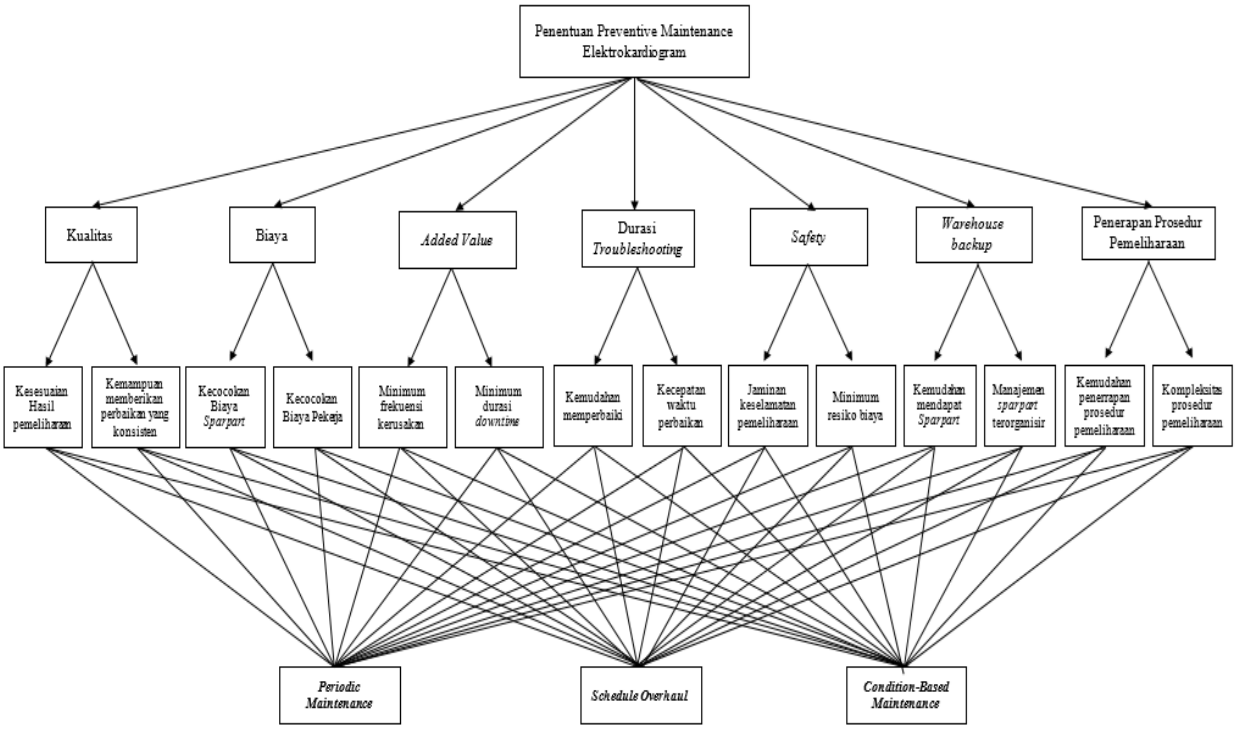


**Figure 2** Hierarchical structure of preventive maintenance strategy selection in Electrocardiogram.

## Criteria Data Processing

In the research conducted and establishing seven criteria used, the following results were obtained based on 14 respondents and the consistency ratio was obtained. If the consistency ratio (CR) value is <0.1, then the comparison is considered consistent. However, if the CR value exceeds 0.1, then the pairwise comparison must be repeated. Based on the data processing results, the weights for each criterion and consistency ratio values were obtained as shown in Table 3 below.

**Table 3** Priority Vector criteria.

| *CRITERIA* | *Priority Vector* | *CR* |
|---|---|---|
| *Quality* | *0.148* | |
| *Cost* | *0.163* | |
| *Added Value* | *0.103* | *0.046* |
| *Troubleshooting Duration* | *0.113* | |
| *Safety* | *0.169* | |
| *Warehouse Backup* | *0.184* | |
| *Implementation of Maintenance Procedures* | *0.120* | |

Based on the data in Table 4.3, it can be seen that the most influential criterion in selecting preventive maintenance on electrocardiograms is the Warehouse Backup criterion with the highest weight of 0.184. In calculating the weight of this criterion, a CR (consistency ratio) value of 0.046 was also obtained. Thus, the data is consistent or valid because the CR value is <0.1.

**Sub-criteria Data Processing**

The overall subcriteria analysis can be obtained through the results of processing the subcriteria data from each criterion. Thus, Table 4.4 shows the overall details of the subcriteria. Based on the data processing that has been done, it can be seen that of the 14 subcriteria obtained from each criterion, the subcriteria that influence respondents in choosing electrocardiogram maintenance are the subcriteria of ease of obtaining spare parts and organized spare parts management with a weight of 0.092.

**Table 4** 2Subcriteria priority weight.

| Subcriteria | Weight |
|---|---|
| Conformity of maintenance results | 0.074 |
| Ability to deliver consistent improvements | 0.074 |
| Spare part cost compatibility | 0.082 |
| Labor cost compatibility | 0.082 |
| Minimum frequency of failure | 0.052 |
| Minimum duration of downtime | 0.052 |
| Ease of repair | 0.057 |
| Speed of repair time | 0.057 |
| Maintenance safety guarantee | 0.084 |
| Minimum risk cost | 0.084 |
| Ease of getting spare parts | 0.092 |
| Organized spare parts management | 0.092 |
| Ease of implementation of maintenance procedures | 0.060 |
| Complexity of maintenance procedures | 0.060 |

**Alternative Data Processing**

Furthermore, the alternative priority weights presented in table 4.5 are obtained and the alternative priority order is summarized in figure 4.2, so that the alternative priority order for selecting preventive maintenance strategies on electrocardiograms can be known from the highest to the lowest respectively, namely Periodic Maintenance of 0.3744, then followed by Schedule Overhaul of 0.3184 and the last is Condition Based Maintenance of 0.3072. So that

with the determination of appropriate maintenance, it is expected to reduce the level of damage to the electrocardiogram and be able to improve performance in accordance with the expected specifications and can provide optimal maintenance on the electrocardiogram.

**Table 5** Alternative priority weights.

| ***Alternative*** | *P1* | *P2* | *P3* | *P4* | *P5* | *P6* | *P7* | *P8* | *P9* | *P10* | *P11* | *P12* | *P13* | *P14* | *Priority* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Periodic Maintenance* | 0.0<br>248 | 0.0<br>300 | 0.0<br>328 | 0.0<br>291 | 0.0<br>203 | 0.0<br>206 | 0.0<br>219 | 0.0<br>205 | 0.0<br>317 | 0.0<br>321 | 0.0<br>283 | 0.0<br>364 | 0.0<br>233 | 0.0<br>226 | **0.3**<br>**744** |
| *Overhaul Schedule* | 0.0<br>245 | 0.0<br>220 | 0.0<br>249 | 0.0<br>285 | 0.0<br>168 | 0.0<br>157 | 0.0<br>181 | 0.0<br>174 | 0.0<br>271 | 0.0<br>268 | 0.0<br>314 | 0.0<br>281 | 0.0<br>185 | 0.0<br>187 | **0.3**<br>**184** |
| *Condition-Based Maintenance* | 0.0<br>248 | 0.0<br>220 | 0.0<br>238 | 0.0<br>240 | 0.0<br>144 | 0.0<br>152 | 0.0<br>167 | 0.0<br>188 | 0.0<br>257 | 0.0<br>256 | 0.0<br>322 | 0.0<br>274 | 0.0<br>180 | 0.0<br>185 | **0.3**<br>**072** |
| | **0.0**<br>**740** | **0.0**<br>**740** | **0.0**<br>**816** | **0.0**<br>**816** | **0.0**<br>**515** | **0.0**<br>**515** | **0.0**<br>**567** | **0.0**<br>**567** | **0.0**<br>**845** | **0.0**<br>**845** | **0.0**<br>**919** | **0.0**<br>**919** | **0.0**<br>**598** | **0.0**<br>**598** | |

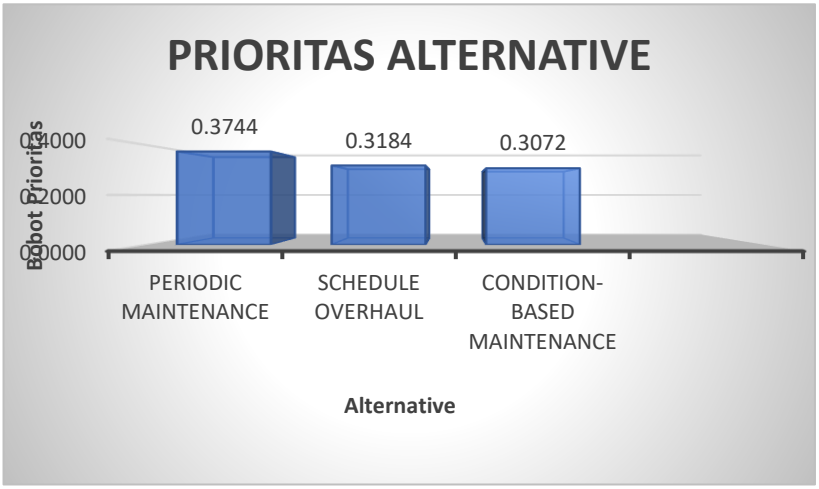


**Figure 3** Alternative Priority Chart.

## 5. CONCLUSION AND SUGGESTIONS

Based on the results of the Analytical Hierarchy Process (AHP) calculations, the alternative priority values obtained in selecting a preventive maintenance strategy for electrocardiograms are Periodic Maintenance of 0.3744, followed by Schedule Overhaul of 0.3184 and finally Condition Based Maintenance of 0.3072.

Based on the research results, the following suggestions are provided: The criteria and sub-criteria from the research results can be used in selecting preventive maintenance strategies for electrocardiograms. Research results using the Analytical Hierarchy Process (AHP) can be considered for use in preventive maintenance strategies for electrocardiograms.

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