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Determination of Maintenance Priority Based on Analytical Hierarchy Process for Magnetic Resonance Imaging

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Abstract : Magnetic Resonance Imaging (MRI) is a high-tech medical diagnostic equipment that plays an important role in healthcare, but in its operation it faces problems in the form of very large maintenance costs. This is due to the complexity of MRI technology, where the main unit of MRI is an imported product, while supporting equipment such as UPS, chiller, and AHU system are domestic products, thus impacting the increase in maintenance costs in hospitals and potentially reducing the quality of service. The solution to reduce maintenance costs, because maintenance cost efficiency can increase hospital profits. This study discusses the determination of maintenance priorities on MRI using a multi-criteria-based decision-making model by considering: the age of the MRI, the number of error logs, the condition of supporting equipment, and the expertise of the operator in operating the MRI. The Analytical Hierarchy Process (AHP) method is used with the stages of forming a decision hierarchy, pairwise comparisons, matrix normalization, priority weight calculation, and consistency testing. Data were obtained through questionnaires given to competent respondents, with the object of research at the Orthopedic Hospital, Surakarta, Indonesia. The results of the study indicate that the AHP method can be used to determine MRI maintenance priorities effectively. This is evidenced by the best alternative results, namely the Medium type (0.3372), followed by All Risk (0.3315), and Labor Only (0.3311). The Medium type is the most optimal choice. The AHP method has been proven to provide objective, structured, and accountable recommendations for hospital management in determining maintenance contracts that are appropriate to the technical condition of the equipment and budget constraints..

Keywords : determination, maintenance, MRI, AHP

1. Introduction

Magnetic Resonance Imaging (MRI) is a crucial diagnostic tool in hospitals. It utilizes magnetic fields and radio waves to produce detailed images of organs and tissues without the use of X-ray radiation [1]. These advantages make MRI crucial in the diagnosis of tumors, neurological disorders, cardiovascular disorders, bone infections, and the evaluation of soft tissue and the musculoskeletal system [2]. The reliability of MRI directly impacts diagnostic accuracy, service quality, and patient confidence. However, the complexity of MRI technology and its dependence on supporting equipment such as UPSs, chillers, and AHU systems pose challenges in maintenance management. High maintenance costs and the risk of downtime can impact service levels, break-even points, and a hospital's financial sustainability.

MRI equipment management is a crucial activity that presents serious challenges. This is due to the complexity of MRI technology, where MRI equipment is often imported while supporting equipment (UPS, chillers, and AHU systems) is manufactured locally. This impacts equipment maintenance costs. High maintenance costs can impact the hospital's Magnetic Resonance Imaging service rates. High maintenance costs will impact the hospital's break-even point (BEP) and profitability. The solution is to reduce MRI maintenance costs. Proper MRI maintenance activities will reduce the risk of equipment failure and service disruptions, which can impact consumer confidence in healthcare facilities. Monitoring MRI function by implementing a proper maintenance system can extend the lifespan of MRI equipment. High-tech and complex equipment requires a maintenance system that collaborates with vendors.

Previous research has demonstrated various approaches to MRI maintenance, such as the use of machine learning to predict component failures [4], analysis of reliability, availability, and maintainability based on error log data [5], and the application of the Analytical Hierarchy Process (AHP) to heavy equipment maintenance and medical equipment prioritization [6]. However, none of these studies specifically prioritized MRI maintenance. The Analytical Hierarchy Process (AHP) has been proposed as a method to help determine MRI maintenance, a research gap that needs to be addressed.

This research focuses on the Prioritization of Magnetic Resonance Imaging (MRI) Maintenance. The Analytical Hierarchy Process (AHP) method was used to determine maintenance priorities and develop a multi-criteria decision-making model that considers key factors affecting MRI performance and failure risk. Data were obtained through questionnaires to competent respondents, then processed using the AHP stages including decision hierarchy formation, pairwise comparison, matrix normalization, priority weight calculation, and consistency testing. MRI at Surakarta Orthopedic Hospital, Indonesia, was selected as the research object.

2. Research Methods

Magnetic Resonance Imaging (MRI) maintenance management is generally carried out through operational collaboration with vendors in the form of labor-only contracts, medium-term contracts, and all-risk contracts. Inappropriate maintenance priorities have the potential to increase the risk of malfunctions and service disruptions. A multi-criteria-based decision-making approach is needed that can consider factors such as equipment age, frequency of errors, operator performance, and the risk of failure of supporting devices. This study was conducted at Soeharso Orthopedic Hospital in Surakarta, Central Java, Indonesia. The approach used was based on primary data collection from direct observation. Data collection was carried out by conducting questionnaire assessments of criteria and sub-criteria in weighting alternative decisions for selecting MRI maintenance. The AHP method begins with pairwise comparisons by calculating priority weights, calculating consistency ratios, and calculating alternative weights for decision-making.

2.1. Research methods

This research begins with establishing a model consisting of inputs, the AHP process, and outputs. Inputs are defined by criteria and sub-criteria. Outputs are determined by three alternative options: labor only, intermediate, and all risks. The research model is shown in Figure 1.

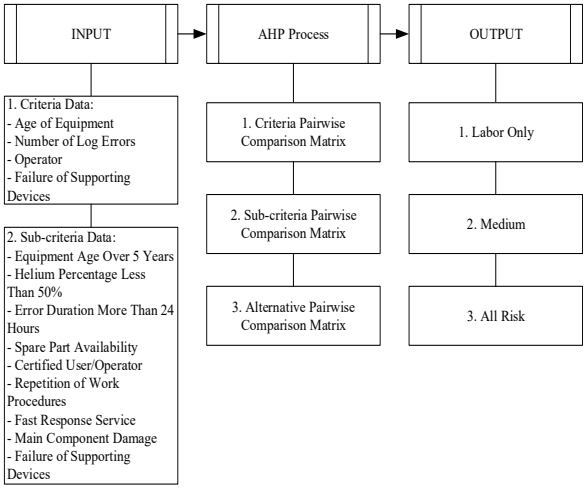

Fig.1. Research Model.

Figure 1 describes a research model consisting of 4 (four) input criteria: equipment age, number of error records, operators, and failure of supporting devices. While the subcriteria consist of 8 (eight) things: equipment age more than 5 years, helium percentage less than 50%, MRI error more than 24 hours, availability of spare parts, job repetition, certified operators, fast handling service, and major component damage. While the output is in the form of 3 (three) maintenance priorities: labor only, medium risk, and all risks as output.

2.2. Research parameters

To facilitate data processing, there are data parameters that will be observed in this study as listed in Table 1.

Table 1. Criteria and Alternative Matrix

Alternative	labor only	Medium	All risk	
Criteria	Equipment Age	Number of Error Logs	Operator	Failure of support systems

The hierarchy of relationships between criteria parameters, subcriteria, and alternatives is shown in Figure 2.

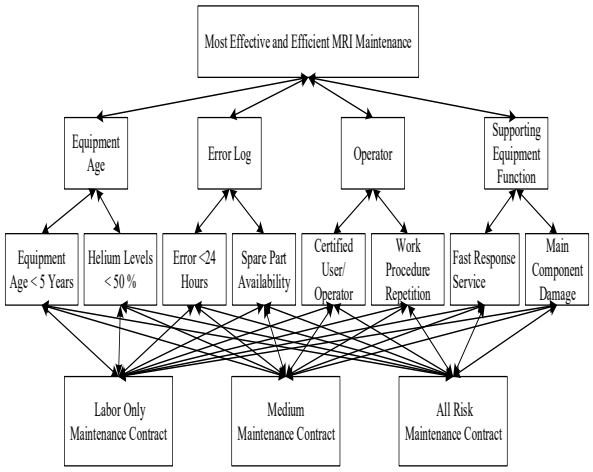

Fig.2. AHP hierarchy as a research framework.

Figure 2 illustrates the relationship between the following parameters: The first level is the maintenance alternatives offered by the vendor as maintenance cooperation options, consisting of labor-only maintenance, intermediate maintenance, and all-risk maintenance. The second level is the sub-criteria that indicate the derived factors of the criteria that affect the MRI condition. The third level is the criteria, and the fourth level is the objectives to be achieved. The relationship between the criteria and sub-criteria is used as a pairwise matrix as the basis for the assessment in weighting. The relationship between other parameters in creating the pairwise matrix also refers to Figure 2. The relationship between the criteria and sub-criteria is shown in Table 2.

Table 2. Criteria and Sub-Criteria

Criteria	**Sub-Criteria**	**Criteria**	**Sub-Criteria**
Usage Age	Usage Age Over 5 Years	Failure of support systems	Rapid response service
	Helium Percentage Less Than 50%		Failure of major components
Number of Error Logs	Errors with Shutdowns of More Than 24 Hours		
	Spare Part Availability		
Operator	Certified Users		
	Repetition of Work Procedures		

2.3. Analytical Hierarchy Process (AHP)

The AHP process begins by creating a pairwise matrix for each criterion, assigning weights on a scale of one to nine. The scale of importance consists of weights ranging from one to nine. Weight values were collected using a preference-ranking questionnaire based on evaluations by MRI operators, MRI technicians, and MRI support equipment technicians. Data is extracted from the questionnaires by summing the scale values of each row in the matrix for each criterion to obtain the geometric mean. Next, data normalization is performed by calculating the consistency index (CI) according to Equation (1) and the consistency ratio (CR) using Equation (2). If the CR value is < 0.1, the data is suitable for use. From the results of the criteria questionnaire, the criteria eigenvectors are calculated. The second step is to collect sub-criteria data from the sub-criteria questionnaire results and then create a pairwise sub-criteria matrix. Subsequently, data normalization is performed, and the sub-criteria eigenvectors are calculated. In the same manner, a pairwise matrix is created for the relationships between alternatives, criteria, and sub-criteria, followed by data normalization. The stages in determining MRI maintenance priorities using the AHP method are designed to simplify the AHP data processing procedure. Each section of the diagram illustrates the data processing stages until the priority weights for each alternative are obtained as the output. The following is an explanation of each stage of the diagram

a. The determination of criteria, subcriteria, and alternatives involves internal and external factors that influence MRI reliability
b. Creation of a pairwise matrix for criteria, subcriteria, and alternatives. The pairwise matrix is created based on AHP principles
c. Collecting questionnaire data based on the pairwise matrix

d. Processing data on criteria, subcriteria, and alternatives
e. Calculating priority weights, eigenvectors, and consistency ratios (CR)
f. Generating consistent data

The AHP data processing procedure is shown in Figure 3, which illustrates the sequence of data processing steps leading to the output of alternative priorities

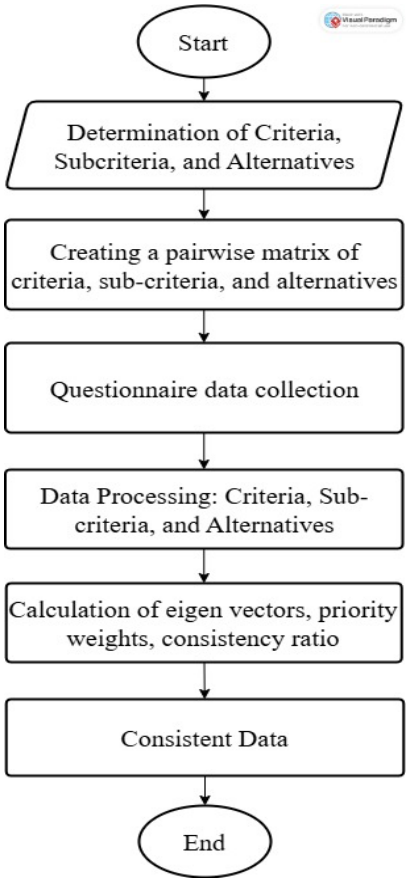

Fig. 3. AHP Process Flowchart.

2.4. Research Stage

This study was conducted in the following stages:

1. Determination of the research model: Selecting the AHP method as the decision-making model to process complex input data in the selection of MRI maintenance alternatives.
2. Identification of criteria and sub-criteria: Determining operational influence factors (equipment age, log errors, operators, supporting equipment) and their specific derivatives, such as helium levels, shutdown duration, spare part availability, and operator certification.
3. Establishment of alternatives: compiling available maintenance contract options, namely labor only, medium, and all-risk.
4. Data normalization and analysis: Process the data by calculating the geometric mean, eigenvectors, and consistency index in accordance with the principles of the AHP method.
5. Consistency Test (CR): Validate the data by ensuring the Consistency Ratio (CR) is <0.1; if it exceeds this limit, data is re-collected to ensure the objectivity of preferences. CR is calculated using equations (1) and (2).

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{\lambda \max - n}{n-1} \quad (2)$$

where: CI = consistency index, $\lambda\ max$ = maximum eigenvalue, n = order of the matrix, RI = random consistency. The values of the Random Consistency Index (RI) are shown in Table 3.

Table 3. Random Consistency Index Values

No	**Indeks Random Consistency (CR)**
1	0,00
2	0,00
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49
11	1,51
12	1,48
13	1,56
14	1,57
15	1,59

If the CR value is 0.1, the pairwise comparison matrix can be considered consistent. However, if the CR value is greater than 0.1, the evaluation must be repeated.

6. Determination of the Optimal Solution: Identifying the best maintenance alternative based on the highest ranking score as the final output of the study. The research stages are illustrated in Figure 4.

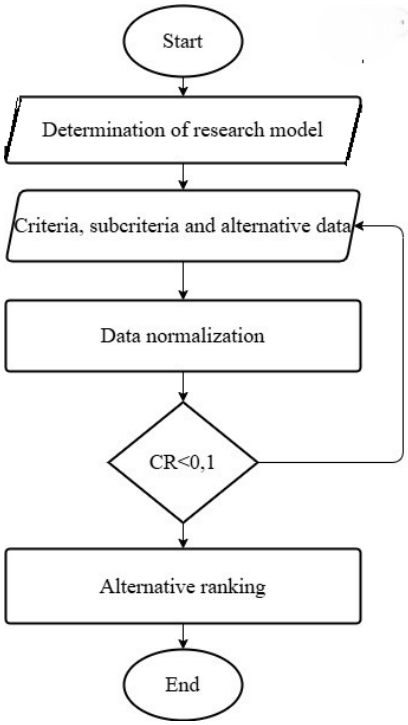

Fig 4. Research Stages

3. Results and Discussion

Referring to the research model shown in Figure 1, the input data includes: criteria, sub-criteria, and alternatives. Data was collected from ten respondents, consisting of: MRI technicians, MRI support equipment technicians, and MRI operators. The data was processed as shown in Figure 4. The data processing began with the processing of criteria, sub-criteria, and alternatives, resulting in a final ranking of the alternatives.

3.1. Results

The alternative priority order for determining maintenance priorities on MRI, as shown in Table 4 and Figure 5, reveals that the alternative priority order for determining maintenance priorities on MRI, from highest to lowest, is as follows: first, medium at 0.3372; then, all risk at 0.3315; and finally, labor only at 0.3311.

Table 4. Priority Weights of Alternatives

Alternatif	P1	P2	P3	P4	
Labor Only	0,0407	0,0407	0,0424	0,0428	
Medium	0,0411	0,0409	0,0430	0,0425	
All Risk	0,0412	0,0415	0,0428	0,0429	
	0,123	**0,123**	**0,128**	**0,128**	
Alternatif	**P5**	**P6**	**P7**	**P8**	**Jml**
Labor only	0,0408	0,0401	0,0414	0,0422	0,3311
Medium	0,0411	0,0420	0,0419	0,0447	0,3372
All risk	0,0416	0,0414	0,0419	0,0382	0,3315
	0,124	**0,124**	**0,125**	**0,125**	

The final scores for each alternative, represented in columns P1 through P8, are calculated by multiplying the final sub-criterion scores by the alternative's priority vector in each category to produce the final sub-criterion scores. The sub-criterion priority vectors are first multiplied by the priority vectors of their parent criteria to ensure a consistent weighting hierarchy. Empirically, the values for P1 (age of use over 5 years) and P2 (helium percentage less than 50%) are obtained by multiplying the sub-criterion final score of 0.123 by the priority vector of each alternative. The values for P3 (errors resulting in shutdowns exceeding 24 hours) and P4 (availability of spare parts) use a multiplier of 0.128. This process continues for P5 (certified users) and P6 (repetition of work procedures) with a multiplier of 0.124, as well as P7 (rapid response service) and P8 (failure of major components) with a multiplier of 0.125. The result of multiplying the final sub-criteria values by the alternative's priority vector yields specific contribution weights, which are then accumulated horizontally in the total column to determine the final priority ranking of the alternatives: labor only, medium, and all risk.

3.2. Discussion

The analysis in this study was conducted by establishing 4 (four) criteria, 8 (eight) sub-criteria, and 3 (three) alternatives. The data were obtained from a questionnaire distributed to 10 respondents. The results obtained were the consistency ratio (CR) of the data distribution. If the consistency ratio (CR) value is < 0.1, the comparison is considered consistent. However, if the CR value exceeds 0.1, the pairwise comparison must be repeated. Based on the data processing results, weights for each criterion and consistency ratio values were obtained, as shown in Table 5

Table 5. Priority Vector of Criteria

Kriteria	Priority Vector	CR
Usage Age	0,246	
Number of Error Logs	0,256	
Operator	0,247	-0,861
Failure of support systems	0,250	

Table 5 shows that the criterion with the greatest influence on determining maintenance priorities for MRI is the number of error logs, with the highest weight of 0.256. Next is the criterion of failure of support equipment, which ranks second in influencing the determination of maintenance priorities for MRI with a weight of 0.250. The calculation of these criterion weights also yielded a CR value of -0.861. Thus, the data is consistent or valid because the CR value is > 0.1.

An overall analysis of the subcriteria can be obtained through the results of processing the subcriteria data for each criterion. Table 6 shows the overall subcriteria weight results

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Tabel 6. Priority Vecktor Sub-criteria

Sub-criteria	**Weight**
Usage Age Over 5 Years	0,123
Helium Percentage Less Than 50%	0,123
Errors with Shutdowns of More Than 24 Hours	0,128
Spare Part Availability	0,128
Certified Users	0,124
Repetition of Work Procedures	0,124
Rapid response service	0,125
Failure of major components	0,125

Based on the data analysis conducted, it can be seen that, out of the 8 (eight) sub-criteria, the two with the highest weights that influence respondents' choice of MRI maintenance priorities are "Errors resulting in shutdowns lasting more than 24 hours" and "Availability of spare parts," each with a weight of 0.128.

4. Conclusion

Based on the results of the questionnaire regarding the selection of criteria and subcriteria, four criteria and eight subcriteria were identified for determining maintenance priorities for MRI (Magnetic Resonance Imaging) systems. The four criteria are: equipment age, error log, operator, and failure of supporting devices. Meanwhile, the eight subcriteria used are: equipment age over 5 years, helium percentage below 50%, errors resulting in shutdowns lasting more than 24 hours, spare part availability, certified users, repetition of work procedures, rapid response service, and damage to major components.

The results of the Analytical Hierarchy Process (AHP) yielded priority values for the alternatives, with maintenance priorities ranked from highest to lowest in the following order: first, Medium at 0.3372; All Risk at 0.3315; and Labor Only at 0.3311. Based on the AHP results in this study, it is concluded that the highest weight is for the Medium maintenance contract, as shown in Figure 5.

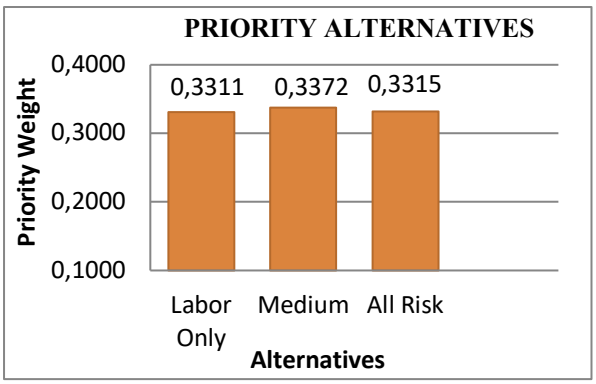

Fig 5. Alternative priority chart

Based on this study, hospital management can use the prioritization method to select a "Medium" maintenance contract for MRI systems. The AHP method has proven to be effective for prioritizing MRI maintenance. The final conclusion of this study is that the "Medium" maintenance contract should be selected.

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