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Implementation of a Mobile-Based Expert System for Anesthesia Type Recommendation Using Bayes' Theorem

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A B S T R A C T

The selection of anesthesia type is a critical stage in surgical procedures that must consider the patient's clinical condition and risk level. Inappropriate anesthesia selection may increase perioperative complications. This study aims to implement a mobile-based expert system to recommend anesthesia types using the Bayes Theorem based on the American Society of Anesthesiologists (ASA) classification. The system was developed by constructing a knowledge base consisting of anesthesia classifications, patient symptom data, and their relationships. System evaluation was conducted by comparing the system's recommendations with expert decisions. The results indicate that the expert system provides accurate anesthesia recommendations. These findings demonstrate that the Bayes Theorem is effective in handling uncertainty in clinical data, and the mobile-based expert system can serve as a decision support tool for anesthesia selection.

INTRODUCTION

Anesthesia is an essential component of surgical procedures and invasive medical interventions. Choosing the wrong type of anesthesia can increase the risk of perioperative and postoperative complications. Therefore, pre-anesthetic evaluation of the patient's condition is a crucial factor in determining the appropriate type of anesthesia [1].

The choice of anesthetic type is a crucial step in medical procedures because it directly affects patient safety before, during, and after the surgical procedure. This decision is influenced by various factors, such as the patient's physical condition, age, comorbidities, type of medical procedure, and the risk of perioperative complications [2]. To help assess these risks, the American Society of Anesthesiologists (ASA) Physical Status Classification System is widely used as a standard for evaluating patients' pre-anesthetic physical condition. The ASA classification serves to group patients based on their level of anesthetic risk, with increasing ASA scores correlating with an increased risk of postoperative complications and mortality [3].

Although the ASA classification has proven beneficial in anesthesiology practice, its assessment process remains subjective and relies on the clinician's experience, potentially leading to inter-rater variability. This variability can affect the accuracy of anesthesia planning and the consistency of clinical decision-making. Therefore, a tool is needed that can systematically and objectively process patients' clinical parameters to support the accuracy of anesthesia type recommendations based on ASA standards [4].

Expert systems are one of the artificial intelligence approaches designed to mimic the decision-making process of an expert thru a knowledge base and inference mechanism [5]. In the medical field, expert systems are widely developed to assist in diagnosis and clinical recommendations when dealing with data uncertainty [6]. Bayes' Theorem method is one of the most frequently used methods due to its ability to calculate the probability of a decision based on available evidence, making it suitable for clinical problems involving many variables and levels of uncertainty, such as determining the type of anesthesia [7].

Based on these issues, this research aims to implement a mobile-based expert system using the Bayes' Theorem method to provide recommendations for the type of anesthesia, considering ASA classification as one of the main parameters. The developed system is expected to improve the accuracy and consistency of anesthesia recommendations, and to serve as a decision support tool for medical personnel in anesthesiology practice.

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METHOD

2.1 Research Stages

The stages of this research are systematically arranged to ensure the development of the expert system proceeds in a structured and scientifically accountable manner. The research stages carried out are as follows:

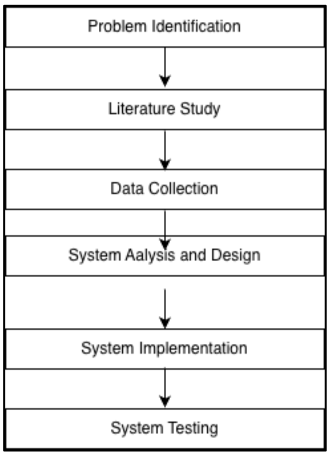

Figure 1. Research Flow

1. Problem Identification
   The initial stage of the research was conducted by identifying the problems that occur in the process of selecting the type of anesthesia. Anesthetic selection is a complex clinical decision because it must consider the patient's physical condition, comorbidities, and perioperative risks, represented by the ASA classification. This process still relies on the subjective assessment of medical personnel, potentially leading to inconsistencies. Therefore, this research aims to develop a mobile-based expert system that can provide objective and consistent recommendations for the type of anesthesia using the Bayes' Theorem method.
2. Literature Study
   At this stage, a literature review is conducted on previous research related to:
   - Expert systems in healthcare
   - Bayes' Theorem Method in Decision Making
   - ASA classification in anesthesiology practice
   - Utilization of mobile applications as a clinical decision support system

   This literature study aims to obtain a strong theoretical foundation and identify research gaps that serve as the basis for system development.
3. Data Collection
   Data collection was carried out to obtain the information needed for the development of the expert system's knowledge base. The data collected included pre-anesthetic patient clinical data, ASA classification, and the type of anesthesia recommended by anesthesia experts.
   Data were obtained thru a review of medical literature, clinical standards, and case studies used as test data in the research. This data is used to determine the initial probability (prior probability) and conditional probability in the calculation of Bayes' Theorem.
4. System Analysis and Design
   At this stage, a system requirements analysis is conducted, including both functional and non-functional requirements. Functional analysis encompasses determining system inputs such as patient data and ASA classification, the inference process using Bayes' Theorem, and the output being recommendations for the type of anesthesia.
   Next, system design was carried out, including:
   - Expert system architecture design
   - Knowledge base and IF-THEN rule design
   - Design of an inference machine based on Bayes' Theorem
   - Mobile application user interface design.

   This design aims to ensure the system can run in a structured, user-friendly manner and meets user needs.
5. System Implementation
   The implementation phase is carried out by realizing the design results into a mobile-based expert system application. In this phase, the system's knowledge base and rules are implemented into the program, and the Bayes' Theorem method is applied as an inference engine to calculate the probability of recommending the type of anesthesia.
   Implementation also includes developing a user interface so that medical personnel can easily use the system to enter patient data and obtain recommendation results.
6. System Testing
   System testing is conducted to ensure that the expert system functions correctly and produces appropriate recommendations. Testing includes functional testing using the black box testing method to evaluate the performance of each system feature.
   Additionally, accuracy testing was conducted by comparing the system's recommendation results against the decisions of anesthesia experts using 30 patient test data points. The test results were used to assess the system's level of agreement and reliability.

2.2 Anesthesia

Anesthesia is a medical intervention aimed at eliminating pain sensation and creating a safe condition for patients during surgical procedures or invasive interventions [8]. A comprehensive pre-anesthetic evaluation is crucial for selecting the appropriate type of anesthesia, reducing the risk of complications, and optimizing clinical outcomes. The American Society of Anesthesiologists (ASA) Physical Status Classification is a widely used tool for assessing patients' perioperative risk based on their medical condition [9]. Although the ASA does not directly determine the choice of anesthetic type, this classification is an important component in establishing an anesthetic plan because a higher score is associated with an increased risk of complications. Integrating these parameters into an expert system using a probabilistic approach like Bayes' Theorem can provide more objective and consistent recommendations for the anesthesia decision-making process.

2.3 Bayes' Theorem

Bayes' Theorem is a probabilistic approach commonly applied in expert systems to calculate the probability of a hypothesis based on available evidence [10]. In various medical domains,

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Bayesian-based expert systems have been used to improve diagnostic capabilities and recommendations based on patients' clinical symptoms [11]. The Bayesian approach is highly relevant for handling the uncertainty of medical data and providing probability-based recommendations that are clinically interpretable [12]. Therefore, in this study, the Bayes' Theorem method is integrated into a mobile-based expert system to calculate the probability of anesthetic type recommendations based on patient data and ASA classification as the primary evidence.

As for the algorithm applied in the Bayes' theorem method, it is [6]:

- Determine the disease and its symptoms (knowledge base)
- Determine the rule base
- Determine the probability based on evidence and assumptions using the formula:

$$P(H|E) = \frac{P(E|H).P(H)}{P(E)} \quad (1)$$

- Calculating the probability result using the formula:

$$\sum_{k=1}^{3} Bayes = Bayes1 + \cdots + Bayesn \quad (2)$$

RESULTS AND DISCUSSION

3.1 Result of The Bayes' Theorem Process

Bayes' Theorem method in this study is used as the basis for forming the knowledge base of the expert system to provide recommendations for the type of anesthesia based on patient conditions. The knowledge base is built thru several main stages as follows.

1. Classification of Anesthetic Types in Patients

   The initial step is to determine the class (hypothesis) in the expert system. This class represents the classification of patient conditions based on ASA, which influences the selection of anesthetic type.

   Table 1. Classification of Anesthetic Types in Patients

Code	ASA Clasification	Description
P01	ASA I	Normal and healthy patient
P02	ASA II	Mild–moderate systemic disease
P03	ASA III	Severe systemic disease
P04	ASA IV	Severe systemic disease threatening life
P05	ASA V	Critically ill patient, unlikely to survive
P06	ASA VI	Brain dead, organ donor

   At this stage, each class is considered a hypothesis (H) in Bayesian calculations.

2. Data on Symptom Types in Patients

   The second step is to define the patient's symptoms or clinical condition that serve as evidence (E). Symptoms are obtained from the results of pre-anesthetic observations and medical interviews.

   Table 2. Data on Symptom Types in Patients

Symptom Code	Symptom	Symptom Value
G01	Low hemoglobin	0.9
G02	Normal hemoglobin	0.8
G03	High Hemoglobin	0.8
G04	Low leuckocytes	0.5
G05	Normal leuckocytes	0.8
G06	High leuckocytes	0.8
G07	Low platelets	0.7
G08	Nomal platelets	0.8
G09	High platelets	0.6
G10	Low blood pressure	0.8
G11	Nomal blood pressure	0.8
G12	High blood pressure	0.6
G13	Low heart rate	0.8
G14	Nomal heart rate	0.8
G15	High heart rate	0.7
G16	Rapid breathing rate	0.8
G17	Normal breathing rate	0.8
G18	Slow breathing rate	0.8
G19	High body temperature normal	0.5
G20	Normal body temperature normal	0.8
G21	Slow body temperature normal	0.8
G22	High blood sugar	0.8
G23	Normal blood sugar	0.5
G24	Low blood sugar	0.8
G25	Tuberculocis	0.8
G26	Not tuberculocis	0.6
G27	Pneumonia	0.8
G28	Not pneumonia	0.7
G29	Coronary heart disases	0.8
G30	Not coronary heart disases	0.7
G31	Enlarged heart	0.8
G32	Heart not enlarged	0.6

3. Percentage Probability of Identification Result

   Table 3. Percentage Probability of Identification Result

No.	Weight Range	Certainty Value (%)	Description
1.	0 s/d 0.2	0 s/d 0.20	Uncertain
2.	>0.2 s/d 0.4	>0.20 s/d 0.40	Less Certain
3.	>0.4 s/d 0.6	>0.40 s/d 0.60	Possible
4.	>0.6 s/d 0.8	>0.60 s/d 0.80	Certain
5.	>0.8	1	Very Certain

   This value is used to interpret the level of confidence in the anesthesia recommendation.

4. Identify the Relationship between Anesthesia Classification and Symptoms

   The relationship between symptoms and anesthesia classification is presented in the form of a conditional probability table, P(E|H).

   Table 4. Identify the Relationship between Anesthesia Classification and Symptoms

Symptom Code	Type of Anesthesia					
	P01	P02	P03	P04	P05	P06
G01			✓	✓	✓	
G02	✓					
G03	✓					
G04		✓	✓	✓	✓	
G05	✓					
G06		✓	✓	✓	✓	
G07			✓	✓	✓	
G08	✓					
G09	✓					

G10			✓	✓	✓	
G11	✓					
G12			✓	✓	✓	
G13						
G14	✓					
G15				✓	✓	
G16				✓	✓	
G17	✓					
G18			✓	✓	✓	
G19			✓	✓	✓	
G20						
G21						
G22				✓	✓	
G23						
G24				✓	✓	
G25				✓	✓	
G26						
G27				✓	✓	
G28						
G29				✓	✓	
G30						
G31				✓	✓	
G32						

3.2 Testing with Bayes' Theorem Method

Test data for patients with a single case study, the sympstoms experienced are as follows:

Table 5. Test Data Patient

Symptom Code	Symptom	Symptom Value
G01	Low hemoglobin	0.9
G05	Normal leuckocytes	0.8
G08	Nomal platelets	0.8
G12	High blood pressure	0.6
G14	Nomal heart rate	0.8
G16	Rapid breathing rate	0.8
G19	High body temperature normal	0.5
G23	Normal blood sugar	0.5
G26	Not tuberculocis	0.6
G28	Not pneumonia	0.7
G30	Not coronary heart disases	0.7
G32	Heart not enlarged	0.6

Based on the symptom-anesthesia classification relationship in Table 4, the patient's symptoms are related to the following classes:

Table 6. Symptom-anesthesia classification relationship

Clasification	Relevant Symptoms
P01 - ASA I	G05, G08, G14
P02 - ASA II	G01
P03 - ASA III	G01, G12, G19
P04 - ASA IV	G01, G12, G16, G19
P05 - ASA V	G01, G12, G16, G19
P06 - ASA VI	-

Since there are 6 classifications, then:
P(P01) = P(P02) = . . . = P(P06) = 61 = 0,167
Calculation of Posterior Probability using Bayes' Theorem Formula:
P(Pi|E) = P(Pi) × ∏ P(Gj|Pi)

Here is the calculation for Anesthesia Type by ASA Category – I, ASA - II, ASA - III, ASA - IV, ASA - V, and ASA - VI:

1. Calculation of P01 (ASA I)
   Relevant symptoms: G05 (0.8), G08 (0.8), G14 (0.8)
   P(P01) = 0.167 × 0.8 × 0.8 × 0.8
   P(P01) = 0.085
2. Calculation of P02 (ASA II)
   Relevant symptoms: G01 (0.9)
   P(P02) = 0.167 × 0.9 = 0.150
3. Calculation of P03 (ASA III)
   Relevant symptoms: G01 (0.9), G12 (0.6), G19 (0.5)
   P(P03) = 0.167 × 0.9 × 0.6 × 0.5
   P(P03) = 0.045
4. Calculation of P04 (ASA IV)
   Relevant symptoms:
   P(P04) = 0.167 × 0.9 × 0.6 × 0.8 × 0.5 = 0.036
5. Calculation of P05 (ASA V)
   Relevant symptoms are the same as
   P04: P(P05) = 0.036
6. Calculation of P06 (ASA VI)
   No matching symptoms:
   P(P06) = 0

Total score:
Total = 0.085 + 0.150 + 0.045 + 0.036 + 0.036 = 0.352
Final probability value:

Table 7. Final Probablity Value

Clasification	Final Value	Percentage
P01 - ASA I	0.241	24.1%
P02 - ASA II	0.426	42.6%
P03 - ASA III	0.128	12.8%
P04 - ASA IV	0.102	10.2%
P05 - ASA V	0.123	10.2%
P06 - ASA VI	0	0%

The results of the Bayesian Theorem method calculation on one patient test data show that the classification with the highest probability is ASA II at 42.6% with a "possible" certainty level. Based on these results, the system recommends the use of local or regional anesthesia. This indicates that the expert system is capable of integrating patient symptom data and knowledge base to generate anesthesia recommendations probabilistically.

3.2 System Implementation Results

This research resulted in a mobile-based expert system that functions to provide recommendations for the type of anesthesia based on the patient's pre-operative condition. The system was developed using a probabilistic approach based on Bayes' Theorem, utilizing patient physical classification according to the American Society of Anesthesiologists (ASA) as the main parameter for assessing anesthesia risk.
Here's the interface of the anesthesia recommendation mobile application:

- Main page interface Anesthesia

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Figure 2. Main page interface Anesthesia

- Type page interface Anesthesia

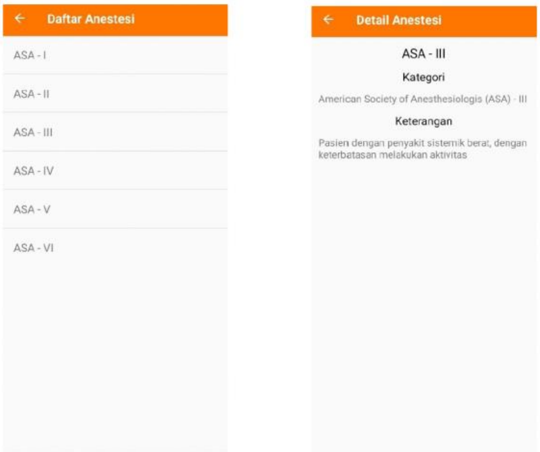

Figure 3. Type page interface Anesthesia

- Type identification page interface

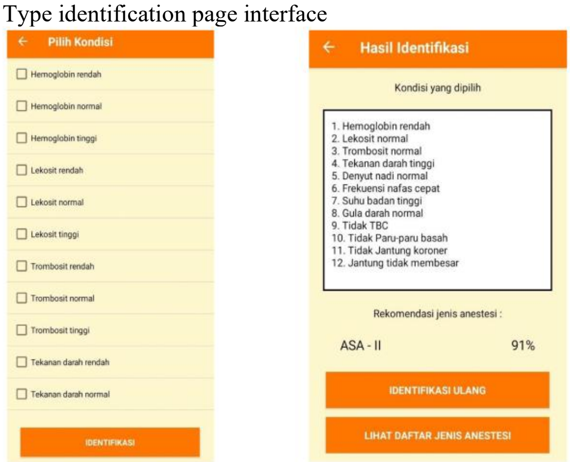

Figure 4. Type identification page interface

3.3 System Functional Testing

Functional testing was performed using the black box testing method to ensure that all system functions operated according to the predetermined requirements. Here is the table of functional system testing results:

Table 7. Black Box Testing Results

Tasted Features	Test Scenario	Expected Result	Test Result	Description
Input ASA Classification	User selects ASA I–V	ASA data received by the system	Successful	Compliant
Bayesian inference process	The system calculates probabilities	The probability of each type of anesthesia is displayed	Successful	Compliant
Anesthesia recommendation	The system displays the recommendation results	The type of anesthesia is shown	Successful	Compliant
Result display	Users see the final results	The information is clear easy to understand	Successful	Compliant

The test results show that all the main features of the system, such as patient data input, the Bayesian probability calculation process, and the display of anesthesia recommendations, function well without any functional errors. This indicates that the system has met the functional requirements as a decision support system for selecting the type of anesthesia.

3.4 Discussion

This research successfully implemented a mobile-based expert system to provide anesthesia type recommendations using the Bayesian Theorem method. The system utilizes the American Society of Anesthesiologists (ASA) classification as a representation of patient risk level and combines it with clinical symptom data to generate probabilistic anesthesia recommendations.

The evaluation results show that the system is able to provide recommendations that align with the decisions of anesthesia experts in most cases. This indicates that the Bayesian Theorem method is effective in handling the uncertainty of clinical data that often arises in the pre-anesthesia assessment process. The probabilistic approach allows the system to not only provide a single decision, but also present a confidence level regarding the results of the recommendations generated.

Some differences in recommendation results were found in patients whose condition was at the transition point between ASA classifications, particularly in the medium to high-risk categories. Clinically, this condition does indeed require additional consideration, such as the type of surgical procedure, the duration of the operation, and the patient's overall physiological condition. Therefore, the expert system developed in this study is positioned as a decision support system and is not intended to replace the clinical decisions of anesthesiologists.

The example calculation of Bayes' Theorem performed shows that the system is capable of processing the knowledge base systematically and transparently. The resulting probability values are used as the basis for selecting the type of anesthesia recommendation with the highest probability. Thus, this mobile expert system has the potential to assist medical personnel in the anesthesia planning process, particularly in the early stages of pre-operative evaluation.

CONCLUSIONS

Based on the research results that have been conducted, it can be concluded that:

1. A mobile-based expert system using the Bayesian Theorem method was successfully implemented to provide recommendations for the type of anesthesia based on ASA classification and patient clinical symptom data.
2. The formation of a knowledge base consisting of anesthesia type classification, patient symptom data, and the relationship between the two can effectively support the system's inference process.
3. The Bayes' Theorem method has proven capable of handling the uncertainty of medical data and generating anesthesia recommendations with a good level of accuracy.
4. The developed system can be utilized as a decision support tool for medical personnel in determining the type of anesthesia before surgical procedures.

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