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ARTIFICIAL INTELLIGENCE-BASED EXPERT SYSTEM FOR DIPHTHERIA DIAGNOSIS

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Abstract

Conventional diagnostic techniques frequently depend on the observational conclusion of lab results and clinical indicators, which can cause delays. Consequently, there is a need for a fast, precise and cost-effective technology to diagnose infectious diseases and thus reduce morbidity and mortality in the under-developed and developing countries. Although numerous research in the medical domain have been conducted by different researchers utilizing diverse diagnosis approach, In this study, A V-P Expert System shell was utilized in the creation of a diphtheria diagnosis system (DDS). This is a rule-based system that employs forward-chaining approach for diagnosis. It consists of three modules, the User Interface to facilitate user interaction, allowing input of queries and displaying result, the Inference Engine to process queries and applies rules to derive conclusions and lastly, the Knowledge Base to store facts, rules, and relationships about the domain. The knowledge base was created by compiling accurate knowledge from medical experts in diphtheria. The system offers a simple, interactive user interface, where diagnosis of patient is achieved based on microbiological and clinical examinations. Preliminary testing shows that the system provides consistent and reliable diagnostic support, making it beneficial for remote areas with limited access to medical experts. However, its accuracy depends on the completeness of the knowledge base, and it may be less effective in cases with atypical symptoms. Future improvements could include expanding the knowledge base and integrating adaptive learning techniques. This automated approach enhances diphtheria detection in underdeveloped regions, improving diagnosis and treatment outcomes.

Keywords: Clinical Decision Support, Medical Expert System, Artificial Intelligence, Diphtheria Diagnosis, Visual Prolog.

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INTRODUCTION

Diphtheria, a potentially fatal infectious disease remains a significant global health concern despite being vaccine-preventable (Samirah, 2023). It is a bacterial disease in which the clinical manifestations result from the action of an exotoxin produced by the causative organism *Corynebacterium diphtheriae*. When there is an adherent membrane lining the tonsils, throat, or nose, the disease most frequently affects these anatomical regions as well as the skin. It primarily transmits between humans by physical touch or respiratory droplets in the air. All age groups are susceptible to the sickness, but children who are not vaccinated are most vulnerable. Myocarditis can occur in up to 25% of patients, and the illness can also impact the peripheral nerve system, occasionally resulting in transient paralysis. Extracellular toxin is the cause of C. diphtheriae's pathogenicity, and those with low antitoxin antibody levels or inadequate immunization histories are more vulnerable to infection (Valles & Barrantes, 2022).

As of January 14, 2024, Nigeria, Guinea, Niger, Mauritius, and South Africa have reported a total of 27,991 suspected and 18,540 confirmed cases of diphtheria, with 828 fatalities (Austin & Dombroskie, 2020). Nigeria is the most badly impacted, with 72% of deaths and 80.1% of cases. Although diphtheria is still widespread in developing countries, fewer cases have been documented after the vaccine program was implemented. Nigerian cases were reported in the year 1989 at 5,039, 2000 at 3,995, 2001 at 2,468, 2002 at 790, 2006 at 312, and 2022 at 8576. The outbreak was exacerbated by variables such as population increase, climate-related reductions in hygiene due to water scarcity, and insufficient diphtheria immunization coverage. Although hospitals occasionally encountered cases of diphtheria in the past, the occurrence of five cases in a single year raises concerns about the state of the disease's control in the nation today (Jumba, 2024).

Prompt and accurate diagnosis is paramount for effective treatment and prevention of diphtheria outbreaks. However, diagnosing diphtheria can be challenging due to its varied clinical presentation and similarity to other respiratory illnesses. In resource-constrained areas where laboratory facilities may be unavailable, the demand for trustworthy diagnostic tools is especially apparent (Borisova et al 2020).

Traditional methods of diagnosing diphtheria involve laboratory culture and identification of C. diphtheria from clinical specimens, which can be time-consuming and require specialized equipment and expertise. Consequently, there is a growing interest in the creation of expert systems for the detection of infectious diseases, such as diphtheria; these are computer-based systems that mimic the decision-making capabilities of human experts. With computation capabilities, the expert system will integrate domain-specific knowledge to proffer accurate and timely diagnostic support.

An artificial intelligence (AI) area known as an ES (Expert System) offers a solution to a particular issue under particular circumstances. AI refers to the study and building of computer systems capable of replacing human intelligence (Qi & Haladin, 2021) AI analyzes human decision-making and task accomplishment, even in dangerous situations. The results of the analysis are then used to develop extremely clever computer programs and frameworks. It then leverages techniques like procedural metadata and structural knowledge to facilitate human-like cognition and behavior.

Although expert systems have been studied for the diagnosis of a range of medical conditions, including infectious diseases, there is a notable absence of creation of an expert system specifically developed for the diagnosis of diphtheria in the literature. Expert systems in use today sometimes lack the specificity necessary to detect diphtheria or are not designed to capitalize on the unique characteristics of the disease (Gherbaoui, Ouali & Benamrane, 2021). Additionally, in my research, I haven't come across a work that utilizes VP (visual prolog) expert system shell for the diagnosis of infectious diseases like diphtheria.

Utilizing the VP expert system software for diphtheria diagnosis is bridging the aforementioned gap. The developed system seeks to deliver precise and effective diagnosis support as it combines specific-domain knowledge and information about diphtheria, epidemiology, clinical signs and symptoms, and laboratory data. The system's logical reasoning abilities and user-friendly interface would predictably enhance the diagnosis procedure and patient outcomes especially in situations with low resources where access to laboratory facilities may be restricted.

1.1 Research Objectives

This study aims to:

1. Develop a rule-based expert system for diphtheria diagnosis using V-P Expert System Shell.
2. Design a knowledge base that integrates microbiological and clinical examination data.
3. Implement a forward-chaining inference engine to automate the diagnostic process.
4. Evaluate the system's diagnostic accuracy compared to traditional methods.

1.2 Research Questions

This study seeks to answer the following questions:

1. How can an expert system be designed to diagnose diphtheria accurately?
2. What is the effectiveness of a rule-based expert system compared to existing diagnostic approaches?
3. How can an automated diagnostic tool improve early detection in low-resource settings?

2.0 Literature Review

A Knowledge Base (KB) and an Inference Engine are the two main components of an expert system's kernel, as they are in most expert system dedicated computer (The effect of diphtheria antitoxin (DAT).., 2020). A knowledge base is a repository for all the information and guidelines related to a specific topic within a given field. A collection of algorithms that carry out judgment, reasoning, and decision-making is called an inference engine. An expert system's typical conceptual architecture is shown in Figure 1

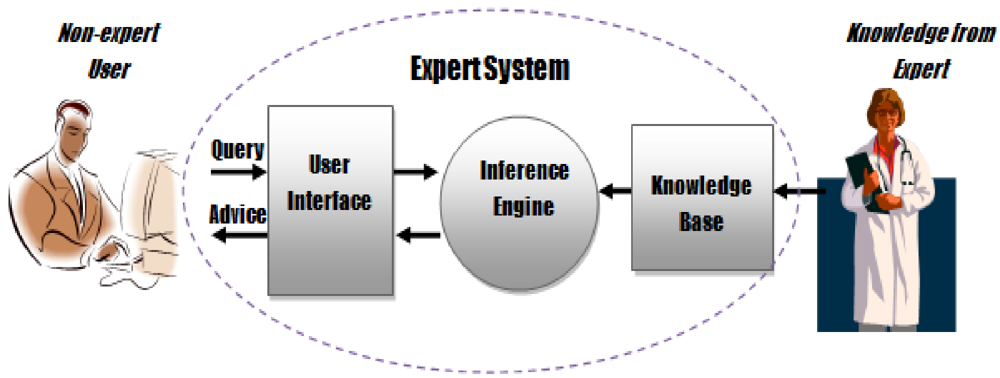

Figure 1: Expert System Kernel

Expert system applications have yielded several positive and fruitful outcomes. A few of its advantages include "cloning" scarce expertise, requiring less knowledge to operate complex devices, providing diagnostic guidance for machine repair, interpreting complex data, archiving the knowledge of soon-to-retire experts, combining the knowledge of multiple experts, and intelligent training (Xiang et al, 2022).

2.1 General Applications of Expert Systems

Expert systems technology has a vast range of applications, making it challenging to categorize all of the problems it can solve in the commercial, industrial, and other domains. For expert systems technologies, about seven application categories have been identified (Xu et al, 2023). These include: Diagnosis and Troubleshooting of Devices and Systems of all Kinds; Planning and Scheduling; Configuration of Manufactured Objects from Subassemblies; Financial Decision Making; Knowledge Publishing; Process Monitoring and Control; and Design and Manufacturing. The most widely used expert system application category is reportedly Diagnosis and Troubleshooting of Devices and Systems of All Kinds. It includes programs that identify flaws in a device or process and provide fixes for it (Maylawati, Darmalaksana & Ramdhani, 2018). Diagnoses in medicine and engineered systems are two instances of this. In addition to this classification of expert system applications, it may be observed in relation to a number of important application domains, including power systems, agriculture, education, the environment, legal manufacturing, medical, and so forth.

Currently, expert systems are used extensively in medicine, medical practice, and medical care. It has been determined that computer expert systems are used in different fields of medicine. These include Clinical Decision Support Systems (CDSS), Prognostic Systems, Radiology, Pathology, Dermatology, Cardiology, Treatment Planning, Drug Interaction and Prescription Management, Telemedicine and Remote Patient Monitoring, Surgical Planning and Robotics, Emergency Medicine and Triage, Genomics and Personalized Medicine, Healthcare Administration and Workflow Optimization (Sheiktaheri, Sadoughi & Dehaghi, 2014). The following medical practice tasks can benefit from the usage of expert systems: creating warnings and reminders; providing diagnostic support; planning and criticizing therapy; Information retrieval agents (Ana, 2020). As can be seen in Fig 1.1 above, the user a non-expert interacts with the expert system by responding to questions and get recommendations. The system's performance is enhanced and its knowledge is shaped by user interaction. The user and the expert system are connected by the (UI) user interface. It includes all of the functionality and design elements that promote smooth interaction. Efficient communication between the user and the system is ensured by a well-designed UI. Within the expert system, reasoning and decision-making are handled by the inference engine, which is the central component. In order to produce insightful and pertinent outputs or recommendations, it processes the data entered by the user, consults the knowledge base, and applies logic and rules (Warnes, 2019). The knowledge base serves as the central store for the data that the expert systems consult while making choices. Facts, guidelines, heuristics, and domain-specific expertise make up this system.

2.2 Related Work Done

Up until now, medical diagnosis has been the most prevalent use of expert systems. This is perhaps because expert systems have shown to be quite effective in this area. Expert systems can be employed to help doctors diagnose health conditions in patients or interpret test results.

An expert system for conventional medical diagnosis is called the MYCIN. It was developed to document medical practitioners' knowledge of infectious blood diseases (Patricia, Santiago & Javier, 2020). MYCIN was able to quickly and accurately diagnose the current ailment and offer the best course of treatment by capturing the clinical expertise of physicians in blood diseases.

Apart from its diagnostic power for infectious blood illnesses, MYCIN's value stems from its contributions to the knowledge of implementing an expert system in the workplace.

In addition to MYCIN, Diagnosis Pro provides differential diagnosis for general internal medicine, family practice, pediatrics, geriatrics, and obstetrics. The system generates a list of potential diseases in a hierarchical style whenever the doctor enters the most crucial data, such as signs, symptoms, test findings, and X-ray results. Any disease on the list can be highlighted to provide the doctor with a fast evaluation that includes information on its pathophysiology, clinical presentation and characteristics, suggested lab testing, consequences, and more. By inputting the disease's name and obtaining all relevant data, a doctor can also rule out or confirm an illness.

The Global Infectious Diseases & Epidemiology Network, or GIDEON, is an additional expert system used in diagnosis. In addition to diagnostics, GIDEON is used for informatics and simulation in the fields of clinical microbiology, infectious diseases, and geographic medicine. The expert system was designed to detect every infectious illness known to man based on symptoms, indications, laboratory tests, and dermatological characteristics. GIDEON is country-specific, though. 205 nations, 806 bacterial data, 185 antibacterial agents, and 327 illnesses are all included in the database. The user may access all epidemiological information, clinical recommendations, diagnostic tests, and the optimal treatment plan via Gideon's diagnostic module. GIDEON creates a prioritized differential diagnosis list based on the patient sign and symptoms, acquisition, suspected country of disease, and patient sign.

Next, a decision support system for post-operative care is offered by POEMS, the Post-Operative Expert Medical System. POEMS was created to provide less experienced workers with advising and decision support. It interacts with the patients to collect data through interactive means, using the conventional approach employed by the medical team, which includes past medical history, surgical history, examinations, and investigative testing.

Using these data, POEMS may generate an ordered list of candidate diagnoses that are likely, plausible, and unlikely. It also includes information on how the diagnosis was reached and what more study could be conducted to focus on a specific diagnostic possibility (Keshimiri et al, 2021).

2.3 Diphtherias' Signs, Symptoms and Diagnosis

The bacterial disease diphtheria is caused by an exotoxin produced by the pathogenic organism, *Corynebacterium diphtheriae*. This toxin causes the disease's clinical manifestations. The nose, throat, larynx, skin, and tonsils are the most commonly afflicted organs by the disease (Yusoff et al, 2021). Phytonaemia symptoms include fever, cough, runny nose, weariness, sore throat, appetite loss, red, raised rash, body pains, dysphagia, swollen neck gland, drooling, hoarseness, nausea and vomiting, chills, nerve, renal, or heart failure, paralysis, and convulsions. In most cases of advanced disease, a clinical diagnosis would take precedence over a microbiologic one.

Clinical diagnosis of diphtheria can be difficult, especially in countries where the disease is rare. Many times, various illnesses such as acute streptococcal (sore throat), glandular fever, Vincent's angina, epiglottitis, tonsillitis, scarlet fever, and mononucleosis (mono) are mistaken for diphtheria (Pikul et al, 2021). As such, precise microbiologic diagnosis is of paramount importance and is consistently considered as an adjunct to clinical diagnosis. In order to save unnecessary treatment or control measures like isolation, the laboratory may also help the clinician by excluding suspected cases or contacts from additional clinical evaluation (Broker, 2016). The following test may be part of the microbiological diagnosis of diphtheria.

2.4 Microbiological Test for Diphtheria

2.4.1 Culture Test

The name given to the traditional method used for diagnosing diphtheria is called Culture Test, in this test; sample is collected from the infected area, usually the throat or nose, using a swab. From this sample, the growth of *Corynebacterium diphtheria*, which is the bacteria that causes diphtheria, is observed in the medium (Qu, Harmelik & Baldwin, 2022). Microbiologists identify the bacteria by using a Gram stain to detect C. diphtheriae, which are extremely pleomorphic, Gram-positive organisms that frequently resemble Chinese characters. Stains like Ponder's and Albert's are used to demonstrate the metachromatic granules produced in the polar regions. The particles are called polar particles, Babes Ernst, or volutin. Löffler's medium is a preferred enrichment media for the growth of C. diphtheriae. After that, on a differential plate known as tellurite agar, all Corynebacteria, including C. diphtheriae, are capable to converting tellurite to metallic tellurium. For most Cornyebacterium species, brown colonies reveal the tellurite reduction colorimetrically; for C. diphtheriae, a black halo surrounds the colonies.

2.4.2 Antigen Test

A blood test called the Diphtheria Immunity Test, also referred to Diphtheria Antitoxoid Antibody test is used to determine if a person is immune to the dangerous infectious disease diphtheria, which is caused by the C. diphtheriae bacteria. The purpose of this test is to determine the blood level of diphtheria antibodies, which can be acquired through vaccination or a prior illness (Maas et al, 2022). It is recommended by the CDC (Center for Disease Control) that all children receive a diphtheria vaccination along with a tetanus and whooping cough vaccine. In general, adults and teens should have booster injections every ten years. The person may be at risk for diphtheria if the test findings indicate a level below 0.01 to 0.1 Iu/mL. This test is rarely used to confirm a diphtheria infection and is typically conducted by taking blood from a vein in the arm or hand.

Antigen tests, which are frequently employed as quick screening tools, may have a somewhat lower sensitivity than culture tests despite their rapidity.

2.4.3 PCR (Polymerase Chain Reaction) Test

A sensitive and specific technique for identifying the presence of the diphtheria-causing bacteria, Corynebacterium diphtheriae, is PCR testing. The presence of both the bacterium and the diphtheria toxin gene, which indicates the presence of potentially toxic C. diphtheriae, can be detected by PCR in clinical samples or isolates taken from culture. When PCR is utilized instead of just culturing and toxigenicity testing for the diagnosis of diphtheria, the rate of positive detection can rise (Polonsky et al, 2021). Compared to culturing and toxigenicity testing, PCR can yield results more quickly and is less impacted by the length of sample transit and the past use of antibiotics. All the same, non-toxigenic tox gene-bearing NTTB type bacterial toxins cannot be accurately identified by PCR (Buhler et al, 2019). As a result, while PCR is advised as a supplementary diagnostic technique, it should not be used in place of the traditional approach as the gold standard. The Elek test should be used to confirm the results of PCR screening for bacterial toxicity, according to WHO recommendations. (Mori et al, 2024). A number of variables, including sensitivity, rapidity, and the particulars of the clinical scenario, influence the diagnostic method selection.

2.4.4 Elek Test

The toxigenicity of Corynebacterium diphtheria which is the bacteria that causes diphtheria is assessed using the Elek test, sometimes referred to as the Elek plate test, an in vitro immunoprecipitation method (Al-Khayri et al,2023). In order to perform this test, the strains to be tested must first be incubated on a specific agar plate with a strip of filter paper coated with diphtheria antitoxin immediately beneath the surface. After incubation, fine precipitin lines at a 45-degree angle to the streaks are inspected for the presence of antitoxin on the plates. These lines show that the strain was toxigenic, indicating that it produced a toxin that responded with the antitoxin (Kumar et al, 2009). This test is a more humane and effective test than prior toxigenicity tests.

3.0 Materials and Methods

In developing DDS, Prolog (Programming logic) was utilized as the programming language which is frequently applied to tasks that involves symbolic and logic reasoning, including creating programs for expert systems. A software tool called VP (Visual Prolog) ES (expert system) shell was utilized for the project. although there are other expert systems shells out there, VPES was chosen because it offers a user-friendly interface for creating and developing expert systems without requiring the writing of complex code, and it is based on visual Prolog.

The VPES shell was built by a company owned by Brian Sawyer called Visual Prolog International and was founded by Idea Ware Inc (Kotsiri & Tsangaris, 2024). In this project, the DDS design was integrated into the VPES shell’s production environment. It is rule-based system because the knowledge base of the expert system was developed using a combination of expert consultations with medical professionals specializing in infectious diseases, publicly available hospital records on diphtheria cases, and validated medical literature. Expert input was obtained from hospital records and physicians across Infectious Disease Control Hospital (IDCC), Infectious Disease Hospital (IDH), Kano state and Barau Dikko Teaching Hospital. These information and are expressed in the form of rules ensuring a robust rule-based system.

VP-Expert is base on inference approach for backward reasoning. The user interface, the inference engine, and all other parts required for complete expert system architecture are all included in it.

3.1.0 Main Menu in VP-Expert

Options in the menu can be chosen using the navigation function keys, numerals, and the first characters of the option phrase. Under the main menu, there is a sub-menu for the option that is currently highlighted. The Escape button can always be used to precisely backspace out of an already-selected option. Table 1 below displays the key options from the main menu.

Table 1: ***Options key from the main menu***

Consult	To Execute the program on the present KB
Path	Navigating different pathways of the KB.
Edit	Used for building and modifying the KB.
File name	To access, create or edit a file in the knowledge base.
Quit	Quit VP-Expert.

3.1.1 VP-Expert Editor

The editor menu of the VPES system shell provides a wide range of capabilities for managing and altering expert system files. The "File" option allows users to create new expert system files, open existing ones, save changes, and close or exit the software. This menu allows users to efficiently edit the contents of their expert system files. In general, the editor menu of a VPES shell simplifies the process of establishing, modifying, executing, and debugging expert systems, allowing users to quickly manage their knowledge bases and analyze complicated problem domains. The editor's file names should all always finish in .KBS as shown in Figure.2

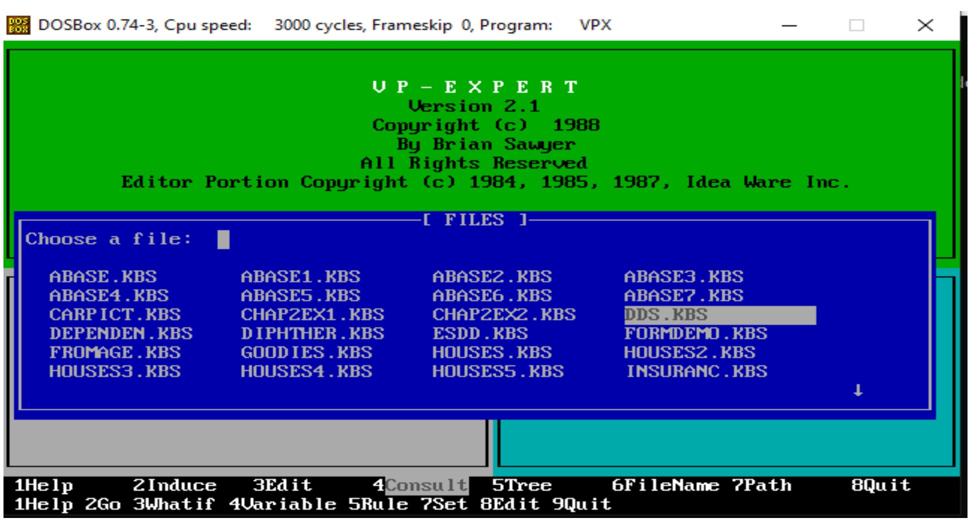

Figure 2: ***VPX Edit Command Menu***

3.1.2 Editor Command Menu

Located at the bottom of the screen before the consult menu, as seen in the Figure.2, is the third menu which is the edit command menu. The "Edit" window allow users to efficiently input and modify the content of their expert system files, this is where the executable program of the system is been written. All the executable commands of DDS are written here as shown in Figure.3.

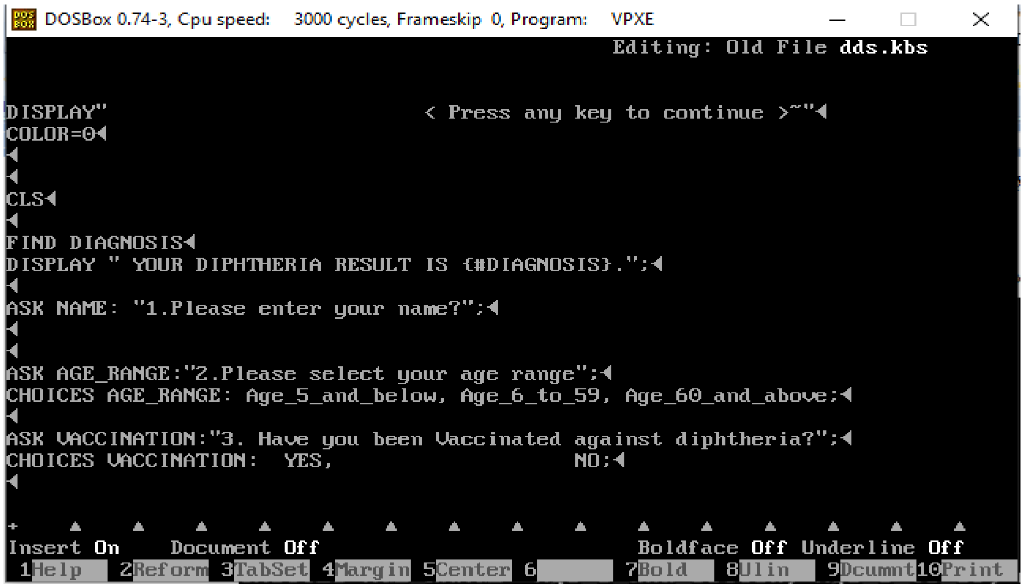

Figure 3: Edit Command Window

3.2 Knowledge Base Intelligent System Building

We may start building the ES after deciding on the best expert system design tool and gaining the required information. In order to make the process of creating and understanding information easier, we first choose to develop a matrix decision tree, systematic flow diagram, or other techniques. Knowledge is reduced to "If-Then" statements as a result of these guidelines (Su et al, 2021). Once the fundamental structure is finished, we may begin working on a system component prototype. We can continue to improve the system until it reaches the point where it is considered complete.

Knowledge engineers may appropriately identify the information in the knowledge base system, which is dependent on the job domain (Cordon et al, 2001). The individual with the requisite expertise to analyze the issue and offer solutions is the field specialist. The skill designer takes the expert's expertise and turns it into a configuration that lets the system react to the patient appropriately. The intelligent system, which is composed of knowledge ideas, is the foundation for transition procedures that entail substituting one element for another (Sajjadi & Troyer, 2022). Expert information in a particular process area is stored in the KB, and the unit in question is crucial since the reliability and caliber of the expertise it contains determines how well the process is implemented (Yu & Duan, 2024). Figure 4 illustrates a portion of the knowledge-based intelligent system procedure.

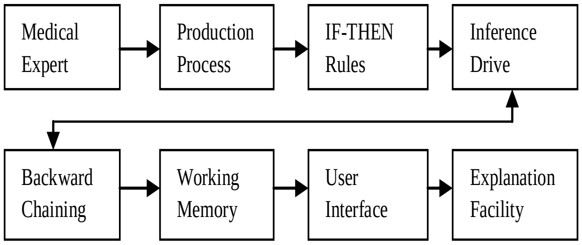

Figure 4: ***Knowledge Base Intelligent System***

Many components need to be integrated in order for ES to be developed, and the end product is a control process with a major objective idea, real, ruling, deduction drive, and so on (Yen & Lin, 2010). Consequently, we no longer refer to the system as merely a software program, but rather as an expert system. The inference engine selects the appropriate search type to address the issue. An autonomous advisory software, or ES, simulates the knowledge and thought process of experts to offer a solution to an issue (Chen, Wu & Chen, 2022).

The deduction driver really operates the expert system, clarifies which rules are applicable, completes the decision, and analyses the results when a sufficient suspension is achieved. The inference engine employs many rules in the conclusion section, although the facility for explanation offers reasoning (Arvind, 2024). Mostly, forward and backward chaining approaches are used in rule-based workflows. One method of data-driven search is forward chaining. When the opposing drive is applied, the system explores the condition region, moving from the ideal condition to the beginning condition known as backward chaining. Another name for backward chaining is an idea controller or progressive explorer. In human-centered problem solving, hypothesis testing is comparable to backward chaining. A specialized physician could have doubts regarding some parts of a patient's situation, for instance.

Rules were created to improve the VP-Expert system's ability to identify diphtheria in patients by the use of extensive materials, including books, articles, and journals, as well as in-person interviews with medical lab scientists and doctors. The intended system development process may be divided into two categories: knowledge acquisition and knowledge representation. The gathering of data is a crucial component of knowledge acquisition. Coding an IF-THEN statement is the process of identifying the type of information represented through knowledge representation. The system is executed on the VP expert shell before any programs are loaded for consultation.

3.2.1 ACTIONS block

This is the code that controls how the inference engine is implemented. Declarations that regulate system activities are included in the ACTIONS block. These declarations are made inside the command where they appear. The DISPLAY explanation instructs the client on what to perform. The FIND statement expresses the framework's goals, which is to diagnose in this case. The outcomes are presented in the final declaration.

3.2.2 Query Statements:

When a query is conducted, Visual Prolog looks for solutions that match the query in the knowledge base. It will then display the results, which may include variable bindings if they were specified in the query. If a query matches multiple facts, it will return multiple answers. If no matches are discovered, it returns false. The ASK and CHOICES statements conclude this process.

3.2.2.1 ASK statement:

The ASK statement describes how to prompt for a variable. These prompts must be useful, just like any other application. It includes the following steps:

ASK variable: "prompt";

For instance:

ASK VACCINATION: ”Have you been vaccinated against diphtheria?”;

3.2.2.2 The CHOICES statement:

If there are just a limited number of possible answers to a query, they may be found in a menu created by a CHOICES declaration. It includes the following procedure:

CHOICES variable: list of values separated by a comma;

For instance:

CHOICES VACCINATION: YES, NO;

Once the inquiry has been submitted, this menu is published. Please be aware that if there was no CHOICES statement for a variable, the client must enter the value on the cursor later in the prompt.

The diagnosis system is comprised of thirteen condition questions such as, the age range, vaccination duration history of vaccination which includes booster shots, signs and symptoms, and microbiological test results. The diagnosis process has thirteen inputs total, these includes four laboratory analyses. The inference engine assesses all the rules in light of the user's responses when the user completes all the questions using the options on the user interface window, resulting in the diagnosis results (Elbrus & Fidelis, 2021). Table 2 presents a decision worktable of signs and symptoms.

Table 2: Decision worktable of Signs and Symptoms of Diphtheria

Sign and Symptoms	Mild	Severe
Catarrhal		
Common cold	yes	
Flu	yes	
Sore throat	yes	
Mild fever	yes	
General Malaise	yes	
Paroxysmal		
Severe throat inflammation		yes
Thick grey membrane in throat		yes
Difficulty Swallowing		yes
Difficulty Breathing		yes
Swollen Neck Gland		yes
Hoarseness		yes
Nasal discharge		yes
“Barking” Cough		yes

The decision work tables for the “sign and symptoms” is designed to take into account the many signs and symptoms that a person infected with diphtheria may experience. The clinical Signs and Symptoms section included a compilation of patients' possible diphtheria and related sickness signs and symptoms from mild to severe. The system constructs queries based on this input to match against the knowledge base. Through logical inference and pattern matching, the system identifies diseases that correlate with the symptoms provided in terms of mild (catarrhal) and sever (paroxysmal) signs and symptoms.

The system uses information from microbiological tests as well, such as the required analytical report that contains the

culture test, antigen test, PCR (polymerase chain reaction) and Elek test to make decisions.
This section includes questions that may be used to find potential microbiological studies, such as lab tests that can be performed to detect diphtheria.

The systematic flow chart and decision table for diagnosis in figure 5 and table 3 respectively illustrate how the signs, symptoms, and results of laboratory tests are analyzed in diagnosing diphtheria. The flowchart 2, which comprises of the clinical manifestation section and the laboratory examination in between the user and the diagnosis nodes illustrate the consultation process analysis from start to finish. On the chart, a single ***Y*** denotes a Yes, ***N*** denotes a No/Negative, ***P*** denotes a Positive , ***NV*** is No Vaccination, ***NS*** is No signs/symptoms, ***NC*** is No culture test, ***NA*** is No antigen test, ***NP*** is No PCR test and lastly ***NE*** denotes No Elek test. For example, In the case of the patient in *Fact 7* of the decision table of diagnosis, the users' age is in between 6 to 59 years. Users from this age group are not as vulnerable as users from the other two age groups in the choice of options the users could select. Here, the user is vaccinated, not up to 10 years from when the user last had the diphtheria vaccine. Despite having a booster, the user still exhibited both the mild and severe signs and symptoms of diphtheria. Clinically, the user would be diagnosed with diphtheria due to the signs and symptoms experienced. To confirm the clinical diagnosis, the user had to enter in the microbiological examinations result which turned out positive for both PCR and Elek test. Consequently, such a case will be diagnosed as positive and will be recommended for isolation before treatment. The entire process of the diagnosis can be traced on Figure 5. Both the systematic flow chat and the decision table for diagnosis will be referenced during results discussion.

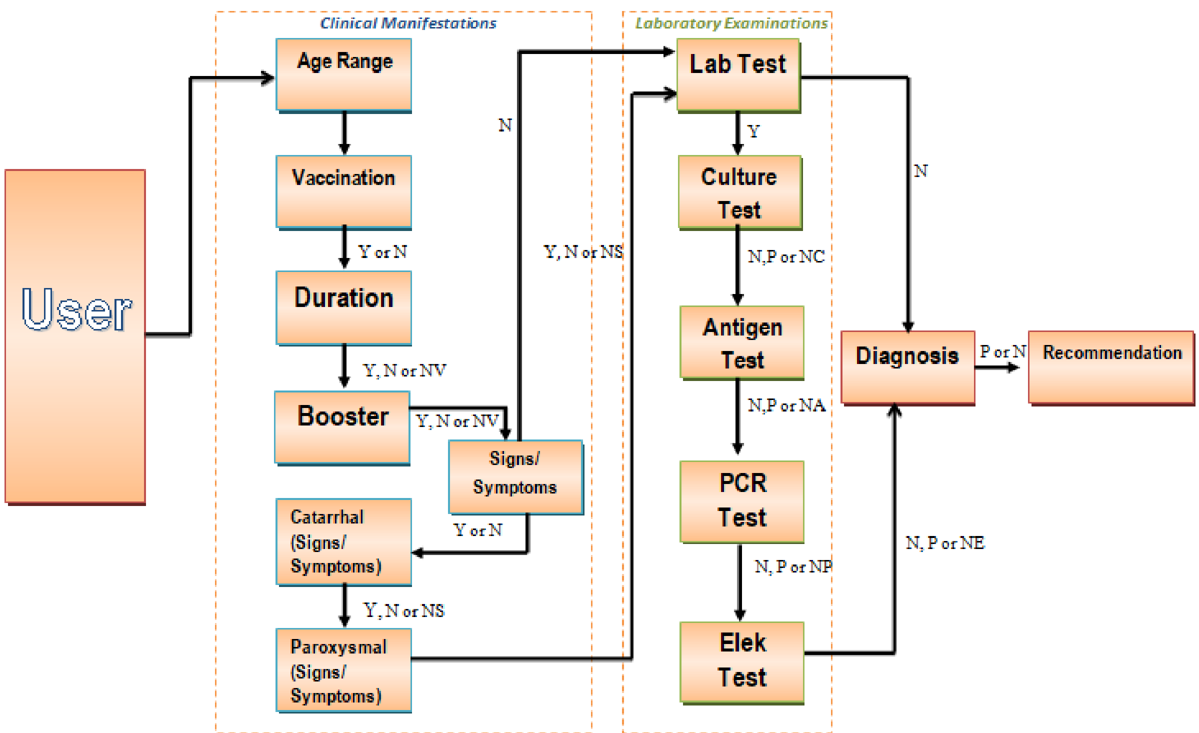

Figure 5: Systematic Flow chart for Diphtheria Diagnosis

Table 3: ***Decision Table for Diphtheria Diagnosis***

Users	Age Range	Vaccination	Duration	Booster	Catarrhal	Paroxysmal	Culture Test	Antigen Test	PCR Test	Elek Test	Diagnosis	Recommendation
Fact 1	5 and below	No	Not vaccinated	Not vaccinated	Yes	No	No Culture Test	No Antigen Test	No PCR Test	No Elek Test	Positive CNF 50	Lab test required
Fact 2	6 to 59	No	Not vaccinated	Not vaccinated	Yes	No	Positive	Reactive	Positive	Positive	Positive	Isolation
Fact 3	5 and below	Yes	Yes	No	Yes	No	Negative	Non reactive	Negative	Negative	Negative	See a specialist
Fact 4	60 and above	Yes	Yes	No	Yes	Yes	Positive	Non reactive	Positive	Positive	Positive	Isolation
Fact 5	60 and above	Yes	No	Yes	Yes	No	Negative	Non reactive	Negative	Negative	Negative	See a specialist
Fact 6	6 to 59	No	Not vaccinated	Not vaccinated	Yes	No	Negative	Non reactive	No PCR Test	No Elek Test	Positive CNF 50	PCR Test required
Fact 7	6 to 59	Yes	No	Yes	Yes	Yes	No Culture Test	No Antigen Test	Positive	Positive	Positive	Isolation
Fact 8	5 and below	Yes	No	No	Yes	Yes	Negative	Reactive	Positive	Positive	Positive	Isolation
Fact 9	60 and above	Yes	Yes	No	Yes	Yes	No Culture Test	No Antigen Test	No PCR Test	Positive	Positive CNF 85	Isolation & Lab test
Fact 10	5 and below	No	Not vaccinated	Not vaccinated	Yes	No	No	No Antigen Test	Negative	Positive	Positive	Isolation

DDS Production Rule Sample

IF NAME <>a AND
AGE RANGE = Age 5 & Below AND
VACCINATION = YES AND
DURATION = YES
BOOSTER SHOTS = NO
SIGN & SYMPTOMS = YES AND
CATARRHAL = YES AND
PAROXYSMAL = NO AND
LAB TEST RESULT = YES AND
CULTURE TEST RESULT = NEGATIVE AND
ANTIGEN TEST RESULT = NON REACTIVE AND
PCR TEST RESULT = NEGATIVE AND
ELEK TEST RESULT = NEGATIVE THEN
DIAGNOSIS = NEGATIVE
DISPLAY "DDS recommends you consult with a specialist for the signs and symptoms you are experiencing"

Knowledge was represented in the DDS knowledge base in the form of a production rule. Above is command designed to execute the users query on Fact 3 of the decision table for diphtheria diagnosis on Table.3.

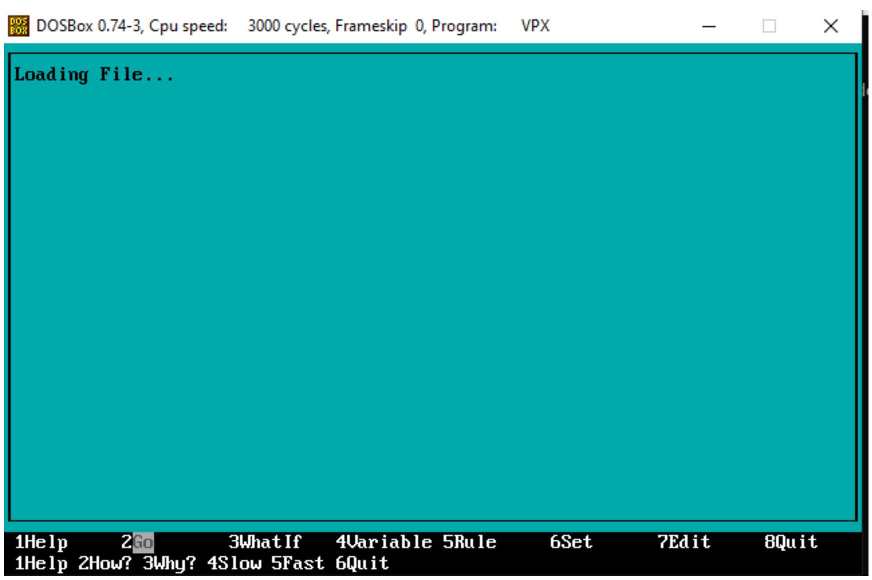

Figure.6: DDS Consulting the KB as its loading

In consulting the DDS, The user clicks the VP Expert icon to access the VP Expert dialog box each time he boots up the system. After that, the user locates the DDS.KBS file from the list of stored files as shown in Figure. 2 and loads the file by selecting and pressing the "Enter" button on the keyboard. Upon selection, a new window pops up indicating "loading file" as shown in Figure 6.

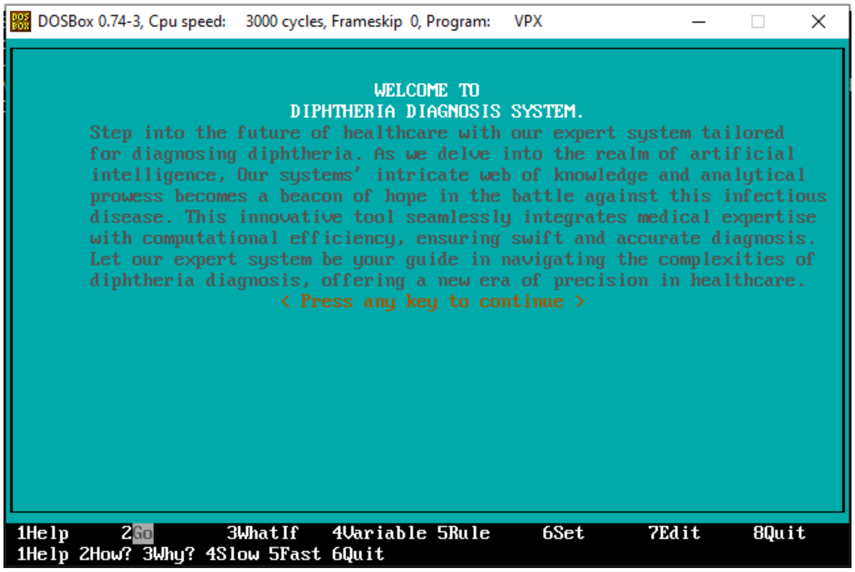

Figure 7: DDS Welcoming Window after Loading

Upon loading, it launches the consultation welcoming window, preparing the user for the consultation process as shown in Figure 7. By pressing any key on the keyboard, the user can begin the consultation by responding to the series of questions that will appear on the screen as displayed on Figure 8.

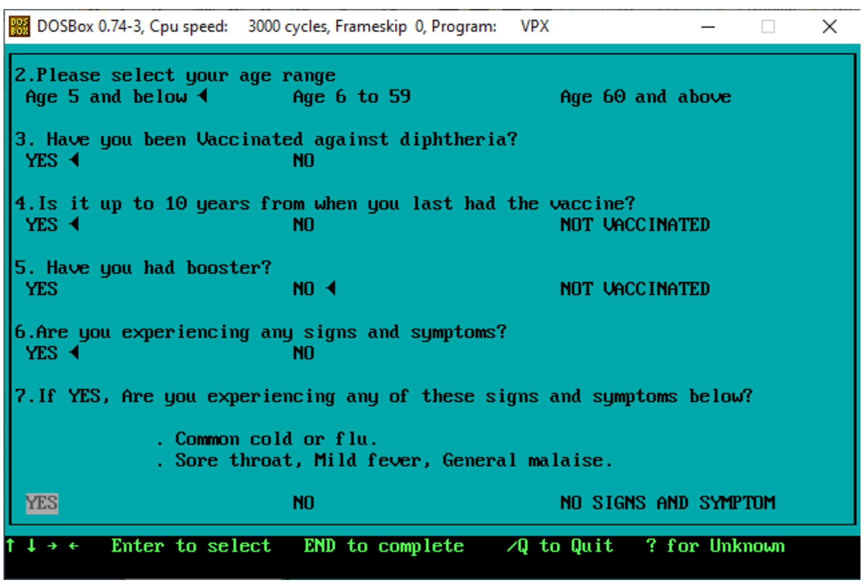

Figure 8: User Begin Answering Questions after System Consulted the KB

To assess the diagnostic reliability of the expert system, standard performance metrics were calculated. These include accuracy, sensitivity (recall), specificity, precision, and F1-score, which are widely used in medical diagnostics to measure system effectiveness. DDS was tested on a dataset of 200 diagnosed diphtheria cases collected from Infectious Disease Hospital (IDH), Kano state records. Below is a table of the sample test case evaluation.

Table 4:Test Case Evaluation Sample

Patient	DDS	Microbiological Diagnosis (PCR & Elek)	Correct?	Recommendation
1	Positive CNF 90	Positive	Yes	Isolation Required
2	Negative	Negative	Yes	No Diphtheria
3	Positive CNF 50	Positive	Yes	Isolation Required
4	Positive CNF 50	Negative	No	Lab Test Required
5	Negative	Positive	No	Lab Test Required

From the above table of case evaluation, the values of the true positive cases, false positive cases, true negative cases and false negative cases were gotten as shown below. From those values, the Accuracy, sensitivity, Specificity, Precision and F1-score of DDS was calculated.

TP = 91 Cases (Correctly diagnosed as diphtheria)
FP = 15 Cases (Incorrectly diagnosed as diphtheria)
TN = 85 Cases (Correctly diagnosed as non-diphtheria)
FN = 9 Cases (Missed diphtheria cases)

Now, we calculate:

$$1.\ \text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \times 100\% = \frac{91+85}{91+85+15+9} = \frac{176}{200} \times 100 = 88\%$$

$$2.\ \text{Sensitiuvity} = \frac{\text{TP}}{\text{TP+FN}} \times 100\% = \frac{91}{91+9} = \frac{91}{100} \times 100 = 91\%$$

$$3.\ \text{Specificity} = \frac{\text{TN}}{\text{TN+FP}} \times 100\% = \frac{85}{85+15} = \frac{85}{100} \times 100 = 85\%$$

$$4.\ \text{Precision} = \frac{\text{TP}}{\text{TP+FP}} \times 100\% = \frac{91}{91+15} = \frac{91}{106} \times 100 = 86\%$$

$$5.\ \text{F1} - \text{Score} = 2 \times \frac{\text{Precision} \times \text{Sensitivity}}{\text{Precision+Sensitivity}} = 2 \times \frac{86 \times 91}{86+91} = 2 \times \frac{7826}{177} = 88\%$$

4.0 Results and Discussions

In most cases, the user will have to respond to all the questions one after the other by selecting an option from the list of choices displayed under each question. The system proceeds in a diagnostic manner, based on the users' answers to all the questions displayed on that window. Figure 8: shows a sample of those questions with answers selected by the user from the options. Generally, users within the age group of 5 and below are young children (infant and toddler) and users within the age of 60 and above and are considered older adults or elderly. These two groups of users are considered more vulnerable to diphtheria infection due to their weaker immune systems compared to users within the age of 6 to 59 which are adults. Again, users that have received vaccination and booster shots within the period of ten years will be far less susceptible to the diphtheria infection compared to those whom had had their vaccines or booster shots over ten years ago. All these information and more constitute the KB from which the inference engine makes decisions that yields results. The result of the diagnosis is displayed at the end of the consultation just after the last question and recommendations as well.

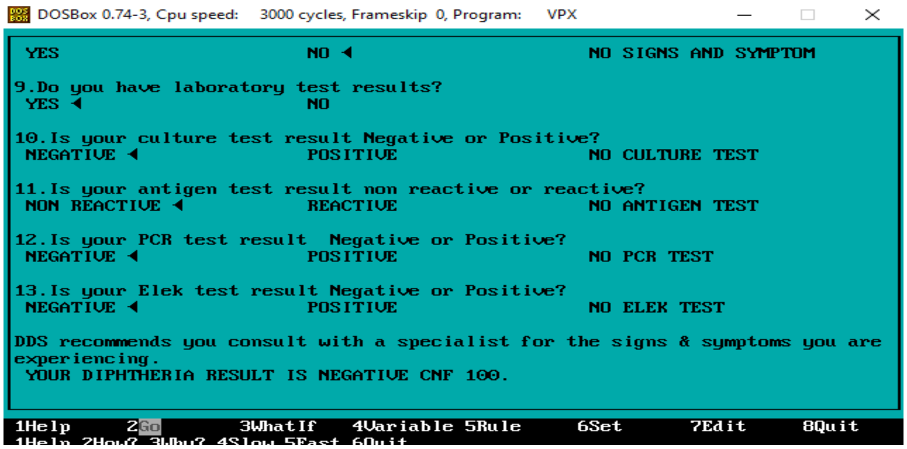

Figure 9: Result of the Diagnosis from Fact 3 user query

Few samples of the outputted results from different users query sited on the decision table of diagnosis are captured here in the form of screenshots. Figure 9 is the result from the fact 3 user query. The diagnosis result is negative with a confidence factor of 100, meaning that the system is 100 percent certain of the result outcome of the diagnosis, which is based on all the response from the user. Even though the user had experienced only some or all of the catarrhal signs and symptoms, the laboratory results confirmed that the user had not contracted diphtheria. Those signs and symptoms experienced by the user might be due to other infectious diseases that have similar signs and symptoms as that of diphtheria, examples, Influenza, Pharyngitis and streptococcal. DDS will recommend user to consult with specialist for differential diagnosis and treatment in such a case.

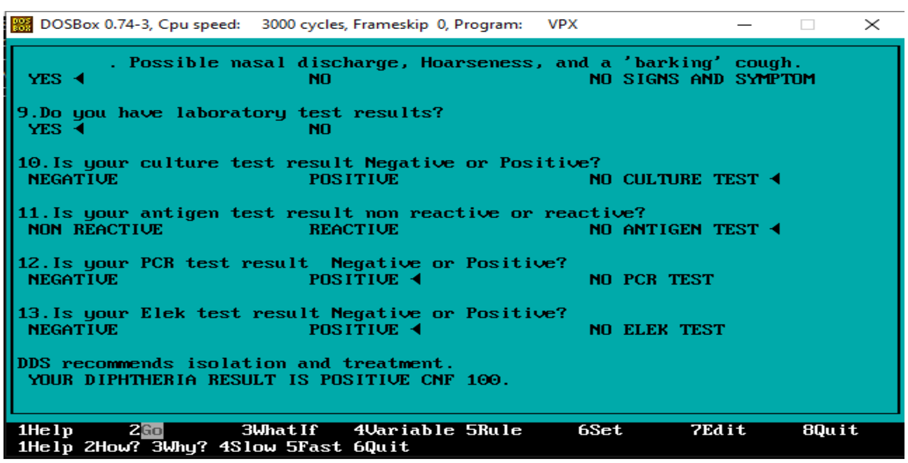

Figure 10: Result of the Diagnosis from user query in Fact 7 of the Decision Table

Result fact for user 7 (fact 7) from the decision table of diagnosis, turned out positive as seen in Figure 10 above. Although, the user had not undergone both culture and the antigen test, the positive results from the PCR and Elek reliable enough to diagnose user positive for diphtheria without the need for a confirmatory test. These two tests are more reliable and sensitive compared to the culture and antigen test. DDS outputs a confidence factor of 100 which is a percentage estimation of the certainty of the result and recommends immediate isolation and treatment of the patient.

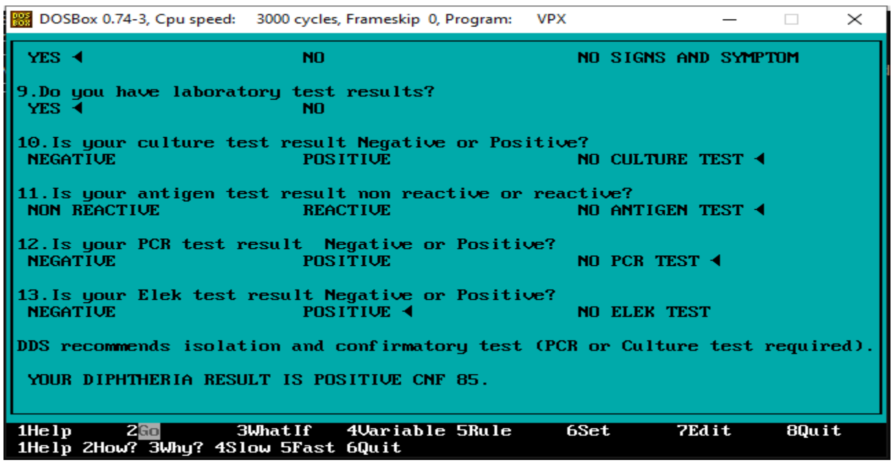

Figure 11: Result of the Diagnosis from user query in Fact 9 of the Decision Table

Fact 9 user is another interesting case, here the user falls within the age of 60 and above, vaccinated and had exhibited some of both the catarrhal and paroxysmal signs and symptoms of diphtheria. Figure 11 shows that the user was diagnosed with diphtheria but with a confidence factor of 85 percent, this estimation by DDS depicts that it's not completely certain of the result but chances are high and is due to the fact that even though Elek test is an immunological test for the detection of diphtheria toxin produced by the diphtheria bacteria, it is not as sensitive or specific as molecular method like PCR. Consequently, a confirmatory and more specific test needs to be carried out as recommended by DDS.

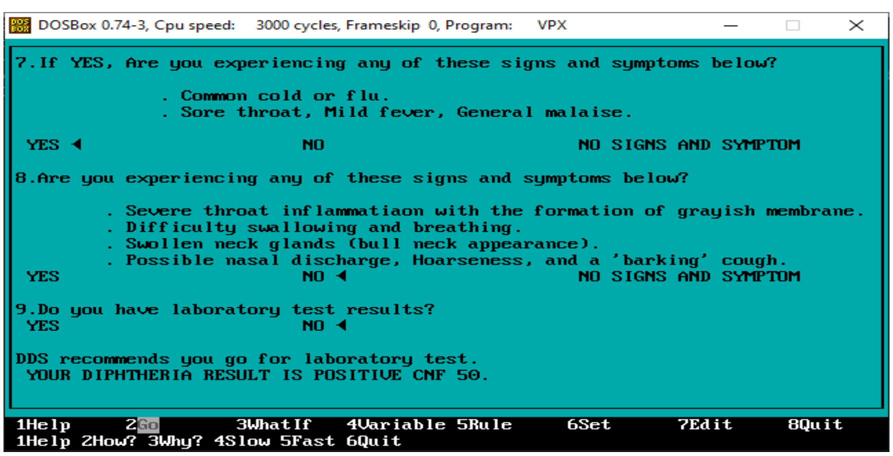

Figure 12: Result of the Diagnosis from user query in Fact 1 of the Decision Table

The diagnosis result from the user query in the fact 1 of the decision table is another unique case. Here, the user had experienced only some or all of the catarrhal signs and symptoms of diphtheria but had no laboratory test result. From Figure 12, question 9 was to know if the user had undergone any laboratory test. In this case, the user hasn't, as he/she responded with a "NO" and since DDS had no reason to continue with the remaining questions concerning the types of lab test conducted, it truncated the process and outputs the result of the diagnosis at that point. The user was diagnosed with diphtheria but with confidence factor of 50. This is DDS's way of estimating the percentage of the uncertainty in the result from the diagnosis which is moderately certain, and this is due to the absence of laboratory test result to confirm the signs and symptoms experienced by the user. In this case, DDS would recommend the user to go for laboratory test.

4.1 Comparison with Traditional Diagnostic Accuracy

The DDS performance metrics results was compared with traditional diagnostic results for Polymerase Chain Reaction (PCR) test and the Elek test, which are widely used for diphtheria diagnosis. Scherer et al. (2024) & Williams et al (2020) reported that PCR testing for diphtheria achieves 95% sensitivity and 98% specificity, while the Elek Test reaches 90% sensitivity and 95% specificity. Table 7: shows the comparison between DDS and traditional diagnostic methods with regards to the sensitivity and specificity.

Table 7: Comparison between DDS System's Metrics with Conventional Methods

Diagnostic Method	Accuracy (%)	Sensitivity (%)	Specificity (%)
Expert System	88	91	85
PCR Test	95 – 98	95	98
Elek Test	85 – 95	90	95

The results showed that DDS achieved an accuracy of 88%**,** a sensitivity of 91% and a specificity of 85%. Comparatively, published studies indicate that PCR has an accuracy of approximately 95–98%, 95% sensitivity and 98% while the Elek test has a reported accuracy ranging from 85% to 95%, 90% sensitivity and 95% specificity. Although the expert system did not surpass the accuracy of PCR, it demonstrated a competitive diagnostic performance, particularly in sensitivity and specificity, making it a viable low-cost, rapid alternative for resource-limited settings.

5.0 Conclusion and Recommendations

DDS holds great promise for improving diagnostic accuracy, particularly in areas with limited access to specialized healthcare facilities. A system that integrates domain-specific information, computer algorithms, and logical reasoning can provide prompt and reliable diagnostic help, improving patient outcomes and contributing to effective disease surveillance and control initiatives.

If a medical doctor is able to manually diagnose 100 cases of diphtheria each day, DDS might possibly diagnose over 300 cases of diphtheria each day. Therefore, the method facilitates an accurate, quicker, and easier diagnosis of this fatal infection. The study has effectively demonstrated the viability and prospective benefits of applying artificial intelligence, more especially expert systems to the field of infectious disease diagnosis. We addressed a major gap in the literature and showed the technology's applicability to a critical public health issue by developing a system specifically for diphtheria. The review and testing of the expert system produced positive outcomes, indicating that it can accurately diagnose diphtheria based on clinical and laboratory data.

In addition, the system's straightforward design and user-friendly interface make it easier for healthcare professionals to utilize, especially in settings with limited resources.

Despite its promising performance, the DDS has some limitations. The knowledge base relies on expert-defined rules, which could introduce biases in knowledge representation. Additionally, the system has not yet undergone large-scale clinical validations necessary to further assess its effectiveness. Moreover, the system currently focuses on diphtheria and does not support differential diagnosis with similar bacterial infections such as streptococcal pharyngitis. Addressing these limitations will be crucial for enhancing its reliability and scope.

Future research should focus on expanding the system's capabilities to diagnose multiple infectious diseases, allowing for differential diagnosis in real-world clinical settings. Additionally, integrating the system with electronic health records (EHRs) could enhance its ability to provide real-time, patient-specific recommendations, improving its clinical utility. These advancements would make the system more robust and applicable in broader medical contexts.

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