NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

EXPLOSIVE ORDNANCE DISPOSAL ASSOCIATE - AN EXPERT SYSTEM FOR LANDMINE IDENTIFICATION

by

Paul J. Arcangeli

September 1997

…or: Nelson D. Ludlow

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1997	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE
EXPLOSIVE ORDNANCE DISPOSAL ASSOCIATE - AN EXPERT SYSTEM FOR LANDMINE IDENTIFICATION

5. FUNDING NUMBERS

6. AUTHOR(S)
Arcangeli, Paul J.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Today there are over 110 million mines scattered across 60 countries, and these mines kill or injure more than 26,000 people annually. In order for deminers to remove these mines, they must be able to quickly and accurately identify them. Existing methods for landmine identification involve tedious searching through reference books.

This thesis presents an expert system for landmine identification, based on the set of thirty Bosnian mines from the MineFacts landmine database. The user is queried about the landmine, and heuristics are applied to the answers which are then used to calculate other information about the mine. This information is then filtered through decision trees to generate a small group of candidates which are displayed with a photo and confidence factor.

The system was modeled and tested using a Microsoft Excel spreadsheet. The system can narrow candidates to within two choices when all queries are correctly answered and to within three candidates when 70% of the queries are correctly answered. The results show that this technique has potential for all types of ordnance identification. A similar system could be implemented to cover all UXO for EOD use and as a reconnaissance tool by non-EOD trained individuals.

14. SUBJECT TERMS
Landmine identification, Expert System, Artificial Intelligence, Explosive Ordnance Disposal

15. NUMBER OF PAGES
152

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

Approved for public release; distribution is unlimited

EXPLOSIVE ORDNANCE DISPOSAL ASSOCIATE - AN EXPERT SYSTEM FOR LANDMINE IDENTIFICATION

Paul Arcangeli
Captain, United States Army
B.S., North Georgia College, 1987

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 1997

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This research was possible only through the assistance and support of many people. I would like to thank Major Nelson Ludlow for his tireless help as my advisor. His guidance and enthusiasm helped me carry this project to completion. Also, his instruction was integral to my understanding of expert systems and knowledge engineering. I would also like to thank Professor Carl Jones for his help on this project, especially during the more difficult times when I needed advice.

I would also like to thank the students and faculty members at the Naval Postgraduate School. I have found the educational experience to be a positive one and this is only possible with the outstanding faculty and peers with which this institution is blessed.

Finally, I am grateful to my wife Loretta, her advice was essential during my research and writing of this thesis. I truly appreciate all of her help and patience through my studies over the past two years.

I. INTRODUCTION

A. OBJECTIVES

The objective of this thesis is to design and test a prototype expert system to assist deminers and Explosive Ordnance Disposal (EOD) technicians in identifying landmines. The prototype is based on the Bosnian subset of landmines from the MineFacts database. A successful expert system will assist an inexperienced deminer in quickly identifying a landmine, based on its distinguishing characteristics. This will make demining safer and more efficient. The prototype expert system has direct application in humanitarian demining and could eventually be expanded to cover all landmines. The prototype also demonstrates that an expanded system could be useful in identifying all other types of unexploded ordnance (UXO). Such systems would make valuable expert EOD knowledge available to all EOD personnel and enhance the speed and accuracy of identifying ordnance.

B. BACKGROUND

Landmines have become a serious problem in the world today. As a weapon of war, they are a cheap, effective way to channel the enemy and protect vulnerable areas. Unfortunately, landmines are rarely removed after a conflict and as a result, there are now over 110 million mines scattered across 60 countries [UNIT 97]. Landmines remain lethal indefinitely, and over 26,000 people are injured or killed annually because of them

[TERR 94]. Because of this problem, the new field of humanitarian demining has emerged to clear mines from former battlefields, thereby making them safe, habitable places once again.

Planting landmines is easy - removing them has proven to be a much more difficult problem. Over 700 types of landmines are used in the world today. About 100 new types have been developed just over the past three years [UNIT 97]. Each type of mine is unique and may have one of many different types of firing systems. The removal technique for one mine may cause another type of mine to function, so before any mine can be safely removed, it must first be positively identified. For this reason, computer based training programs and landmine identification systems are vital in assisting inexperienced humanitarian deminers. Furthermore, these programs can help make up for the shortage of qualified experts by extracting years of EOD knowledge and making it widely available.

The MineFacts Database is one type of landmine identification system presently in use. It was developed by the Humanitarian Demining Program Office of the U.S. Army Night Vision Electro-Optical Directorate and ESSEX Corporation [MINE 97]. MineFacts has been fielded to Bosnia, Cambodia, and other nations to assist humanitarian deminers. The current interface for the database is a simple query, based only on the mine's size, shape, country of manufacture, and casing. During the selection process, no visual assistance is given to the user, and possible matches are displayed simply as a list of landmine nomenclatures. Depending on the information given, this list could vary from a few landmines to hundreds. An expert system is ideally suited for improving the

MineFacts database. It could be used to select a group of landmine candidates based on more information, narrowing down the final selection. It will still require the deminer to make the final identification, but it could present pictures of possible landmine candidates for the selection. Furthermore, the candidates will be presented to the user with a level of confidence of how well they meet the attributes specified in the search. It can provide a faster, more efficient search method with more varied information [QUIN 89].

C. THESIS QUESTIONS

The following questions are addressed in this thesis:

- *Can an expert system be useful in landmine identification?*

Currently, all identification is based on the deminer's knowledge or access to publications. Mines are examined and then painstakingly matched to pictures in the reference books for identification. This is a very time consuming process which is prone to errors.

- *How is expert landmine knowledge described? How is the knowledge best extracted?*

Expert knowledge is difficult to understand and model. In order to create an expert system, an examination of the methods used by experts to identify a landmine must be conducted. Once this method is understood, the knowledge must be captured and displayed in a format useful to the non-expert user.

- *What methodology is best suited for the landmine identification problem?*

This problem is similar to other identification problems but it has some unique points. Unlike other items to be identified, the landmine cannot always be painstakingly studied and examined. Often, the information gathered on the mine will be missing fields or will be an approximation. The methodology used must take this uncertainty into account when presenting a solution.

- *What questions and sub-questions are best to implement an expert system that will integrate well with the MineFacts database?*

Questions are developed from the fields available in the MineFacts database. These questions are based on an EOD technician's landmine reconnaissance technique. Each question must be logically examined to determine how it may be affected by situations that are unique to landmine warfare.

- *What are possible applications for similar expert systems that could be applied to other EOD databases?*

There is currently no decision support tool available for EOD Technicians. Application of an expert system to the other EOD databases could improve accuracy and speed of UXO identification. There are over 5,000 items currently in the EOD publications set, and a mistaken ordnance identification could be fatal for the EOD technician.

D. ORGANIZATION OF THE STUDY

This thesis presents the use of a prototype expert system for ordnance identification.

- Chapter II provides background information regarding landmine warfare and expert systems. Background is also given on landmine clearance and unexploded ordnance clearance. Finally, an explanation is provided of the MineFacts database and the 60-series EOD database.
- Chapter III presents the methodology used in the implementation of the expert system. Each field of the MineFacts database will be examined and appropriate metrics and questions will be proposed. An evaluation of each question will also be given, focusing on the logic used to generate the question.
- Chapter IV presents the implementation of the prototype expert system. Analysis of the efficiency of the prototype will be discussed. This chapter also covers the user interface and hardware requirements.
- Chapter V gives a summary of the thesis, the expert system design and the working prototype. Also, recommendations are given for future study based on the conclusions drawn from the prototype. Finally, recommendations are given for expanded use of this technology in EOD operations.

II. BACKGROUND

A. LANDMINE WARFARE

1. History of Landmines

Modern landmines first gained popular use in World War I as the German response to the new British tank. The term "mine" comes from the earlier practice of tunneling under an enemy's fortifications and placing explosives to breach their defenses. Early landmines were simply artillery shells with contact fuzes. These shells were buried fuze up in the hope that enemy tanks would be stopped during an assault [SLOA 86].

Landmines became more widely used in World War II. In some cases minefields were laid miles wide in an attempt to stop enemy armor. World War II also saw the rise of antipersonnel mines. These mines were initially developed to protect antitank minefields, but were later used specifically against the infantry soldier [SLOA 86]. As mine clearance techniques improved, so did techniques to prevent their removal. Anti-lift and anti-handling devices were developed. Fuze functioning, which had previously been limited to pressure actuation, expanded to include pressure release, tripwire and command detonation. In addition to new actuation techniques, mine construction was improved with the use of non-metallic materials such as plastic and bakelite to make mine location more difficult [STOF 72].

The last 50 years has seen the largest growth in landmine technology. Mass production has made them cheap and reliable. Construction materials have improved, and completely non-metallic mines are in use in many areas. Fuzing technology has advanced to include magnetic influence, seismic influence, anti-disturbance and selective targeting [HIDD 94]. Scatterable mines now allow placement to be done mechanically or by artillery, increasing the number of mines deployed and making tracking them nearly impossible. These new advances have made modern mines prolific, harder to detect and more deadly.

2. Classification of Landmines

There is a great deal of variety amongst modern landmines. Each country produces their own designs and there are over 700 unique landmines in use in the world today [MINE 97]. This number does not take into account outdated mines already in the ground which are no longer used but still present a hazard. Mines may be classified in several ways. The most common classification is by intended target: antitank or antipersonnel. These two major groups are further sub-divided into more specific categories such as anti-vehicular, multi-use, alarm, and illumination. Within the two major groups mines can be classified by size, country of use or manufacture, effect, method of emplacement, and method of actuation.

Antipersonnel mines are usually small in size and come in a variety of shapes (Figure 2.1). These mines are intended to cause personnel casualties by means of fragmentation or blast. They can be either buried or surface laid, and the newest mines can be scattered by machine, artillery, or aircraft. Depending on their size and design, antipersonnel mines can produce casualties up to 100 meters away. Antipersonnel mines may be actuated by pressure, trip wire, magnetic influence or command detonation. Antipersonnel mines are usually smaller than six inches in size and rarely contain more than one kilogram of explosive.

Fragmentation mines come in three varieties: omni-directional, directional, and bounding fragmentation. Injuries from omni-directional fragmentation mines are caused by shrapnel from the mine case. The mines can be buried or surface laid but the are often mounted on a stake above the ground to increase their killing radius. Directional fragmentation mines are designed to control the direction of the fragmentation. This is normally accomplished by embedding steel balls into one side of a block of explosive. Bounding fragmentation mines are considered the most menacing of all fragmentation mines. They are buried below the ground and function when a tripwire or pressure fuze is tripped. When this occurs, a small explosive charge launches a fragmentation projectile into the air. This projectile detonates around one meter off the ground maximizing the fragmentation radius of the mine and causing traumatic upper body injuries.

All of the early antipersonnel mines were fragmentation mines, but many new mines are now blast only. Blast mines cause casualties by the explosive force of the mine's detonation. They are almost exclusively pressure actuated, as this assures the victim is in close proximity to the explosion. Blast antipersonnel mines are generally produced in 40 gram and 200 gram explosive weights. The smaller mines are meant to blow off a foot, while the larger mines can cause amputation of the entire leg or even death.

Figure 2.1 Yugoslav PMA-3 Antipersonnel Mine
This is a pressure actuated, blast antipersonnel mine. It is constructed of plastic and rubber and contains 34.5 grams of explosive. The photo shows a deminer removing the fuze [MINE 97].

Antitank mines are always larger than antipersonnel mines. They are also most often pressure actuated, but may be set off by magnetic influence, tilt-rod, command detonation, seismic influence or even infrared [MINE 97] [SLOA 86] [UNEX 94]. These mines are normally fuzed to prevent actuation by an individual soldier, but they are normally protected with antipersonnel mine or anti-removal devices. Antitank mines are five inches or larger, with most being a foot or more across. They can be buried, surface laid, or scattered by artillery, machinery, or aircraft.

There are several varieties of antitank mines: blast, shaped-charge, or Miznay-Schardin. Blast type mines often contain more than ten kilograms of explosive and are designed to damage a tank or destroy a light vehicle. Shaped-charge mines attempt to pierce the hull of a tank using an explosively formed jet of gas and molten metal. They can penetrate armor several inches thick, and are sometimes used to attack vehicles from the side. These mines are emplaced next to a road, horizontally with the ground. A passing vehicle trips the mine and the shaped-charge fires into the side or rear or the vehicle. Miznay-Schardin mines are "belly attack mines," so called because when tripped, they throw a curved steel plate into the "belly" of the tank. This plate strikes the hull with such force that metal spalling occurs on the inside surface of the hull. These metal fragments kill the crew inside the vehicle.

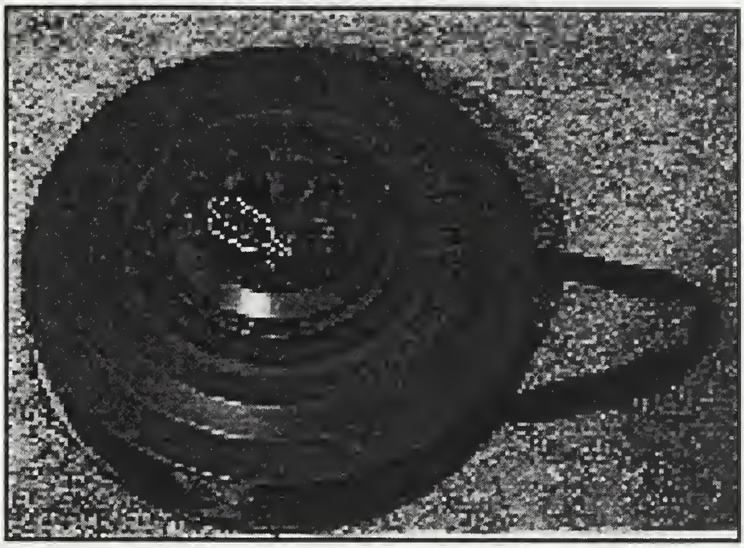

Figure 2.2 Former Soviet TM-62M Antitank mine
This mine is a metal cased, antitank blast mine. The TM-62 was the mainstay of the Soviet antitank mine inventory. It accepts a variety of fuzes and comes in four different models [MINE 97].

There are a few other ways that mines can be classified. The way a mine is emplaced is sometimes used to classify mines. Some classifications are scatterable, manually emplaced, buried, stake, or surface laid. Mines manufactured by one country often have similar features and are sometimes referred to as a "family" of mines. Mines that belong to a family may have completely different firing systems from each other and due to their similar outer construction can sometimes be very difficult to tell apart [SAPP 90]. Some mines can also be recognized by non-standard design features such as an unusual shape (Figure 2.3) or the use of an unusual case material, such as concrete.

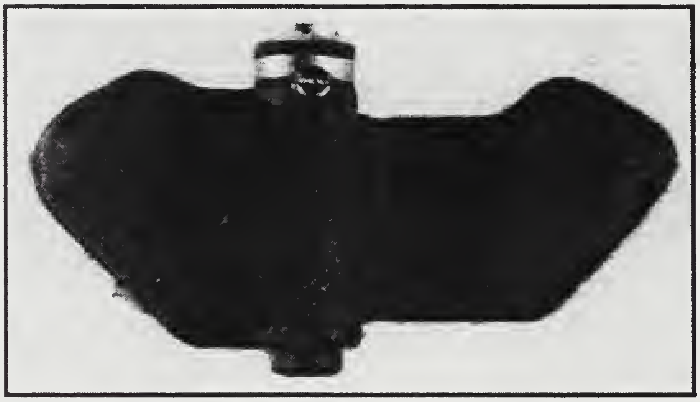

Figure 2.3 Former Soviet Union PFM Antipersonnel mine (shown to scale)
This scatterable mine is also known as a butterfly mine and is often picked up by children. It is usually employed in clusters ranging from 1,000 to 6,000 mines and can be delivered by helicopters or high-performance aircraft [MINE 97] [UNIT 96].

3. Future Trends in Land Mine Technology

As the technology used to locate and disarm landmines improves, so will technology to avoid detection and location. Recent years have seen a large growth in plastic mines and this has all but eliminated the effectiveness of magnetometers for detection. Future mines will attempt to avoid detection by incorporating a shielding scheme against high-energy detectors or will be sealed to avoid chemical detection by a sniffer. Mines may also have new firing systems that will detonate when they sense an active detection system, such as a magnetometer or high energy detector. New firing systems incorporating microchips will allow mines to identify friend or foe and select targets of higher value such as communications vehicles.

Politically, landmines are losing their appeal as acceptable weapons. There is a move to ban the use and production of landmines, and the U.S. has joined in the international moratorium on their use. This moratorium does not include the new "smart mines", which are designed to self-destruct some time after they are deployed. While self-destruction will remove a large number of mines, 5-10% of the mines are likely not function as designed and will remain live in the minefield [TERR 94]. Even if the moratorium is accepted worldwide, there are still over 110 million mines that must be removed from existing minefields [TERR 94].

4. Landmine Clearance

Once a landmine is in the ground, it takes a tremendous amount of effort to remove it. It is estimated that it costs three dollars to produce a mine and one-thousand dollars to remove it once it is in the ground [TERR 94]. These costs are a result of the difficulty and danger involved in landmine clearance. There are basically two approaches to landmine clearance: the tactical military method and the humanitarian method.

a. Military Mine Clearance

Landmines are a nuisance to military forces. As a weapon, they are only effective in channeling the enemy's maneuver or harassing ground troops. When a military force encounters a minefield, they will either change direction to bypass the obstacle, or attempt to breach the minefield to continue their advance. Breaching will be accomplished with mine rollers or some other mechanized method if possible, or explosively with a mine clearing charge such as a Mine Clearing Line Charge (MICLIC). Mines are only removed by hand when these other options are not feasible, or for lone mines. When hand removal is used, the deminers will remove the minimum number of mines necessary to allow the mission to continue [SAPP 90].

b. Humanitarian Demining

Humanitarian demining is a relatively new concept. It has come about as a result of the proliferation of landmines in small regional and civil conflicts. Because the mines are very cheap, they have gained wide use in third world in countries, which are not equipped to remove them after a conflict ends. Countries like Cambodia, Afghanistan, Iraq and Somalia are a sampling of the 60 countries where mines have been used in recent years [UNIT 96]. Humanitarian demining came about to remove those mines and make the land habitable again.

The first principle of humanitarian demining is that one hundred percent of the mines must be removed. This differs from military mine clearance in strategy, methodology and goal. Each mine must be located, identified and rendered safe. Unlike military mine clearance, deminers must avoid detonating any landmines as this will contaminate the minefield with shrapnel and undetonated explosive and hinder future searches with magnetometers or explosive sniffers. For this reason meticulous care is taken to find every mine, properly identify it and then remove it for destruction elsewhere [TERR 94].

Humanitarian mine clearance also differs from military mine clearance in the level of expertise of its technicians. Humanitarian deminers are often local people who have been trained to remove the mines. They are often inexperienced and, unlike military EOD personnel, have little reference material to assist them.

c. Unexploded Ordnance Clearance

UXO clearance is often confused with mine clearance. While it is similar in many aspects, it is fundamentally different in location, identification and methods of disarming. A UXO is a dangerous, uncontrollable piece of ordnance that failed to function as it was designed. This type of clearance takes place on the battlefield and also on former firing ranges here in the United States. UXO's are usually found on the surface which makes them easier to locate than landmines. However, UXO identification is much more difficult than for landmines due to the huge variety of ordnance in use in the world [TERR 94]. Once identified, the neutralization of the item is often complicated by the unstable condition of the ordnance.

In the past few years, the U.S. military has closed many installations in the U.S. and overseas. These bases often had firing ranges and impact areas which contain huge numbers of unexploded ordnance. Clean-up operations on these installations have some characteristics from both military mine clearance and humanitarian demining. These operations work to achieve 100% clearance, but are not limited in detection methods or in methods of disposal. Because UXO's are generally metal cased, they are easily located, and once identified are often relatively safe to move to a disposal area. For this reason, this type of ordnance contamination problem may benefit from a similar expert system approach as the one described here for landmine identification.

B. EXPERT SYSTEMS AND DATABASES USED FOR OBJECT IDENTIFICATION

1. Expert Systems

Ever since computers were invented man has tried to make the machine think like a human. An expert system attempts to use human knowledge to solve a problem that has traditionally required human intelligence to be solved. More specifically, an expert system is, "a computer-based system that performs at the level of an expert in some specialized domain using domain specific knowledge (usually acquired from experts)" [BHAR 96]. This domain specific expert knowledge is represented by heuristics or "rules of thumb" within the computer. This differs from the ordinary algorithmic computing method where the computer has very little knowledge and solves tasks based only on a basic algorithm and set boundaries for the problem. An expert system contains a large knowledge base, uses symbolic logic rather than an algorithm, and applies knowledge appropriate to the problem to reach a conclusion. These attributes allow the program to solve a vast array of problems within its domain of knowledge. An algorithmic program may have to be reprogrammed for each new problem, because the algorithm and knowledge used to solve the problem are integral to the program's design [WIDM 96].

Humans solve problems in a very different way from a computer. The human mind integrates bits of knowledge retrieved from a large collection of experience to solve a problem. If a problem is too large, the human expert will break the problem into smaller parts. The expert system attempts to mimic this process - rules are used to represent those small fragments of human knowledge and a database is substituted for a range of experience. Problems are broken down into manageable parts, which are applied to the knowledge base. This allows even unfamiliar problems to be solved, if the rules in the knowledge base are sufficient to create a path to a solution. One advantage of an expert system over a human expert is that the program can explain explicitly how it arrived at a conclusion and give a level of confidence for the answer [PCAI 97] [WIDM 96].

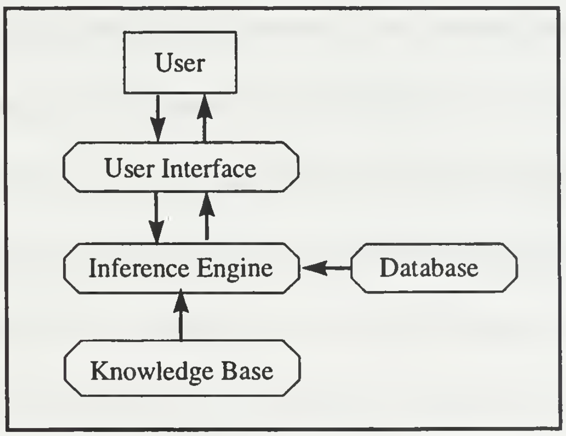

Figure 2.4 Shows the components in an expert system and their interaction [WIDM 96].

An expert system is usually composed of a user interface, an inference engine, a standard database, and a knowledge base (Figure 2.4). The knowledge base consists of a series of heuristics, in a IF-THEN format. The user interacts with the user interface to input the information the expert system requires. This information is passed to the inference engine which integrates the data provided by the user with expert knowledge from the knowledge base and with data specific to the problem from the database. The inference engine then attempts to use all this data to make sub-conclusions and conclusions about the problem [PCAI 97] [WIDM 96].

One very common part of most expert systems is the explanation subsystem. This feature allows the user to query the system about conclusions it has made and trace back through the reasoning used to arrive at that conclusion. Because expert systems represent human knowledge in formal rules, the explanations of reasoning used to reach a conclusion are produced in the same natural language format in which the rules are written [PCAI 97] [WIDM 96].

Expert systems are used for a variety of tasks including diagnostics, data interpretation, object classification, and construction [BHAR 96]. They can be applied to these problems in two ways. In a decision support role, they can be used to remind an expert of options that can be considered or information that may have been overlooked. This use is most commonly seen in medical expert systems. The second way an expert system can be applied is as a decision maker, to allow a person with little knowledge to make a decision above their level of experience. This application is most often used in manufacturing and industry [WIDM 96].

An example of a medical expert system is MYCIN, an expert system that was designed to diagnosis meningitis and blood infections and then recommend treatment. MYCIN was developed in the early 1970's by Dr. Edward Shortliffe at Stanford University, and though it never gained wide clinical use, it did serve as a template for future diagnosis systems that are in use. Its major impact on expert system programming was its ability to clearly explain its conclusions. [WIDM 96] [FORT 89] [HART 86] [SLAT 87]

MYCIN used about 400 heuristic rules to reach a conclusion. These rules were written in an "IF-THEN" type structure [SLAT 87]. These heuristics were probabilistic in nature. This allowed MYCIN to make some diagnoses with uncertain information, based on some "certainty factor" [FORT 89]. MYCIN was able to explain its diagnosis, by tracing back through its rules and giving the user its reasoning from each rule.

Expert systems have gained wide use in other areas. One example is the system used by credit card companies to check credit transactions. The system rapidly makes a decision whether to extend approval for credit whenever the credit card is used by the customer. Other popular uses include grammar checkers in word processing programs and "wizards" in popular software packages. [WIDM 96]

Expert Systems do have some drawbacks. The knowledge base is restricted and there may be an instance where the question is beyond the systems domain of knowledge. Problems outside the knowledge base cannot be solved without adding to the knowledge base. Also, if the rules for the expert system are not correctly entered, there is the risk that some conclusions may be wrong. This should be identified in testing, but if the error is small, it may be missed. The system would treat this rule as correct and make explanations based on this rule since it has no way of determining if the rule is in fact correct. [BENE 89]

2. Current Expert Systems for Ordnance Identification

There are currently no expert systems in use for ordnance identification. The EOD field has only recently seen the use of automation with the arrival of CD-ROM references in 1994. These electronic references are discussed below.

3. Explosive Ordnance Disposal Databases

The U.S. military has developed several ordnance databases for EOD. The most important is the 60-series publication used by all branches of the U.S. Military. This joint service series of publications is used by EOD technicians to identify over 5000 types of ordnance and contain specific information on how to render each of these items safe.

The 60-series has recently been placed on CD-ROM, but previous versions were on paper and microfiche format. Both the paper and CD-ROM sets consist of an Identification Guide and a collection of individual publications for each piece of ordnance. The Identification Guide contains line drawings of ordnance ordered by size, and is used as an index to find the correct publication for an unknown item. To make an identification, the EOD technician makes a close measurement of the unknown item. The technician must then make a subjective judgment about what kind of ordnance the item is (bomb, projectile, submunition, landmine, etc.). Then the Identification Guide for that type of ordnance is selected and the pictures in the guide are compared to a drawing made by the technician during his reconnaissance. Once the unknown item is matched, the

Identification Guide will list the 60-series location where the render-safe procedures and other detailed information on the ordnance can be found.

This 60-series identification method does present some problems when information is incomplete or incorrect. If the EOD technician fails to properly identify the type of the item (e.g. he calls a landmine a submunition), then he will be looking for the unknown item in the wrong book. Also, since many types of ordnance are similar in size, a large number of items must be screened to find the correct item. Moreover, if the technician is unable to get a measurement, the entire guide must be searched to find a match to the picture.

The method for locating an item on the 60-series CD-ROM has not changed from the paper and microfiche version, and the process still requires tedious searching to make an identification. Ordnance is still searched by type and size, using an automated Identification Guide. The CD-ROM is much faster, but because it uses the same methods as the paper system, its efficiency is not greatly improved.

C. THE MINEFACTS DATABASE

MineFacts is a CD-ROM based database that contains information on all landmines that are in use in the world today. It was designed specifically as a tool to assist in landmine identification by humanitarian deminers. MineFacts was developed by Essex Corporation under contract to the U.S. Army Night Vision and Electronic Sensors Directorate and the U.S. Navy Office of Special Technology [MINE 97]. It has been distributed to Bosnia, Angola, Croatia, Cambodia and other countries where humanitarian demining activities are being conducted.

The MineFacts database is a way to provide vital information to humanitarian deminers. The procedures for identifying and disarming ordnance have always been closely guarded secrets, and historically, humanitarian deminers have no references to assist them. The U.S. government commissioned the MineFacts database as a way to aid and encourage demining. While the database does not contain secret information, it does contain useful data on each mine and neutralization methods for most mines.

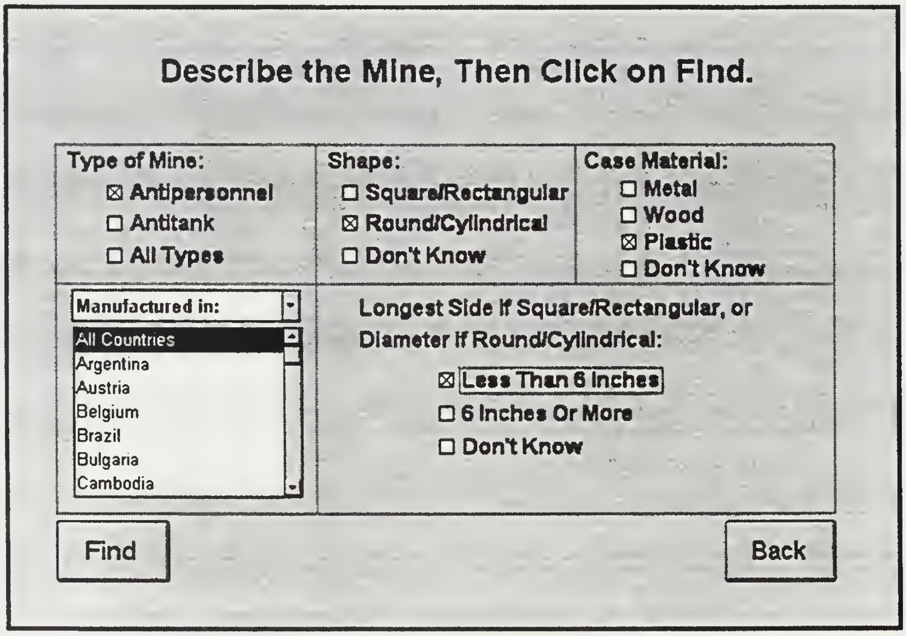

Figure 2.5 MineFacts Search Screen [MINE 97].

The database is programmed in Microsoft FoxPro and has a user interface that allows mines to be searched by name or characteristics. The user may only search six fields: mine type, shape, case material, general size, county of use or the country of manufacture (figure 2.5). The selections are limited and do not cover the variation found in the actual mine set. Mines which do not fit in the given options must be listed as unknown.

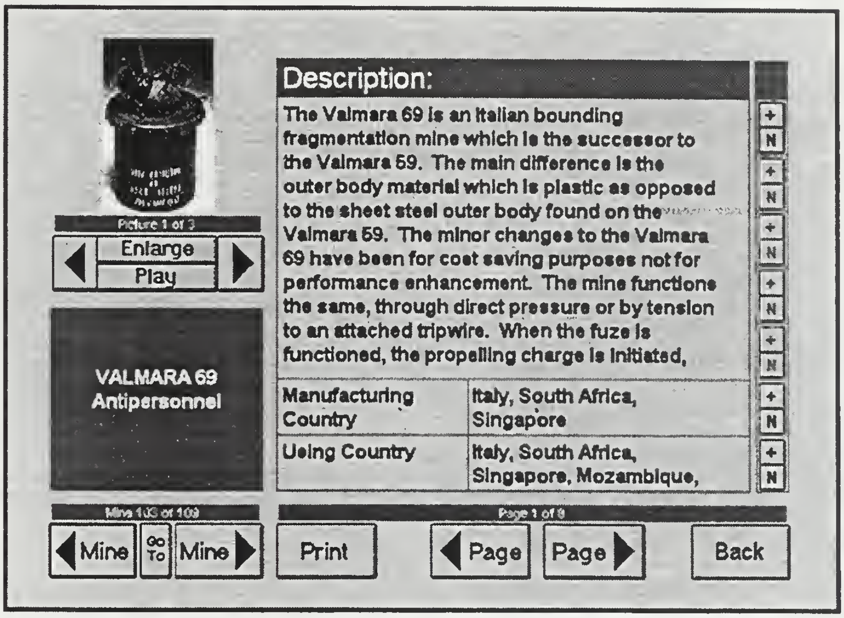

Figure 2.6 MineFacts Description Results Screen [MINE 97].

Once the available information has been entered, MineFacts will report the number of mines found and allow the user to look at this list, one mine at a time (Figure 2.6). Each page shows a photo of the mine, nomenclature, general description, and country(s) of use and manufacture. More detailed information on each mine is available on eight supplementary pages (Figure 2.7).

Because many mines follow the same basic design, searches based on these few parameters can produce very large lists, and paging to find the correct mine can be tedious and time consuming. As an example, Figures 2.5 - 2.7 show the results of a search for a cylindrical, plastic, antitank mine under six inches in diameter. This search produced 109 mines, requiring the user to page through the mines until a photo match

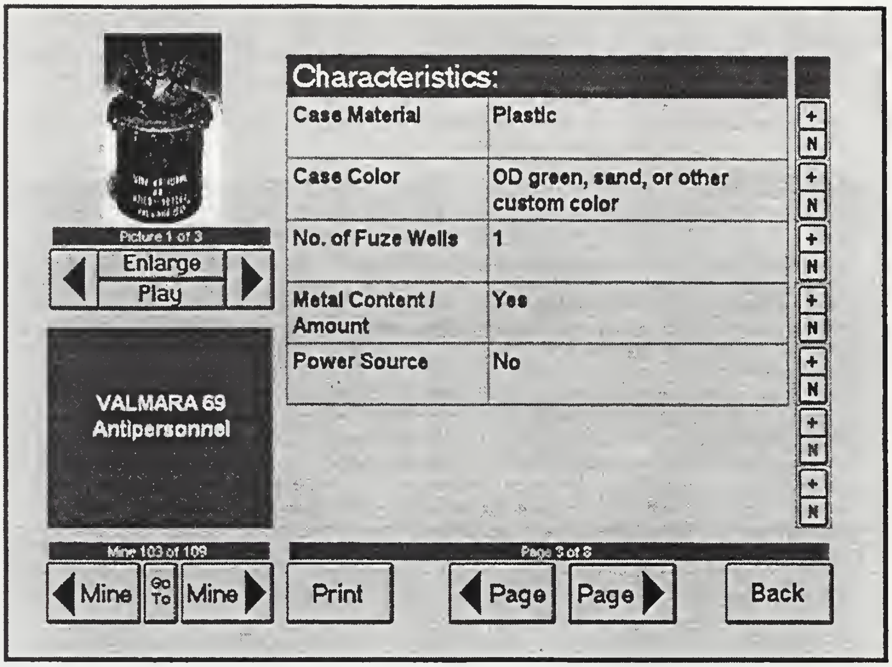

Figure 2.7 MineFacts Detailed Mine Information Screen [MINE 97].

was found. This search method produces even less useful results when the user cannot answer one or more of the search questions.

This is where an expert system could be applied. It is obvious that the user interface is limited on the MineFacts database but adding more options to the query would not fully solve the problem. Users may still have incomplete information, or the data may not be accurate. An expert system can aid the user in making a positive identification with this data, and give the user some level of confidence for its recommendations. The system can also explain how it arrived at its decision, allowing the user to modify the search as necessary. Chapter III discusses the methodology used to construct an expert system for the MineFacts database.

III. METHODOLOGY

A. APPROACH

The intention of this thesis was to develop an intelligent associate to assist deminers in landmine classification. This identification is based on information gathered by the deminer and input into the system. To develop this system, the author first looked at the logic required to produce the desired outcome and then determined a plan for system development. This chapter will discuss the knowledge base, knowledge acquisition, and the methods used to develop the inference engine.

1. Selection of a Method

There are many different methods that could be used to create a system for object identification. The author's intention was to follow as closely as possible the approach that EOD technicians currently use, while maximizing the use of all available information. This required querying the user on as many fields as the database allowed and make inferences based on the data provided by the user. This inferred data along with the user supplied data, would then be used to derive the identification of the mine.

2. Selection of Data - Landmine Set

The first task in this project was to select a landmine set to use with the prototype. The landmine set is used to give a defined starting point for an expert to examine the data.

The MineFacts database contains 700 landmines which is too large a number to manage, so the prototype was limited to the thirty mines in the Bosnian mine subset. Several versions of the MineFacts database have been used by humanitarian deminers in Bosnia for three years, affirming that the information on these mines is current and correct. Although this subset lacks some of the more unusual mines, it does include a fairly broad variety of antitank and antipersonnel mines and is a fair representation of the entire database. Inclusion of rare mines would require greatly expanding the landmine set and is not practical at this time.

3. Examination of the Landmine Database Fields

Once the landmine set was identified, the author began a detailed examination of the tables and fields in the MineFacts database. All relevant data in MineFacts is carried in two separate tables, the ENGLRMKS table and the ENGLDATA table. These tables are indexed with the field MINEID and are used to search for and then display information and photographs associated with each mine. The ENGLRMKS table contains all landmine data with the exception of the fields listing the photos for each landmine. The ENGLDATA table only contains a few information fields and is the table that the database currently uses for mine queries. The more complete ENGLRMKS table was used for the structuring of questions and searching. The ENGLRMKS table will be discussed in more detail in Section B.

4. Knowledge Acquisition

Knowledge acquisition is a central part of an expert system [HART 86]. The expert knowledge must be collected, examined and represented in a logical format. This is very challenging, as many tasks in the identification process are intuitive to the expert and therefore difficult to define. The expert collects information on the item, its location, other mines in the area, the mine's condition and the mine's intended target. This information is used by the expert to make certain inferences about the mine before the mine is even researched. An experienced EOD technician can determine if a mine is antipersonnel or antitank, its effect, country of manufacture, whether it is a scatterable mine, and its method of actuation, without ever having seen it before.

The process of identifying a mine is complex, involving the examination of many characteristics. To simplify the process, the problem was broken down into individual questions which addressed specific characteristics of the landmine and determined which of these questions were supported by fields in the database. Further examination using the landmine set allowed me to identify sub-questions that were important to finding a solution, without introducing false positive or ambiguous answers that could lead to an erroneous conclusion.

5. Construction of a Question Set

To generate the questions used to extract query information from the deminer, an examination was made of the logical process that is used by expert deminers to identify a landmine. As discussed in Chapter II, EOD technicians use a combination of size and visual recognition to make a positive identification of a landmine. Closer examination shows that visual recognition involves several steps. The first is the collection of visual information such as color or markings that will be used to compare the unknown mine with the known mines in the identification guides. Next, the expert makes a mental comparison of this visual information from the unknown mine with his or her previous experience. This allows the technician to make inferences about the type of mine, its function, what country manufactured it, and its method of actuation. These inferences assist in making a positive identification and reduce the risk of error.

The method used to represent the rules for mine taxonomy was the question tree shown in Figure 3.1. This method is similar to the dichotomous key used by taxonomists to determine the species of a living organism. The difference is that the trees used in the expert system allow for more than two answers for each question. Trees were based on a single question about a mine's attribute. Following the question, the number of mines

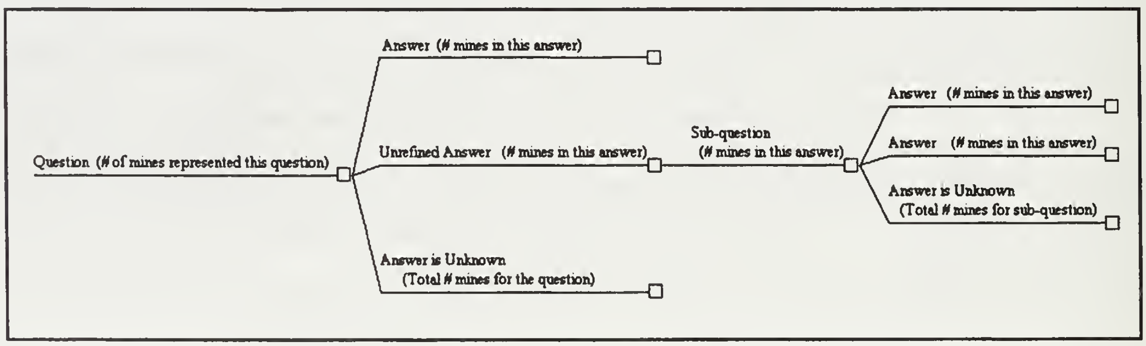

Figure 3.1 is an example of the question tree format.

that the question applied to would be listed in parentheses. Each question was fully explored to account for all possible answers for the landmine set. These answers were listed on the branches of the question. In cases where the answer needed further refinement, a sub-question was developed to further differentiate the answer. An "unknown" branch was added where appropriate to allow the question to be left unanswered. These unknown branches are discussed further in Section 6, below. Individual question trees representing a query are displayed in Section C. There is no single tree displaying all the questions. If the questions were combined into one tree it would be so large that it would be difficult to display or understand.

6. Heuristics

Once the question trees had been developed the next step was development of heuristics. These heuristics are based on general landmine information and are used to expand the available data on the unknown mine. This is done by applying the heuristics to the user supplied data. The heuristics used for the expert system are explained in more detail in Section D.

7. Dealing with Uncertainty

This topic will be dealt with in more detail in Chapter IV, but it needed to be considered when the questions were developed. Throughout the question process, there were several instances of uncertain data and uncertain rules. This was due partly to the subjective nature of some questions and, in some cases, the lack of certainty in the database. Some questions contained both certain and uncertain outcomes. One example is the question of shape. While there is little question what constitutes a cylinder, the difference between a rectangle and a square could be very slight and necessitates the taking of exact measurements. In addition to subjective uncertainty, there was also uncertainty in the database, in fields where data was not available. Items for which there is no available information must be included on every possible branch of the question tree to ensure they are not erroneously eliminated.

The "unknown" branch is found on many of the question trees. This branch is used to carry all mines to the next level if the deminer is unable to provide the requested information. In some cases, the "unknown" branch falls under a sub-question, and in these cases, it is intended to collect all mines of that sub-question and carry them to the next level. Once again, this may be due to missing information on the deminer's part, or it may be due to a lack of specificity on the part of the database.

8. Application of the Question Trees to the Landmine Set

To test the possible outcomes from the question trees, truth tables were developed for all the landmine attributes. These tables list each mine, and the attributes that that mine can have. This method allowed testing of the questions and heuristics to investigate their applicability. The complete truth tables are listed in Section E.

B. MINEFACTS DATABASE ENGLDATA TABLE

This section presents a detailed look at the data in the MineFacts database. There are fifty-three fields in the ENGLDATA table. This is the heart of the MineFacts Database, containing all the text information on each mine. In addition to this text data, each mine also has one or more photos in .BMP format that are linked to the record via the ENGLRMKS table.

While most of the fields of the database are complete, there are a number of fields that are blank or have non-standard data. Information is not available on all landmines, as the information is often classified or simply not complete when it was collected. Nonstandard data presented a lack of continuity within some fields. For example, a "Cylinder" was also referred to as a "Flat Cylinder" or "Cylindrical". Also some fields had remarks added such as the size "109mm (not including the tiltrod)". For this expert system, blank fields were treated as unknown, and inconsistencies were corrected.

Table 3.1 below shows the title for each field in the ENGLDATA table and a description for each field. The fields that were used for the expert system are noted with an asterisk. The complete ENGLRMKS table for the Bosnian mines can be found in Appendix A.

Field Name	**Field Description**
MINEID	The key field for the table
*Nomenclature	Mine Name
Country of origin	Country where the mine was developed
Manufacturing country	Country(s) where the mine is produced
*Using Country	Country where the mine has been used
*Mine Type	Antitank or antipersonnel
*Case Material	What material is used to construct the outer case e.g. metal, plastic, concrete
*Number of fuze wells	The number of the exposed fuze wells on the mine
*Case Color	e.g. OD green, black gray white
*Effect	Intended effect of the landmine. Mines can be blast, fragmentation, directional fragmentation, bounding fragmentation, Miznay-Schardin, or shaped-charge
*Length	Longest side of rectangular mine in millimeters, otherwise blank
*Width	Shortest side of rectangular mine in millimeters, otherwise blank

*denotes a field used in by the expert system
Table 3.1 Fields in the ENGLDATA Table

Field Name	Field Description
*Height	From base to top of mine not including fuze in millimeters
*Diameter - Max	For cylindrical mines, only in millimeters, otherwise blank
*Diameter - Min	For cylindrical mines, only in millimeters, otherwise blank
Total Weight	Mine's weight in kilograms
Main Explosive Weight	Weight of the main explosive in the mine kilograms
Non-Explosive Weight	Weight of all non-explosive components kilograms
Explosive Type	Explosive filler (e.g. TNT, RDX, C-4)
Booster Charge Weight	Weight of explosive booster in kilograms, if any
Fuze Model	Model and nomenclature of fuze(s)
Arm Delay - Max	Maximum Time allowed for arming delay
Arm Delay - Min	Minimum Time allowed for arming delay
Range	Casualty producing range/maximum effective range in meters
Neutralization	Acceptable methods for to neutralize the mine
Max Penetration	For Antitank mines, Max armor penetration in millimeters
Detonation Height	For bounding mines, Height of detonation above ground in meters
Emplacement Method	Scatterable/manual also stake, buried, etc.
Burial Depth - Max	Maximum possible depth to base of mine in millimeters
Burial Depth - Min	Minimum possible depth to base of mine in millimeters
Metal Content	Yes/No and description
Metal content Amount	Quantity of metal in mine
Power Source	Yes/No and Description of mine power source, if any
Self Destruct	Yes/No and Time to self destruction, if any
Self Neutralize	Yes/No and Time to self neutralization, if any
*Detectability	Yes/No Magnetometer Detectability
Anti-handling	Yes/No if present
*Underwater Operations	Yes/No and maximum depth
Description	The text description for the mine. This field can be 2000 characters long
Techniques of employment	Description of special employment techniques

*denotes a field used in by the expert system

Table 3.1 (continued) Fields in the ENGLDATA Table

Mine plow with Dog Bone	Yes/No if mine can be neutralized with a Mine Plow
General Information	The general information on the mine. This field can be 2000 characters long and contains plain English information on the mine
Characteristics	Text on additional characteristics
Components	Additional components
Fuze	Additional information
Analysist's Information	Additional information
Mine Roller	Yes/No if mine can be neutralized with a mine roller
Magnetic Mine Countermeasures	Yes/No
MICLIC	Yes/No if mine can be neutralized with a MICLIC
Bangalore Torpedo/APOBS	Yes/No if mine can be neutralized with a Bangalore Torpedo
Manual	Yes/No if mine can be neutralized manually by any method
Visual	Visual indications (e.g. tripwires, tiltrods), often blank
Electronic	Signals from the mine

*denotes a field used in by the expert system

Table 3.1 (continued) Fields in the ENGLDATA Table

Because of the problems with continuity and missing fields as explained above, the expert system was limited to the following fields: Nomenclature, Using Country, Mine Type, Case Material, Number of Fuze Wells, Case Color, Effect, Length, Width, Height, Min/Max Diameter, Detectability, and Underwater Operations. These fields represented the most important data on each mine and also were the most complete, with fewest blank fields. The questions used to query these data fields are explained in the next section.

C. QUESTION SET

The questions in this set are derived from information an expert would use to make an identification and the fields that were available from the ENGLDATA table.

There are other questions that the fields do not support, and some of those questions will be found in the heuristics in Section D. These questions are presented in no particular order, except in the case of sub-questions for the shape question tree. Each question tree diagram displays the results for that question against the Bosnian mine set.

1. Shape

Shape is an obvious attribute from the MineFacts database that can be requested from the deminer. There are fourteen different shapes in the MineFacts database, but the Bosnian set only displays four of these: cylindrical, rectangular, square, and egg-shaped. Over 87% of the landmines in the MineFacts database are cylindrical or square [MINE 97]. The remainder of the mines are rectangular, spherical or some unique shape. The determination of the mine's shape will lead to questions about the length and width or the diameter of the mine.

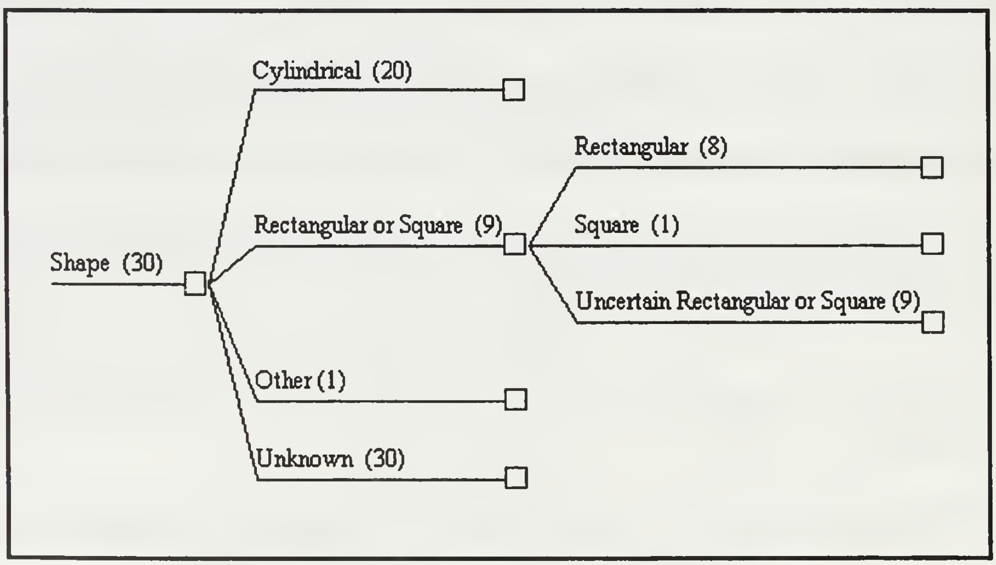

Figure 3.2 Land Mine Shape Question Tree

When dealing with shape, rectangular and square mines must be grouped together at this level. The reason is that the deminer may only have an approximate measurement, and may mistake a rectangular mine for square. The difference between length and width may be only a few millimeters, and since an exact measurement is not always possible, all square and rectangular mines must be carried through the tree to the next level.

In the question tree, mines with unique shapes are treated as "other" and will be separated for identification by their other features. These mines often have shapes that are difficult to describe and measurement of these mines may be subjective and error prone. Luckily, these mines make up a minuscule number of the overall mine population, and their unique shape can be used to "zero-in" on their identification.

2. Cylindrical Size

The cylindrical size question tree is given below:

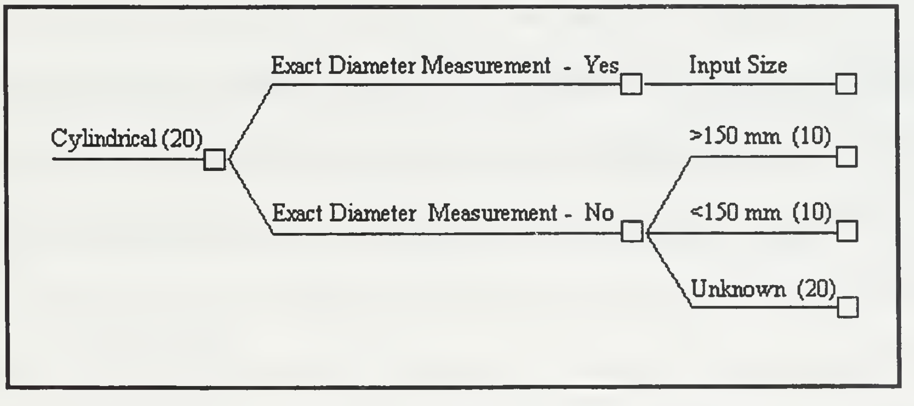

Figure 3.3 Cylindrical Size Question Tree

The next query level after shape is size. This question is based on the answer to the shape question and is, "Do you have the exact diameter measurement for the cylinder?". If the deminer can acquire exact measurements for the unknown mine this will greatly limit the number of possible mines. While an exact measurement is preferred, this requires close examination which may not always be possible. For this reason, the deminer may approximate the mine's size and use this to assist in identification.

The cylindrical size question tree only addresses the mine's diameter. The cylindrical mines in the Bosnian mine set can be nicely divided into mines larger or smaller than 150mm. Within the Bosnian set, mine diameters in the "under 150mm" subset range between 32mm and 103mm. Mines in the "over 150mm" subset range between 260mm and 326mm. These size ranges generally hold true for the entire mine population and allow for approximations to be made with a high degree of confidence. This question is very efficient because it divides the set of cylindrical mines in half.

3. Rectangular Size

Rectangular mines are measured by width and length. The first question asked here is, "Do you have an exact measurement for this mine?" (Figure 3.4). If the answer is yes the measurement will be input. If the answer is no, the next question is, "What is the approximate width?". To answer this, width must be defined. For our purposes, width is assumed to be the shorter of the two measurements. This convention was not universally followed in the MineFacts database, and one field from the Bosnian set had to be reversed. Width choices are offered for above and below 150mm. This range was selected because it is a good breakpoint between large and small mines. If the width cannot be approximated, the question moves to the next level.

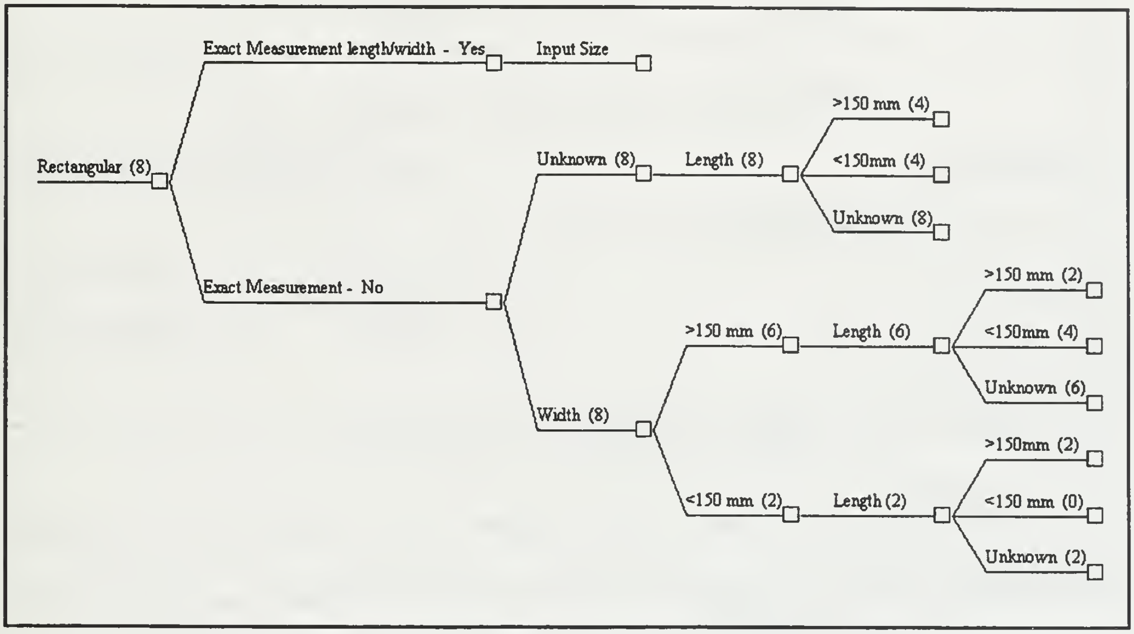

Figure 3.4 Rectangular Size Question Tree

The next sub-question in this tree is, "What is the approximate length for the mine?". Here length is defined to the user as the longer of the two sides. The range remains the same as for width, above or below 150mm. If the length is unknown, all possible mines are carried on the unknown branches. This question is very efficient and divides the rectangular mines in the landmine set into three smaller groups.

4. Square Size

For square mines, the question is only slightly different from the question for rectangular mines. Once again, the first question is for an exact measurement. If this is unavailable, the sub-question is, "What is the approximate measurement for the length/width of the mine?" (Figure 3.5). Here the size range is again above or below 150mm.

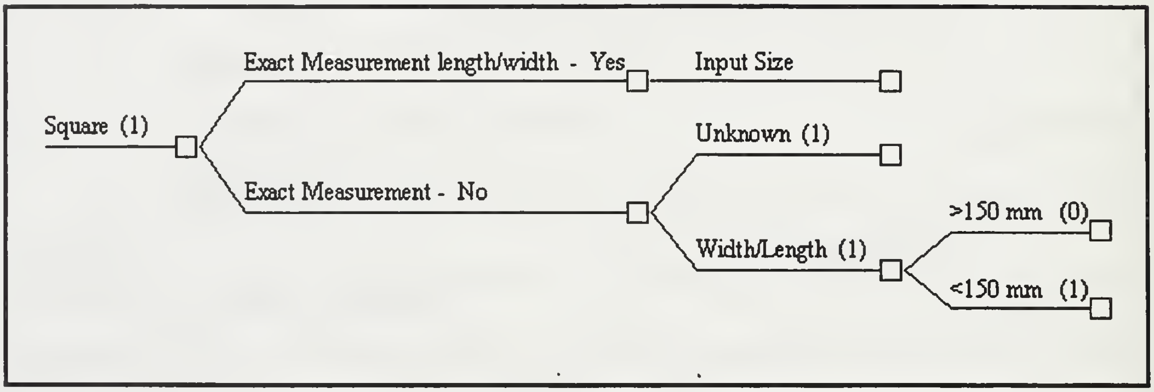

Figure 3.5 Square Size Question Tree

In the landmine set, there is only one square mine, so this shows no distribution. In the entire population of mines, this question will not produce much differentiation. There are only twenty-six square mines in the MineFacts database and only two are smaller than 150mm.

5. Rectangular/Square Size

The combined shape branch of rectangular or square is required to remove some of the uncertainty that may occur if an exact measure is unavailable. As stated above, this is important to avoid mistakes when the difference between length and width is small or the mine is partially obscured. The sub-questions for this tree are very similar to the rectangular tree. The only difference is that the exact measurement is not requested and the unknown branch appears at every level to allow for partial information. (Figure 3.6)

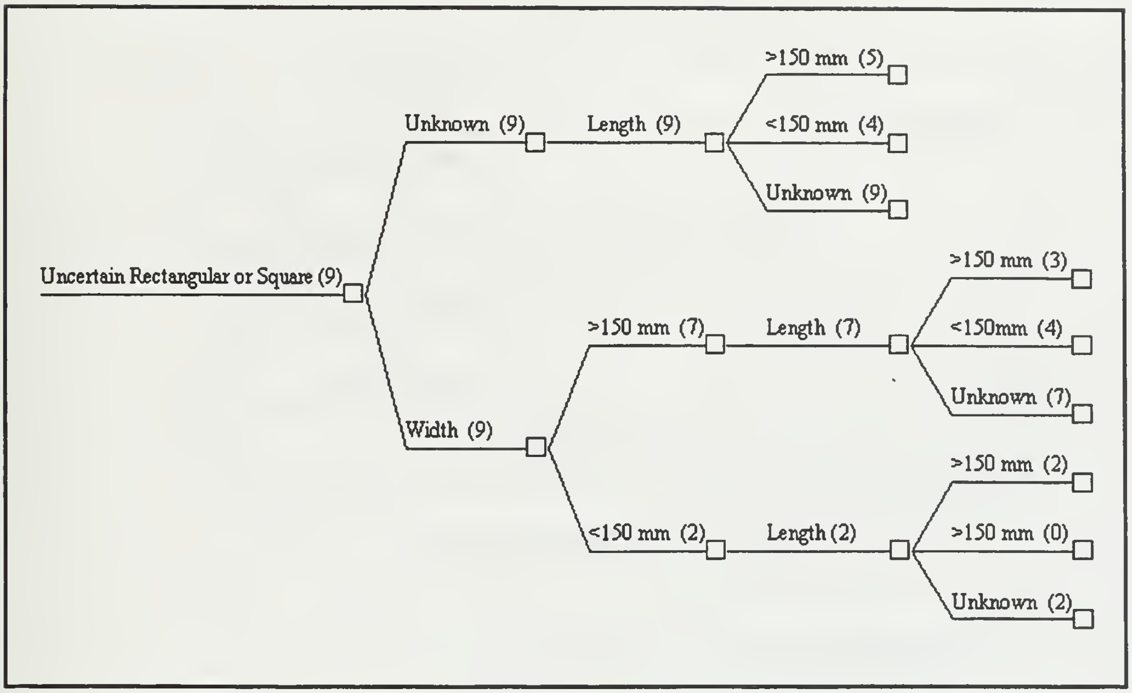

Figure 3.6 Uncertain Rectangular/Square Size Question Tree

6. Height

The height is completely unrelated to all other landmine characteristics. It can be difficult to get for buried mines and requires partial excavation of the mine. Both the antitank and antipersonnel mines were distributed over the whole range of sizes. The range between 50mm and 150mm is separated from the ranges above and below by a 25mm buffer. Once again, an exact measurement will greatly limit the number of possible mines and make identification much easier. (Figure 3.7)

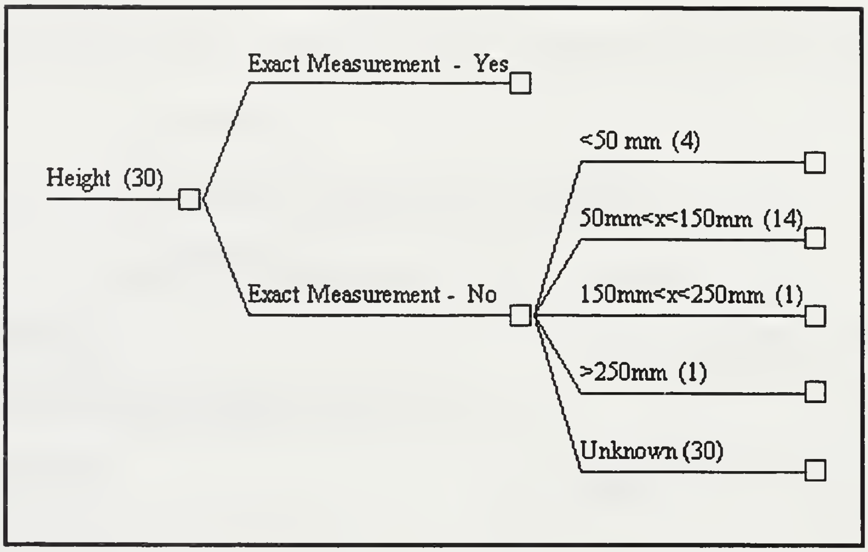

Figure 3.7 Height Question Tree

7. Case Material

Landmines come in a variety of case materials. Metal and plastic are the most common, but mines may also be encased in cardboard, fiberglass, bakelite, concrete or rubber. They may also be caseless, cast explosive. The division of case material is straight forward at the first level. Determination is not difficult, but some danger of misclassification exists, such as between fiberglass and plastic. The determination of a case material may also be confused by long exposure to the elements.

The sub-types of this question allow for a more detailed explanation of the case material. Because sheet metal and cast metal are both types of metal, all mines of this type are also carried on the unknown branch. The unknown branch also carries all other types of metal construction which are listed in the database as unspecified "metal". (Figure 3.8)

The plastic sub-type takes into account the use of rubber with some plastic mines. This is often used as a cover for the mine's pressure plate and will be visible on top of the mine. If the deminer is unsure, the unknown branch again carries all types of plastic mines to the next level.

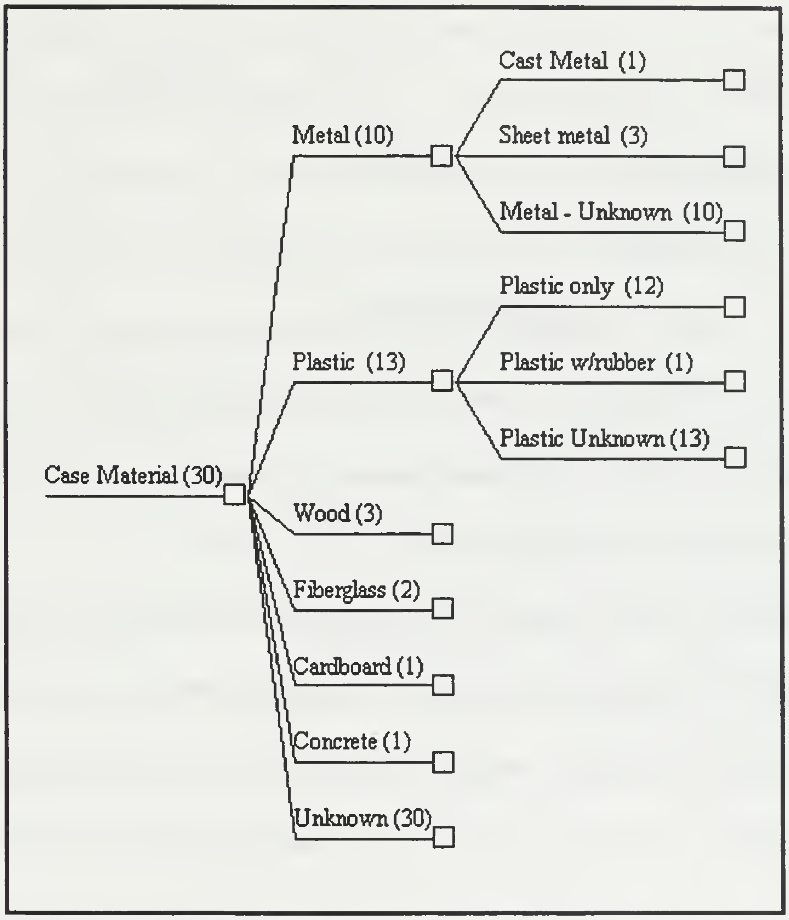

Figure 3.8 Case Material Question Tree

As noted before, some case materials often are difficult to distinguish after weathering. In many cases, the deminer may be able to narrow down the possible case materials to two or three possibilities. In these cases a possible method for querying the user would be to allow the user to select more than one possible answer from the question tree. The system then efficiently extracts the information from the deminer and reduces the uncertainty without using the unknown branch.

8. Color

Mines in the Bosnian set are predominately monochromatic. Color is an attribute that is extremely subjective, and it could easily lead to mistakes if too many options are listed. Most mines are camouflaged to blend in with their intended surroundings. The most common color is olive drab (OD) green, but black, gray, brown and unpainted wood are also used. Some mines are produced in several different colors for use in different environments. Mines are usually only one solid color, but some may have additional components of a different color. These combinations are most often OD green and black, where black is the color of additional screw-in fuze adapters. Figure 3.9 shows the possible answers for the Bosnian mines.

Color can be very useful to the deminer. The first level of the question tree removes mines with more than one color from the group. The second level addresses the available colors for the mines. Notice that green is also reduced to light green and OD green. While this is helpful here, it would be even more helpful to add more choices to this category in an expanded system. To an EOD technician, the difference between light green and pea green is significant and provides important clues about the country of origin of the mine. Although additional color choices could be helpful for the expert deminer it would most certainly cause confusion for the less experienced.

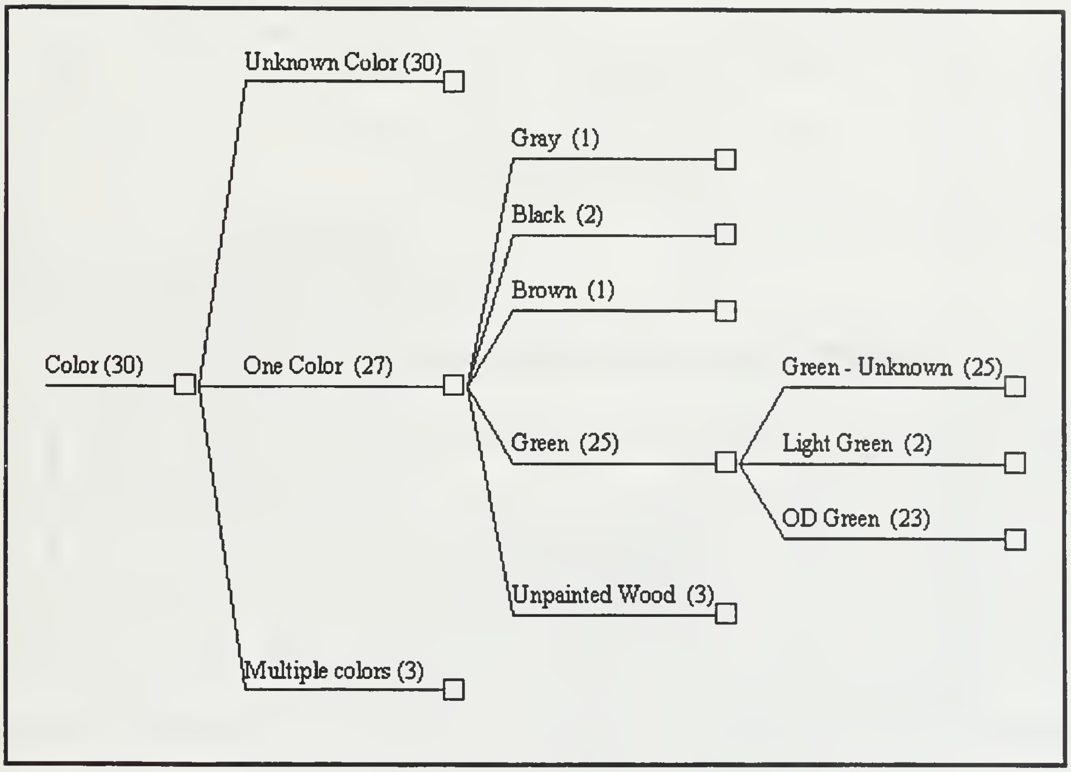

Figure 3.9 Color Question Tree

One important feature to notice about the color question tree is that the branches at each level add up to more than the initial number of landmines. This is because some mines come in more than one color. These mines must be carried on each color branch to avoid being missed as possible candidates.

9. Landmine Effect

The intended effect of a landmine is an esoteric attribute compared to the other physical characteristics of a landmine. The question asked is, "What is the intended effect of the landmine?" (Figure 3.10). The effect is a feature that may not be apparent in

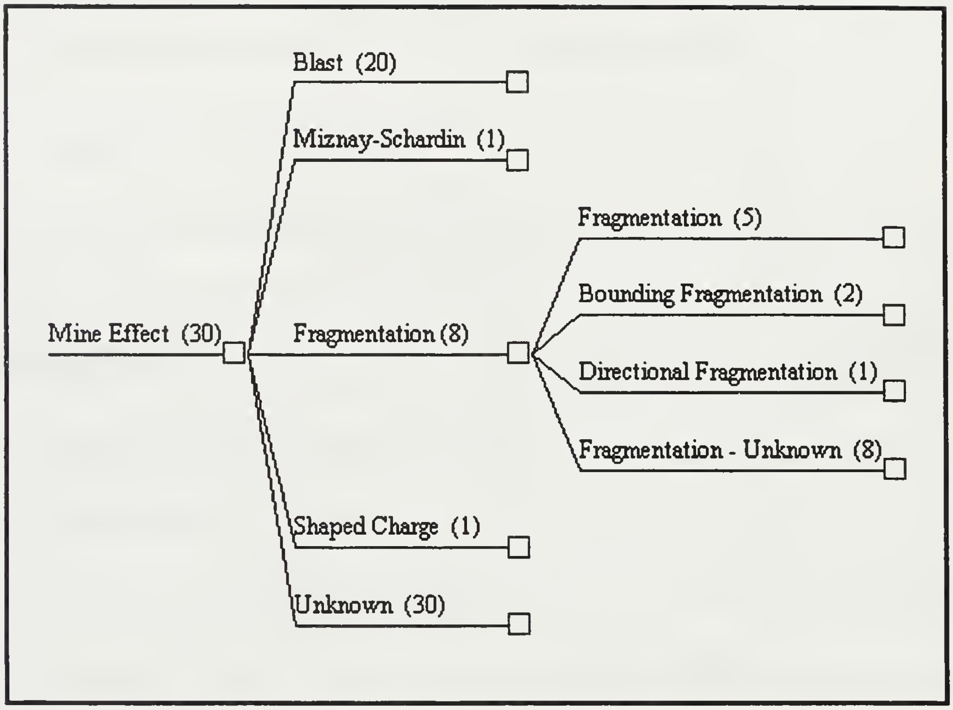

Figure 3.10 Land Mine Effect Question Tree

all cases, and is difficult to identify without some experience or reference. The question tree itself is a straightforward hierarchy, with no unusual levels. However this knowledge itself requires a certain level of expertise.

To determine the possible effect of a mine, a trained EOD technician will examine the size, shape, and case material. The technician will also compare the mine with other mines in their experience base. Because this question is difficult for the novice to answer, heuristics could be used to assist in the determination of the intended effect of the unknown mine. By using the information that the deminer is able to gather, the effect could possibly be determined, or if the deminer did select an effect, it could be checked against the heuristics that apply.

10. Number of Visible Fuze Wells

Fuze wells can be located on the top, sides or bottom of a mine. They are holes in the mine case that allow an initiator to be placed in contact with the main explosive charge. A fuze well can be used for the main fuze or for an anti-handling device to prevent the easy neutralization of the mine.

The question tree must take into consideration that a deminer may not be able to see all of the fuze wells on the mine due to the mine being partially obscured. Landmines are usually buried, and though the deminer may partially excavate the mine, some fuze wells may be missed or may not be visible because they are on the bottom of the mine. For these reasons, the tree is constructed so that the smaller number branches include mines with more fuze wells to account for miscounts. As an example, all mines are listed on the "zero" branch. If one fuze well is located then it will rule out the mines with zero

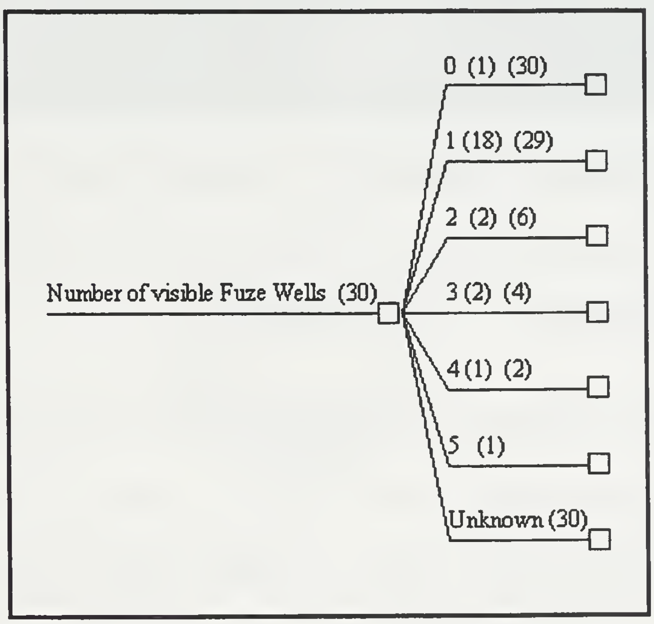

Figure 3.11 Number of Fuze Wells Question Tree

fuze wells. The deminer can answer one and this will account for all mines with one or more fuze wells. (Figure 3.11)

To assist the deminer in identifying what a fuze well looks like, the system will have to present an explanation and several examples (Figure 3.12). Some mines have holes in the case for rope handles and these may be mistaken as fuze wells. Photographic representation of a fuze well and other cavities which may be confused with a fuze well will remove some of the uncertainty from this question.

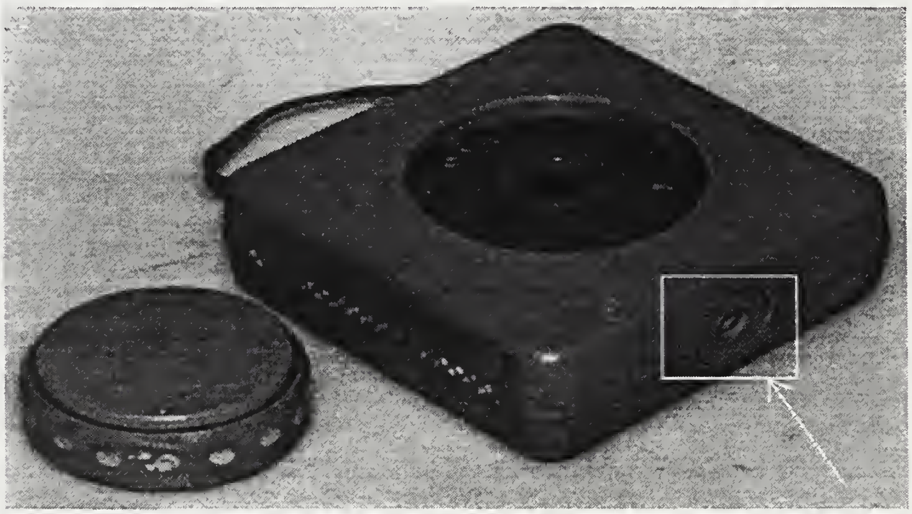

Figure 3.12 PRB M3 A1 Antitank mine. Secondary fuze well is noted [MINE 97]

11. Metal Content

The MineFacts database has a field that notes the amount of metal found in a landmine. Landmines can contain varying amounts of metal, and modern blast mines may be completely non-metallic. Mines containing metal can be located with a magnetometer. Once a mine has been located, a trained magnetometer operator can easily determine if there is a large or small amount to metal around the mine. (Figure 3.13)

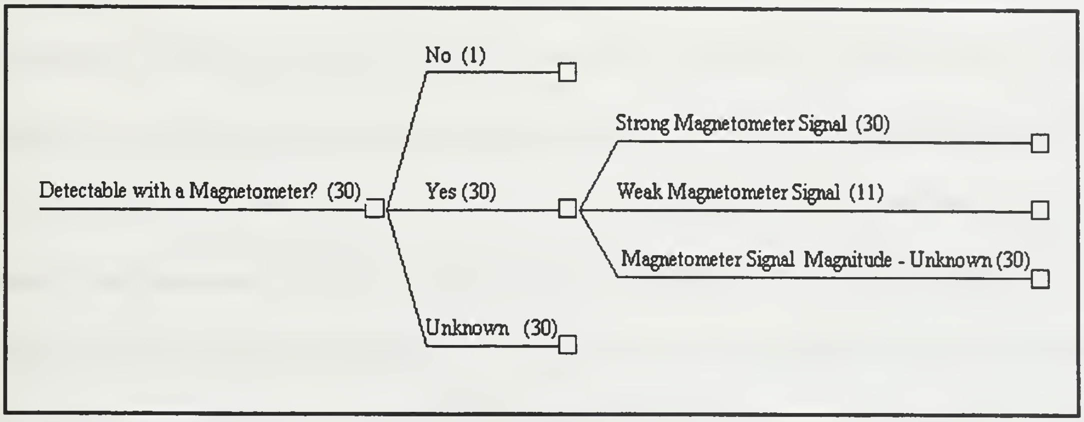

Figure 3.13 Metal Content Question Tree

However, detection of metal around a mine does not necessarily mean that the mine contains metal. The landmine could be booby-trapped with a metallic anti-handling device to prevent its removal, or the area could be contaminated with metal from an already detonated mine. This means that the question tree cannot confirm the identification of metallic mines, it can only confirm mines that have no metal.

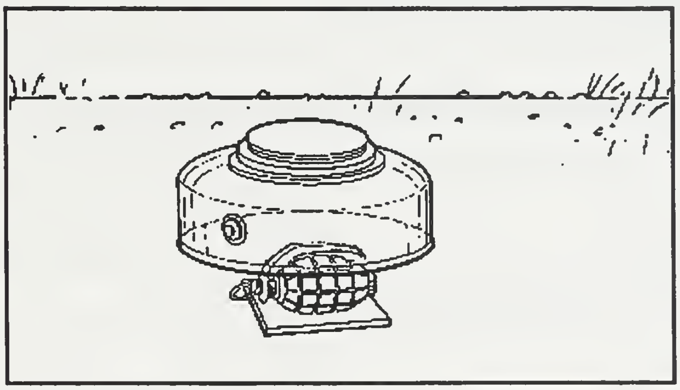

Figure 3.14 Landmine booby-trapped with a grenade. The pin is removed from the grenade and the mine is placed on the spoon. When the mine is moved, the grenade functions. In this case, a non-metallic mine appears metallic to the magnetometer [SAPP 90].

As an example, if the non-metallic TMA-5 mine is booby-trapped with a hand grenade (Figure 3.14), it will produce a strong signal from a magnetometer. If the system follows the "Detectable with a magnetometer" branch, the mine could be erroneously eliminated. To prevent the wrong path being followed, the branches for metallic mines must also contain the non-metallic mines.

Once metal has been detected around the mine, a trained magnetometer operator can determine if the signal is strong or weak. A weak signal confirms low-metal mines. It cannot rule them out by the same reasoning that non-metal mines can't be ruled out. This portion of the question tree must also be weighted to take into consideration the subjective nature of "strong" versus "weak" signals. Magnetometers are not standardized; several factors may contribute to the subjectivity of strong versus weak; operators have different levels of training; and battery power often affects performance. The answers to this question should be weighted very lightly.

12. Mine Type - Intended Target

This question tree asks for the mine type or intended target.

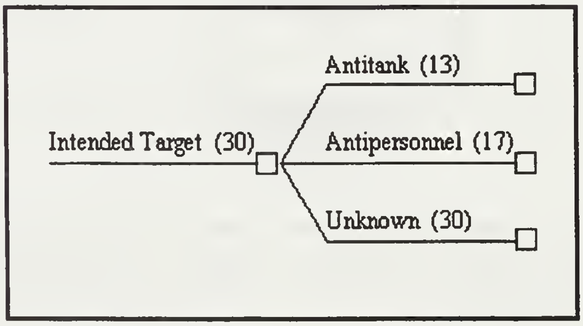

Figure 3.15 Intended Target Question Tree

The question asked is, " What is the intended target for the unknown mine?". The answer to this question is not always readily apparent to the deminer. Often, an experienced deminer can easily identify a mine's intended target by its size or emplacement. Larger mines tend to be antitank mines, and the use of tiltrods or emplacement on a road could lead the deminer to believe the mine was antitank. Antipersonnel mines are smaller and sometimes use tripwires or have prong-type fuzes. Inexperienced deminers may not be able to answer this question, but if they provide enough other information, the heuristics may be able to fill in the blank for them.

13. Underwater Capability

The underwater capability question tree is given below:

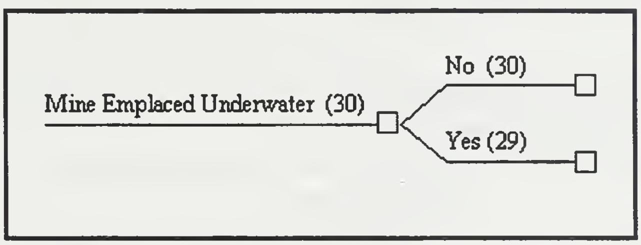

Figure 3.16 Underwater Capability Question Tree

Not all mines can be used underwater. The question asked here is, "Is the mine deliberately emplaced underwater?". Twenty-nine of the Bosnian mines can be emplaced underwater so this question will only rule out one mine from the landmine set. This mine, the L.PZ.MI antitank mine, uses a percussion primer and will not function if submerged. This question is not as straightforward as it appears. The system must caveat the question with the warning to ensure the mine was deliberately emplaced underwater, and was not washed into a river or flooded following emplacement. Because it may not be obvious whether submerged emplacement was deliberate, this question will also receive a reduced weight against other questions.

14. Country of Use

The country of use can be a very useful question to ask of the deminer. Information on what country a mine is being used in is usually very accurate. Since it is obvious what country the deminer is working in, the input from the user will be very

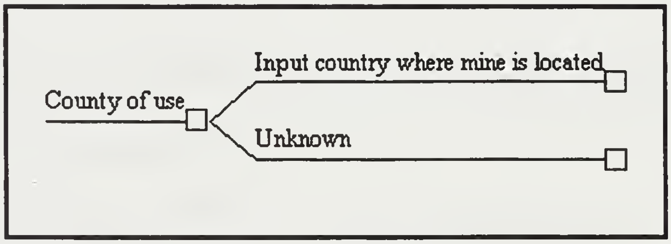

Figure 3.17 County Where Land Mine is Located
Question Tree

reliable. With respect to the landmine set for this thesis, this question has already been answered, as the set was limited to only Bosnian mines. (Figure 3.17)

D. HEURISTICS

The question trees that are listed above are based on the data fields in the MineFacts database. Heuristics allow more data to be collected from the deminer by making certain inferences based on the basic information supplied by the deminer. The heuristics used for this system were based on general landmine characteristics. These rules were first developed with words to show some degree of certainty (e.g. never, rarely, sometimes, often, usually, always). Below is a list of the rules used.

- Blast mines are usually plastic.
- Stake mines are usually cast metal.
- Stake mines are always fragmentation.
- Tripwires are always an indication of an antipersonnel mine.
- Tilt-rod actuated mines are always antitank mines.
- Concrete cased mines are always fragmentation.
- Cast metal mines are always fragmentation.
- Antipersonnel mines are usually smaller than 150mm in diameter or length.
- Antipersonnel mines rarely have carrying handles.
- Antitank blast mines are usually larger than 150mm in diameter or length.
- Antitank mines are usually emplaced on roads.
- Square/rectangular mines are never shaped-charge mines.
- Bounding fragmentation mines are always antipersonnel mines.
- Bounding fragmentation mines are usually metal cased.
- Bounding fragmentation mines are usually round.
- Mines with prongs are always antipersonnel.
- Mines smaller than 40mm high are always blast mines.
- Cardboard mines are always blast mines.
- Serrated metal case mines are always fragmentation.
- Fragmentation mines are usually emplaced above ground.
- Fragmentation mines are always antipersonnel.
- Miznay-Schardin mines are usually circular.
- Miznay-Schardin mines are never smaller that 6 inches in diameter.
- Miznay-Schardin mines are always antitank.
- Directional fragmentation mines are usually square.
- Directional fragmentation mines are usually emplaced vertically with the ground.

These rules were used to generate heuristics in an IF-THEN format. This format will allow the user-supplied data to be easily evaluated, and the reasoning explained to the user. As an example:

> IF a mine has a carrying handle,
> THEN it is an antitank mine.

IF a mine is plastic,
AND it has no metal,
THEN it is a blast mine.

These heuristics are used to fill in blanks in the user supplied data, make conclusions and also to check user input against known rules. As an example, examine the heuristic:

IF a mine is has a wood case,
AND it has 2+ fuze wells,
THEN it is an antitank mine.

First, the inference engine checks to determine if the user has supplied the information needed for this heuristic. If the information isn't available, the heuristic is skipped. If the information is available, as in this case, that the mine is wooden and has at least two fuze wells, the system then reasons that the mine is an antitank mine. There are three possible outcomes that could be made with this new data:

1. If the user did not specify that the mine was an antitank mine, the inference engine would fill in that blank.
2. If the user did specify the mine was an antitank mine, then the system would move to the next heuristic.
3. If the user specified that the mine was an antipersonnel mine, the system halts and asks the user for clarification pointing out the inconsistency.

Once this heuristic has been fully explored, the system moves on to the next rule. The information from the first heuristic is added to the observed data and can be used for the next heuristic. Assume the next rule states:

> IF a mine is antitank,
> AND it has a wood case,
> THEN it is a blast mine.

If the first rule determined that the mine was indeed an antitank mine, the sub-conclusion can be drawn that the mine is also a blast mine. This is data that the user could not provide, and is valuable for making a final conclusion about the mine's identification.

Appendix B contains a complete list of all heuristics used in the expert system.

E. TRUTH TABLE

To determine how the landmine set was broken down, a truth table was developed displaying the answers for the question trees against the list of the Bosnian mines. They were vital for the construction and testing of the expert system. Table 3.2 displays the answers for the shape, size and height questions.

Table 3.3 below displays the continuation of the Bosnian mine truth table. This section answers the case material, effect, mine type, and underwater operations questions. A "Y" indicated an attribute does not apply to that mine.

Table 3.4 displays the last page of the Bosnian mine truth table. This section answers the number of fuze wells, color and metal content questions. The fuze well question is represented here with the actual number of fuze wells first, and then in the remaining columns, the possible number(s) of visible fuze wells. The magnetometer fields are used to describe the signal level received when determining metal content of a landmine. Mines could all be identified as having "zero" visible fuze wells, but as we move across the table, only mines with more fuze wells get a "Y".

	Case Material									Effect							
Nomenclature	Plastic Only	Plastic and Rubber	Metal	Sheet Metal	Cast Metal	Wood	Fiberglass	Concrete	Cardboard	Blast	Mlznay-Schardin	Shaped-charge	Fragmentation	Directional Frag	Bounding Frag	MineType	Underwater Operations
MAT-76 Antitank Mine	N	N	N	N	N	N	Y	N	N	Y	N	N	N	N	N	Antitank	Y
TM-100 Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
TM-200 Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
TM-62M Antitank Mine	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
L.PZ.MI Antitank Mine	N	N	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	Antitank	N
PMR-1 Antipersonnel Mine	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N	Antipersonnel	Y
PMA-1A Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
PMR-2 Antipersonnel Mine	N	N	N	N	N	N	N	Y	N	N	N	N	Y	N	N	Antipersonnel	Y
TMA-5 Antitank Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
TMRP-6 Antitank Mine	Y	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	Antitank	Y
MRUD Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	N	N	N	Y	Y	N	Antipersonnel	Y
TMA-2 Antitank Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
TMA-3 Antitank Mine	N	N	N	N	N	N	Y	N	N	Y	N	N	N	N	N	Antitank	Y
TMA-4 Antitank Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
PMA-1 Antipersonnel Mine	N	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
PMA-2 Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
PMA-3 Antipersonnel Mine	N	Y	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
PMR-2A Antipersonnel Mine	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N	Antipersonnel	Y
PROM-1 Antipersonnel Mine	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	Y	Antipersonnel	Y
TM-500 Antipersonnel Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y
MT-4 Antipersonnel Mine	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N	N	Antipersonnel	Y
PMR-3 Antipersonnel Mine	N	N	Y	N	Y	N	N	N	N	N	N	N	Y	N	N	Antipersonnel	Y
TMA-1 Antitank Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
TMD-2 Antitank Mine	N	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N	Antitank	Y
PMR-2AS Antipersonnel Mine	N	N	Y	N	N	N	N	N	N	N	N	N	Y	N	N	Antipersonnel	Y
PSM-1 Antipersonnel Mine	N	N	Y	Y	N	N	N	N	N	N	N	N	Y	N	Y	Antipersonnel	Y
MC-71 Antitank Mine	N	N	Y	N	N	N	N	N	N	N	N	Y	N	N	N	Antitank	Y
TMM-1 Antitank Mine	N	N	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
Type 69 Antitank Mine	Y	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	Antitank	Y
PMD-1 Antipersonnel Mine	N	N	N	N	N	Y	N	N	N	Y	N	N	N	N	N	Antipersonnel	Y

Table 3.2 Truth table for the Bosnian landmine set

		Rectangular/Square		Cylindrical		
Nomenclature	Shape	Length	Width	Diameter - Max	Diameter - Min	Height
MAT-76 Antitank Mine	Cylindrical			320 mm		
TM-100 Antipersonnel Mine	Cylindrical				33.0 mm	107.0 mm
TM-200 Antipersonnel Mine	Rectangular	59.0 mm	32.0 mm			109.0 mm
TM-62M Antitank Mine	Cylindrical			320 mm		101.85 mm
LPZ M Antitank Mine	Flat cylinder			266 mm		62 mm
PMR-1 Antipersonnel Mine	Cylindrical				80 mm	120 mm
PMA-1A Antipersonnel Mine	Rectangular	140.0 mm	68.0 mm			31.0 mm
PMR-2 Antipersonnel Mine	Cylinder			75 mm		120 mm
TMA-5 Antitank Mine	Rectangular	312 mm	275 mm			113 mm
TMRP-6 Antitank Mine	Cylindrical			290 mm		132 mm
MRUD Antipersonnel Mine	Rectangular	231.0 mm	46.0 mm			89.0 mm
TMA-2 Antitank Mine	Rectangular	330 mm	260 mm			100 mm
TMA-3 Antitank Mine	Cylindrical			265 mm		80 mm
TMA-4 Antitank Mine	Cylindrical			280 mm		65 mm
PMA-1 Antipersonnel Mine	Rectangular	140 mm	70 mm			30 mm
PMA-2 Antipersonnel Mine	Cylindrical				68 mm	30 mm
PMA-3 Antipersonnel Mine	Cylindrical				103 mm	36 mm
PMR-2A Antipersonnel Mine	Cylindrical				66 mm	132 mm
PROM-1 Antipersonnel Mine	Cylindrical				75 mm	178 mm
TM-500 Antipersonnel Mine	Rectangular	70.0 mm	50.0 mm			108.0 mm
MT-4 Antipersonnel Mine	Cylindrical			94.0 mm		500.0 mm
PMR-3 Antipersonnel Mine	Cylindrical			78.0 mm		134.0 mm
TMA-1 Antitank Mine	Cylindrical			315.0 mm		100.0 mm
TMD-2 Antitank Mine	Square					
PMR-2AS Antipersonnel Mine	Cylindrical				66 mm	132 mm
PSM-1 Antipersonnel Mine	Cylindrical			75.0 mm		135.0 mm
MC-71 Antitank Mine	Other			260 mm		
TMM-1 Antitank Mine	Cylindrical			326.0 mm		90.0 mm
Type 69 Antitank Mine	Cylindrical				270 mm	100 mm
PMD-1 Antipersonnel Mine	Rectangular	200 mm	89 mm			64 mm

Table 3.3 Continuation of the Truth table for the Bosnian landmine set

	Number of Fuze Wells							Color							Magnetom		
Nomenclature	Number of Fuze Wells	0 Fuze wells	1 Fuze well	2 Fuze wells	3 Fuze wells	4 Fuze wells	5 Fuze wells	Multiple Colors	OD Green	Black	Gray	Light Green	Brown	Natural Wood	No Signal	Weak Signal	Strong Signal
MAT-76 Antitank Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TM-100 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y
TM-200 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y
TM-62M Antitank Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
L.PZ.MI Antitank Mine	5	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	N	N	N	N	Y
PMR-1 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
PMA-1A Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	Y	N	N	N	N	N	Y	Y
PMR-2 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TMA-5 Antitank Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	Y	Y	Y
TMRP-6 Antitank Mine	2	Y	Y	Y	N	N	N	N	N	N	N	Y	N	N	N	N	Y
MRUD Antipersonnel Mine	2	Y	Y	Y	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TMA-2 Antitank Mine	3	Y	Y	Y	Y	N	N	N	Y	N	N	N	N	N	N	Y	Y
TMA-3 Antitank Mine	4	Y	Y	Y	Y	Y	N	N	Y	N	N	N	N	N	N	Y	Y
TMA-4 Antitank Mine	3	Y	Y	Y	Y	N	N	N	Y	N	N	N	N	N	N	Y	Y
PMA-1 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	Y	N	N	Y
PMA-2 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	Y	N	N	N	Y	Y
PMA-3 Antipersonnel Mine	0	Y	N	N	N	N	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N	Y	Y
PMR-2A Antipersonnel Mine	1	Y	Y	N	N	N	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N	N	Y
PROM-1 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TM-500 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y
MT-4 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	N	Y	N	N	Y	N	N	Y	Y
PMR-3 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TMA-1 Antitank Mine	2	Y	Y	Y	N	N	N	N	Y	N	N	N	N	N	N	Y	Y
TMD-2 Antitank Mine	2	Y	Y	Y	N	N	N	N	N	N	N	N	N	Y	N	N	Y
PMR-2AS Antipersonnel Mine	1	Y	Y	N	N	N	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N	N	Y
PSM-1 Antipersonnel Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
MC-71 Antitank Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
TMM-1 Antitank Mine	3	Y	Y	Y	Y	N	N	N	Y	N	N	N	N	N	N	N	Y
Type 69 Antitank Mine	1	Y	Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y
PMD-1 Antipersonnel Mine	0	Y	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	Y

Table 3.4 Continuation of the Truth table for the Bosnian landmine set

F. LIMITS OF THE THESIS

This thesis is limited in several respects. First, the system is limited to only thirty mines. While this is somewhat representative of the whole population of 700 mines, it is by no means a complete system. The implementation for these thirty mines makes assumptions and inferences based only on this set. If the entire 700 mines were used, these assumptions and questions would have to be refined and re-tested. The second limitation is in the overall design. This thesis places emphasis on the EOD knowledge in this expert system. It may not represent the most efficient method for constructing an expert system. That said, it should also be pointed out that the logic used for the EOD portion is sound and correct. This thesis attempts to provide a proof of concept, that an expert system could be helpful for the EOD community and deminers.

IV. IMPLEMENTATION

A. OVERVIEW OF THE SYSTEM DESIGN

This expert system relies on information provided by the user to make a positive identification of the landmine. Figure 4.1 is a data flow diagram of how the system is designed.

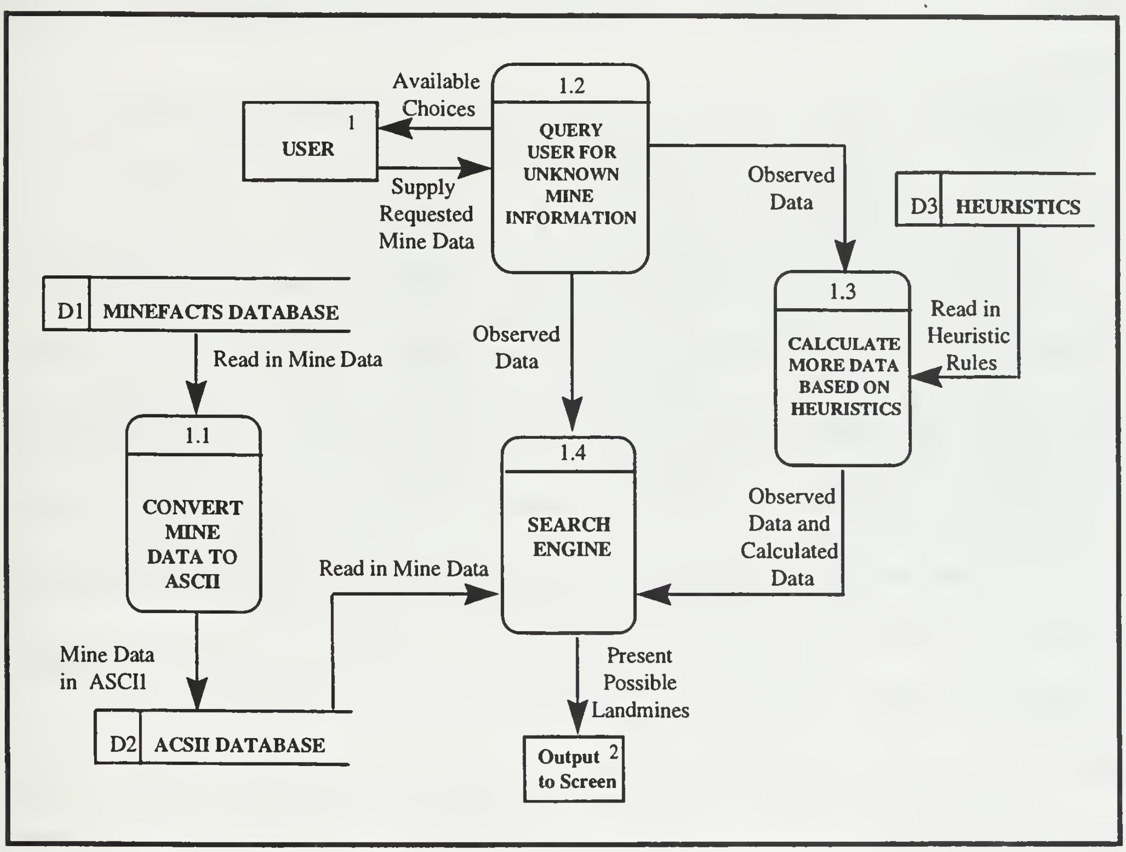

Figure 4.1 DFD for the Expert System

Before the program could be used, the data from the MineFacts database (D1) would have to be read and converted to ASCII text format. With this information in place, the user (1) can begin a search by providing information to the user interface (1.2). This is facilitated by the interface providing answer choices for each query. Once this information is collected, it is integrated with the heuristics (D3) to infer additional data that the user may not have been able to provide (1.3). The observed and calculated data are passed to the search engine (1.4). The search engine compares this data with an ASCII version of the MineFacts database to determine the most likely landmine candidates. These candidates are output to the screen by nomenclature and photo for final selection by the user.

B. IMPLEMENTATION

The expert system was implemented on an IBM PC using Microsoft Excel for Windows 95. This approach was used to model and test the weights for the expert system and was not a full implementation of the heuristics or decision trees. This method was selected to allow the rapid prototyping of question weights, which required extensive manipulation and testing. The immediate output supplied by the spreadsheet allowed the numbers to be quickly changed and evaluated. An analytical programming language would not have allowed this type of testing.

Ultimately, this program should be fully implemented using C++, Java or Ada to allow for the user interface and data handling features that these types of languages offer. A full implementation could also take advantage of an expert system shell (ESS), which would speed construction by providing a framework for input of the knowledge base, heuristics and weights.

1. Construction

The model is designed to test weights, and model the use of some simple heuristics. Table 4.1 is a scaled down sample from the model. Observed data is entered on the bottom row of the table, and each mine receives a probability value (P) for each question based on the observed data. If an observed characteristic closely matches that characteristic for the mine, it receives a number close to 1.0, if it clearly doesn't match it receives a number close to 0.0. Unknown receives 0.5.

NOMENCLATURE	Shape	(P_1)	Case Material	(P_2)	Total Weights	Likelihood (LV)
MAT-76	Cyl	0.90	FIB	0.30	15.90	69.13%
TM-100	Cyl	0.90	PLA	0.30	15.90	69.13%
TM-200	Rec	0.01	PLA	0.30	2.55	11.09%
TM-62M	Cyl	0.90	MET	0.99	21.42	93.13%
L.PZ.MI	Cyl	0.90	PLA	0.30	15.90	69.13%
PMR-1	Cyl	0.90	CAR	0.05	13.90	60.43%
PMA-1A	Rec	0.01	PLA	0.30	2.55	11.09%
PMR-2	Cyl	0.90	CON	0.05	13.90	60.43%
TMA-5	Rec	0.01	PLA	0.30	2.55	11.09%
Field Weights	15		8		23	100.00%
Observed Data	**CYL**		**MET**			

Table 4.1 Shows the format used for the EOD associate model.

The probability value is then multiplied with the question weight (W) to give a confidence factor. Confidence factors for all questions are summed to get a Total Weight for each Landmine (TWL). This total weight is divided by the Total Field Weight (TFW) to get the Likelihood Value (LV)for each mine.

$$W_1P_1 + W_2P_2 + ...W_iP_i = TWL$$
$$W_1 + W_2 + ...W_i = TFW$$
$$TWL/TPW = LV$$

2. Question Weights and Answer Probabilities

There are several possible outcomes for the questions used by the model. The answers to these questions are assigned probabilities to account for uncertainty. This uncertainty may be because the answer is difficult to determine, or the answer is very similar to other possible answers.

a. True/False Questions

True or false answers are weighted as 1.0 or 0.0 respectively. There is no uncertainty about the possible answers. Some examples of this type of question are, "does the mine have a tripwire?" or, "is the mine a stake mine?".

b. Choice from Several Clear Choices

This is a question with multiple answers, but there is a clear separation between the possible answers. With this type of question, the user's answer is assumed to be correct since the answers are not subjective. As an example, the Shape question assumes that the user can select the correct shape from the given choices of "cylindrical", "rectangular", "square", or "other". For answers where the user could be mistaken, say between rectangular and square shapes, the question is handled as a choice from several unclear choices, as explained below in Section C.

c. Choice from Several Unclear Choices

This situation results when some of the answers are similar to each other. The case material question presents exactly this type of problem. The case material for a mine may not always be easy to determine, especially if the mine has been exposed to the elements. A user may look at the mine and not be able to tell if it is plastic or fiberglass, though they are pretty sure it isn't metal and are positive it isn't made of wood or concrete. To account for this uncertainty, weights were given to each different case material based on its "similarity" to another material. Table 4.2 shows the matrix used in the Excel model to manage the case material weights. A value of .99 is a perfect match, .01 is no match, and 0.50 is the value for "Unknown".

OBSERVED Material	Plastic	Plastic/ Rubber	Fiberglass	Metal	Sheet Metal	Cast Metal	Cardboard	Concrete	Wood
Plastic	0.99	0.95	0.85	0.30	0.30	0.05	0.05	0.05	0.05
Plastic/Rubber	0.95	0.99	0.65	0.30	0.30	0.05	0.05	0.05	0.05
Fiberglass	0.85	0.65	0.99	0.30	0.30	0.05	0.05	0.05	0.05
Metal	0.30	0.30	0.30	0.99	0.99	0.99	0.05	0.05	0.05
Sheet Metal	0.30	0.30	0.99	0.99	0.99	0.25	0.05	0.05	0.05
Cast Metal	0.05	0.05	0.99	0.99	0.25	0.99	0.05	0.35	0.05
Cardboard	0.05	0.05	0.05	0.05	0.05	0.05	0.99	0.05	0.35
Concrete	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.99	0.05
Wood	0.05	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.99

Table 4.2 Matrix of weights used for case material, where some items may be easily confused with another.

Notice the "plastic" row in Table 4.2. An answer of "Plastic" in the observed column would produce weights of 0.99 for all the plastic mines, 0.95 for the rubber and plastic mines, and 0.85 for the fiberglass mines. The metal mines receive 0.30 as that category includes some sheet metal mines, and the sheet metal category also receives 0.30. The reasoning behind these weights is that fiberglass could easily be mistaken for plastic so it receives the high weight of 0.85. Sheet metal is not likely to be mistaken, but it is possible if the mine was dirty or wet, so it is assigned a value of 0.30, a value that is nearer to unknown.

d. Closeness to Value (Ranges)

Ranges are used for the "size" questions in the model. When the user inputs a measurement for a size question, there must be some allowance for error. This could be done by applying weights to the possible range of input values (Table 4.3). For example, if a mine was +/- .05 mm from the size input by the user, the certainty factor would be 0.99. As the difference from the actual size increases, the certainty factor decreases. Sizes that are greater than 5 mm off the exact size are given a certainty factor of 0.01.

Difference from Mine's Exact Size	Certainty Factor
+/- 0.5 mm	0.99
+/- 1.0 mm	0.9
+/- 2.0 mm	0.8
+/- 3.0 mm	0.5
+/- 4.0 mm	0.25
> +/- 5.0 mm	0.1

Table 4.3 This table shows the weights for ranges when an exact measure is given for an item. These certainty factors assume that exact measurements are made using calipers. If an exact measurement is not available, the user can always use the approximate ranges to describe the size.

In the model, exact measurements were not addressed. But this same method works for ranges. As an example, the possible approximations for a mine's diameter are less than 150 mm and greater than 150 mm. If a mine is 135 mm in diameter, it could be given a certainty factor of 0.95 for an answer of less than 150 mm and 0.30 for an answer of greater than 150 mm. This would allow some level of error in the case the user's size estimate was incorrect.

e. Weighting Questions

Another way to model the logic with the information available is to weight certain questions based on their potential value or the overall certainty of their answers. In the model, questions were assigned weights between one and twenty. A question with a weight of twenty, for example, is considered twenty times more important than a question with a weight of one.

The "shape" question was given a weight of fifteen in the model. It received this weight because the user can be expected to easily make a correct determination of the mine's shape. Also, this question provides a great deal of differentiation within the data set, and a heavy weight will amplify that differentiation in the results. An example of a lightly weighted question is the "underwater emplacement" question. Here the user is asked if the mine was deliberately emplaced underwater. This question, while having only two possible answers, is very uncertain. A mine found underwater could have been washed there, or could have been flooded after it was emplaced. Also, this question also will only eliminate one mine from the data set. For these reasons, this question's value is very limited, and it is given a low weight.

e. Heuristic Certainty Factors

The heuristics are weighted with a certainty factor that is determined by the reliability and quality of the data input into the heuristic. This value is important when the calculated data is used to fill in for data that the user did not observe. For purposes of heuristic weights, observed data is assumed to have a certainty of 1.0 on a scale of 0.0 to 1.0. Data calculated with a heuristic may have a certainty factor lower than 1.0, because it may use data that is uncertain or error prone. This certainty value is used to modify the answer weight for a mine. Note, for example, the heuristic below:

IF a mine is smaller than 150mm in diameter or length,
AND it is less than 50 mm in height,
THEN it is an antipersonnel mine (0.75)

Because, this heuristic deals with size, there is a possibility of uncertainty in the generated answer. The input data, that the mine is a certain size may be error prone since sizes may be approximate. Also, while this heuristic is *almost* always true, it is not *always* true. However, there are only two antitank mines for the 700 known landmines which could fit this heuristic. For these reasons, the certainty factor for this heuristic is set at 0.75. If the heuristic-generated answer "antipersonnel" is used, the overall weight for that question will be affected: Antitank mines which are lightly weighted at 0.05, will move slightly higher, whereas. antipersonnel mines which are weighed as 0.95 will move lower.

3. Proposed Outputs

The model will produce an overall certainty for each mine in the Bosnian set and list the top five values. The full implementation for the program would offer three possible outcomes based on the input and calculated data.

a. Top Five

If the user has input enough information to limit the database to a near match, the top five candidates will be displayed on the screen. This display would show the nomenclature, the certainty factor and a picture of the candidate mines. Figure 4.4 shows an example of how this information could be shown if the program had a GUI written for it.

b. None Acceptable

If the results fail to meet a threshold value set by the expert system programmer, the system should offer no candidates to the user. This minimum threshold is used to protect the user from candidate mines with confidence values that are dangerously low. Since the render-safe procedure is based on the mine's identification, a poor answer is worse than providing the user with no answer. If the search failed to produce acceptable results, the user would be informed that the information provided produced no acceptable candidates. The user would be prompted for a new search, and cautioned to recheck the input information.

c. *Too many acceptable*

In some cases the input and calculated information provided may leave more than three acceptable candidates. When this occurs, the user is informed that not enough information is available to make an exact determination. The user could then be allowed to page through the available choices, enter more information, or begin a new search.

C. TESTING AND RESULTS

The model was tested in several ways. For the first test, all available data for each landmine was entered to see if the system could identify it with the highest confidence level. The model was able to do this for twenty of the thirty mines in the Bosnian set. The remaining ten mines were identified with the highest value, but were tied with another mine. A print-out of the results for each mine can be found in Appendix C.

The model was next tested to determine how well it handled incomplete information. Instead of entering all the data on a mine, only 70% of the data was input. For this test, the less obvious attributes were excluded and only shape, color, number of fuze wells and approximate length/width or diameter was used. In this test the model was able to place the correct mine amongst the top three candidates 87% of the time. The exception in this test was with the stake mine category. For these mines, the system could not do better than a four way tie. This tie was only broken when the case material attribute was added to the available data.

The last test involved having a non-expert select four mines at random from the Bosnian set. The novice then attempted to describe the mines using the pictures and some limited data from the database. The results of this test are listed in Table 4.4. Notice that the novice included incorrect information, once for number of fuze wells and once for case material. These mistakes did lower the confidence factor, and for the PMD-1 caused the correct mine to fall to second place.

Name	Data Supplied (Incorrect data)	Results	Confidence
PMA-2	Shape, Approximate Diameter, Case material, Color, Number of fuze wells,	Tm-100 PMA-2	81.07% 81.07%
PMR-1	Shape, Approximate Height and Diameter, Case Material, Color, (Number of fuze wells) Stake Mine	PMR-1 PMR-3 PSM-1	82.72% 82.72% 82.72%
PMD-1	Shape, Approximate Height, Length and Width, (Case material), Color, Number of fuze wells	TMD-2 PMD-1	62.62% 62.43%
TMA-2	Shape, Approximate Height, Length and Width, Case material, Color, Number of fuze wells	TMA-2 TMA-5	86.06% 81.40%

Table 4.4 Results from tests using non-expert supplied data.

D. PROPOSED USER INTERFACE

The user interface for this system serves two important functions. First, it is the method that the user will use to communicate with the system. The second purpose, is to extract the important information about the mine from the user. To accomplish these tasks, the interface must be robust, displaying all possible choices with explanations and examples. The proposed interface for the EOD Associate can be divided into three sections: Query, Explanation, and Results.

1. Query Screen

The expert system asks the user questions about the unknown landmine with a query screen. Figure 4.2 shows a possible layout for such a screen. The questions should be brief, and all fit on one page if possible. This will speed data entry once the user understands the program. Questions are listed with pull-down boxes containing all the possible answers in a multiple-choice type format. This focuses the user on the answers

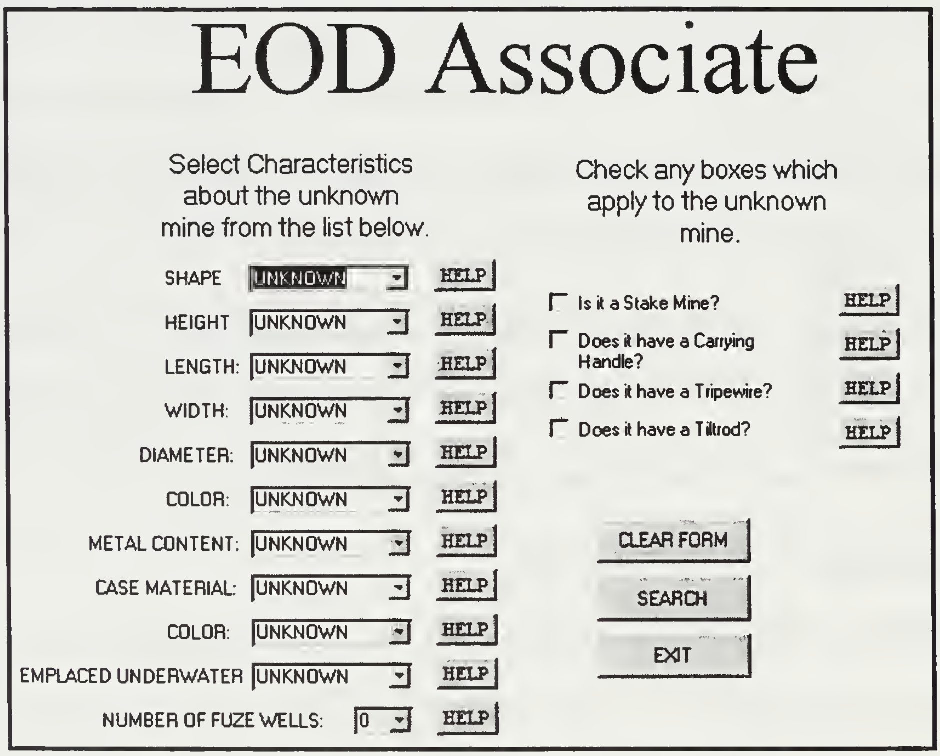

Figure 4.2 Example of a GUI to be used with the EOD Associate. Notice that all fields on the User Query page default to "Unknown". The "HELP" buttons take the user to a screen with examples and text describing the requested field.

that are recognized by the system. When the user supplies no answer for a specific characteristic, the system defaults to "Unknown".

2. Explanation Screen

In many cases, the user may not understand the question asked or may want more information about the possible answers. By pressing the "HELP" button, the user can link to an explanation screen with more information. This help screen could contain text and graphical explanations of the question and possible answers. Figure 4.3 shows a help screen for the question "Is it a stake mine?". In this case, key features are listed and examples are shown.

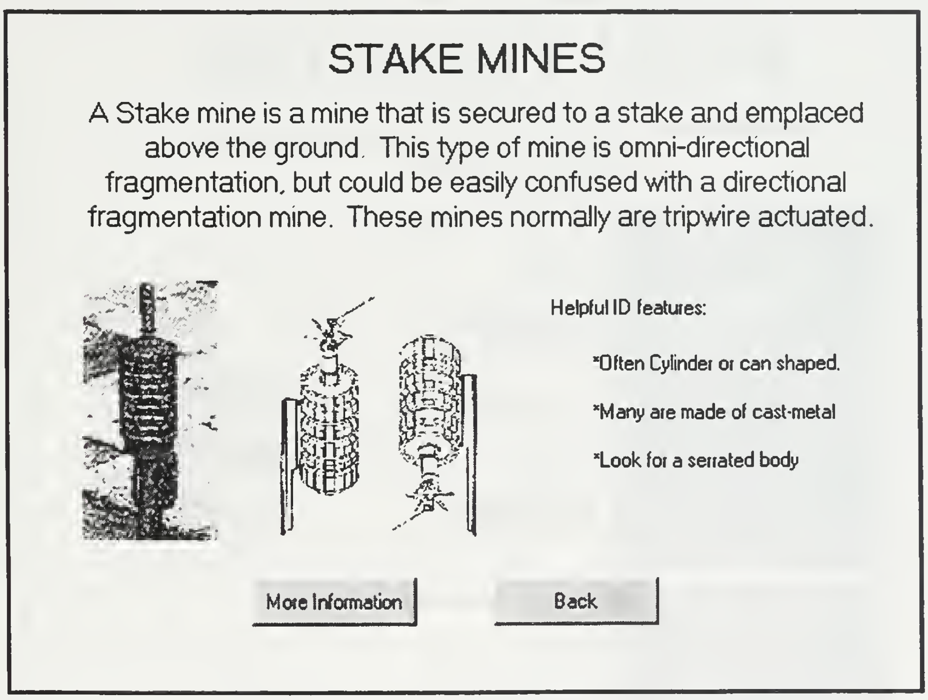

Figure 4.3 This an example of a help screen to assist the user with more detailed information about questions on the User Query page.

More detailed help screens could be layered to produce a very robust reference library. This layered data could be very helpful when describing subjective questions such as color. For this type of question, the help screen could show examples of the possible colors, and discuss factors which may alter a mine's color. The help screen could even show the examples of the effects of fading, or examples of mines with unusual colors. The amount of data available can increase the quality of the user supplied input.

3. Results Screen

Once the user has entered all the available information on the mine, candidate landmines are displayed on the results screen. Figure 4.4 is a sample output screen. In

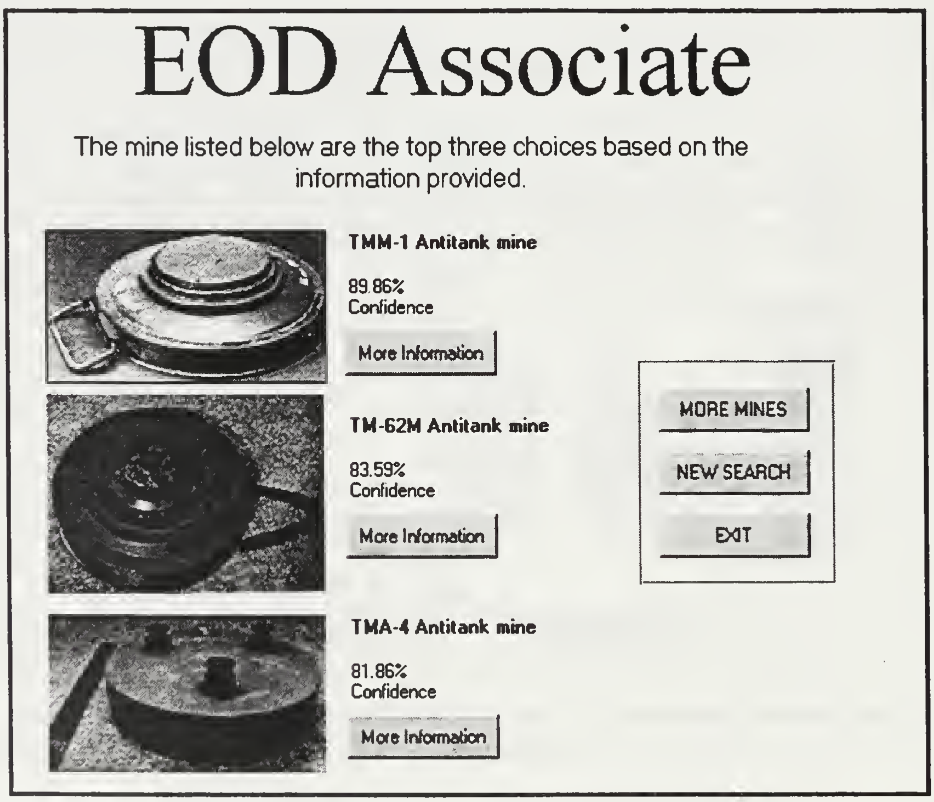

Figure 4.4 This is an example of a GUI page to display the results of a search. The confidence values are from an actual search for the TMM-1 landmine on the model expert system.

this example, the top three candidate mines are shown with photo, nomenclature and confidence value. The key feature of this screen is that the user can make the final determination of the correct mine, and this is easily done with a photograph. The user can then link to more information about the desired mine with the "More Information" button.

V. SUMMARY

A. SUMMARY OF WORK

Landmine clearance is one of the most pressing problems in the world today. In order for humanitarian deminers to perform this task they must first be able to quickly and accurately identify unknown landmines. The existing methods for landmine identification involve tedious searching through reference books, looking for a line drawing that matches the unknown item or paging through a CD-ROM reference such as the MineFacts database.

This thesis presented the use of an expert system for landmine identification. The system is based on the set of thirty Bosnian mines from the MineFacts landmine database on CD-ROM. The methodology involved first creating questions based on the more obvious attributes. Heuristics were then developed to describe general characteristics of the landmine set. The user is queried about the unknown landmine and the answers are applied to heuristics which are then used to calculate other information about the mine. This collection of information is then filtered through decision trees to generate candidate landmines. A small group of candidates are displayed with a confidence factor based on each question weight and the supplied answer.

The system was implemented on an Microsoft Excel spreadsheet. This allowed testing of the weights used for the questions and answers.. The completed system was based on fifty-one heuristics and fourteen landmine attributes. The system can narrow candidates to within two choices when all queries are correctly answered and to within three candidates when 70% of the queries are correctly answered.

The results from the research show that this technique has potential for all types of ordnance identification. A similar system could be implemented to cover all UXOs and be used by EOD technicians. It could also be used as a reconnaissance tool by non-EOD trained individuals.

B. THESIS QUESTIONS

The following questions are addressed in this thesis:

- *Can an expert system be useful in landmine identification?*

Yes, the implementation for the system shows that an expert system does have usefulness in landmine identification. With the implementation of a GUI, the system would provide the user a much faster and easier method of searching the landmine database.

- *How is expert landmine knowledge described? How is the knowledge best extracted?*

Expert knowledge is best described as expert experience. Knowledge is represented by bits of information about landmine characteristics, and ordnance identification is largely pattern matching. This knowledge is best represented using heuristics based on the landmines. Extraction of this knowledge was done using questions and heuristics.

- *What methodology is best suited for the landmine identification problem?*

The methodology used for this thesis involved determining the bounds of the database, developing questions based on those bounds and then developing heuristics to support those questions. The question-tree format was very helpful in identifying the attributes for each mine. These attributes were then examined to determine what general heuristics could be formed to make inferences about other attributes. Once the questions and heuristics were developed the system was implemented on the Excel spreadsheet.

- *What questions and sub-questions are best to implement an expert system that will integrate well with the MineFacts database?*

The MineFacts system presented basic questions on shape, size, case material and country of use. These were expanded to cover more visual aspects of the mine, but the expert system was limited by the fields available in the MineFacts database. A complete list of the questions used is in Chapter III, Section C. The use of a GUI to query the user would greatly enhance the quality of the system to extract information.

- *What are possible applications for similar expert systems that could be applied to other EOD databases?*

The results to this thesis show that an expert system has potential for all ordnance identification. The EOD community could easily use this technology to improve the speed and accuracy of ordnance identification. Further discussion about these uses is found in Section C below.

C. RECOMMENDATIONS FOR FUTURE STUDY

1. Add the Complete landmine Set to the EOD Associate

The EOD Associate covers only thirty of the landmines currently in use worldwide. Since the program is based on the MineFacts database it could be expanded to cover the complete mine set. This would allow deminers to easily identify landmines with only one reference. It could also allow reconnaissance of minefields by non-deminers for referral to landmine clearance teams. Any expansions require some modifications to the database, heuristics, and questions.

As noted earlier, there are some consistency problems in certain fields of the MineFacts database. This problem was easily handled with the small set used for the program, but will have to be corrected before the full database can be used with an expert system. The number of different descriptions appearing in the fields is unimportant, but duplicate types must match in case and spelling.

In addition to changes to the MineFacts database, the EOD Associate will have to be adjusted to account for the larger variety of values. As an example, the Bosnian mine set has only four shapes and eight possible case materials. The complete database will expand those fields to sixteen and fifteen respectively. These additional variables are sometimes sub-categories of existing variables. In some cases they can be consolidated with other categories to reduce confusion, but many will have to be added to the heuristics and decision trees.

2. EOD 60-Series Publications

An expert system approach also has potential application to the 60-series publications. As previously noted in Chapter II, the method of searching the 60-series has not been up-dated to make full use of the computer's processing power. The search method still requires the EOD technician to make subjective judgements about the type of ordnance being searched, and also does not make use of identifying features besides size to assist in the identification. EOD Associate, or some other expert system could improve speed and accuracy by offering more categories and a friendlier user interface.

The 60-series publications will require some modifications to allow an expert system to use the data collected on it. Although the current 60-series is on CD-ROM, it is only an automated version of the old microfiche publications. To make it compatible to an expert system, a machine-readable database needs to be developed to allow application of heuristics and searches. This database could be used by the EOD technician for a simple query, or in conjunction with the expert system. Additionally, the current line-drawings of ordnance would need to be catalogued and available for display individually to allow the user to see available choices on one screen. This could be improved further if the line-drawings were supplemented with digitized photographs of the ordnance.

3. C4I EOD Reconnaissance System

One last application for an expert system is as part of a C4I system to improve EOD reconnaissance and reporting. Tactical EOD reconnaissance is now done by untrained personnel who encounter a UXO hazard. The collection and reporting of the information to the EOD unit is not automated and is subject to errors. Often, the reporting personnel gather incomplete or inaccurate information, and the EOD Control unit must make decisions about the UXO's disposition based on that information. To combat this incorrect information and poor communication, a PC based system could be developed for issue to field units as an EOD reconnaissance tool. Figure 5.1 shows one possible implementation of such a system. When a UXO is found, the EOD reconnaissance computer would be used to gather all the necessary information about the item without requiring the individual doing the reconnaissance to remain in the danger area for an extended period. The user could take a photo of the ordnance using a tethered digital camera. The computer would collect a grid coordinate for the item from the Global Positioning System also tethered to the system. The user could then retreat to a safe area, and enter the additional data about the ordnance. The expert system could be used to prompt for and check the information provided by the user. Once this has been accomplished, the photo and collected data could be relayed to the EOD Control Unit by wire, radio, or satellite.

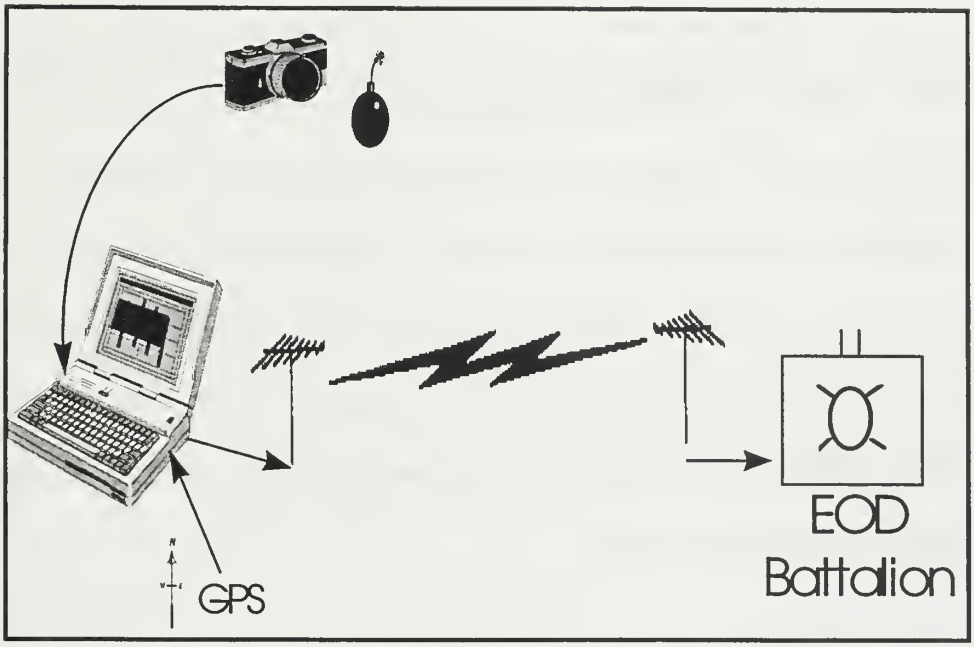

Figure 5.1 Layout for EOD Recon System

This type of system would increase the speed and accuracy of UXO reporting. The EOD control could easily interpret which ordnance was hazardous and required immediate attention, and which could be left for later disposal.

D. LESSONS LEARNED

There are several things I learned during the course of this thesis that could be of benefit to others working on similar projects. First, the data from the database must be correctly formatted. Problems with data consistency and missing data must be addressed early in the project's design. The database should also be machine readable to allow easy exchange of data between the database and the expert system.

An expert system shell would be very helpful for an expert system such as this one. It would reduce the complexity of the programming by providing a framework for the knowledge and logic. An ESS would greatly speed the system's development time.

Landmine and UXO identification require a high degree of certainty to prevent accidents. For this reason, a significant amount of time should be devoted to the development of heuristics, weights and testing for the expert system. There is no way to assure 100% accuracy in the output, but every opportunity should be taken to eliminate the possibility of a dangerous mistake.

E. CONCLUSION

Expert systems have tremendous potential for landmine identification. Even more important are the potential benefits that expert systems offer for the explosive ordnance disposal community. EOD technicians must identify ordnance quickly and accurately with information that is not always complete. This thesis has discussed ways that an expert system can improve accuracy, speed search time, and increase available information to solve these problems. There is no tolerance for a mistake when identifying landmines, and an expert system can help ensure that the identification is always correct.

APPENDIX A - ENGLRMKS TABLE FROM MINEFACTS V1.2 - BOSNIAN MINES

MINEID	Nomenclature	Country of Origin	Manufacturing Country	Using Country	Case Material
0775	PSM-1 Antipersonnel Mine	Bulgaria	Bulgaria, Poland	Bulgaria, Bosnia, Cambod	Sheet Steel
1253	L.PZ.MI Antitank Mine	Old Germany	Old Germany	Old Germany, Netherland	Sheet steel
1351	MAT-76 Antitank Mine	Romania	Romania	Iraq, Romania, Angola, Za	Caseless; with fiberglass r
1405	MC-71 Antitank Mine	Romania	Romania	Romania, Former Yugosla	Metal
2089	TM-62M Antitank Mine	Former Soviet Unio	Former Soviet Union, Bul	Afghanistan, Bulgaria, Cu	Metal
2152	TMA-5 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Afgha	Plastic
2224	TMRP-6 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3192	MRUD Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3264	TMA-2 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Angol	Plastic
3273	TMA-3 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Angol	Fiberglass coating
3282	TMA-4 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Angol	Plastic
3336	PMA-1 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Wood
3345	PMA-2 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3354	PMA-3 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic, rubber
3375	PMR-1 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Metal
3384	PMR-2A Antipersonnel Min	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Metal
3402	PROM-1 Antipersonnel Min	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Steel
3537	PMA-1A Antipersonnel Min	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia	Plastic
3546	TM-100 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3700	TM-200 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3709	TM-500 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
3718	MT-4 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Cardboard
3727	PMR-3 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Cast steel
3745	TMM-1 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Sheet metal
3754	TMA-1 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Plastic
4276	Type 69 Antitank Mine	China	China	Bosnia, China, Iraq	Plastic (ABS III)
5237	TMD-2 Antitank Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Wood
6210	PMR-2 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Angol	Concrete and scrap metal
6498	PMD-1 Antipersonnel Mine	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Wood
7511	PMR-2AS Antipersonnel Mi	Former Yugoslavia	Former Yugoslavia	Former Yugoslavia, Bosni	Metal

Number of Fuze Wells	Case Color	Mine Type	Effect	Shape	Legnth	Width	Height
1, or 3 with adaptor	OD green	Antipersonnel	Bounding fragmentation	Cylindrical			135.0 mm (without f
5	Gray	Antitank	Blast	Flat cylinder			62 mm
1	OD green	Antitank	Blast	Cylindrical			
1	OD green	Antitank	Shaped-charge	Double truncated c			
1	OD green	Antitank	Blast	Cylindrical			101.85 mm
1	OD green	Antitank	Blast	Rectangular	312 mm	275 mm	113 mm
2	Light OD gre	Antitank	Miznay-Schardin charge	Cylindrical			192 mm (with tiltrod
2	OD green	Antipersonnel	Directed, fragmentation	Rectangular	46.0 mm	231.0 mm	89.0 mm, Body.
3 (possibly 4)	OD green	Antitank	Blast	Rectangular	330 mm	260 mm	100 mm
4	OD green	Antitank	Blast	Cylindrical			140 mm (with fuze),
3	OD green	Antitank	Blast	Cylindrical			110 mm (with fuze),
1	OD green or	Antipersonnel	Blast	Rectangular	140 mm	70 mm	30 mm
1	OD green or	Antipersonnel	Blast	Cylindrical			61 mm, With fuze; 3
1 (under the mine)	OD green an	Antipersonnel	Blast	Cylindrical			36 mm
1	OD green	Antipersonnel	Fragmentaion	Cylindrical			120 mm (body only,
1	OD green wi	Antipersonnel	Fragmentation	Cylindrical			132 mm (body only,
1	OD green	Antipersonnel	Bounding fragmentation	Cylindrical			178 mm (without fu
1	OD green or	Antipersonnel	Blast	Rectangular	140.0 mm	68.0 mm	31.0 mm
1	OD green	Antipersonnel	Blast	Cylindrical			107.0 mm
1	OD green	Antipersonnel	Blast	Rectangular	59.0 mm	32.0 mm	109.0 mm
1	OD green	Antipersonnel	Blast	Rectangular	70.0 mm	50.0 mm	108.0 mm
1 for fuzes, 2 for detonati	Dark brown,	Antipersonnel	Blast	Cylindrical			500.0 mm (estimate
1	OD green	Antipersonnel sta	Fragmentation	Cylindrical			134.0 mm, Body onl
3	OD green	Antitank	Blast	Cylindrical			90.0 mm
2	OD green	Antitank	Blast	Cylindrical			100.0 mm
1	Green	Antitank	Blast	Cylindrical			100 mm
2	Natural	Antitank	Blast	Square			
1	OD green	Antipersonnel	Fragmentation	Cylinder			120 mm
0	Natural woo	Antipersonnel	Blast	Rectangular	200 mm	89 mm	64 mm
1	OD green wi	Antipersonnel	Fragmentation with flare	Cylindrical			132 mm (body only,

Diameter - Max	Diameter - Min	Total Weight	Main Explosive Weight	Non-Explosive Weight	Explosive Type
75.0 mm		2.7 kg	0.17 kg	2.53 kg	TNT
266 mm		4.10 kg	2.27 kg	1.83 kg	TNT
320 mm		10.0 kg	9.51 kg	0.49 kg	Cast TNT
260 mm		8.800 kg	5.325 kg	2.875 kg	TNT
320 mm		8.5 kg	7.2 kg	1.5 kg	TNT, TNT/RDX, TNT/RDX/Aluminu
		6.6 kg	5.5 kg	1.1 kg	TNT
290 mm		7.2 kg	5.1 kg	2.1 kg	TNT
		1.5 kg	0.9 kg	0.6 kg	PETN
		7.0 kg	5.5 kg	1.5 kg	Cast TNT
265 mm		6.5 kg	6.5 kg	Negligible	Cast TNT
280 mm		6.3 kg	5.5 kg	0.8 kg	TNT
		0.400 kg	200 kg	0.2 kg	TNT
	68 mm	0.135 kg	0.1 kg	0.035 kg	TNT
	103 mm	0.183 kg	0.035 kg	0.148 kg	Pressed TNT
	80 mm	2.0 kg		1.925 kg	TNT
	66 mm	1.7 kg		1.6 kg	TNT
	75 mm	3.0 kg	0.425 kg	2.575 kg	TNT
		0.4 kg	0.2 kg	0.2 kg	TNT
	33.0 mm	0.115 kg (not includi	0.1 kg		TNT
		0.215 kg	0.2 kg	0.015 grams	Pressed TNT
		0.530 kg	0.5 kg	0.015 kg	TNT
94.0 mm		3.8 kg	3.8 kg		TNT
78.0 mm		2.41 kg	0.410 kg	2.0 kg	TNT
326.0 mm		8.65 kg	5.6 kg	3.05 kg	TNT
315.0 mm		6.5 kg	5.55 kg	0.95 kg	TNT
	270 mm	6.5 kg	5.64 kg	2.86 kg	TNT/RDX (50/50)
		7.5 kg	4.5 kg	3.0 kg	TNT
75 mm		2.2 kg	0.1 kg	2.1 kg	TNT
		0.4 kg			TNT
	66 mm	1.7 kg		1.6 kg	TNT

Booster Charge Type	Booster Charge Weig	Fuze Model	M2210	M2220	M2225	M2227	Arm Delay - Max
		EVU-3, MUV, MVN-2N, "T" adaptor					Unless an MUV-3 or
		Integral					
Cast TNT	0.160 grams	P-62					
Cast TNT	225.0 grams						
Pentryt	175 grams	MVCh-62, MVP-62, MVZ-62, VM-62Z,					1.0 minutes
RDX	200.0 grams	UTMAH-1, UANU-1					
Tetryl		UTMRP-6					1.0 minutes, 4.0 min
		Command initiation					
		UANU-1, UTMAH-1					
		UTMAH-3					
Tetryl	10.6 grams	UTMA-4					
No. 8 nonelectric detona		UPM-1 (MUV-type)					
Hexogen (90% RDX, 8%	14.5 grams	UPMAH-2					
None, detonator capsule		UPMAH-3					
		UPM-1, UMNP-1					
		UPM-2A, UPMR-2A					
		UPROM-1, UPMR-3					0.0 minutes
None, only uses a No. 8	0 grams	UPMAH-1					
None, detonator capsule	0 grams	Varies: UMP-1, UMP-2, UMNP-1, UM					
None, detonator capsule		Varies: UMP-1, UMP-2, UMNP-1, UM					0.0 minutes
None, detonator capsule	0.0 grams	Varies: UMP-1, UMP-2, UMNP-1, UM					0.0 minutes
None, detonator capsule	0.0 grams	Varies: UMP-1, UMP-2, UMNP-1, UM					0.0 minutes
None, detonator capsule	0.0 grams	UPMR-3, UPROM-1					0.0 minutes
		UTMM-1					
TNT, Tetryl mixture	0.15 grams, 0.001 gra	UTMAH-1, UANU-1					0.0 minutes
		Type 69, Type 72A, Type 81					
		MUV-type					
		UPMA-1					
		UPM-2A, UPMR-2A					

Arm Delay - Min	Range	Neutralization	Max Penetration	Detonation Height	Emplacement Method
	20 meters (lethal)			1.5 meters	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual, mechanical
	Across full width of vehi		> 100 mm RHAE	Surface burst	Manual or mechanical (claimed b
2.0 minutes	Across full width of vehi		> 27 mm RHAE	Surface burst	Manual, mechanical, chute
	Contact		N/A	Surface burst	Manual, mechanical
	45.0 meters, in side-atta		40.0 mm RHAE at		Manual, chute, mechanical
	50 meters (60 degree h			Varies, depending upon em	Manual
	Contact		N/A	Surface burst	Manual, mechanical
	Contact		N/A	Surface burst	Manual or mechanical
	Contact		N/A	Surface burst	Manual, mechanical
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	8 meters (lethal), 30 met			30 cm (normal height on mo	Manual
	15 meters (lethal), 30 m			30 cm (normal mounting hei	Manual, stake mine
	22 meters (lethal)			0.7 meters	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual
	25 meters (lethal), 50 m			30 cm (normal height on mo	Manual, stake mine
	Contact		N/A	Surface burst	Manual
	Contact		N/A	Surface burst	Manual or mechanical
	Contact		N/A	Surface burst	Manual, mechanical
	Contact		N/A	Surface burst	Manual
	10 meters (lethal), 30 m			30 cm (normal height on mo	Manual
	Contact		N/A	Surface burst	Manual
	15 meters (lethal), 30 m			30 cm (normal height on mo	Manual, stake mine

Burial Depth - Max	Burial Depth - Min	Metal Content / Detectability	Metal Content Amout	Power Source	Self Destruct
21 cm	17 cm	Yes		Yes, if command	No
10 cm	63 cm	Yes, 1830 grams	1830 grams	No	No
20 cm, to bottom of mi	0 cm, to bottom of m	Yes (only within the mine's fuze)		No	No
30.0 cm, to bottom of	0.0 cm, to bottom of	Yes		No	No
20.0 cm	0.0 cm	Yes, 1000 grams (approximate)	1000 grams, Approxim	Yes, In magnetic	No
16 cm, to bottom of mi	0 cm, to bottom of m	No		No	No
13.2 cm	0.0 cm	Yes		No	No
		Yes, 650 steel balls (5.5 mm in d		Yes, external	No
200 cm, To bottom of	0 cm, To bottom of	Extremely limited, difficult mine t		No	No
18 cm, to bottom of mi	0 cm, to bottom of m	Extremely limited, difficult mine t		No	No
16 cm, to bottom of mi	0 cm, to bottom of m	Yes, minimal amount		No	No
12.0 cm	0.0 cm	Yes		No	No
9.0 cm	0.0 cm	Almost none, very difficult mine t		No	No
8.0 cm	0.0 cm	Almost none, very difficult mine t		No	No
		Yes, heavy fragmenting body		No	No
		Yes, 400 grams	4000 grams	No	No
29 cm, to bottom of mi	17 cm, to bottom of	Yes		No	No
9.0 cm, to bottom of mi	0.0 cm, to bottom of	Less than 0.4 grams, difficult min		No	No
14.0 cm, to bottom of	11.0 cm, to bottom o	None, except in fuze		No	No
14.0 cm, to bottom of	11.0 cm, to bottom o	None, except in fuze		No	No
14.0 cm, to bottom of	11.0 cm, to bottom o	None except in fuze		No	No
54.0 cm, to bottom of	50.0 cm, to bottom o	None except in fuze		No	No
		Yes		No	No
150 cm, to bottom of m	0 cm, to bottom of m	Yes		No	No
16 cm, to bottom of mi	0 cm, to bottom of m	Extremely limited, very difficult to		No	No
20.0 cm	0.0 cm	Yes (in the type 69 and 72A fuze		No	No
		Yes		No	No
		Yes		No	No
		Yes		No	No
		Yes, 400 grams	4000 grams	No	No

Self Neutralize	Detectability	Antihandling
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well or AD features)
No		Probable (tension initiated device)
No		Possible (however, no secondary fuze well or AD features except in the magnetic fuzes)
No		Possible (however, no secondary fuze wells or AD features)
No		Yes (with secondary fuzing)
No		Possible (however, no secondary fuze well beyond the two well on top of the mine)
No		Probable (there is a secondary fuze well on the bottom of the mine for boobytrap purposes
No		Probable (there is a secondary fuze well on the bottom of the mine for boobytrap purposes)
No		Possible (handle hole fits standard detonator and detonating cord)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Possible (however, no secondary fuze well)
No		Probable (there are two secondary fuze wells for boobytrap purposes)
No		Probable (there is a secondary fuze well for boobytrap purposes)
No		No
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)
No		Possible (however, no secondary fuze well or AD features)

Underwater Operations	Description	Techniques of Employment
Limited to 0.25 m	The PSM-1 is a Bulgarian bounding fragmentation antipersonn	
No	The Old German light antitank mine L.PZ.MI is a metallic mine	To employ the L.PZ.MI antitank mine as an antipe
Extremely limited	The MAT-76 is a blast antitank mine made of cast TNT covere	
Limited	The Romanian MC-71 is a shaped-charge antitank mine that c	Installed properly, this mine would be very difficult
Yes, limited duration	The TM-62 series of conventional antitank blast mines are con	The TM-62 mines can be emplaced manually or
Limited to 0.25 m	The TMA-5 and TMA-5A are rectangular, plastic-cased, blast-e	
Yes, limited	The TMRP-6 is a plastic-cased antitank mine containing a Miz	
Yes, limited to 0.2 m	The MRUD is a directional fragmentation antipersonnel mine.	Normally employed by infantry for perimeter defe
Limited to 0.25 m.	The TMA-2 and TMA-2A are rectangular shaped, plastic-cased	
Limited to 0.25 m	The TMA-3 is a blast antitank mine made from cast TNT coate	
Limited to 0.25 m	The TMA-4 is a blast-effect antitank mine made of cast TNT wi	
Limited to 0.25 m.	The PMA-1 is a wooden version of a box or "shu" mine with a t	
Limited to 0.25 m	The PMA-2 is a relatively small antipersonnel mine with a cylin	This mine is often buried so that only the tip of the
Limited to 0.25 m	The PMA-3 is a small antipersonnel mine, which consists of a f	
	The PMR-1 was patterned loosely after the POMZ-2 stake mi	This mine is normally employed in covering veget
Limited to 0.5 m	The PMR-2A and PRM-2AS are stake-mounted fragmentation	This mine is normally employed in covering veget
Limited to 0.25 m	The PROM-1 is a bounding fragmentation antipersonnel mine,	
Yes, limited to 0.25 m	The PMA-1A is a plastic version of a box or "shu" mine with a t	
Yes, limited to 0.25 m	The TM-100 is a general purpose demolition charge. It is a cyli	
Yes, limited to 0.25 meters	The TM-200 is a general-purpose demolition charge which is al	
Yes, limited to 0.25 meters	The TM-500 is a general-purpose demolition charge. It is a rec	
Limited to 0.25 meters	The MT-4 is a general-purpose demolition charge. It is a cylin	
Yes, limited to 0.25 meters	The PMR-3 is a stake-mounted fragmentation mine with seven	This mine is normally employed in covering veget
Yes, limited to 0.25 meters	The TMM-1 antitank blast mine is cylindrically shaped, low prof	
Yes, limited to 0.25 meters	The TMA-1 and TMA-1A are plastic-cased antitank mines with	
Yes	The Chinese Type 69 AT mine is constructed of green plastic.	
	The TMD-2 is a simple, pressure-initiated, wooden-cased, blas	
	The PMR-2 is a Former Yugoslavian-produced antipersonnel fr	
	The PMD-1 is a former Yugoslavian produced pressure-initiate	
Limited to 0.5 m	The PMR-2A and PRM-2AS are stake-mounted fragmentation	This mine is normally employed in covering veget

Manual	Mine Plow w/Dog Bone	Mine Roller w/Dog Bone	Magnetic Mine Countermeasures	MICLIC
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	MMCMS is 95% effective against m	Blast overpressu
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	MVN-62&72:	Ineffective.
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Provides full width neutrali	Ineffective.	Blast overpressure
Blow-in-place not recomm	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Blow-in-place not recomm	Removes mines from trac	Detonates tripwire fuzed	Ineffective.	Blast overpressure
Blow-in-place not recomm	Removes mines from trac	Detonates tripwire fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure or trip	Ineffective.	Fuze type depende
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Fuze type depende
Place charge adjacent to t	Removes mines from trac	Detonates pressure or trip	Ineffective.	Fuze type depende
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Fuze type depende
Buried: Place charge adjac	Removes mines from trac	Detonates tripwire or pres	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Blow-in-place not recomm	Removes mines from trac	Detonates tripwire fuzed	Ineffective.	Blast overpressure
Place charge adjacent to t	Removes mines from trac	Detonates pressure fuzed	Ineffective.	Blast overpressure
Blow-in-place not recomm	Removes mines from trac	Detonates tripwire fuzed	Ineffective.	Blast overpressure

Bangalore Torpeodo/A	Manual -	Visual	Electronic
	Normal probe	Use normal visual c	Readily detectable with
	Normal probe s	Use normal visual cue	Difficult to detect with a
Bangalore torpedo can	Normal probe s	Use normal visual cue	Readily detectable with a
Bangalore torpedo can	Normal probe s	Use normal visual cue	Difficult to detect with a
Bangalore torpedo can	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Not needed. Mi	Command firing wires	Not needed. Mine body i
Bangalore torpedo can	Normal probe s	Use normal visual cue	Difficult to detect with a
Bangalore torpedo can	Normal probe s	Use normal visual cue	Difficult to detect with a
Bangalore torpedo can	Normal probe s	Use normal visual cue	Difficult to detect with a
Blast overpressure fro	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Small mine ma	Use normal visual cue	Difficult to detect with a
Blast overpressure from	Normal probe s	Use normal visual cue	Difficult to detect with a
Blast overpressure from	Not needed. Mi	Look for mine body an	Not needed. Mine body i
Blast overpressure from	Not needed. Mi	Look for mine body an	Not needed. Mine body i
Blast overpressure from	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Normal probe s	Use normal visual cue	Difficult to detect with a
Fuze type dependent.	Small mine ma	Use normal visual cue	Readily detectable with a
Fuze type dependent.	Small mine ma	Look for mine body an	Readily detectable with a
Fuze type dependent.	Small mine ma	Use normal visual cue	Readily detectable with a
Fuze type dependent.	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Buried: Normal	Buried: Use normal vi	Buried: Readily detectabl
Bangalore torpedo can	Normal probe s	Use normal visual cue	Difficult to detect with a
	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Not needed. Mi	Look for mine body an	Not needed. Mine body i
Blast overpressure from	Normal probe s	Use normal visual cue	Readily detectable with a
Blast overpressure from	Not needed. Mi	Look for mine body an	Not needed. Mine body i

APPENDIX B - HEURISTICS

The following Heuristics apply to the entire population of landmines:

IF a mine is plastic,
AND it has no metal,
THEN it is a blast mine (0.99)

IF a mine has a wood case,
AND it has 2 or more fuze wells,
THEN it is Antitank Mine (0.95)

IF a mine is smaller than 150mm in diameter or length,
AND it is less than 60 mm in height,
THEN it is an antipersonnel mine (0.99)

IF a mine is less that 40mm in height,
THEN it is a blast mine (0.99)

IF a mine has a carrying handle,
THEN it is an antitank mine (0.99)

If a mine is square/rectangular,
AND it is emplaced vertically with the ground,
THEN it is a directional fragmentation mine (0.95)

IF a mine is fiberglass,
AND it has no metal,
THEN it is a blast mine (0.99)

IF a mine is wood,
AND it has no metal,
THEN it is a blast mine (.99)

IF a mine is caseless,
THEN it is a blast mine (0.99)

IF a mine is on a stake,
THEN it is a fragmentation mine (0.98)

IF a mine has prongs
THEN it is an antipersonnel mine

IF a mine is cast metal
THEN it is a fragmentation mine (0.99)

IF a mine is fragmentation,
THEN it is antipersonnel (0.99)

IF a mine is directional fragmentation,
THEN it is antipersonnel (0.99)

IF a mine is bounding fragmentation,
THEN it is antipersonnel (0.99)

IF a mine is concrete cased,
THEN it is a fragmentation mine (0.99)

IF a mine is cardboard cased,
THEN it is a Blast mine (0.99)

IF a mine is blast,
AND it is antipersonnel,
THEN it is plastic (0.60)

IF a mine has Shaped-charge effect,
THEN it is antitank (0.99)

IF a mine is Miznay-Schardin,
THEN it is antitank (0.99)

The following Heuristics apply to this Bosnian landmines:

IF a mine is cylindrical,
AND it is antitank,
AND it is not light green,
THEN it is a blast mine (0.95)

IF a mine is cylindrical,
AND it is light green,
THEN it is a PMA-2 antipersonnel Mine(0.95)

IF a mine is cylindrical,
AND it is antitank,
AND it is OD green,
THEN it is a blast mine (0.95)

IF a mine has a fiberglass case,
THEN it is an antitank mine (0.95)

IF a mine is cylindrical,
AND it has a diameter >150mm,
THEN it is an antitank mine (0.95)

IF a mine is cylindrical,
AND it has a plastic case,
AND it is blast,
THEN it is an antipersonnel mine(0.95)

IF a mine is cylindrical,
AND its has a fiberglass case,
THEN it is a blast mine (0.95)

IF a mine is cylindrical,
AND its has a fiberglass case,
THEN it is an antitank mine (0.95)

IF a mine is fiberglass,
THEN it is a blast mine (0.95)

IF a mine has 5 fuze wells,
THEN it is an L.PZ.MI Antitank Mine(0.95)

IF a mine has 4+ fuze wells,
THEN it is an antitank mine (0.95)

IF a mine is gray,
THEN it is a L.PZ.MI Antitank Mine (0.95)

IF a mine is light green,
AND it is >150mm,
THEN it is an TMRP-6 Antitank Mine(0.95)

IF a mine is light green,
AND it is <150mm,

THEN it is a PMA-2 antipersonnel Mine(0.95)

IF a mine is OD green and Black,
THEN it is a antipersonnel mine(0.95)

IF a mine is OD green and Black,
AND it is > than 75mm,
THEN it is a PMA-3 Antipersonnel Mine(0.95)

IF a mine is OD green and Black,
AND it is > than 75mm,
THEN it is a fragmentation mine(0.95)

IF a mine has a wood case,
THEN it is blast (0.95)

IF a mine has a wood case,
AND it has 2+ fuze wells,
THEN it is TMD-2 Antitank Mine(0.95)

IF a mine is antitank
AND it has a wood case,
THEN it is a blast mine (0.95)

IF a mine has a wood case,
AND it is rectangular,
THEN it is an antipersonnel (0.95)

IF a mine is egg shaped,
THEN it is a MC-71 Antitank Mine (0.95)

IF a mine is square,
THEN it is TMD-2 Antitank Mine(0.95)

IF a mine rectangular,
AND it is an antitank mine,
THEN it is a blast (0.95)

IF a mine has a sheet metal case,
THEN it is cylindrical (0.95)

IF a mine is metal cased,
AND it is blast,

THEN it is an antitank mine (0.95)

IF a mine has a metal case,
AND it has prongs,
THEN it is a Bounding fragmentation mine (0.95)

IF a mine is concrete,
THEN it is PMR-2(0.95)

IF a mine has a rubber cover,
THEN it is a PMA-3 antipersonnel mine (0.95)

IF a mine has a plastic case,
AND it has prongs,
THEN it is a blast mine (0.95)

IF a mine has Shaped-charge effect,
THEN it is a MC-71 Antitank Mine (0.95)

IF a mine has no metal,
THEN it is a TMA-5 (0.95)

APPENDIX C - WEIGHTS USED IN THE EODA MODEL

	Shape					Height				
Nomenclature	Shape	Cylindrical	Rectangular	Square	Other	Height	<50mm	150mm>X>50mm	250mm>X>150mm	>250mm
MAT-76 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	Unknown	0.50	0.50	0.50	0.50
TM-100 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	107.0 mm	0.01	0.99	0.01	0.01
TM-200 Antipersonnel Mine	Rectangular	0.01	0.99	0.40	0.01	109.0 mm	0.01	0.99	0.01	0.01
TM-62M Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	101.85 mm	0.01	0.99	0.01	0.01
L.PZ.MI Antitank Mine	Flat cylinder	0.99	0.01	0.01	0.01	62 mm	0.69	0.90	0.01	0.01
PMR-1 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	120 mm	0.01	0.99	0.01	0.01
PMA-1A Antipersonnel Mine	Rectangular	0.01	0.99	0.20	0.01	31.0 mm	0.99	0.01	0.01	0.01
PMR-2 Antipersonnel Mine	Cylinder	0.99	0.01	0.01	0.01	120 mm	0.01	0.99	0.01	0.01
TMA-5 Antitank Mine	Rectangular	0.01	0.99	0.45	0.01	113 mm	0.01	0.99	0.01	0.01
TMRP-6 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	132 mm	0.01	0.96	0.20	0.01
MRUD Antipersonnel Mine	Rectangular	0.01	0.99	0.10	0.01	89.0 mm	0.10	0.97	0.01	0.01
TMA-2 Antitank Mine	Rectangular	0.01	0.99	0.45	0.01	100 mm	0.01	0.99	0.01	0.01
TMA-3 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	80 mm	0.20	0.97	0.01	0.01
TMA-4 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	65 mm	0.60	0.90	0.01	0.01
PMA-1 Antipersonnel Mine	Rectangular	0.01	0.99	0.20	0.01	30 mm	0.99	0.01	0.01	0.01
PMA-2 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	30 mm	0.99	0.01	0.01	0.01
PMA-3 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	36 mm	0.99	0.01	0.01	0.01
PMR-2A Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	132 mm	0.01	0.96	0.01	0.01
PROM-1 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	178 mm	0.01	0.40	0.01	0.01
TM-500 Antipersonnel Mine	Rectangular	0.01	0.99	0.45	0.01	108.0 mm	0.01	0.99	0.01	0.01
MT-4 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	500.0 mm	0.01	0.01	0.01	0.99
PMR-3 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	134.0 mm	0.01	0.97	0.01	0.01
TMA-1 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	100.0 mm	0.01	0.99	0.01	0.01
TMD-2 Antitank Mine	Square	0.01	0.80	0.99	0.01	Unknown	0.50	0.50	0.50	0.50
PMR-2AS Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	132 mm	0.01	0.96	0.01	0.01
PSM-1 Antipersonnel Mine	Cylindrical	0.99	0.01	0.01	0.01	135.0 mm	0.01	0.97	0.01	0.01
MC-71 Antitank Mine	Other	0.60	0.01	0.01	0.99	Unknown	0.50	0.50	0.50	0.50
TMM-1 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	90.0 mm	0.08	0.95	0.01	0.01
Type 69 Antitank Mine	Cylindrical	0.99	0.01	0.01	0.01	100 mm	0.01	0.99	0.01	0.01
PMD-1 Antipersonnel Mine	Rectangular	0.01	0.99	0.15	0.01	64 mm	0.60	0.90	0.01	0.01

Nomenclature	Rectangular/Square						Cylindrical		
	Length	<150mm	>150mm	Width	>150mm	>150mm	Diameter - Max	>150mm	>150mm
AT-76 Antitank Mine		0.00	0.00		0.00	0.00	320 mm	0.01	0.99
M-100 Antipersonnel Mine		0.00	0.00		0.00	0.00	33.0 mm	0.99	0.01
M-200 Antipersonnel Mine	59.0 mm	0.99	0.01	32.0 mm	0.99	0.01		0.00	0.00
M-62M Antitank Mine		0.00	0.00		0.00	0.00	320 mm	0.01	0.99
.PZ.MI Antitank Mine		0.00	0.00		0.00	0.00	266 mm	0.01	0.99
MR-1 Antipersonnel Mine		0.00	0.00		0.00	0.00	80 mm	0.99	0.99
MA-1A Antipersonnel Mine	140.0 mm	0.90	0.60	68.0 mm	0.99	0.01		0.00	0.00
MR-2 Antipersonnel Mine		0.00	0.00		0.00	0.00	75 mm	0.99	0.01
MA-5 Antitank Mine	312 mm	0.01	0.99	275 mm				0.00	0.00
MRP-6 Antitank Mine		0.00	0.00		0.00	0.00	290 mm	0.01	0.99
RUD Antipersonnel Mine	231.0 mm	0.02	0.97	46.0 mm	0.99	0.01		0.00	0.00
MA-2 Antitank Mine	330 mm	0.01	0.99	260 mm	0.01	0.99		0.00	0.00
MA-3 Antitank Mine		0.00	0.00		0.00	0.00	265 mm	0.01	0.99
MA-4 Antitank Mine		0.00	0.00		0.00	0.00	280 mm	0.01	0.99
MA-1 Antipersonnel Mine	140 mm	0.90	0.60	70 mm	0.99	0.01		0.00	0.00
MA-2 Antipersonnel Mine		0.00	0.00		0.00	0.00	68 mm	0.99	0.01
MA-3 Antipersonnel Mine		0.00	0.00		0.00	0.00	103 mm	0.99	0.01
MR-2A Antipersonnel Mine		0.00	0.00		0.00	0.00	66 mm	0.99	0.01
ROM-1 Antipersonnel Mine		0.00	0.00		0.00	0.00	75 mm	0.99	0.01
M-500 Antipersonnel Mine	70.0 mm	0.99	0.01	50.0 mm	0.99	0.01		0.00	0.00
T-4 Antipersonnel Mine		0.00	0.00		0.00	0.00	94.0 mm	0.99	0.01
MR-3 Antipersonnel Mine		0.00	0.00		0.00	0.00	78.0 mm	0.99	0.01
MA-1 Antitank Mine		0.00	0.00		0.00	0.00	315.0 mm	0.01	0.99
MD-2 Antitank Mine		0.00	0.00		0.00	0.00		0.00	0.00
MR-2AS Antipersonnel Mine		0.00	0.00		0.00	0.00	66 mm	0.99	0.01
SM-1 Antipersonnel Mine		0.00	0.00		0.00	0.00	75.0 mm	0.99	0.01
C-71 Antitank Mine		0.00	0.00		0.00	0.00	260 mm	0.01	0.99
MM-1 Antitank Mine		0.00	0.00		0.00	0.00	326.0 mm	0.01	0.99
ype 69 Antitank Mine		0.00	0.00		0.00	0.00	270 mm	0.01	0.99
MD-1 Antipersonnel Mine	200 mm	0.10	0.95	89 mm	0.99	0.01		0.00	0.00

	Case Material											
Nomenclature	Plastic Only	Plastic and Rubber	Metal	Sheet Metal	Cast Metal	Wood	Fiberglass	Concrete	Cardboard	MineType	AT	AP
MAT-76 Antitank Mine	0.85	0.65	0.30	0.30	0.05	0.05	0.99	0.05	0.05	Antitank	0.99	0.01
TM-100 Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
TM-200 Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
TM-62M Antitank Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antitank	0.99	0.01
L.PZ.MI Antitank Mine	0.30	0.30	0.99	0.99	0.25	0.05	0.30	0.05	0.05	Antitank	0.99	0.01
PMR-1 Antipersonnel Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antipersonnel	0.01	0.99
PMA-1A Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
PMR-2 Antipersonnel Mine	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.99	0.05	Antipersonnel	0.01	0.99
TMA-5 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
TMRP-6 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
MRUD Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
TMA-2 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
TMA-3 Antitank Mine	0.85	0.65	0.30	0.30	0.05	0.05	0.99	0.05	0.05	Antitank	0.99	0.01
TMA-4 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
PMA-1 Antipersonnel Mine	0.05	0.05	0.05	0.05	0.05	0.99	0.05	0.05	0.35	Antipersonnel	0.01	0.99
PMA-2 Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
PMA-3 Antipersonnel Mine	0.95	0.99	0.30	0.30	0.30	0.05	0.65	0.05	0.05	Antipersonnel	0.01	0.99
PMR-2A Antipersonnel Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antipersonnel	0.01	0.99
PROM-1 Antipersonnel Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antipersonnel	0.01	0.99
TM-500 Antipersonnel Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antipersonnel	0.01	0.99
MT-4 Antipersonnel Mine	0.05	0.05	0.05	0.05	0.05	0.35	0.05	0.05	0.99	Antipersonnel	0.01	0.99
PMR-3 Antipersonnel Mine	0.05	0.05	0.99	0.25	0.99	0.05	0.05	0.35	0.05	Antipersonnel	0.01	0.99
TMA-1 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
TMD-2 Antitank Mine	0.05	0.05	0.05	0.05	0.05	0.99	0.05	0.05	0.35	Antitank	0.99	0.01
PMR-2AS Antipersonnel Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antipersonnel	0.01	0.99
PSM-1 Antipersonnel Mine	0.30	0.30	0.99	0.99	0.25	0.05	0.30	0.05	0.05	Antipersonnel	0.01	0.99
MC-71 Antitank Mine	0.30	0.30	0.99	0.99	0.99	0.05	0.30	0.05	0.05	Antitank	0.99	0.01
TMM-1 Antitank Mine	0.30	0.30	0.99	0.99	0.25	0.05	0.30	0.05	0.05	Antitank	0.99	0.01
Type 69 Antitank Mine	0.99	0.75	0.30	0.30	0.05	0.05	0.85	0.05	0.05	Antitank	0.99	0.01
PMD-1 Antipersonnel Mine	0.05	0.05	0.05	0.05	0.05	0.99	0.05	0.05	0.35	Antipersonnel	0.01	0.99

Nomenclature	Effect						Color						
	Blast	Miznay-Schardin	Shaped-charge	Fragmentation	Directional Frag	Bounding Frag	Multiple Colors	OD Green	Black	Gray	Light Green	Brown	Natural Wood
IAT-76 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TM-100 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TM-200 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TM-62M Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
.PZ.MI Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.20	0.20	0.95	0.20	0.20	0.10
PMR-1 Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.10	0.20	0.95	0.40	0.20	0.70	0.20	0.10
PMA-1A Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.95	0.20	0.70	0.20	0.10
PMR-2 Antipersonnel Mine	0.10	0.01	0.01	0.99	0.10	0.10	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMA-5 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMRP-6 Antitank Mine	0.30	0.99	0.01	0.01	0.01	0.01	0.20	0.70	0.20	0.20	0.95	0.20	0.10
MRUD Antipersonnel Mine	0.10	0.01	0.01	0.40	0.99	0.05	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMA-2 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMA-3 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMA-4 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
PMA-1 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.95
PMA-2 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.95	0.20	0.10
PMA-3 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.95	0.40	0.40	0.20	0.20	0.20	0.10
PMR-2A Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.10	0.95	0.40	0.40	0.20	0.20	0.20	0.10
PROM-1 Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.10	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TM-500 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
MT-4 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.20	0.95	0.20	0.20	0.95	0.10
PMR-3 Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.10	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMA-1 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMD-2 Antitank Mine	0.99	0.20	0.01	0.01	0.01	0.01	0.10	0.10	0.10	0.10	0.10	0.10	0.95
PMR-2AS Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.10	0.95	0.40	0.40	0.20	0.20	0.20	0.10
PSM-1 Antipersonnel Mine	0.01	0.01	0.01	0.99	0.10	0.99	0.20	0.95	0.40	0.20	0.70	0.20	0.10
MC-71 Antitank Mine	0.01	0.01	0.99	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
TMM-1 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
Type 69 Antitank Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10
PMD-1 Antipersonnel Mine	0.99	0.01	0.01	0.01	0.01	0.01	0.20	0.95	0.40	0.20	0.70	0.20	0.10

		Number of Fuze Wells						Metal				
Nomenclature	**Number of Fuze Wells**	**0 Fuze wells**	**1 Fuze well**	**2 Fuze wells**	**3 Fuze wells**	**4 Fuze wells**	**5 Fuze wells**	**No Metal**	**Limited Metal**	**Metal in/with Mine**	**Emplaced Underwater**	**Emplaced On Land**
MAT-76 Antitank Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TM-100 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
TM-200 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
TM-62M Antitank Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
L.PZ.MI Antitank Mine	5	0.50	0.50	0.50	0.65	0.72	0.99	0.05	0.35	0.50	0.01	0.95
PMR-1 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PMA-1A Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
PMR-2 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TMA-5 Antitank Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.95	0.50	0.25	0.50	0.95
TMRP-6 Antitank Mine	2	0.50	0.50	0.50	0.10	0.01	0.01	0.05	0.35	0.50	0.50	0.95
MRUD Antipersonnel Mine	2	0.50	0.50	0.50	0.10	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TMA-2 Antitank Mine	3	0.50	0.50	0.50	0.65	0.05	0.01	0.20	0.50	0.45	0.50	0.95
TMA-3 Antitank Mine	4	0.50	0.50	0.50	0.65	0.80	0.05	0.20	0.50	0.45	0.50	0.95
TMA-4 Antitank Mine	3	0.50	0.50	0.50	0.65	0.05	0.01	0.20	0.50	0.45	0.50	0.95
PMA-1 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PMA-2 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
PMA-3 Antipersonnel Mine	0	0.50	0.10	0.05	0.01	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PMR-2A Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PROM-1 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TM-500 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
MT-4 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.20	0.50	0.45	0.50	0.95
PMR-3 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TMA-1 Antitank Mine	2	0.50	0.50	0.50	0.10	0.01	0.01	0.20	0.50	0.45	0.50	0.95
TMD-2 Antitank Mine	2	0.50	0.50	0.50	0.10	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PMR-2AS Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PSM-1 Antipersonnel Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
MC-71 Antitank Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
TMM-1 Antitank Mine	3	0.50	0.50	0.50	0.65	0.05	0.01	0.05	0.35	0.50	0.50	0.95
Type 69 Antitank Mine	1	0.50	0.50	0.10	0.05	0.01	0.01	0.05	0.35	0.50	0.50	0.95
PMD-1 Antipersonnel Mine	0	0.50	0.10	0.05	0.01	0.01	0.01	0.05	0.35	0.50	0.50	0.95

APPENDIX D - RESULTS FROM EODA MODEL

LANDMINE	QUESTIONS	ANSWERS
PMR-2	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	CON
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	FRG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	YES

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	44.23%
TM-100	73.08%
TM-200	44.04%
TM-62M	50.00%
L.PZ.MI	43.40%
PMR-1	78.85%
PMA-1A	44.04%
PMR-2	88.49%
TMA-5	31.35%
TMRP-6	44.23%
MRUD	49.42%
TMA-2	31.35%
TMA-3	50.00%
TMA-4	50.00%
PMA-1	32.50%
PMA-2	73.08%
PMA-3	56.27%
PMR-2A	78.77%
PROM-1	69.49%
TM-500	44.04%
MT-4	55.26%
PMR-3	81.92%
TMA-1	50.00%
TDM-2	19.81%
PMR-2AS	78.77%
PSM-1	78.46%
MC-71	37.50%
TMM-1	50.00%
Type 69	50.00%
PMD-1	38.85%

Top 5 Values
88.49%
81.92%
78.85%
78.77%
78.77%

LANDMINE	QUESTIONS	ANSWERS
PMD-1	Shape	REC
	Height	50-150
	Width	<150
	Length	>150
	Diameter	
	Case Material	WOO
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	0
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	29.81%
TM-100	40.93%
TM-200	69.44%
TM-62M	35.37%
L.PZ.MI	29.01%
PMR-1	35.37%
PMA-1A	69.44%
PMR-2	35.37%
TMA-5	63.89%
TMRP-6	24.26%
MRUD	73.89%
TMA-2	63.89%
TMA-3	35.37%
TMA-4	35.37%
PMA-1	67.62%
PMA-2	40.93%
PMA-3	29.74%
PMR-2A	35.30%
PROM-1	26.73%
TM-500	69.44%
MT-4	26.73%
PMR-3	35.37%
TMA-1	35.37%
TDM-2	57.43%
PMR-2AS	35.30%
PSM-1	35.37%
MC-71	24.26%
TMM-1	35.37%
Type 69	35.37%
PMD-1	88.73%

Top 5 Values
88.73%
73.89%
69.44%
69.44%
69.44%

LANDMINE	QUESTIONS	ANSWERS
PMR-2AS	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	MET
	AT or AP	AP
	Color	MUL
	# of Fuze Wells	1
	Metal Content	YES
	Effect	FRG
	Underwater capable	UNK

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	YES

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	40.45%
TM-100	69.29%
TM-200	40.26%
TM-62M	53.29%
L.PZ.MI	53.29%
PMR-1	82.14%
PMA-1A	40.26%
PMR-2	72.50%
TMA-5	27.56%
TMRP-6	46.22%
MRUD	45.64%
TMA-2	27.56%
TMA-3	46.22%
TMA-4	46.22%
PMA-1	26.15%
PMA-2	69.29%
PMA-3	58.33%
PMR-2A	87.91%
PROM-1	72.78%
TM-500	40.26%
MT-4	54.68%
PMR-3	82.14%
TMA-1	46.22%
TDM-2	19.23%
PMR-2AS	87.91%
PSM-1	81.76%
MC-71	40.79%
TMM-1	53.29%
Type 69	46.22%
PMD-1	32.50%

Top 5 Values
87.91%
87.91%
82.14%
82.14%
81.76%

LANDMINE	QUESTIONS	ANSWERS
PSM-1	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	SHE
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BFG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	46.79%
TM-100	75.64%
TM-200	46.60%
TM-62M	59.64%
L.PZ.MI	53.04%
PMR-1	86.95%
PMA-1A	46.60%
PMR-2	77.31%
TMA-5	33.91%
TMRP-6	46.79%
MRUD	46.60%
TMA-2	33.91%
TMA-3	52.56%
TMA-4	52.56%
PMA-1	32.50%
PMA-2	75.64%
PMA-3	58.83%
PMR-2A	86.87%
PROM-1	79.51%
TM-500	46.60%
MT-4	55.26%
PMR-3	79.36%
TMA-1	52.56%
TDM-2	19.81%
PMR-2AS	86.87%
PSM-1	88.49%
MC-71	47.14%
TMM-1	59.64%
Type 69	52.56%
PMD-1	38.85%

Top 5 Values
88.49%
86.95%
86.87%
86.87%
79.51%

LANDMINE	QUESTIONS	ANSWERS
L.PZ.MI	Shape?	CYL
	Height?	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	SHE
	AT or AP	AT
	Color	GRA
	# of Fuze Wells	3
	Metal Content	YES
	Effect	BST
	Underwater capable	NO

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	62.15%
TM-100	50.90%
TM-200	30.69%
TM-62M	76.07%
L.PZ.MI	89.82%
PMR-1	52.32%
PMA-1A	30.69%
PMR-2	41.88%
TMA-5	36.94%
TMRP-6	62.15%
MRUD	24.44%
TMA-2	44.44%
TMA-3	75.90%
TMA-4	75.90%
PMA-1	15.42%
PMA-2	50.90%
PMA-3	38.40%
PMR-2A	52.32%
PROM-1	42.60%
TM-500	30.69%
MT-4	35.07%
PMR-3	44.10%
TMA-1	68.40%
TDM-2	27.92%
PMR-2AS	52.32%
PSM-1	52.32%
MC-71	56.28%
TMM-1	83.57%
Type 69	68.40%
PMD-1	27.92%

Top 5 Values
89.82%
83.57%
76.07%
75.90%
75.90%

LANDMINE	QUESTIONS	ANSWERS
MAT-76	Shape?	CYL
	Height?	UNK
	Width	
	Length	
	Diameter	>150
	Case Material	FIB
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	1
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	82.72%
TM-100	58.21%
TM-200	39.55%
TM-62M	75.06%
L.PZ.MI	68.46%
PMR-1	46.22%
PMA-1A	39.55%
PMR-2	43.65%
TMA-5	52.24%
TMRP-6	69.17%
MRUD	33.21%
TMA-2	52.24%
TMA-3	82.72%
TMA-4	81.28%
PMA-1	30.77%
PMA-2	58.21%
PMA-3	50.88%
PMR-2A	46.14%
PROM-1	46.22%
TM-500	39.55%
MT-4	44.23%
PMR-3	43.65%
TMA-1	81.28%
TDM-2	37.69%
PMR-2AS	46.14%
PSM-1	46.22%
MC-71	62.56%
TMM-1	75.06%
Type 69	80.71%
PMD-1	25.58%

Top 5 Values
82.72%
82.72%
81.28%
81.28%
80.71%

LANDMINE	QUESTIONS	ANSWERS
MC-71	Shape?	OTH
	Height?	UNK
	Width	
	Length	
	Diameter	>150
	Case Material	MET
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	SCG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	YES
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	51.79%
TM-100	28.72%
TM-200	28.14%
TM-62M	58.87%
L.PZ.MI	52.27%
PMR-1	35.79%
PMA-1A	28.14%
PMR-2	26.15%
TMA-5	40.83%
TMRP-6	46.03%
MRUD	28.14%
TMA-2	40.83%
TMA-3	51.79%
TMA-4	51.79%
PMA-1	25.58%
PMA-2	28.72%
PMA-3	23.45%
PMR-2A	35.72%
PROM-1	35.79%
TM-500	28.14%
MT-4	20.38%
PMR-3	35.79%
TMA-1	51.79%
TDM-2	32.50%
PMR-2AS	35.72%
PSM-1	35.79%
MC-71	82.72%
TMM-1	58.87%
Type 69	51.79%
PMD-1	20.38%

Top 5 Values
82.72%
58.87%
58.87%
52.27%
51.79%

LANDMINE	QUESTIONS	ANSWERS
TM-62M	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	MET
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	75.64%
TM-100	58.33%
TM-200	39.68%
TM-62M	88.49%
L.PZ.MI	81.88%
PMR-1	59.64%
PMA-1A	39.68%
PMR-2	50.00%
TMA-5	52.37%
TMRP-6	69.87%
MRUD	33.91%
TMA-2	52.37%
TMA-3	81.41%
TMA-4	81.41%
PMA-1	25.58%
PMA-2	58.33%
PMA-3	41.53%
PMR-2A	59.56%
PROM-1	50.67%
TM-500	39.68%
MT-4	37.95%
PMR-3	59.64%
TMA-1	81.41%
TDM-2	38.27%
PMR-2AS	59.56%
PSM-1	59.64%
MC-71	70.22%
TMM-1	88.49%
Type 69	81.41%
PMD-1	31.92%

Top 5 Values
88.49%
88.49%
81.88%
81.41%
81.41%

LANDMINE	QUESTIONS	ANSWERS
TMA-5	Shape	REC
	Height	50-150
	Width	>150
	Length	>150
	Diameter	
	Case Material	PLA
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	1
	Metal Content	NONE
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	45.29%
TM-100	41.40%
TM-200	58.64%
TM-62M	45.40%
L.PZ.MI	39.48%
PMR-1	28.85%
PMA-1A	58.64%
PMR-2	26.55%
TMA-5	90.71%
TMRP-6	41.40%
MRUD	61.75%
TMA-2	88.64%
TMA-3	51.49%
TMA-4	52.78%
PMA-1	38.62%
PMA-2	41.40%
PMA-3	25.97%
PMR-2A	28.78%
PROM-1	20.80%
TM-500	58.64%
MT-4	16.78%
PMR-3	26.55%
TMA-1	52.78%
TDM-2	55.00%
PMR-2AS	28.78%
PSM-1	28.85%
MC-71	35.06%
TMM-1	45.40%
Type 69	51.75%
PMD-1	53.62%

Top 5 Values
90.71%
88.64%
61.75%
58.64%
58.64%

LANDMINE	QUESTIONS	ANSWERS
TMRP-6	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	PLA
	AT or AP	AT
	Color	LTG
	# of Fuze Wells	2
	Metal Content	YES
	Effect	MIZ
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	YES
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	64.55%
TM-100	48.68%
TM-200	30.03%
TM-62M	64.68%
L.PZ.MI	69.04%
PMR-1	41.60%
PMA-1A	30.03%
PMR-2	39.04%
TMA-5	42.72%
TMRP-6	88.49%
MRUD	35.22%
TMA-2	47.91%
TMA-3	75.51%
TMA-4	76.95%
PMA-1	8.85%
PMA-2	54.45%
PMA-3	36.73%
PMR-2A	41.60%
PROM-1	32.63%
TM-500	30.03%
MT-4	26.99%
PMR-3	39.04%
TMA-1	76.95%
TDM-2	32.50%
PMR-2AS	41.60%
PSM-1	41.60%
MC-71	52.18%
TMM-1	69.87%
Type 69	71.76%
PMD-1	20.38%

Top 5 Values
88.49%
76.95%
76.95%
75.51%
71.76%

LANDMINE	QUESTIONS	ANSWERS
MRUD	Shape?	REC
	Height?	50-150
	Width	<150
	Length	>150
	Diameter	
	Case Material	PLA
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	2
	Metal Content	YES
	Effect	DFG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	32.72%
TM-100	34.10%
TM-200	62.62%
TM-62M	32.84%
L.PZ.MI	31.48%
PMR-1	31.36%
PMA-1A	62.62%
PMR-2	28.89%
TMA-5	68.17%
TMRP-6	39.10%
MRUD	83.17%
TMA-2	73.17%
TMA-3	43.27%
TMA-4	44.65%
PMA-1	42.22%
PMA-2	34.10%
PMA-3	22.52%
PMR-2A	31.28%
PROM-1	18.64%
TM-500	62.62%
MT-4	7.65%
PMR-3	28.89%
TMA-1	44.65%
TDM-2	48.15%
PMR-2AS	31.28%
PSM-1	27.28%
MC-71	27.28%
TMM-1	37.84%
Type 69	39.65%
PMD-1	63.33%

Top 5 Values
83.17%
73.17%
68.17%
63.33%
62.62%

LANDMINE	QUESTIONS	ANSWERS
TMA-2	Shape	REC
	Height	50-150
	Width	>150
	Length	>150
	Diameter	
	Case Material	PLA
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	3
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	42.18%
TM-100	37.26%
TM-200	54.51%
TM-62M	41.78%
L.PZ.MI	42.07%
PMR-1	25.23%
PMA-1A	54.51%
PMR-2	22.93%
TMA-5	84.51%
TMRP-6	37.78%
MRUD	58.13%
TMA-2	90.71%
TMA-3	53.56%
TMA-4	54.85%
PMA-1	35.00%
PMA-2	37.26%
PMA-3	26.48%
PMR-2A	25.16%
PROM-1	17.18%
TM-500	54.51%
MT-4	12.64%
PMR-3	22.93%
TMA-1	48.64%
TDM-2	51.38%
PMR-2AS	25.16%
PSM-1	25.23%
MC-71	31.44%
TMM-1	47.99%
Type 69	48.13%
PMD-1	54.66%

Top 5 Values
90.71%
84.51%
58.13%
54.85%
54.66%

LANDMINE	QUESTIONS	ANSWERS
TMA-3	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	FIB
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	4
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	77.53%
TM-100	58.78%
TM-200	40.13%
TM-62M	75.64%
L.PZ.MI	76.54%
PMR-1	46.79%
PMA-1A	40.13%
PMR-2	44.23%
TMA-5	52.82%
TMRP-6	69.74%
MRUD	33.78%
TMA-2	52.82%
TMA-3	90.79%
TMA-4	81.86%
PMA-1	19.81%
PMA-2	58.78%
PMA-3	45.12%
PMR-2A	46.72%
PROM-1	37.82%
TM-500	40.13%
MT-4	32.76%
PMR-3	44.23%
TMA-1	81.86%
TDM-2	32.50%
PMR-2AS	46.72%
PSM-1	46.79%
MC-71	57.37%
TMM-1	75.64%
Type 69	81.28%
PMD-1	31.35%

Top 5 Values
90.79%
81.86%
81.86%
81.28%
77.53%

LANDMINE	QUESTIONS	ANSWERS
TMA-4	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	PLA
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	3
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	76.09%
TM-100	60.22%
TM-200	41.56%
TM-62M	76.22%
L.PZ.MI	76.54%
PMR-1	47.37%
PMA-1A	41.56%
PMR-2	44.81%
TMA-5	54.26%
TMRP-6	71.76%
MRUD	35.79%
TMA-2	61.18%
TMA-3	88.78%
TMA-4	90.22%
PMA-1	20.38%
PMA-2	60.22%
PMA-3	48.19%
PMR-2A	47.29%
PROM-1	38.40%
TM-500	41.56%
MT-4	32.76%
PMR-3	44.81%
TMA-1	83.29%
TDM-2	33.08%
PMR-2AS	47.29%
PSM-1	47.37%
MC-71	57.95%
TMM-1	83.14%
Type 69	83.29%
PMD-1	31.92%

Top 5 Values
90.22%
88.78%
83.29%
83.29%
83.14%

LANDMINE	QUESTIONS	ANSWERS
PMA-1	Shape?	REC
	Height?	<50
	Width	<150
	Length	<150
	Diameter	
	Case Material	WOO
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	29.81%
TM-100	29.81%
TM-200	68.33%
TM-62M	24.26%
L.PZ.MI	19.14%
PMR-1	24.26%
PMA-1A	63.46%
PMR-2	24.26%
TMA-5	42.78%
TMRP-6	13.15%
MRUD	52.78%
TMA-2	42.78%
TMA-3	25.49%
TMA-4	25.49%
PMA-1	82.62%
PMA-2	32.28%
PMA-3	35.85%
PMR-2A	24.19%
PROM-1	24.26%
TM-500	68.33%
MT-4	26.73%
PMR-3	24.26%
TMA-1	24.26%
TDM-2	57.43%
PMR-2AS	24.19%
PSM-1	24.26%
MC-71	24.26%
TMM-1	24.26%
Type 69	24.26%
PMD-1	63.85%

Top 5 Values
82.62%
68.33%
68.33%
63.85%
63.46%

LANDMINE	QUESTIONS	ANSWERS
PMA-2	Shape?	CYL
	Height?	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	PLA
	AT or AP	AP
	Color	LTG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	56.39%
TM-100	81.69%
TM-200	50.24%
TM-62M	56.53%
L.PZ.MI	55.63%
PMR-1	67.78%
PMA-1A	50.24%
PMR-2	65.00%
TMA-5	43.99%
TMRP-6	64.19%
MRUD	43.99%
TMA-2	43.99%
TMA-3	62.64%
TMA-4	64.19%
PMA-1	27.29%
PMA-2	87.94%
PMA-3	63.13%
PMR-2A	67.78%
PROM-1	58.06%
TM-500	50.24%
MT-4	58.19%
PMR-3	65.00%
TMA-1	64.19%
TDM-2	27.29%
PMR-2AS	67.78%
PSM-1	67.78%
MC-71	36.74%
TMM-1	56.53%
Type 69	64.19%
PMD-1	34.17%

Top 5 Values
87.94%
81.69%
67.78%
67.78%
67.78%

LANDMINE	QUESTIONS	ANSWERS
PMA-3	Shape?	CYL
	Height?	<50
	Width	
	Length	
	Diameter	<150
	Case Material	PAR
	AT or AP	AP
	Color	BLK
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	54.17%
TM-100	68.75%
TM-200	37.29%
TM-62M	44.03%
L.PZ.MI	48.68%
PMR-1	55.28%
PMA-1A	44.93%
PMR-2	52.50%
TMA-5	31.04%
TMRP-6	45.00%
MRUD	31.04%
TMA-2	31.04%
TMA-3	49.31%
TMA-4	52.64%
PMA-1	39.79%
PMA-2	71.53%
PMA-3	81.07%
PMR-2A	60.28%
PROM-1	55.28%
TM-500	37.29%
MT-4	64.44%
PMR-3	52.50%
TMA-1	51.25%
TDM-2	27.29%
PMR-2AS	60.28%
PSM-1	55.28%
MC-71	36.74%
TMM-1	44.03%
Type 69	51.25%
PMD-1	23.06%

Top 5 Values
81.07%
71.53%
68.75%
64.44%
60.28%

LANDMINE	QUESTIONS	ANSWERS
PMR-1	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	MET
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	FRG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	YES

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	46.79%
TM-100	75.64%
TM-200	46.60%
TM-62M	59.64%
L.PZ.MI	53.04%
PMR-1	88.49%
PMA-1A	46.60%
PMR-2	78.85%
TMA-5	33.91%
TMRP-6	46.79%
MRUD	51.99%
TMA-2	33.91%
TMA-3	52.56%
TMA-4	52.56%
PMA-1	32.50%
PMA-2	75.64%
PMA-3	58.83%
PMR-2A	88.41%
PROM-1	79.13%
TM-500	46.60%
MT-4	55.26%
PMR-3	88.49%
TMA-1	52.56%
TDM-2	19.81%
PMR-2AS	88.41%
PSM-1	88.10%
MC-71	47.14%
TMM-1	59.64%
Type 69	52.56%
PMD-1	38.85%

Top 5 Values
88.49%
88.49%
88.41%
88.41%
88.10%

LANDMINE	QUESTIONS	ANSWERS
PMR-2A	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	MET
	AT or AP	AP
	Color	MUL
	# of Fuze Wells	1
	Metal Content	YES
	Effect	FRG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	YES

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	41.03%
TM-100	69.87%
TM-200	40.83%
TM-62M	53.87%
L.PZ.MI	53.04%
PMR-1	82.72%
PMA-1A	40.83%
PMR-2	73.08%
TMA-5	28.14%
TMRP-6	46.79%
MRUD	46.22%
TMA-2	28.14%
TMA-3	46.79%
TMA-4	46.79%
PMA-1	26.73%
PMA-2	69.87%
PMA-3	58.91%
PMR-2A	88.49%
PROM-1	73.36%
TM-500	40.83%
MT-4	55.26%
PMR-3	82.72%
TMA-1	46.79%
TDM-2	19.81%
PMR-2AS	88.49%
PSM-1	82.33%
MC-71	41.37%
TMM-1	53.87%
Type 69	46.79%
PMD-1	33.08%

Top 5 Values
88.49%
88.49%
82.72%
82.72%
82.33%

LANDMINE	QUESTIONS	ANSWERS
PROM-1	Shape	CYL
	Height	150-250
	Width	
	Length	
	Diameter	<150
	Case Material	MET
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BFG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	46.79%
TM-100	64.10%
TM-200	35.06%
TM-62M	48.10%
L.PZ.MI	41.50%
PMR-1	75.41%
PMA-1A	35.06%
PMR-2	65.77%
TMA-5	22.37%
TMRP-6	36.54%
MRUD	35.06%
TMA-2	22.37%
TMA-3	41.03%
TMA-4	41.03%
PMA-1	31.99%
PMA-2	63.59%
PMA-3	58.32%
PMR-2A	76.62%
PROM-1	88.49%
TM-500	35.06%
MT-4	55.26%
PMR-3	76.69%
TMA-1	41.03%
TDM-2	19.81%
PMR-2AS	76.62%
PSM-1	78.23%
MC-71	47.14%
TMM-1	48.10%
Type 69	41.03%
PMD-1	27.31%

Top 5 Values
88.49%
78.23%
76.69%
76.62%
76.62%

LANDMINE	QUESTIONS	ANSWERS
PMA-1A	Shape?	REC
	Height?	<50
	Width	<150
	Length	<150
	Diameter	
	Case Material	PLA
	AT or AP	AP
	Color	BLK
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	32.16%
TM-100	33.54%
TM-200	72.06%
TM-62M	21.17%
L.PZ.MI	25.31%
PMR-1	21.17%
PMA-1A	72.74%
PMR-2	18.70%
TMA-5	46.51%
TMRP-6	22.43%
MRUD	56.51%
TMA-2	46.51%
TMA-3	27.84%
TMA-4	29.22%
PMA-1	67.78%
PMA-2	36.01%
PMA-3	43.70%
PMR-2A	25.62%
PROM-1	21.17%
TM-500	72.06%
MT-4	29.32%
PMR-3	18.70%
TMA-1	27.99%
TDM-2	48.15%
PMR-2AS	25.62%
PSM-1	21.17%
MC-71	21.17%
TMM-1	21.17%
Type 69	27.99%
PMD-1	49.01%

Top 5 Values
72.74%
72.06%
72.06%
67.78%
56.51%

LANDMINE	QUESTIONS	ANSWERS
TM-100	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	PLA
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	62.64%
TM-100	87.94%
TM-200	56.49%
TM-62M	62.15%
L.PZ.MI	55.00%
PMR-1	73.40%
PMA-1A	56.49%
PMR-2	70.63%
TMA-5	50.24%
TMRP-6	57.32%
MRUD	49.61%
TMA-2	50.24%
TMA-3	68.89%
TMA-4	70.44%
PMA-1	32.92%
PMA-2	87.94%
PMA-3	69.29%
PMR-2A	73.32%
PROM-1	63.68%
TM-500	56.49%
MT-4	58.19%
PMR-3	70.63%
TMA-1	70.44%
TDM-2	26.67%
PMR-2AS	73.32%
PSM-1	73.40%
MC-71	42.36%
TMM-1	62.15%
Type 69	69.82%
PMD-1	39.79%

Top 5 Values
87.94%
87.94%
73.40%
73.40%
73.32%

LANDMINE	QUESTIONS	ANSWERS
TM-200	Shape	REC
	Height	50-150
	Width	<150
	Length	<150
	Diameter	
	Case Material	PLA
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	37.72%
TM-100	50.21%
TM-200	88.73%
TM-62M	37.28%
L.PZ.MI	30.93%
PMR-1	37.28%
PMA-1A	82.62%
PMR-2	34.81%
TMA-5	63.17%
TMRP-6	32.99%
MRUD	72.62%
TMA-2	63.17%
TMA-3	43.27%
TMA-4	44.65%
PMA-1	61.67%
PMA-2	50.21%
PMA-3	33.63%
PMR-2A	37.21%
PROM-1	28.64%
TM-500	88.73%
MT-4	23.77%
PMR-3	34.81%
TMA-1	44.65%
TDM-2	47.59%
PMR-2AS	37.21%
PSM-1	37.28%
MC-71	26.17%
TMM-1	37.28%
Type 69	44.10%
PMD-1	63.89%

Top 5 Values
88.73%
88.73%
82.62%
72.62%
63.89%

LANDMINE	QUESTIONS	ANSWERS
TM-500	Shape	REC
	Height	50-150
	Width	<150
	Length	<150
	Diameter	
	Case Material	PLA
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	SOME
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	37.72%
TM-100	50.21%
TM-200	88.73%
TM-62M	37.28%
L.PZ.MI	30.93%
PMR-1	37.28%
PMA-1A	82.62%
PMR-2	34.81%
TMA-5	63.17%
TMRP-6	32.99%
MRUD	72.62%
TMA-2	63.17%
TMA-3	43.27%
TMA-4	44.65%
PMA-1	61.67%
PMA-2	50.21%
PMA-3	33.63%
PMR-2A	37.21%
PROM-1	28.64%
TM-500	88.73%
MT-4	23.77%
PMR-3	34.81%
TMA-1	44.65%
TDM-2	47.59%
PMR-2AS	37.21%
PSM-1	37.28%
MC-71	26.17%
TMM-1	37.28%
Type 69	44.10%
PMD-1	63.89%

Top 5 Values
88.73%
88.73%
82.62%
72.62%
63.89%

LANDMINE	QUESTIONS	ANSWERS
MT-4	Shape?	CYL
	Height?	>250
	Width	
	Length	
	Diameter	<150
	Case Material	CAR
	AT or AP	AP
	Color	BRN
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	47.50%
TM-100	58.75%
TM-200	27.29%
TM-62M	41.25%
L.PZ.MI	40.35%
PMR-1	52.50%
PMA-1A	27.29%
PMR-2	52.50%
TMA-5	21.04%
TMRP-6	35.00%
MRUD	21.04%
TMA-2	21.04%
TMA-3	41.25%
TMA-4	41.25%
PMA-1	33.40%
PMA-2	58.19%
PMA-3	52.57%
PMR-2A	52.50%
PROM-1	52.50%
TM-500	27.29%
MT-4	88.22%
PMR-3	52.50%
TMA-1	41.25%
TDM-2	33.96%
PMR-2AS	52.50%
PSM-1	52.50%
MC-71	33.96%
TMM-1	41.25%
Type 69	41.25%
PMD-1	25.00%

Top 5 Values
88.22%
58.75%
58.19%
52.57%
52.50%

LANDMINE	QUESTIONS	ANSWERS
PMR-3	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	<150
	Case Material	CAS
	AT or AP	AP
	Color	ODG
	# of Fuze Wells	1
	Metal Content	YES
	Effect	FRG
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	YES
Tiltrod?	NO
Stake Mine?	YES

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	44.23%
TM-100	73.08%
TM-200	44.04%
TM-62M	59.64%
L.PZ.MI	45.45%
PMR-1	88.49%
PMA-1A	44.04%
PMR-2	81.92%
TMA-5	31.35%
TMRP-6	44.23%
MRUD	49.42%
TMA-2	31.35%
TMA-3	50.00%
TMA-4	50.00%
PMA-1	32.50%
PMA-2	73.08%
PMA-3	56.27%
PMR-2A	88.41%
PROM-1	79.13%
TM-500	44.04%
MT-4	55.26%
PMR-3	88.49%
TMA-1	50.00%
TDM-2	19.81%
PMR-2AS	88.41%
PSM-1	80.51%
MC-71	47.14%
TMM-1	52.05%
Type 69	50.00%
PMD-1	38.85%

Top 5 Values
88.49%
88.49%
88.41%
88.41%
81.92%

LANDMINE	QUESTIONS	ANSWERS
TMM-1	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	SHE
	AT or AP	AT
	Color	ODG
	# of Fuze Wells	3
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	70.45%
TM-100	53.14%
TM-200	34.49%
TM-62M	83.29%
L.PZ.MI	83.62%
PMR-1	54.45%
PMA-1A	34.49%
PMR-2	44.81%
TMA-5	47.18%
TMRP-6	64.68%
MRUD	28.72%
TMA-2	54.10%
TMA-3	83.14%
TMA-4	83.14%
PMA-1	20.38%
PMA-2	53.14%
PMA-3	41.53%
PMR-2A	54.37%
PROM-1	45.47%
TM-500	34.49%
MT-4	32.76%
PMR-3	46.86%
TMA-1	76.22%
TDM-2	33.08%
PMR-2AS	54.37%
PSM-1	54.45%
MC-71	65.03%
TMM-1	90.22%
Type 69	76.22%
PMD-1	31.92%

Top 5 Values
90.22%
83.62%
83.29%
83.14%
83.14%

LANDMINE	QUESTIONS	ANSWERS	NOMENCLATURE	LIKELIHOOD	Top 5 Values
TMA-1	Shape	CYL	MAT-76	76.09%	88.49%
	Height	50-150	TM-100	60.22%	88.49%
	Width		TM-200	41.56%	87.05%
	Length		TM-62M	75.64%	82.72%
	Diameter	>150	L.PZ.MI	74.23%	80.83%
	Case Material	PLA	PMR-1	46.79%	
	AT or AP	AT	PMA-1A	41.56%	
	Color	ODG	PMR-2	44.23%	
	# of Fuze Wells	2	TMA-5	54.26%	
	Metal Content	SOME	TMRP-6	76.37%	
	Effect	BST	MRUD	40.41%	
	Underwater capable	YES	TMA-2	59.45%	
			TMA-3	87.05%	
	HEURISTICS	**YES or NO**	TMA-4	88.49%	
	Is there a handle?	YES	PMA-1	19.81%	
	Tripwire?	NO	PMA-2	60.22%	
	Tiltrod?	NO	PMA-3	48.19%	
	Stake Mine?	NO	PMR-2A	46.72%	
			PROM-1	37.82%	
	HEURISTICS OK!		TM-500	41.56%	
			MT-4	32.76%	
			PMR-3	44.23%	
			TMA-1	88.49%	
			TDM-2	37.69%	
			PMR-2AS	46.72%	
			PSM-1	46.79%	
			MC-71	57.37%	
			TMM-1	80.83%	
			Type 69	82.72%	
			PMD-1	31.35%	

LANDMINE	QUESTIONS	ANSWERS
TYPE-69	Shape	CYL
	Height	50-150
	Width	
	Length	
	Diameter	>150
	Case Material	PLA
	AT or AP	AT
	Color	GRE
	# of Fuze Wells	1
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	NO
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	78.89%
TM-100	69.19%
TM-200	48.99%
TM-62M	79.03%
L.PZ.MI	73.13%
PMR-1	55.28%
PMA-1A	48.99%
PMR-2	52.50%
TMA-5	55.24%
TMRP-6	80.44%
MRUD	42.74%
TMA-2	55.24%
TMA-3	85.14%
TMA-4	86.69%
PMA-1	21.04%
PMA-2	69.19%
PMA-3	45.63%
PMR-2A	50.28%
PROM-1	45.56%
TM-500	48.99%
MT-4	40.69%
PMR-3	52.50%
TMA-1	86.69%
TDM-2	33.54%
PMR-2AS	50.28%
PSM-1	55.28%
MC-71	59.24%
TMM-1	79.03%
Type 69	87.94%
PMD-1	32.92%

Top 5 Values
87.94%
86.69%
86.69%
85.14%
80.44%

LANDMINE	QUESTIONS	ANSWERS
TMD-2	Shape	SQR
	Height	UNK
	Width	UNK
	Length	UNK
	Diameter	
	Case Material	WOO
	AT or AP	AT
	Color	WOO
	# of Fuze Wells	2
	Metal Content	YES
	Effect	BST
	Underwater capable	YES

HEURISTICS	YES or NO
Is there a handle?	YES
Tripwire?	NO
Tiltrod?	NO
Stake Mine?	NO

HEURISTICS OK!

NOMENCLATURE	LIKELIHOOD
MAT-76	29.66%
TM-100	18.28%
TM-200	40.52%
TM-62M	29.66%
L.PZ.MI	33.56%
PMR-1	13.10%
PMA-1A	40.52%
PMR-2	13.10%
TMA-5	51.90%
TMRP-6	29.14%
MRUD	40.00%
TMA-2	56.55%
TMA-3	34.31%
TMA-4	34.31%
PMA-1	54.33%
PMA-2	18.28%
PMA-3	18.28%
PMR-2A	13.10%
PROM-1	13.10%
TM-500	40.52%
MT-4	21.03%
PMR-3	13.10%
TMA-1	34.31%
TDM-2	74.68%
PMR-2AS	13.10%
PSM-1	13.10%
MC-71	24.48%
TMM-1	34.31%
Type 69	29.66%
PMD-1	54.33%

Top 5 Values
74.68%
56.55%
54.33%
54.33%
51.90%

LIST OF REFERENCES

[BHAR 96] Bhargava, H., "Decision Support Systems Lecture Notes", p 132, Naval Postgraduate School, Monterey, CA, 1996.

[BENE 89] The Council for Science and Society, *Benefits and Risks of Knowledge Based Systems*, pp. 44-59, 1989.

[FORT 89] Forsyth, R., *Expert Systems: Principles and Case Studies*, Chapman and Hill LTD, New York, NY, 1989.

[HART 86] Hart, A., *Knowledge Acquisition for Expert Systems*, McGraw-Hill, New York, NY, 1986.

[HIDD 94] US Department of State, Bureau of Political-Military Affairs, *Hidden Killers - The Global Landmine Crisis,* Office of International Security and Peacekeeping Operations, 1994.

[HIGH 93] U.S. Army, *High-Risk Munitions Identification Guide*, Explosive Ordnance Disposal Division, US Army Research labs, Picatinny Arsenal, NJ, 1993.

[KANT 97] Kantrowitz, M., "Answers to Frequently Asked Questions about Expert System Shells", ftp.cs.cmu.edu:/user/ai/pubs/faqs/expert/expert_1.faq, July 1997.

[MINE 97] U.S. Army, *MineFacts*, Version 1.2, U.S. Army Night Vision and Electronic Sensors Directorate, Fort Belvior, VA, 1997.

[PCAI 97] PC AI, "Expert Systems", http://www.pcai.com/pcai/New_Home_Page/ai_info/expert_systems.html, Knowledge Technology, Inc, 1997.

[QUIN 87] Quinlan, J., *Applications of Expert Systems*, Turing Institute Press, Sydney, Australia, 1987.

[SAPP 90] U.S. Army, *Sapper Countermine Handbook*, BRDEC PAM 350-4, Belvior Research, Development and Engineering Center, Countermine Systems Directorate, Fort Belvior, VA, November 1990.

[SLAT 87] Slatter, P., *Building Expert Systems: Cognitive Emulation*, Ellis Horwood LTD, New York, NY, 1987.

[SLOA 86] Sloan, C., *Mine Warfare on Land,* p.7, Brassey's Defense Publishers, London, England, 1986.

[STIL 95] Stillings, A., et al., *Cognitive Science: An Introduction*, Second Edition, MIT Press, Cambridge, MA, 1995.

[STOF 70] Stolfi, R., "Mine and Countermine Warfare in Recent History, 1914-1970", pp.9, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, 1972.

[UNEX 94] U.S. Army, *Unexploded Ordnance (UXO) Procedures,* FM 21-16, Department of the Army, 30 August, 1994.

[UNIT 97] United Nations, "Demining News from the United Nations", Volume 1.2, http://www.un.org/Depts/Landmine/NewsLetter/, April 1997.

[WIDM 96] Widman, L., MD, Ph.D., "Expert Systems in Medicine", http://amplatz.uokhsc.edu/acc95-expert-systems.html, 1996.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center..2
   8725 John J. Kingman Road, Ste 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library..2
   Naval Postgraduate School
   411 Dyer Rd.
   Monterey, CA 93943-5101

3. Chairman, Code SM..1
   Systems Management Department
   Naval Postgraduate School
   Monterey, CA 93943

4. MAJ. Nelson D. Ludlow, USAF, Ph.D. Code CS/Ld...............................2
   Computer Science Department
   Naval Postgraduate School
   Monterey, CA 93943

5. Dr. Carl Jones, Code SM/js...1
   Systems Management Department
   Naval Postgraduate School
   Monterey, CA 93943

6. CPT Paul J. Arcangeli 7
   USMA DOIM BOPD Plans
   ATTN: CPT Arcangeli
   Bldg 2101 Spellman Hall
   West Point, N.Y. 10996