T-3174

AI DETERMINATION

OF

SEISMIC FIELD PARAMETERS

by

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PREFACE

A new era has begun in Computer Science. In this era even the word computer is obsolescent and the subject is, according to the words of Lord Kelvin, not a science. This is the era of artificial intelligence or more precisely the era of knowledge engineering.

William Thomson (Lord Kelvin) 1824-1907:

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science."

HAVE WE REACHED THE BEGINNING OF KNOWLEDGE?

PERSONAL CONSULTANT* User's Guide:

"The computers, as well as the programs that TI has created to use with them, are tools that can help people better to manage the information used in their business; but tools -- including TI computers -- cannot replace sound judgment nor make the manager's business decisions."

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ABSTRACT

This thesis presents the first published report of the application of knowledge engineering to the problem of the design of Vibroseis[1] reflection seismology surveys to increase the probability of cost-effective exploration.

Texas Instruments has provided a LISP shell called PERSONAL CONSULTANT[2]. This program was used to write an Expert System called EXPSEIS[3].

EXPSEIS uses heuristics involving equipment inventory, geology, seismology, economics and logistics to determine the following goal parameters:

Far-trace Offset	Near-trace Offset
Group Interval	Number of channels
Multiplicity of Depth Coverage	Cable-spread Configuration
Geophone Array	Number of Geophones
Vibroseis Array	Number of Vibrators

[1] CONOCO Tradename

[2] Texas Instruments, Inc. Trademark

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Like all expert systems EXPSEIS will evolve for a few years as more experts use it and we incorporate their heuristics. At present it serves to guide the beginner and to assure the expert that he has not neglected a step in the design process. More importantly, like its predecessor PROSPECTOR[4], it heralds a bright future for the Expert Systems branch of Artificial Intelligence throughout the mineral exploration business.

[4] Copyrights reserved by Duda, Gaschnig, and Hart, SRI International and Stanford Research Institute

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INTRODUCTION

Recently the area of expert systems, or "knowledge engineering", has emerged as a road to successful and useful applications of Artificial Intelligence (AI) techniques.

Expert systems are computer programs that can help to solve complex, real world problems in specific domains. These systems are most strongly characterized by their use of large bodies of knowledge.

Seismic Field Parameter Determination is a very complex problem. Until now, the determination of seismic field parameters has been a job for the field seismologist. As an expert in the field, he is the most capable of estimating the best parameters to do a seismic reflection survey.

Practitioners of Artificial Intelligence (AI) claim that it is possible to build computer programs that can achieve the same levels of performance as their human counterparts. The goal of AI "knowledge engineers" has always been to develop computer programs that could in some sense think, that is, solve problems in a way that would be considered intelligent if done by a human.

The main objective of this project was to investigate the feasibility of creating an expert system in the area of Seismic Field Parameter Determination.

A prototype system has been created, EXPSEIS. EXPSEIS stands for "Experto Seismologo". It is hoped that the program will develope so that it has the ability to solve the same problems that the field seismologist solves, with the same level of performance, but faster.

The first part of this paper, AI AND EXPERT SYSTEMS, will deal with a general introduction to AI and Expert Systems. This part is intended to give the reader an idea of the field and the multiple applications that expert systems offer today.

The second part, BASIC STAGES FOR BUILDING EXPSEIS, will deal with the different steps in the coding of this prototype knowledge system.

In the last part some conclusions and specific recommendations about the project are stated. Some of these will be helpful and will enhance the power of future projects in AI, here at Colorado School of Mines.

ARTIFICIAL INTELLIGENCE (AI) AND EXPERT SYSTEMS

The field of Artificial Intelligence has achieved considerable success in the development of expert systems since the mid-1960's. This area of AI has concentrated on the construction of high-performance programs in specialized professional domains. The schematic Figure 1 gives an idea of the amount of work that has been done in this area during the last years. (The Handbook of Artificial Intelligence, V. 2, chapter VI).

FORTRAN in Figure 1 represents the amount of code written in the given year using that language. LISP on the other hand, the symbolic language most used in AI and expert systems technologies, represents the new generation of programs (expert systems) that have been created using this language. Note that LISP code is still in the stage of exponential growth.

What are expert systems? Expert systems are computer programs modelled on human experts. They use sophisticated problem-solving techniques and vast stores of knowledge to solve problems in specialized professional domains.

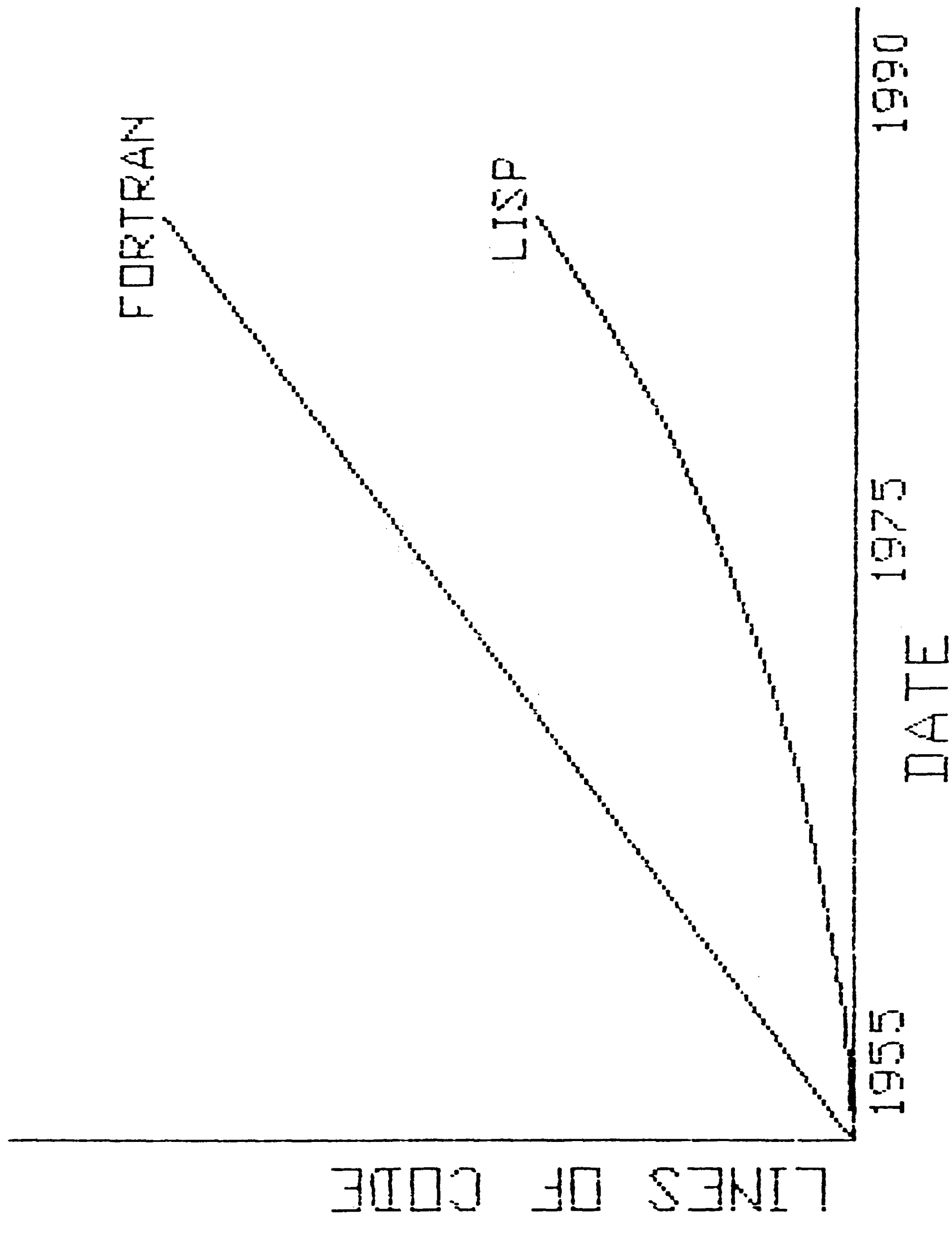


Figure 1. Success in the development of expert systems.

These programs attack the problem with a new approach. Instead of being programmed to follow step-by-step procedures, a computer is programmed to follow a few general procedures for finding solutions to problems. Facts, rules of thumb, models, and other general knowledge about solving a particular class of problem (a "problem domain") are encoded and stored in the computer's memory.

The power of an expert system derives from the knowledge it possesses, not from the particular formalisms and inference schemes it employs to solve problems. Expert performance depends critically on expert knowledge. Human experts achieve outstanding performance, because they are knowledgeable. If computer programs embody and use knowledge, then, they too should attain high levels of performance.

Expert systems differ from conventional data processing systems in the:

i) Use of a more general symbolic representation. In conventional programs, symbols are mostly numbers. In expert systems, a symbol can be anything, a number, a word, a phrase, an object, etc.

ii) Use of symbolic inference. These new programs use symbols for doing the reasoning.

iii) Use of heuristic search. By heuristic search we understand the use of any rule of thumb, of any strategy, trick, simplification or any other kind of device which drastically limits the search for solutions in large problem spaces.

iv) Performance of difficult tasks at expert levels of execution.

v) Employment of self-knowledge to reason about their own inference processes and provide explanations or justifications for the conclusions reached. This is believed to be the most potentially significant and innovative characteristic of expert systems.

Next you will find a general description of some of the aspects of expert systems.

Problem Domains of Expert Systems

Expert systems have been built to solve many different types of problems, but their basic activities can be grouped into the categories shown in Table 1.

This Table will provide the reader with a vision of the breadth of applications found in expert systems currently in use.

Table 1[1]. Generic categories of expert system applications.

Category	Problem addressed
Interpretation	Inferring descriptions from sensor data.
Prediction	Inferring likely consequences of given situations.
Diagnosis	Inferring system malfunctions from observables.
Design	Configuring objects under constraints.
Planning	Designing actions.
Monitoring	Comparing observations to expected outcomes.
Debugging	Prescribing remedies for malfunctions.
Repair	Executing plans to administer prescribed remedies.
Control	Governing overall system behavior.
Instruction	Diagnosing, debugging, and repairing student behavior.

Although the basic activities of expert systems shown in Table 1 are easy to describe, it is misleading to use them to categorize existing expert systems, because many expert systems perform more than just one activity. In Table 2 there is a brief description of selected expert systems in some areas of knowledge.

[1]Adapted from Building Expert Systems.

Table 2. Selected expert systems in different areas of knowledge.

<u>Science</u>	
DENDRAL	Infers a compound's molecular structure from mass spectral data.
MACSYMA	Performs differential and integral calculus symbolically.
<u>Medicine</u>	
MYCIN	Helps diagnose and treat bacterial infections.
ONCOSYN	Helps treat and manage cancer patients undergoing chemotherapy.
<u>Geology</u>	
PROSPECTOR	Helps geologists evaluate the mineral potential of a region.
DIPMETER ADVISOR	Helps geologists interpret dipmeter logs.
<u>Computers</u>	
R1,XCON	Configures DEC VAX computer systems.
<u>Electronics</u>	
ACE	Diagnoses faults in telephone networks.
<u>Military</u>	
RTC	Classifies ships by interpreting radar images.

Components of Expert Systems

A typical "knowledge-based" expert system consists of:

i) An Inference Engine, which solves a problem by interpreting the domain knowledge contained in the Knowledge Base. It is essentially, a computer programmed to process symbols that represent objects.

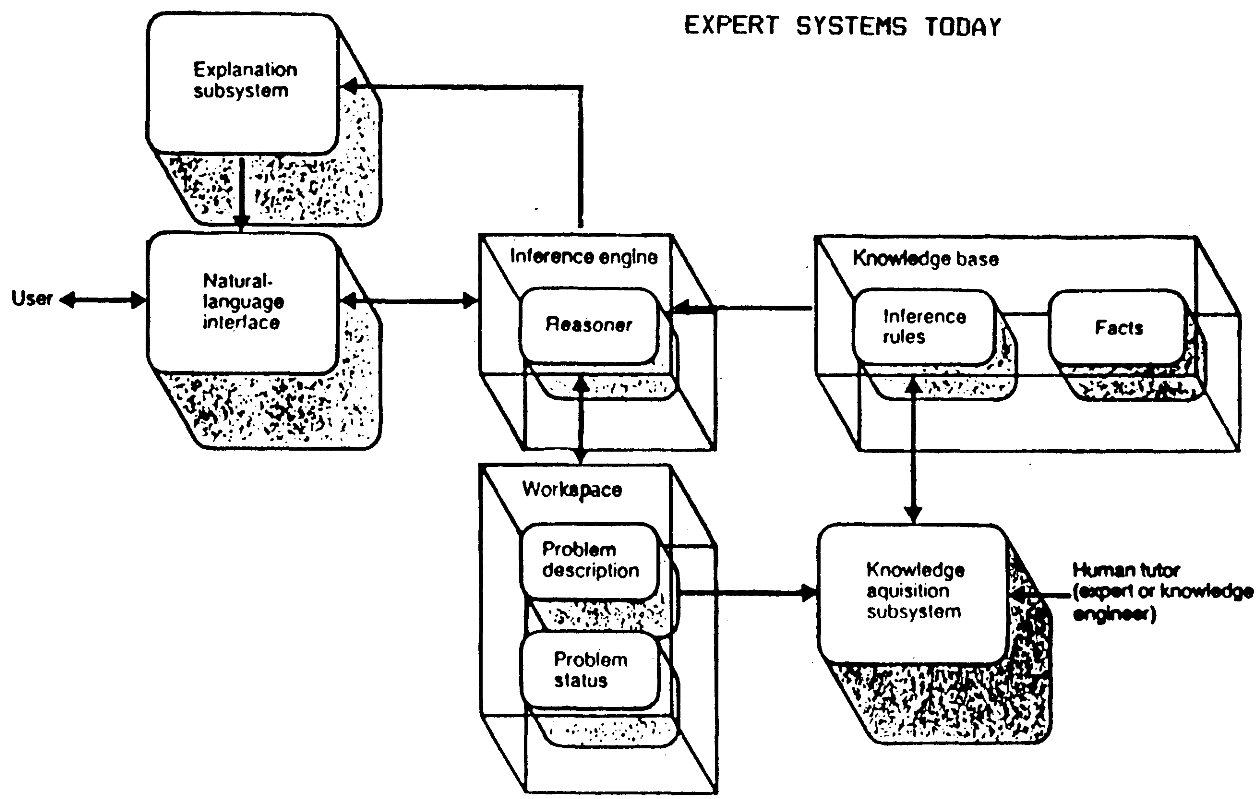
ii) A Knowledge Base, comprising facts, as well as heuristic planning and problem solving rules.

iii) A Workspace, an area of memory set aside for storing a description of the problem constructed by the system from facts supplied by the user, or inferred from the knowledge base during a consultation.

iv) A system may also include a natural-language interface for communicating with the user, a reasoning explanation subsystem, and a knowledge acquisition subsystem for expanding the knowledge base.

Figure 2 gives a clear idea of these components and their interrelation.

One of the most important parts in an expert system is the Inference Engine. A little more information about this major part will help the reader to understand some of the terms that will be used later in this paper.



Taken from Kinnucan, P., 1984, Computers that think like experts.

Figure 2. Components of expert systems today.

Usually two reasoning mechanisms, either alone or in combination, are used by the inference engine to reach the solutions. They are:

i) Forward (Data-directed); starts from the given initial conditions, until it reaches the goal.

ii) Backward (Goal-directed); starts from the hypothetical solution (the goal) until it finds evidence supporting the solution, from the initial conditions.

iii) Bi-directional; involves searching from both ends of a space-search in order to meet somewhere in the middle.

Basic Stages for Building Expert Systems

A quick review of the different stages necessary to build expert systems will be given to introduce the reader to this important topic. Later in the paper each of these stages will be discussed in more detail. The major stages are:

i) Identification; implies the determination of the problem characteristics, resources needed, and goals or objectives of building the expert system.

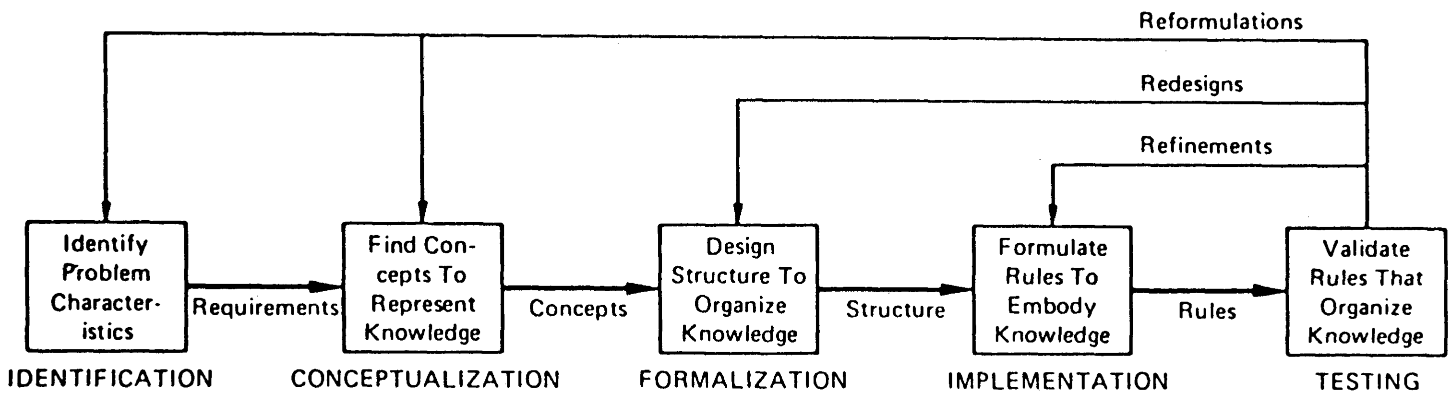
ii) Conceptualization; implies finding the key concepts, relations and information-flow characteristics needed to represent the knowledge in the given domain.

iii) Formalization; implies designing structures and relations to organize the knowledge. The language framework must be selected at this stage. (LISP, PROLOG, PLANNER, etc.)

iv) Implementation; implies formulating the rules that embody the knowledge. The resulting set of rules and associated control structures, define a prototype program ready to be executed and tested.

v) Testing; involves evaluating the performance of the prototype program. The knowledge base is expanded and changed repeatedly until the system reaches a consistent high level of performance.

It is impossible to distinguish between these stages of expert systems development and there is no simple way to describe the order in which they take place. Identification does happen first and testing last; however, at any time it may be necessary to go back to review and change any of the previous work. Expert systems development is a highly interdependent and overlaping process, that involves all the stages. Figure 3 illustrates how these stages interact. Arrows indicate the interactions between the different phases.



Taken from Hayes-Roth, F., and Waterman, D. A., 1983, Building Expert Systems.

Figure 3. Stages of knowledge acquisition.

Tools for Building Expert Systems

To build an expert system to assist or replace an expert in a particular domain, it is necessary to create a software package. This software can be created in one of a number of high-level languages. Well-known high-level languages include BASIC, COBOL, FORTRAN, PASCAL, and C. AI programmers commonly use other high-level languages, such as LISP and PROLOG.

PROLOG makes it easy to write programs that manipulate logical expressions, whereas LISP consists of operators that facilitate the creation of programs that manipulate lists.

Using these AI high-level languages, some companies have special packages of prewritten code that are typically called "programming environments", "expert systems tools", or simply "shells".

These tools are designed to facilitate the rapid development of expert systems. They are essentially skeletal expert systems that come with knowledge representation and reasoning mechanisms, but without a knowledge base.

These shells offer two advantages to expert systems developers:

1. They provide a substantial amount of computer code that would otherwise need to be written, tested, debugged, and maintained.
2. Tools provide specific techniques for building the knowledge representation, inference, and control that will help the expert system developer to model and characterize a particular class of problems.

Table 3 gives some examples of tools available for building expert systems today.

Table 3[2]. Tools for building expert systems.

Tool	Developer	Features
ROSIE	Rand Corporation	Rule-based, Procedure-oriented, general purpose
OPS5	Carnegie-Mellon University	Production-system formalism, general purpose
EMYCIN	Stanford University	Rule-base, diagnosis and explanation
INTERLISP	Xerox Corporation	LISP programming environment, general purpose.
KEE	Intellicorp	LISP-based, production system. Frame and rule based
PERSONAL CONSULTANT	Texas Instruments	LISP-based, rule-based, general purpose
EXPERTEASE	Expert-ease	LISP-based, general purpose

[2]Adapted from Building Expert Systems.

The development of systems such as the ones shown in Table 3 are an important area of current AI research.

For more detailed information on any of the previous topics, the reader should refer himself to any of the AI books or papers listed in "SELECTED BIBLIOGRAPHY". Most of the books cover these topics thoroughly.

BASIC STAGES FOR BUILDING EXPSEIS

The development of EXPSEIS can be viewed as five highly interdependent and overlapping phases: identification (clear idea of the problem), conceptualization (procedure for determining the field parameters), formalization (designing the structure of EXPSEIS), implementation (encoding the knowledge base), testing and maintenance (evaluation of EXPSEIS).

It is possible to distinguish between these construction stages of EXPSEIS; however, there is no simple way to know which stage you are in, at a certain moment of the process. At any time during the development of EXPSEIS, it is necessary to engage one of the other phases to ensure that the logic of the program is maintained. Only by having the knowledge base well structured is it possible to achieve high levels of performance.

Expert systems development is an evolutionary process, and it is only after time and experimentation that an effective expert system can emerge.

Identification of the Problem

Choosing the right problem is perhaps the most critical part of the entire development effort. If the problem domain is inappropriately chosen, one may quickly find the entire effort impeded by design problems, that no one knows how to solve. Also, it is necessary to choose a problem difficult enough that it requires the attention of an expert in the field in order to be solved.

At this stage it is also necessary to identify the required resources (e.g., time and computing facilities), and the goals or objectives of building the expert systems.

The important thing is to measure the complexity of the problem picked, and focus only on a small, but interesting subproblem.

Seismic Field Parameter Determination

The selection of the best seismic field parameters for any sort of seismic exploration survey is a broad and complicated problem. Until now, the field seismologist has been the only expert that has had sufficient experience and knowledge to select good parameters for seismic reflection exploration.

This motivated the creation of the knowledge system EXPSEIS. EXPSEIS was conceived as a Knowledge system that can help any geophysicist in the determination of seismic field parameters.

As a small project it was conceived to demonstrate that expert systems can be helpful in exploration for hydrocarbons, specifically in the area of field parameter design.

EXPSEIS is designed to calculate some of the field parameters for a land seismic survey. Technical and economic factors are considered, using as an example a conventional crew with surface sources (Vibrators) recording along straight lines. Ten major field parameters were picked. These are listed in Table 4.

Table 4. Major seismic field parameters chosen for determination with EXPSEIS.

<u>FIELD PARAMETERS</u>

1. Far-Trace Offset
2. Near-Trace Offset
3. Geophone-group Interval
4. Number of Channels
5. Multiplicity
6. Cable-Spread Configuration
7. Geophone-Array
8. Number of Geophones
9. Vibroseis-Array
10. Number of Vibroseis Units

EXPSEIS follows two approaches to find these seismic field parameters. First, it defines, as closely as possible, the exploration problem that is to be solved and second it designs the field technique that best fit the objective of the survey.

In order to define the problem, there are some questions that need to be asked. Each question has a definite relationship to the seismic field parameters that are going to be determined. Some of the questions that are necessary to be asked are listed in Table 5.

Table 5. Initial parameters that are necessary for seismic field parameter determination.

DEFINING THE PROBLEM

a. Target depth(s)?
b. Reflection quality?
c. Stacking velocity for target horizon?
d. Estimate of the velocity in the shallow-formations?
e. Steepest dip?
f. Maximum frequency to be preserved?
g. Access or logistic problems?
h. Economics?
i. Time available for the survey?
j. Noise wavelengths?
k. Number of channels in your recording system (if fixed)?
l. Number of geophones available?
m. Estimate of the source energy necessary?
n. Number of Vibroseis units (if fixed)?

Conceptualization of the Problem

During conceptualization, it is necessary to find the key concepts, relations and information-flow characteristics needed to represent the knowledge in the given domain. Subtasks, strategies, and constraints related to the problem solving activity are also explored.

At this stage one also considers the level of detail needed to represent the knowledge. At first it is necessary to pick the least detailed representations that still provide adequate discrimination between the key concepts.

Procedure for Determining the Field Parameters

The objective in selecting the best seismic field parameters should be to optimize the information content of the reflections of interest. Techniques are practically unlimited by hardware, although often limited by what we can afford to do. The design of the field techniques should be based on the known or predicted characteristics of target reflectors.

The procedures that EXPSEIS uses to determine the field parameters are the same ones that the field seismologist would use.

The theory that follows is the theory used for the creation of the knowledge base of EXPSEIS. The procedures described herein are based mostly on the Geophysical Service Inc.'s (GSI) and Seiscom Delta's technical operating standards.

At this stage we are only concerned with the theory behind the creation of the knowledge base of EXPSEIS. How this theory is actually encoded into the program will be discussed in a later section.

Far-Trace Offset Heuristics

i) The offset to the far-trace of the spread must be such that the most important reflection comes in just below the front mute (see heuristic iii) on that trace.

ii) To ensure multiple cancellation, the multiple on the far-trace should be out-of-phase with the multiple on the near-trace by at least one multiple period.

iii) When a CDP gather is normal moveout (NMO) corrected, the signal is stretched. The front mute is usually selected so that it zeroes data which involves more than 30-40% trace stretching. No signal of any interest should fall into the mute zone.

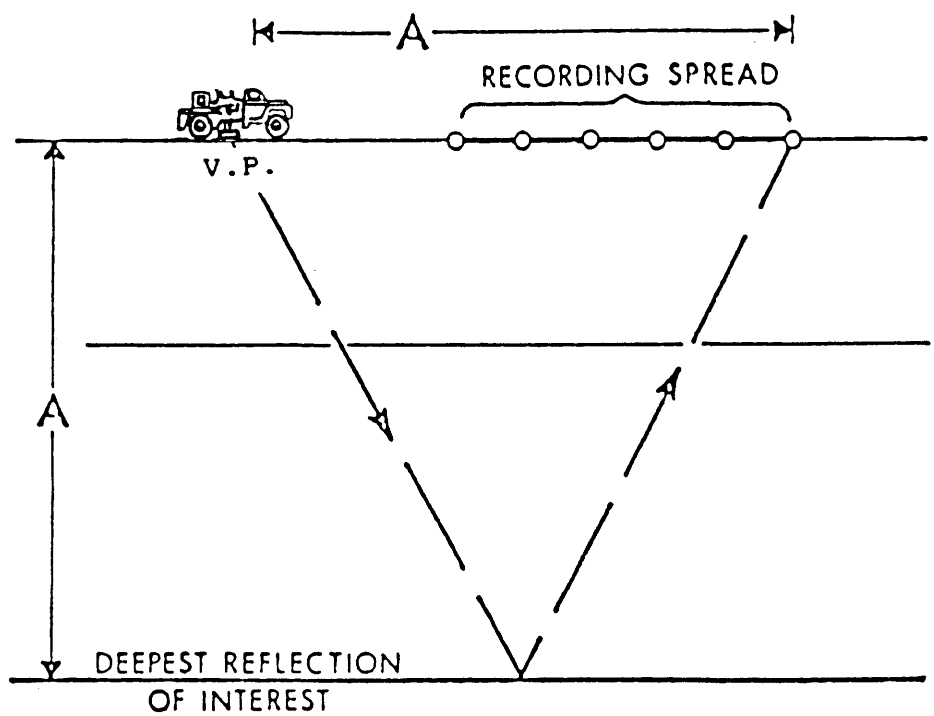
iv) In seismic exploration one of the most important parameters is seismic velocity. Seismic velocity is used for NMO corrections, for depth conversions, for migration, and for lithological investigations. Thus estimation of RMS seismic velocity from field data should be as accurate as practicable.

All these "rules of thumb" can be satisfied in a seismic survey if the Far-Trace offset is equal to the approximate depth of investigation. EXPSEIS use the criterion that Far-Trace offset should be less than or equal to the maximum target depth of any interest. (See Figure 4).

Near-Trace Offset Heuristics

Similar considerations limit the near-trace offset. It is necessary to ensure that at least single coverage is retained on the shallowest reflection of interest.

In most areas no problems arise if the near-trace offset is made as short as one group interval, and the shorter the near-trace offset, the higher the multiplicity on the shallow reflections. However, in zones where high-amplitude horizontally travelling noise is present, it is usual to increase the near-trace offset to two or three group intervals to improve noise cancellation, even though we may lose multiplicity on the shallow events.



Adapted from Denhan, L. R., 1979,
Field Technique Design for
Seismic Reflection Exploration.

Figure 4. Far-trace offset. The distance from the V.P. (Vibration Point) to the furthest geophone group should be approximately equal to the depth to the deepest reflection of major interest.

EXPSEIS uses the criterion that the distance from the shot (V.P.) to the closest geophone group must not exceed the depth of the shallowest reflection of any interest. (See Figure 5).

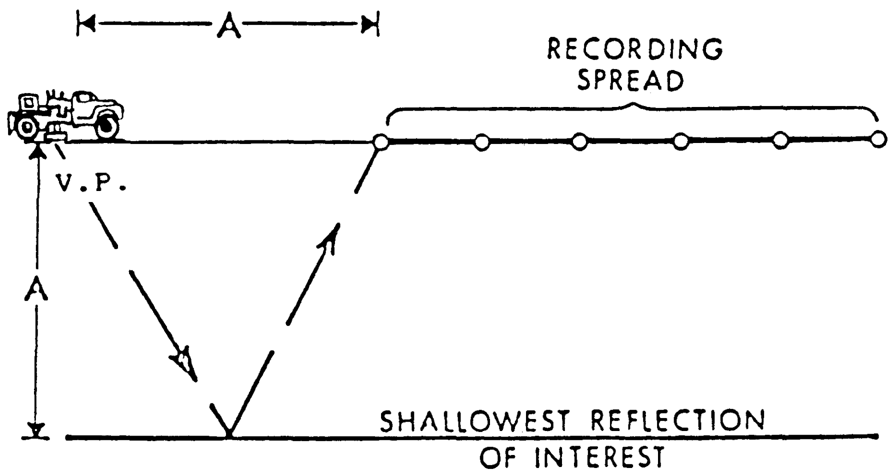
Group Interval Heuristics

In the determination of the group interval two aspects should be taken into consideration:

i) The group interval will depend on the Far-Trace offset and on the number of channels available in the recording system.

ii) When the above aspects do not introduce limitations, the group interval should be chosen to give adequate depth point sampling, or even better to give adequate spatial sampling for migration.

As the depth point interval is half the group interval the closer the groups, the more dense the depth point sampling. In order to avoid aliasing, the depth point interval should be half or less the signal wavelength. This is specially important in the case of steep dip.



Adapted from Denhan, L. R., 1979,
Field Technique Design for
Seismic Reflection Exploration.

Figure 5. Near-trace offset. The distance from the V.P. to the closest geophone group must not exceed the depth of the shallowest reflection of any interest.

EXPSEIS uses two formulas to calculate group interval. These equations are the ones that are commonly used by the field seismologist of GSI and Seiscom Delta to calculate group interval given the above requirements.

$$GI = \frac{V}{2\ F_{MAX}\ SIN\theta} \qquad \text{and,} \qquad GI = \frac{1.667\ V}{F_{MAX}}$$

<u>For dipping events</u> <u>For flat events</u>

where:

GI = Group Interval. (meters)

V = Average velocity to target depth. (meters/sec)

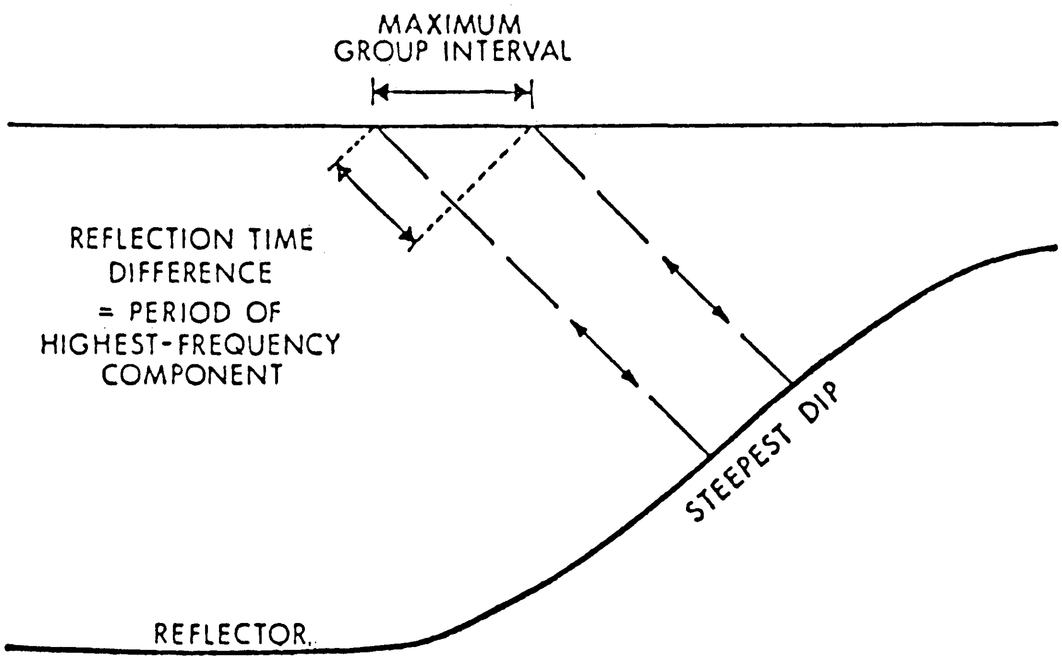
θ = Maximum dip angle of target horizon. (degrees)

F_{MAX} = Maximum frequency to be preserved at target depth

(See Figures 6 and 7).

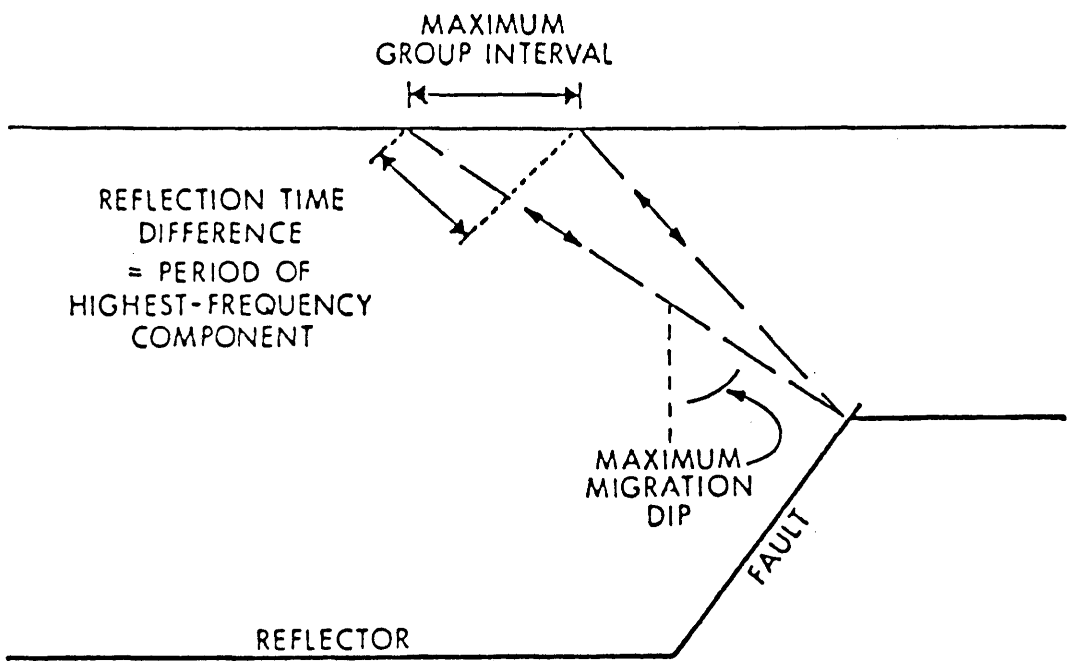
<u>Number of Channels Heuristics</u>

Once the maximun group interval and the maximum and minimum offset have been established, the minimum number of channels is that which will give the required group interval over the required range of offsets.



Taken from Denhan, L. R., 1979, Field Technique Design for Seismic Reflection Exploration.

Figure 6. Group Interval. Where there is no faulting, the maximum group interval is equal to the wavelength of the highest frequency reflection component, projected onto the surface at the steepest dip angle.



Taken from Denhan, L. R., 1979, Field Technique Design for Seismic Reflection Exploration.

Figure 7. Group Interval. If faulting or other discontinuities are present, the maximum group interval is equal to the wavelength of the highest frequency reflection component projected onto the surface at the maximum migration angle.

Thus if enough channels are available in the acquisition equipment

$$N = \frac{X_{MAX} - X_{MIN}}{GI}$$

Here:

N = Number of channels

XMAX = Far-Trace offset (meters)

XMIN = Near-Trace offset (meters)

GI = Group Interval (meters)

EXPSEIS uses this equation when the number of channels in the recording equipment is not a limiting factor. N is then adjusted to 24, 48, 60, 96, 120, 240, 512 or 1024 channels. EXPSEIS then redoes the calculations for group interval with this new number.

If the user answers that he already has recording equipment with a fixed number of channels, EXPSEIS calculates an initial group interval, using the values of velocity, frequency, and dip. If this group interval does not fit the requirements of the number of channels, EXPSEIS tries to find the best compromise.

EXPSEIS will reduce or increase the group interval by a certain amount, or will change the cable spread configuration to find the best match, according to the criteria already established.

Multiplicity Heuristics

Since the number of recording channels has already been set, a decision on multiplicity sets the shotpoint spacing (Move-up) in terms of geophone group intervals.

The equation that EXPSEIS uses to relate the multiplicity and move-up is:

$$\text{MULTIPLICITY} = \frac{N/2}{\text{Move-up (in terms of GI)}}$$

where:

MULTIPLICITY = CDP Fold

N = Number of channels

GI = Group Interval

However, other criteria are important. In the estimate of move-ups EXPSEIS also involves initial conditions such as: 1) access or logistic problems, 2) economics, and 3) time available.

Different certainty factors (CF) are given for each one of the possible combinations. The one with the highest CF is the one that determines the Move-up.

Cable Spread Configuration Heuristics

A choice between using OFF-END or SPLIT-SPREAD shooting must be made. The far and near trace offsets, and group interval have already been defined by target depths and the required sampling and resolution. EXPSEIS will decide on OFF-END or SPLIT-SPREAD according to the following:

i) If the number of channels is enough to use the group interval calculated, and if certain subsurface structures are expected, EXPSEIS will choose SPLIT-SPREAD, because a 3 dB improvement in the signal to noise ratio can be expected.

ii) If the number of channels is not enough to insure proper sampling of the subsurface with SPLIT-SPREAD, EXPSEIS will choose OFF-END.

iii) The expected geologic structure is also a factor in this choice. EXPSEIS will choose the appropriate cable configuration according to that.

Geophone Array Heuristics

The main purpose of an array is to attenuate horizontally travelling noise, and increase the total recorded signal by an additive process. The signal to noise ratio is improved by roughly $\sqrt{N}$, where N is the number of receivers in the array.

For the estimation of the best geophone array EXPSEIS uses the following criteria:

i) The minimum wavelength of any signal should be attenuated less than 3 dB by the array.

ii) The maximum wavelength of any noise should be attenuated at least 20 dB by the array.

Since it is so important to know the minimum possible wavelength of the signal, EXPSEIS uses the following equation to calculate the wavelength of the signal in a dipping model.

$$\lambda = \frac{5\ V}{3\ F_{MAX}} \left[\frac{(1 \pm (24/25)\ \mathrm{SIN}\theta)^{1/2}}{1 \pm 4/3\ \mathrm{SIN}\theta} \right]$$

where: λ = Wavelength of the signal (meters)

V = Average velocity at target depth (meters/sec)

F_{MAX} = Maximum frequency to be preserved (Hz)

θ = Maximum dip angle (degrees)

$\pm$ = + for down-dip; - for up-dip

EXPSEIS uses the minimum wavelength of the signal calculated from the above equation and the maximum wavelength of any noise, found in a noise test done in the area of the survey, to estimate the array. This array is chosen from a set of arrays calculated by using a program that generates array responses. See Figure 8 for a typical array response.

In this figure you can see that the signal should fall in the passed zone of the array filter, where it will be attenuated a maximum of only 3 dB. On the other hand, the band of noise should fall in the rejected zone of the filter, where it will be attenuated at least by 20 dB. Once the array is chosen, EXPSEIS will calculate the geophone interval and array length using the following equations:

For weighted arrays	For linear arrays
$d = K_c \lambda_{NMAX}$	$d = L / (n - 1)$
$L = (n - 1) d$	$L = 0.44 \lambda_{SMIN}$

where:

d = Distance between elements. (meters)

L = Array length. (meters)

K_c = First K with maximun attenuation. (meters^{-1})

n = Number of elements in the array

λ_{NMAX} = Maximum wavelength of any noise. (meters)

λ_{SMIN} = Minimum wavelength of any signal (meters)

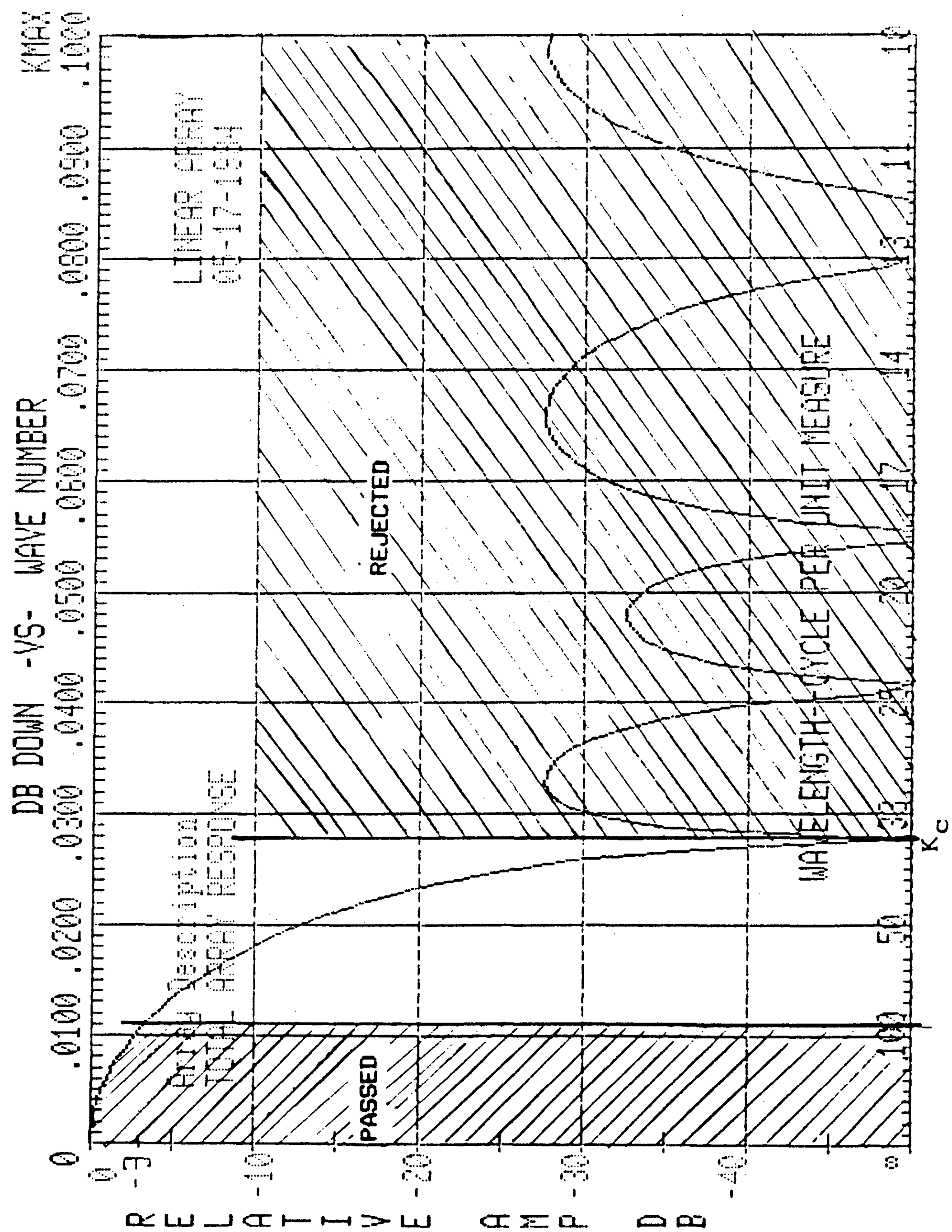


Figure 8. Response curve of a typical weighted geophone array.

EXPSEIS calculates the attenuation of the array filter in dB by using the following equation:

$$dB = 20 \log_{10} \sqrt{N} ,$$

where: N = Number of geophones in the array.

Once all this is calculated, EXPSEIS will also take into consideration such things as: velocity of the near-surface formations and topography of the terrain to adjust the values of the array length. This is to ensure that the signal information will be disturbed, in the least possible way, by the characteristics of the terrain and near-surface geology.

Number of Geophones Heuristics

To determine this parameter EXPSEIS asks the user for the number of geophones available in the crew. If the number of geophones is fixed, EXPSEIS will choose an array that passes the signal and attenuates the noise using the the number of geophones that best accomplishes this. The maximum number of geophones to be used will depend on the number of available geophones per array.

If the number of geophones available is no problem, EXPSEIS will choose the best array based on the signal and noise characteristics, and with this, the number of geophones can be estimated.

EXPSEIS also uses other considerations to choose the number of geophones, such as: economics and time available. The array that fulfills all the considerations is the array chosen. "High resolution" surveys generally use but one, well planted geophone per take out.

Vibroseis Array Heuristics

For the estimation of the best vibroseis array, EXPSEIS uses the same criteria used to estimate the geophone array. The only thing different, in this case, is that the program will choose the best vibroseis array from a set of pre-established arrays in the knowledge base.

The set from which EXPSEIS will choose is composed of 50 different arrays. These arrays cover different situations to be considered, such as: different separation between vibroseis units, different advances of the units in the array, and different amounts of energy to be introduced into the ground.

Number of Vibroseis Units Heuristics

To determine this parameter EXPSEIS asks the user if he already has a fixed number of vibroseis units in the crew. If the user has a fixed number of vibrators, EXPSEIS will choose an array according to this number.

If the user lets the program choose the number of vibroseis units, EXPSEIS will choose the best array that passes the signal and attenuates the noise. Once the array is chosen, the number of vibrators is something intrinsic to that particular array, and that fixes the number of vibrators.

Again, all this is subject to other considerations such as: economics and time available. EXPSEIS will choose the array that is the best compromise between all these parameters.

Formalization of EXPSEIS

Formalization involves expressing the key concepts and relations in some formal way, usually within a framework suggested by an expert system building language.

During this stage, the design of the structures and relations to organize the knowledge base take place. This is also when a building tool is chosen.

In the case of EXPSEIS, the tool that was used to build the knowledge system was "Personal Consultant (Expert Systems Development Tools)" by Texas Instruments. This because, Personal Consultant was the only such tool available at the Colorado School of Mines. Thus, all the design and organization of the knowledge base was based on the characteristics of Personal Consultant.

Review of the Personal Consultant Tool

A brief review of "Personal Consultant" will now be presented. Personal Consultant can be put in the general category of a small systems building tool. Tools in this category can be run on personal computers, and they are generally designed to facilitate the development of systems containing less than 400 rules.

Overview

Personal Consultant is an EMYCIN-like program developed by Texas Instruments to run on its TI professional computers. The recommended configuration is a TI computer with 10M-byte hard disk, a minimum of 512K bytes of RAM (768K bytes if you really want to do a 400-rule system), and MS-DOS 1.1 or 2.1.

Personal Consultant is implemented in IQLISP. As of the beginning of 1985, IQLISP had not released a compiler. Compilers allow one to compact and speed-up a program.

The existing configuration is quite adequate for the development of expert systems, but after you reach 200 plus rules the programs run very slowly. For large systems this problem can be avoided with the use of the compiler.

Knowledge and Inference

Facts are represented as object-attribute-value triplets (O-A-V) or what is the same contexts-parameters-values, with accompanying confidence factors. A rule tests the value of an O-A-V fact and concludes about other facts.

The Personal Consultant's inference engine uses the simple backward chaining type of reasoning. Control is governed primarily by the order of clauses in the rules and by the order of the rules as specified. Uncertain information is marked by confidence factors ranging from 0 to 100.

User Interface

Users interact with Personal Consultant by typing answers to questions posed by the system. There are explanation facilities, as well as trace functions for knowledge debugging.

Menus are available that list appropriate responses. The screen with which the user interacts is especially well thought out, and the function keys allow the user to ask the system How? or Why?

Designing the Structure and Organizing EXPSEIS

The TI Personal Consultant enables us to use three major elements to create the knowledge base: contexts, parameters and rules.

The knowledge base EXPSEIS, with Personal Consultant solves the particular problem of determining seismic field parameters. Such a specific area of expertise is referred to as a domain of the consultation. The information necessary to provide the user with an answer for the seismic field parameters, is structured using one or more contexts. (See Figure 9).

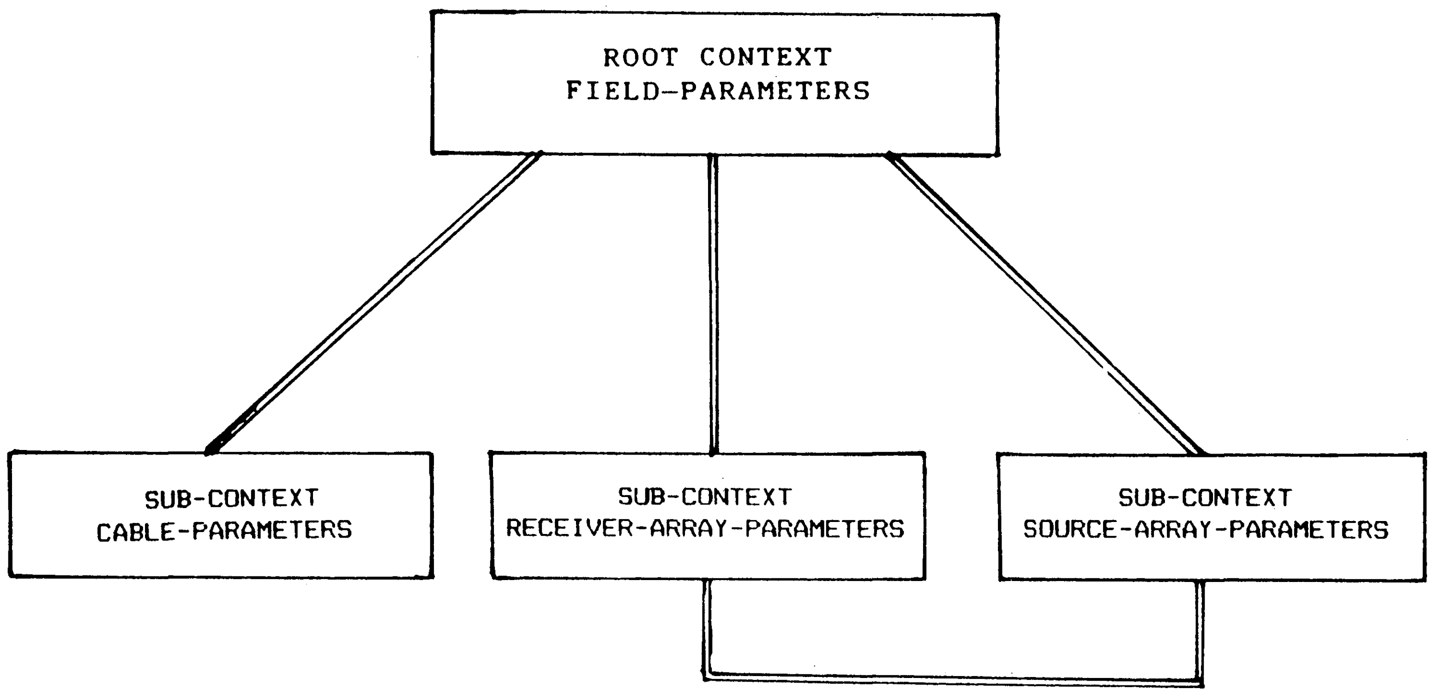


Figure 9. Context tree created for building EXPSEIS.

A context associates a particular problem area in the domain of the consultation, with the information in the knowledge base needed to solve the problem. The TI Personal Consultant allows one to structure the solution into smaller parts through the use of descendent contexts.

These contexts are arranged in a hierarchical fashion known as the context tree. This structure allows us to control the flow of the consultation. It enables us to specify the number of subproblems or contexts to be solved, and the order in which the inference engine will solve them. The context tree helps to structure a knowledge base domain, by allowing separation of a large mass of information or knowledge into logical entities.

For EXPSEIS, the knowledge base was organized in one major root context, the "Field-parameters" context, and three sub-contexts, "Cable-parameters", Receiver-array-parameters", and "Source-array-parameters". (See Figure 9).

Each sub-context deals with a different area of the problem, within the more general domain of the seismic field parameter determination.

The knowledge base also includes parameters or facts. A parameter is a specific piece of information, whose value is used in solving the specific problem.

The user can supply the value of the parameter (initial value), or the inference engine can infer it, using information from the knowledge base during the consultation.

Parameters are also grouped into parameter groups. A parameter group allows logically associated parameters to be kept together, and associates them with specific contexts. A parameter group is named for each context in the context tree. Several contexts can name the same parameter group and so share those parameters.

For EXPSEIS four parameter groups were created having the same names as the contexts to which they belonged. In Figure 9 the double line connecting the contexts represent the use of parameter groups. So, the sub-context "Receiver-array-parameters" shares the parameters of the "Field-parameters" context, and the parameters of the "Source-array-parameters" sub-context.

The third major element of a knowledge base --rules-- specify the logical relationships between several parameter values.

Using the rules of the knowledge base, the inference engine can infer the value of a parameter instead of asking the user for it. Additionally, rules can attach different levels of certainty to the parameter values they infer.

If the level is not that of absolute certainty, the knowledge base cannot be absolutely confident that the inferred value is correct.

Rules are also organized into rule groups. Like parameter groups, rule groups allows keeping rules that relate to a specific topic together. Several contexts can share the same rule group.

As in the case of the parameter groups, EXPSEIS uses four rule groups, keeping the same relationships with the contexts as the corresponding parameter groups.

The knowledge base of EXPSEIS was organized in a way such that the program does not exhaust memory needlessly. If the rules are ordered logically then a particular answer to one question may obviate the need for many others.

EXPSEIS makes use of the logic of the inference engine that short circuits the processing of a rule once it has gathered enough information. Short circuiting means that the inference engine ceases processing the rule as soon as it determines the information needed. For example, in the AND clause of a rule, one false answer causes the whole set of clauses to fail. For this reason, the inference engine stops processing that rule as soon as it finds a false answer.

On the other hand, in the OR clause of a rule, if one OR clause is true the inference engine ceases evaluation of that premise and that rule passes with a true value.

Since the system that was used to create EXPSEIS has memory limitations, the rules where structured in a certain order to take advantage of the short-circuit process.

Such organization of the rules is illustrated in Figure 11 and discussed on page 56. A set of rules is organized in a way such that, the first rules cover the most common cases and the rest of the rules deal with the more particular cases. In that way we save computer time, since the inference engine does not have to check the whole set of rules for the simplest and most common cases.

Implementation of EXPSEIS

During this stage, a formalized version of the knowledge base is turned into a working program. Constructing a program requires content, form, and integration.

The content comes from the domain knowledge made explicit during formalization, that is, the data structures, the key concepts, and control strategies necessary for problem solving.

The form is specified by the tool and the language chosen for systems development. Integration involves combining and reorganizing various pieces of knowledge to eliminate global mismatches between data structures and control specifications. The resulting set of rules and associated control structures define a prototype program ready for execution and testing.

Encoding the Knowledge Base of EXPSEIS

As explained in "Designing the Structures and Organizing EXPSEIS", parameters and rules are two of the major elements of the knowledge base.

Factual information in the knowledge base is placed in parameters. Properties can be assigned to parameters. On the other hand, with rules it is possible to affect the way parameter values are inferred, or communicate information to the user.

Parameters have six basic properties, which will be reviewed briefly. This will help to explain the way in which the knowledge base of EXPSEIS was encoded. These are:

TYPE. This property specifies what type of parameter; e.g., YES/NO, SINGLEVALUED, MULTIVALUED, VARIABLE, etc.

ASKFIRST. This property specifies that the Inference engine ask the user for the parameter value before searching any rules for its value.

EXPECT. This property specifies the acceptable user responses for the value of a specific parameter: as NUMB, POSNUMB, ANY, etc.

PROMPT. This property specifies the phrase to use when prompting the user for a parameter value.

REPROMPT. This property specifies additional text that is shown when the user presses the HELP function key.

TRANS. This property is used in place of the parameter name when translating rules or prompting the user for the value of a parameter. See Figure 10 for the use of this property when the translation of a rule is specified.

Using this translation property it is easier for the program to communicate with the user in simple English. It allows the program to explain in some way its approach to find a solution.

When the user asks the program Why? or How? some parameter value is necessary, the program traces the rules and parameters necessary to obtain a value for that parameter, and presents them to the user in a simple English.

```
RULE003 [CABLE-PARAMETERSRULES]
-------
If 1) information has been gathered about average velocity
      at target depth , and maximum frequency to be
      preserved , and maximum dip, and
   2) maximum dip is greater than 4,
Then it is definite (100%) that trial group interval is [
     average velocity at target depth divided by  [ [
     maximum frequency to be preserved times  2 ] times
  SIN (DEG-RAD (VAL1 CNTXT DIP)) ] ].

PREMISE:  ($AND (ONCEKNOWN* CNTXT (QUOTE (VELTAR FMAX DIP)
              (GREATERP* (VAL1 CNTXT DIP) 4))
ACTION:  (DO-ALL
             (CONCLUDE CNTXT GROUPTEMP
               (FQUOTIENT (VAL1 CNTXT VELTAR)
                 (TIMES (TIMES (VAL1 CNTXT FMAX) 2)
                   (SIN (DEG-RAD (VAL1 CNTXT DIP))))) TALLY
             1000))



RULE028 [CABLE-PARAMETERSRULES]
-------
If 1) it is definite that computer does not check if number
      of channels is fixed, and
   2) information has been gathered about number of channel
      , and depth to the zone of interest , and initial
      near-offset,
Then it is definite (100%) that trial value of geophone
     group interval is [ [ depth to the zone of interest
minus initial near-offset ] divided by  [ number of channel
     minus  1 ] ].

PREMISE:  ($AND (DEFNOT CNTXT NUMBCHFIX)
              (ONCEKNOWN* CNTXT
                (QUOTE (NUMBCHA1 DEPTHZ XMIN0))))
ACTION:  (DO-ALL
             (CONCLUDE CNTXT GROUPTEMP100
               (FQUOTIENT
                 (DIFFERENCE (VAL1 CNTXT DEPTHZ)
                   (VAL1 CNTXT XMIN0))
                 (DIFFERENCE (VAL1 CNTXT NUMBCHA1) 1))
      TALLY 1000))
```

Figure 10. Use of the translation property on some rules.

The English translation of the rules and parameters used in the knowledge base, give the user a simple idea of the reasoning mechanism that the program uses.

Rules on the other hand, have two basic properties that will be reviewed briefly:

PREMISE. This property value is the "if" part of a rule.

ACTION. This property value is the "then" part of an IF-THEN rule.

The inference engine evaluates the clauses that are the ACTION property value if the result of the evaluation of the PREMISE property value is true.

Also, in the knowledge base there are predefined system functions, that can be used to build rules. Functions are used in the premise and action parts of rules to show the relationships among facts. Some of these functions are: SAME (to compare parameter values), ONCEKNOWN (to trace a parameter), GREATERP* (to compare numbers), DIFFERENCE (to subtract numbers), CONCLUDE (to conclude a value and certainty factor for a parameter), etc.

For more information about the way a knowledge base is created, or any other aspect of encoding, the reader is referred to the Personal Consultant User's Guide.

To build the knowledge base, the TI Personal Consultant uses an interactive menu- and window-oriented interface that helps building and running knowledge bases. The window interface allows us to build knowledge bases by using menus and answering prompts for the necessary operations.

Since Personal Consultant is written in IQLISP a version of LISP, some knowledge of this language is necessary to encode the knowledge base, especially for encoding mathematical equations. However, the critical necessity for the construction of EXPSEIS is a thorough understanding of the characteristics and capabilities of the Personal Consultant Tool.

Figures 11, 12, 13, and 14 are some examples of the ways in which parameters and rules are placed into the knowledge base. Each figure has parameters and rules from different contexts. These figures will give the reader an idea of how the knowledge base is encoded.

In Figure 11 the PARAMETER called DIP is under consideration. In this Figure RULE105 is also treated to illustrate the way in which DIP is used. Note the mathematics in the LISP expression of the ACTION. As to the details we observe that:

```
DIP [FIELD-PARMS]
---
TRANS:  (maximum dip)
PROMPT:  (What is the maximum dip angle expected in the
          target zone, or the highest migration angle to
       be used during processing ? (DEGREES)
            (NOTE: If you are expecting horizons with a
       very low angle, please answer with a number less
       than 4 degrees.))
REPROMPT:  (This is the maximum dip angle that you expect
           to find in the sub-surface structures that you are
      could planning to detect with your survey. Also,
            be the maximum angle that you will use in your
            migration algorithms when processing the data.)
ASKFIRST:  T
ANTECEDENT-IN:  NIL
EXPECT:  POSNUMB
CONTAINED-IN:  (RULE260)
USED-BY:  (RULE003 RULE002 RULE101 RULE102 RULE104 RULE105
            RULE260 RULE097 RULE271 RULE107)


RULE105 [FIELD-PARAMETERSRULES]
-------
PREMISE:  ($AND (ONCEKNOWN* CNTXT (QUOTE (DIP VELTAR)))
             (GREATERP* (VAL1 CNTXT DIP) 4))
ACTION:  (DO-ALL
            (CONCLUDE CNTXT WAVE-LENGTH11
              (TIMES
                (TIMES
                  (SQRT
                    (PLUS 1
                      (TIMES
                        (SIN (DEG-RAD (VAL1 CNTXT DIP)))
           .96))) (VAL1 CNTXT VELTAR)) 5) TALLY 1000))
```

Figure 11. Parameters and rule of the "Field-parameters" context.

```
ECONOMICS [FIELD-PARMS]
----------
TRANS:  (money available)
PROMPT:  (How much money do you have available to do the
          survey ?)
ASKFIRST:  T
EXPECT:  (PLENTY ENOUGH TIGHT)
USED-BY:  (RULE066 RULE067 RULE068 RULE069 RULE070 RULE071
           RULE072 RULE114 RULE115 RULE116 RULE117 RULE118
           RULE119)


ENVIRONMENT [FIELD-PARMS]
------------
TRANS:  (type of environment)
PROMPT:  (In what type of area are you planning to do the
          survey ?)
ASKFIRST:  T
EXPECT:  (DESERT JUNGLE MOUNTAINS PLAINS)
USED-BY:  (RULE066 RULE067 RULE068 RULE069 RULE070)


MOVEUP [FIELD-PARMS]
------
TRANS:  (shot point increment in terms of group intervals)
CONTAINED-IN:  NIL
EXPECT:  POSNUMB
USED-BY:  (RULE058 RULE059)
UPDATED-BY:  (RULE066 RULE067 RULE068 RULE069 RULE070
              RULE071 RULE072 RULE114 RULE115 RULE116
              RULE117 RULE118 RULE119 SREFMARK RULE059)


RULE067 [CABLE-PARAMETERSRULES]
-------
PREMISE:  ($AND (SAME CNTXT SCHEDULE TIGHT)
                (SAME CNTXT ECONOMICS TIGHT)
                ($OR (SAME CNTXT ENVIRONMENT DESERT)
                  (SAME CNTXT ENVIRONMENT JUNGLE)
                  (SAME CNTXT ENVIRONMENT MOUNTAINS)
                  (SAME CNTXT ENVIRONMENT PLAINS)))
ACTION:  (DO-ALL (CONCLUDE CNTXT MOVEUP 2 TALLY 1000))
```

Figure 12. Parameters and rule of the "Cable-parameters" context.

```
MAXWANOISE [FIELD-PARMS]
-----------
TRANS:  (maximum wavelength of noise)
PROMPT:  (What is the maximum average wavelength of any
           noise, found in the noise test, and that should
        be attenuated ? (METERS))
REPROMPT:  (Usually this maximum wavelength is associated
             with coherent trains of noise that you will
         find in the noise test and that correspond to
             GROUND-ROLL , AIR-WAVE, etc.)
ASKFIRST:  T
ANTECEDENT-IN:  NIL
CONTAINED-IN:  (RULE261 RULE263 RULE262 RULE264)
EXPECT:  POSNUMB
USED-BY:  (RULE229 RULE228 RULE227 RULE226 RULE225 RULE224
           RULE223 RULE222 RULE221 RULE220 RULE219 RULE218
           RULE217 RULE214 RULE213 RULE212 RULE211 RULE210
           RULE209 RULE208 RULE207 RULE206 RULE205 RULE204
           RULE203 RULE202 RULE201 RULE200 RULE197 RULE196
           RULE195 RULE194 RULE193 RULE192 RULE191 RULE190
           RULE189 RULE188 RULE187 RULE186 RULE185 RULE184
           RULE164 RULE088 RULE089 RULE090 RULE163 RULE162
           RULE085 RULE161 RULE086 RULE087 RULE160 RULE159
           RULE080 RULE158 RULE081 RULE157 RULE082 RULE083
           RULE084 RULE079 RULE077 RULE078 RULE156 RULE155
           RULE154 RULE076 RULE074 RULE153 RULE075 RULE073
           RULE238 RULE251 RULE241 RULE253 RULE244 RULE255
           RULE093 RULE261 RULE263 RULE262 RULE264)


RULE088 [RECEIVER-ARRAYRULES]
--------
PREMISE:  ($AND (NOTSAME CNTXT SCHEDULE TIGHT)
               (NOTSAME CNTXT ECONOMICS TIGHT)
               (GREATEQ* (VAL1 CNTXT GEOPHONESO) 48)
               (GREATEQ* (VAL1 CNTXT WAVE-LENGTH) 145)
               (LESSEQ* (VAL1 CNTXT MAXWANOISE) 90)
               (GREATEQ* (VAL1 CNTXT MINWANOISE) 10))
ACTION:  (DO-ALL
             (CONCLUDE CNTXT GEOCHOICEO (TEXT TXTG17) TALLY
             998) (CONCLUDE CNTXT KC .122 TALLY 998)
             (CONCLUDE CNTXT NUMBELEM 13 TALLY 998)
             (CONCLUDETEXT CNTXT GEOSN (TEXT NIL "17dB")
             TALLY 998))
```

Figure 13. Parameters and rule of the "Receiver-array-parameters" context.

```
ENERGY [FIELD-PARMS]
------
TRANS:  (amount of energy intended to put into the ground)
PROMPT:  (How much energy do you think it is necessary to
          introduce into the ground, with the Vibros?
          EXAMPLE: use HIGH-ENERGY if you suspect volcanic
          near the surface.)
REPROMPT:  (HIGH-ENERGY, means that the shallow formations
             in the area of the survey, could be, volcanics
             very high-velocity carbonate formations, etc.
           In this case it is necessary to put a big amount
           of energy into the ground, if you want to reach
          the deep structures. More energy will be put into
             the ground by increasing the number of sweeps
             per each V.P.)
ASKFIRST:  T
CONTAINED-IN:  (RULE266 RULE262 RULE264)
ANTECEDENT-IN:  NIL
EXPECT:  (LOW-ENERGY HIGH-ENERGY)
USED-BY:  (RULE176 RULE177 RULE229 RULE227 RULE225 RULE224
           RULE222 RULE220 RULE218 RULE217 RULE214 RULE212
           RULE211 RULE209 RULE208 RULE207 RULE206 RULE204
           RULE203 RULE201 RULE200 RULE197 RULE195 RULE194
           RULE193 RULE192 RULE191 RULE190 RULE187 RULE186
           RULE185 RULE184 RULE233 RULE232 RULE231 RULE230
           RULE216 RULE215 RULE199 RULE198 RULE173 RULE266
           RULE262 RULE264)


RULE225 [SOURCE-ARRAYRULES]
-------
PREMISE:  ($AND (GREATEQ* (VAL1 CNTXT VIBROSO) 5)
                (SAME CNTXT ENERGY HIGH-ENERGY)
                (GREATEQ* (VAL1 CNTXT WAVE-LENGTH3) 118)
                (LESSEQ* (VAL1 CNTXT MAXWANOISE) 67))
ACTION:  (DO-ALL (CONCLUDE CNTXT NUMBSWEEP 14 TALLY 991)
               (CONCLUDE CNTXT SEPARATION 10 TALLY 991)
               (CONCLUDE CNTXT ADVANCE 3.33 TALLY 991)
               (CONCLUDETEXT CNTXT VIBROS (TEXT NIL "5")
         TALLY 991)
               (CONCLUDETEXT CNTXT POSITION
                 (TEXT NIL "1.66 meters, before") TALLY 991)
               (CONCLUDETEXT CNTXT SOURCESN (TEXT NIL "25.44
               TALLY 991))
```

Figure 14. Parameters and rule of the "Source-array-parameters" context.

DIP is in the parameter group FIELD-PARMS. For purposes of tracking the logic the computer refers to DIP as 'maximum dip' when relating to a client. When the client is asked for DIP the question is: What is the maximum dip angle ... etc.? From ASKFIRST: we observe that the program will not attempt to derive DIP unless perhaps the client is unable to provide it. ANTECEDENT-IN: NIL indicates that there are not ANTECEDENT RULES which reference this parameter in their PREMISE. Antecedent rules are rules whose ACTION is applied whenever the PREMISE becomes true.

From Figure 11 we next see that DIP is a positive number. (PERSONAL CONSULTANT actually means non-negative.) CONTAINED-IN: (RULE260) tells us that DIP is in the ACTION part of RULE260 but that DIP is not modified in RULE260. USED-BY: (RULE003 RULE002 ... etc. ..) gives the CONSEQUENT RULES with DIP in their PREMISE. Consequent rules are rules in which the inference engine checks the ACTION clause of a rule to see if it assigns a value to a needed parameter. If the rule can provide the value, the PREMISE clause of the rule is then tested to see if it is true.

In Figure 12, RULE067 shows how only symbolic values are assigned to the parameters SCHEDULE, ECONOMICS and ENVIRONMENT; e.g., for ENVIRONMENT we can have DESERT, JUNGLE, MOUNTAINS or PLAINS. One of these four, but no others.

Figures 13 and 14 are simple examples of the PARAMETERS and RULES of the RECEIVER-ARRAY and the SOURCE-ARRAY CONTEXTS. Both the PARAMETERS MAXWANOISE and ENERGY are of the PARAMETER GROUP FIELD-PARMS which is shared by all contexts.

The knowledge base of EXPSEIS consists of 270 rules and 106 parameters, all distributed among the four contexts that form the knowledge base.

<u>Testing and Maintenance of EXPSEIS</u>

Finally, testing and maintenance involves evaluating the performance and utility of the prototype program, and revising it as necessary. The prototype should be tested on many problems to evaluate its logic and knowledge.

Evaluation of the program may uncover problems with the representational scheme, such as missing concepts and relations, or knowledge represented at the wrong level of detail. Such problems force a review of the various development stages; reformulating the concepts and refining and revising the control flow of the consultation.

During testing some questions should be asked to test the performance of the program. Does the system make decisions that experts generally agree are appropriate? Does the solution of the problem help the user in some significant way? Are the system's conclusions appropriately organized and ordered, and presented at the right level of detail? Is the system fast enough to satisfy the user?

Users in any kind of field want more than high-quality performance --they want a system to be fast, reliable, easy to use, and easy to understand.

Personal Consultant provides some testing functions that help in the final phases of testing the knowledge base. These functions are used to detect subtle changes in logical flow resulting from changes to the knowledge base. These facilities are easily accessed from the Main Activity Menu of Personal Consultant. A brief review of these facilities will now be presented.

TRACE. This function enables the knowledge engineer to record the flow of the backward-chaining mechanism. This function will show the following: contexts created, rules that are being tried, rules that pass and fail, parameters that are set, and values and certainty factors assigned to properties.

RECORD. With this function one can record a set of prompts with their respective responses from a given consultation for a later testing.

PLAYBACK. This function enables us to use the responses from a previously saved consultation in an automated session to detect changes in the logical flow of the knowledge base.

As the reader can see these functions are very helpful when you want to change your knowledge base. You should run these facilities every time that you run a consultation during the testing stage.

Evaluation of its Performance

EXPSEIS is a knowledge system that evolved, from a system with only two contexts (Field-parameters, and Cable-parameters) and 80 rules, into one with four contexts and 270 rules.

The testing phase for EXPSEIS was an interactive process. The knowledge base of EXPSEIS has run several hundred sets of examples to find its weaknesses.

During this process, some of the main aspects in its knowledge base were checked such as: combination of certainty factors, system conclusions, inference rules, the logic or rule organization, and also the communications interface of the system.

In the communications interface of the system it is very important to ask the user the right questions. It is essential that they are properly phrased. Also, it is important to give the user enough explanations at any level of the consultation.

The maintenance of EXPSEIS is not very hard at all. Once some type of weakness is found in the system, the first step is to check the rules and parameters that reached that conclusion. The second step is to check the logic of the rules and determine if some of them are incorrect or not complete.

Since rules are not independent, it is important to be sure that they combine in a logical way, so that hypotheses and conclusions produced make semantic sense.

Due to the fact that rules, although not independent are modular in nature, every single rule can be checked and changed separately. The third step is to change the necessary rules using the editing facilities of the TI Personal Consultant. It is very important at this stage to reorganize the rules again to take advantage of the short-circuit process.

And fourth, once the appropriate changes have been made to the rules, and new rules have been added, if necessary, it is essential to check the knowledge base on this single aspect of the problem. It is important, to be sure, that the changes made have not disturbed the logic in the rest of the knowledge base.

Once the skeleton of the knowledge base is created, the most important thing is testing the knowledge base, by running it on as many sets of examples as possible.

The set of examples should not be too simple, but they should not be so complicated that they exceed the scope of the knowledge base. The domain expert is probably the best suited to provide ideas for examples that can best test the knowledge base.

EXPSEIS, can be said to have evolved to the stage of a research, medium-sized, demonstration prototype program, that handles only a portion of the big problem of seismic field parameter determination. EXPSEIS is capable of displaying credible performance on a number of test cases.

EXPSEIS can be viewed in two ways:

A) As a program that demonstrates the potential of AI, and expert systems technology in the field of seismic, and geophysics.

B) As a program that serves to demonstrate that ideas, and abstract concepts can be represented and encoded to form a knowledge base in the field of seismic exploration.

EXPSEIS may still be fragile due to incomplete testing and revision. Like any other expert systems, it will take time, and a lot of testing on real problems, to make, EXPSEIS reach the stage of a production system.

Production systems need to exhibit high quality, reliability, fast execution, and efficient performance in the user environment. These systems may take two to three years to develop. This development process is educational to man as well as machine.

EXPSEIS is available for anyone who wants to run it. For further information contact the Department of Geophysics at Colorado School of Mines.

Some Examples

In Figures 15, 16, and 17 the reader will see some examples of the type of recommendations that EXPSEIS usually gives to the user after a consultation. The recommendation consists of four major parts, associated with each of the contexts.

In the first part of the recommendation, EXPSEIS gives the best estimate of the cable parameters, calculated using the initial data.

This recommendation is for the survey that is planned to be done in the area that is as follows: The area is EXAMPLE-1 Date: 12-4-85 Version 1.7 of EXPSEIS. NOTE: ALL DISTANCES ARE IN METERS

Group interval between stations is as follows: 10

Near-trace offset is as follows: 10

Far-trace offset is as follows: 480

Number of channels in the crew is as follows: 96

Type of shooting is as follows: SPLIT-SPREAD

CDP Fold is as follows: 48

Shot point increment in terms of group interval is as follows: 1 (75%)

Geophone array is as follows: My recommendation for this case is that you should use one (1) geophone per station, or a bunch of 6 geophones all together at the station. Be very careful in planting the geophones.

Source array of Vibroseis units is as follows: My recommendation is that you should use one (1) Vibroseis unit positioned at the V.P. You should use at least 10 sweeps for this survey. The total signal to noise improvement in this case will be 10dB

Initial values for field parameters calculations is as follows: Name of the area where the survey is to be done: EXAMPLE-1 . Type of resolution expected from the survey: HIGH-RESOLUTION . Type of survey planned to be done: SHALLOW-SURVEY . Type of environment where the survey is to be done: PLAINS . Type of topography expected in the area of the survey: FLAT-SURFACE . Type of velocity expected in the near-surface formation: LOW-VELOCITY . Expected structures to be found with the survey: FAULTS . Money available to do the survey: ENOUGH . Time available to do the survey: PLENTY

Initial values for cable parameters calculations is as follows: Depth to the target zone: 500 meters. Depth to the shallowest target of any interest: 0 meters. Average velocity to target depth: 1800 meters/sec. Maximum frequency to be preserved at target depth: 120 Hz. Maximum dip angle expected at target depth: 15 degrees. The number of channels in the crew is fixed: YES

Initial values for geophone array calculations is as follows: Number of geophones per string: 6

Initial values for vibroseis array calculations is as follows: Expected energy that should be introduced into the ground: LOW-ENERGY

Figure 15. Example 1 of an EXPSEIS consultation.

This recommendation is for the survey that is planned to be done in the area that is as follows: The area is EXAMPLE-2 Date: 12-4-85 Version 1.7 of EXPSEIS. NOTE: ALL DISTANCES ARE IN METERS

Group interval between stations is as follows: 100.0

Near-trace offset is as follows: 100.0

Far-trace offset is as follows: 2400

Number of channels in the crew is as follows: 48

Type of shooting is as follows: SPLIT-SPREAD

CDP Fold is as follows: 12

Shot point increment in terms of group interval is as follows: 2 (55%)

Geophone array is as follows: The geophone array that you should use is the weighted array 1-2-3-4-4-4-3-2-1 with geophone interval of 8 meters, being the length of this array 64 meters. The signal to noise improvement for this array will be 14dB For this array you will need 24 geophones, or what is the same, 4 strings of 6 geophones per string.

Source array of Vibroseis units is as follows: My recommendation is that you should use 4 Vibroseis units, vibrating each one 12 sweeps. Vibroseis units should be separated a distance of 10 meters between pads. The Vibros should advance 3.33 meters each vibration. In order that the source-array be symmetrical the first Vibroseis unit should be 3.33 meters, before the V.P. The total signal to noise improvement for this array will be 22.84 dB

Initial values for field parameters calculations is as follows: Name of the area where the survey is to be done: EXAMPLE-2 . Type of resolution expected from the survey: LOW-RESOLUTION . Type of survey planned to be done: DEEP-SURVEY . Type of environment where the survey is to be done: JUNGLE . Type of topography expected in the area of the survey: MODERATELY-RUGGED . Type of velocity expected in the near-surface formation: LOW-VELOCITY . Expected structures to be found with the survey: NOT-KNOWN . Money available to do the survey: ENOUGH . Time available to do the survey: ENOUGH

Initial values for cable parameters calculations is as follows: Depth to the target zone: 2500 meters. Depth to the shallowest target of any interest: 0 meters. Average velocity to target depth: 2500 meters/sec. Maximum frequency to be preserved at target depth: 40 Hz. Maximum dip angle expected at target depth: 15 degrees. The number of channels in the crew is fixed: YES

Initial values for geophone array calculations is as follows: Noise test available for the area of the survey: YES . The crew has geophones available: YES . Number of strings available per group: 4 strings. Number of geophones per string: 6 geophones. Minimum wavelength of the signal to be passed by the array: 140 meters. Maximum wavelength of noise to be attenuated: 50 meters. Minimum wavelength of noise to be attenuated: 15 meters.

Initial values for vibroseis array calculations is as follows: Noise test available for the area of the survey: YES . Minimum wavelength of the signal to be passed by the array: 140 meters. Maximum wavelength of the noise to be attenuated: 50 meters. Vibroseis units available in the crew: YES . Number of Vibroseis units available: 4 vibrators. Expected energy that should be introduced into the ground: LOW-ENERGY

Figure 16. Example 2 of an EXPSEIS consultation.

This recommendation is for the survey that is planned to be done in the area that is as follows: The area is EXAMPLE-3 Date: 12-4-85 Version 1.7 of EXPSEIS. NOTE: ALL DISTANCES ARE IN METERS

Group interval between stations is as follows: 160.0

Near-trace offset is as follows: 320.0

Far-trace offset is as follows: 4000

Number of channels in the crew is as follows: 48

Type of shooting is as follows: SPLIT-SPREAD

CDP Fold is as follows: 24

Shot point increment in terms of group interval is as follows: 1 (75%)

Geophone array is as follows: The geophone array that you should use is the weighted array 1-1-2-2-3-3-3-3-2-2-1-1 with geophone interval of 8 meters, being the length of this array 88 meters. The signal to noise improvement for this array will be 14dB For this array you will need 24 geophones, or what is the same, 4 strings of 6 geophones per string.

Source array of Vibroseis units is as follows: My recommendation is that you should use 5 Vibroseis units, vibrating each one 12 sweeps. Vibroseis units should be separated a distance of 10 meters between pads. The Vibros should advance 5 meters each vibration. In order that the source-array be symmetrical the first Vibroseis unit should be 7.5 meters, before the V.P. The total signal to noise improvement for this array will be 24.77 dB

Initial values for field parameters calculations is as follows: Name of the area where the survey is to be done: EXAMPLE-3 . Type of resolution expected from the survey: LOW-RESOLUTION . Type of survey planned to be done: DEEP-SURVEY . Type of environment where the survey is to be done: PLAINS . Type of topography expected in the area of the survey: FLAT-SURFACE . Type of velocity expected in the near-surface formation: HIGH-VELOCITY . Expected structures to be found with the survey: FAULTS . Money available to do the survey: ENOUGH . Time available to do the survey: PLENTY

Initial values for cable parameters calculations is as follows: Depth to the target zone: 4000 meters. Depth to the shallowest target of any interest: 1000 meters. Average velocity to target depth: 6000 meters/sec. Maximum frequency to be preserved at target depth: 30 Hz. Maximum dip angle expected at target depth: 15 degrees. The number of channels in the crew is fixed: YES

Initial values for geophone array calculations is as follows: Noise test available for the area of the survey: YES . The crew has geophones available: YES . Number of strings available per group: 4 strings. Number of geophones per string: 6 geophones. Minimum wavelength of the signal to be passed by the array: 200 meters. Maximum wavelength of noise to be attenuated: 70 meters. Minimum wavelength of noise to be attenuated: 10 meters.

Initial values for vibroseis array calculations is as follows: Noise test available for the area of the survey: YES . Minimum wavelength of the signal to be passed by the array: 200 meters. Maximum wavelength of the noise to be attenuated: 70 meters. Vibroseis units available in the crew: YES . Number of Vibroseis units available: 5 vibrators. Expected energy that should be introduced into the ground: HIGH-ENERGY

Figure 17. Example 3 of an EXPSEIS consultation.

In the second part, EXPSEIS gives its estimate of the best geophone array, that should be used to pass the signal and cancel the noise, given the established conditions.

In the third part, EXPSEIS gives its estimate of the best Vibroseis array, that should be used to shoot the survey.

In the fourth part, EXPSEIS gives a summary of the initial parameters given by the user during the consultation, for each of the different contexts.

The conclusions and recommendations that EXPSEIS gives are not perfect in any sense, but they are logical. They fit the problem requirements, and can be used with confidence.

The results that can be obtained via the parameters calculated by EXPSEIS, may not be optimum, but at least they will be consistent with themselves and the users conception of the geologic problem.

As it has been said before, EXPSEIS is a prototype system in the stage of testing and research. More testing is necessary, and the supervision of an expert in the field of seismic field parameter determination will be critical in the final stages of refining and improving EXPSEIS.

CONCLUSIONS AND RECOMMENDATIONS

The determination of field parameters for a seismic survey is a very complex problem. Many aspects such as: geophysical subsurface information, geology of the survey area, economics, equipment available, etc., should be considered to obtain the optimum parameters.

EXPSEIS was conceived as an assistant to the field seismologist for the determination of field parameters.

EXPSEIS has proven the following points:

1. AI, and expert systems technology can be applied successfully in the area of seismic field parameter determination in geophysics.
2. The conclusions and recommendations given by EXPSEIS, although at this time not at the expert level are of high quality.
3. EXPSEIS has proven to be powerful in handling complicated geophysical and geological information to reach reasonable conclusions.
4. EXPSEIS has proven to be a fast method to determine seismic field parameters.

5. EXPSEIS has proven that encoding the knowledge of an expert in the field of seismic field parameters can be done in a relatively easy way.
6. Personal Consultant (Expert Systems Development Tools), was demonstrated to be a good tool to create prototype expert systems.
7. EXPSEIS has proven that backward-reasoning methods can be used successfully to achieve results in the area of seismic field parameter determination.
8. EXPSEIS has proven to be easy to maintain and relatively easy to modify for knowledge expansion.

Some recommendations can be extracted from the work done in building EXPSEIS.

1. Personal Consultant is a good tool for building prototype expert systems. Its shortcomings would largely be remedied by a next system which:

   i) has graphics capabilities,
   ii) can access other types of programs in other kinds of programming languages,
   iii) has the ability to use powerful forward-methods of reasoning,

iv) has better editing and debugging facilities, and

v) lets the user modify parameters easily for subsequent runs.

2. EXPSEIS should continue in the stage of testing, under the supervision of an expert in the field of seismic field parameter acquisition. This will be critical in the final refining and improving of EXPSEIS.
3. EXPSEIS has reached a point where hardware is imposing some limitations in the running time of a consultation. Personal computers with more RAM memory will be necessary to avoid the time consuming memory recovery process, that actually takes place in every consultation. This problem is due to the fact that we are working in a LISP environment. It can be improved in two ways: 1) having a computer with at least one megabyte of RAM memory; and/or 2) having the possibility of using a LISP compiler to have a faster version of the program.

GLOSSARY

The following are definitions of commonly used words in AI. (Taken from "Building Expert Systems").

Artificial Intelligence (AI). Is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behavior --understanding language, learning, reasoning, solving problems, and so on..

Attribute. See Property.

Backward-chaining. A control procedure that attempts to achieve goals recursively, first by enumerating antecedents that would be sufficient for goal attainment and second by attempting to achieve or establish the antecedents themselves as goals.

Certainty. A measure of the confidence placed by a user or expert system in the validity of a proposition, hypothesis, or inferential rule.

Concept. A descriptive scheme for a class of things or a particular instance of the scheme with some of its general properties specialized to characterize the specific subclass or element that instantiates the class description.

Control (of expert systems). Any procedure, explicit or implicit, that determines the overall order of problem-solving activities; the temporal organization of subprocesses.

Expert. A person with a high degree of skill or specialized knowledge.

Expert System. A computer system that achieves high levels of performance in task areas that, for human beings, require years of special education and training.

Expertise. The set of capabilities that underlies the high performance of human experts, including extensive domain knowledge, heuristic rules that simplify and improve approaches to problem-solving, metaknowledge and metacognition, and compiled forms of behavior that afford great economy in skilled performance.

Explanation. Motivating, justifying, or rationalizing an action by presenting antecedent considerations such as goals, laws, or heuristic rules that affected or determined the desirability of the action.

Fact. A proposition or datum whose validity is accepted.

Forward-chaining. A control procedure that produces new decisions recursively by affirming the consequent propositions associated within an inferential rule with antecedent conditions that are currently believed. As new affirmed propositions change the current set of beliefs, additional rule are applied recursively.

Heuristic (rule, method). Is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large problem spaces.

Inferential rule. An association between antecedent conditions and consequent beliefs that enables the consequent beliefs to be inferred (deduced) from valid antecedent conditions.

Instantiation. An object that fits the general description of some class or, specifically, a pending process that associates specific data objects with the parameters of a general procedure.

Knowledge. Facts, beliefs, and heuristic rules.

Knowledge acquisition. The extraction and formulation of knowledge derived from extant sources, especially from experts.

Knowledge base. The repository of knowledge in a computer system.

Knowledge engineering. The discipline that addresses the task of building expert system; the tools and methods that support the development of an expert system.

LISP. The principal programming language of AI, which provides an elegant, recursive, untyped, and applicative framework for symbolic computing; actually a family of variants.

Metacognition. The capability to think about one's own thought processes.

Metaknowledge. Knowledge about knowledge.

Natural language. The conventional method for exchanging information between people, such as English as a means of communication for human speakers and various formal written systems as a means of representing intentions in technical disciplines.

Property. A feature or component description of an object in a frame. Properties correspond to intrinsic features such as name, definition, or creator; or may represent derived attributes such as value, significance, or analogous objects.

Rule. A pair, composed of an antecedent condition and a consequent proposition, which can support deductive processes such as back-chaining and forward-chaining.

Rule-based program. A computer program that explicitly incorporates rules or ruleset components.

Ruleset. A collection of rules that constitutes a module of heuristic knowledge.

Semantic. Pertaining to the meaning, intention, or significance of a symbolic expression, as opposed to its form.

Specialist. An expert in a narrow problem domain.

Syntactic Pertaining to the form or structure of a symbolic expression, as opposed to its meaning or significance.

Tools for knowledge engineering. Programming systems that simplify the work of building expert systems, especially generic task packages such as EMYCIN and PERSONAL CONSULTANT.

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APPENDIX A

USER DOCUMENTATION

This appendix is intended to familiarize the reader with the types of questions, the window interface, and the flow required to run and test EXPSEIS.

EXPSEIS is available in the central TI personal computer in the Department of Geophysics at Colorado School of Mines. The program is in a subdirectory called "AI", and the only thing that you need to do is insert the Personal Consultant Expert System Development Tools diskette into drive A: and type PC. For more information contact the professor Hadsell or Knoshaug in the Geophysics Department.

The first screen to appear is the Knowledge Base Selection screen. This screen lists all the knowledge bases present in the AI subdirectory. Select EXPSEIS from the list of options.

The Personal Consultant contains a menu from which you select the activity you want to perform. This menu is called the Main Activity Menu and will appear after you have loaded EXPSEIS. Figure A-1 shows the Main Activity Menu. The following paragraphs contain brief descriptions of the menu options.

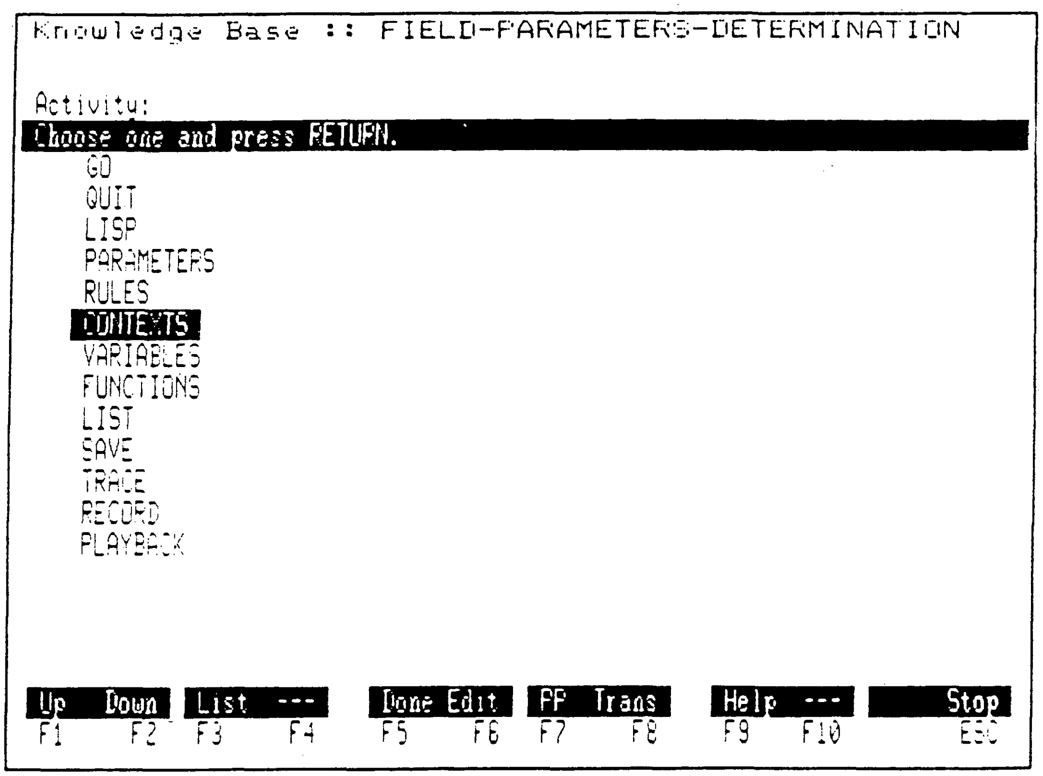

Figure A-1. Main Activity Menu

Main Activity Selection

GO. The GO option allows us to begin a consultation with a knowledge base, using the TI Personal Consultant.

QUIT. The QUIT option returns us to MS-DOS from the Personal Consultant.

LISP. The LISP option allows us to exit Personal Consultant software and enter IQLISP.

PARAMETERS. The PARAMETERS option allows the knowledge engineer to add, delete, or edit the parameters (or facts) and their properties which are used by the knowledge base during a consultation. It is used during implementation and maintenance of EXPSEIS.

RULES. The RULES option permits one to add, delete, or edit the rules governing the operation of the knowledge base. It is also used during implementation and maintenance of EXPSEIS.

CONTEXTS. The CONTEXTS option allows us to add, delete, or edit context trees. Used during formalization and maintenance of EXPSEIS.

VARIABLES. The VARIABLES option is used to add, delete, or edit variables, and is used during implementation and maintenance of EXPSEIS.

FUNCTIONS. The FUNCTIONS option allows us to enter or edit user-defined functions. Used during implementation of EXPSEIS.

LIST. Using the LISP option one can make listings of EXPSEIS. It is possible to list rules, parameters, or both. It is possible to list them in LISP, English, or both.

SAVE. With the SAVE option one saves (to a file) a copy of the knowledge base if changes have been made.

TRACE. The TRACE option allows records the flow of the backward-chaining reasoning mechanism. It is used during testing of EXPSEIS.

RECORD. The RECORD option allows us to record a set of responses from a given consultation. It too is used during testing of EXPSEIS.

PLAYBACK. The PLAYBACK option allows the knowledge engineer to use the responses from a previously saved consultation to test the logical flow of the knowledge base. He does this during testing of EXPSEIS.

Example Session with EXPSEIS

This example session is intended to familiarize the reader with EXPSEIS via a typical consultation. The following steps will take you through the example consultation shown in Figure 16, page 63.

Note: Responses from the computer will start with the symbol (-), answers from the user will start with the symbol (*).

1. Select the option GO from the main activity menu of Personal Consultant.

- "The following program EXPSEIS is part of an advisory system that is going to help you in the determination of seismic field parameters for Vibroseis sources."

2. The following question appears on the screen:

- "Enter the name of the area where you are planning to do the survey, please!"

* EXAMPLE-3

3. The following question appears on the screen:

- "Would you care to determine the cable parameters for SURVEY-1?"

* YES

After this, the program will start asking the user for the initial parameters.

4. The next question is:

- "What type of resolution are you planning to obtain with this survey? LOW-RESOLUTION HIGH-RESOLUTION"

* LOW-RESOLUTION

5. The next question is:

- "What type of survey are you planning to do?
SHALLOW-SURVEY DEEP-SURVEY"

* DEEP-SURVEY

6. The next question is:

- "In what type of area are you planning to do the survey?
DESERT JUNGLE MOUNTAINS PLAINS"

* PLAINS

7. The next question is:

- "What type of topography are you expecting in the area of the survey? FLAT-SURFACE MODERATELY-RUGGED RUGGED SMALL HILLS"

* FLAT-SURFACE

8. The next question is:

- "What do you suspect is the velocity of the near-surface formations? LOW-VELOCITY HIGH-VELOCITY"

* HIGH-VELOCITY

9. The next question is:

- "What type of sub-surface structure are you expecting to localize with the survey? FLAT-HORIZONS MONOCLINES SYNCLINES ANTICLINES FAULTS NOT-KNOWN"

* FAULTS

10. The next question is:

- "How much money do you have available to do the survey?
  PLENTY ENOUGH TIGHT"

* ENOUGH

11. The next question is:

- "How much available time do you have to do the survey?
  PLENTY ENOUGH TIGHT"

* PLENTY

After this, the program will start asking for the geological and geophysical parameters to start the calculations.

12. The next prompt is:

- "What is the depth to the deepest reflection zone of interest? (METERS) Please, answer with a rounded number."

* 4000

13. The next question is:

- "What is the depth to the shallowest reflection zone of any interest? (METERS)"

* 1000

14. The next question is:

- "What is the average velocity to target depth? (METERS/SEC)"

* 6000

15. The next question is:

- "What is the maximum frequency intended to be preserved in the deepest reflection (target) zone? (Hz)"

* 30

18. The next question is:

- "What is the maximum dip angle expected in the target zone, or the highest migration angle to be used during processing? (DEGREES)"

* 15

19. The next prompt to appear is:

- "Do you already have an acquisition system with a fixed number of channels in it?"

* NO

After this, the program starts the calculations for the cable parameters. (e.g. Far-trace offset, Group interval, Cable spread configuration, etc.)

20. The following prompt appears:

- "Would you care to determine a geophone array for SURVEY-1?"

* YES

At this stage the program will start asking the user for the initial parameters to estimate the geophone array.

21. The next question is:

- "Do you have a noise test available for the area where you are planning to do the survey?"

* YES

22. The next question is:

- "Do you have any geophones available?"

* YES

23. The next prompt is:

- "How many strings of geophones will you have available per geophone array?"

* 4

24. The next prompt asks:

- "What is the number of geophones per string in your crew?"

* 6

At this stage the program will start asking for the noise and signal characteristics found in the noise test done in the area of the survey.

25. The next question is:

- "What is the minimum average wavelength of any signal found in the noise test? (METERS)"

* 200

26. The next prompt is:

- "What is the maximum average wavelength of any noise, found in the noise test, and that should be attenuated? (METERS)"

* 70

27. The next question is:

- "What is the minimum average wavelength of any noise, found in the noise test, and that should be attenuated? (METERS)"

* 15

This is the information that EXPSEIS requires to estimate the geophone array for the given survey. Next the program asks if you want to estimate a Vibroseis array

27. The next question is:

- "Would you care to determine a source array for Vibroseis units in SURVEY-1?"

* YES

28. The next prompt appears:

- "Do you already have an acquisition system with a fixed number of Vibroseis units?"

* YES

29. The next question is:

- "Since the number of Vibroseis units in your crew is fixed. How many do you have 3, 4, or 5?"

* 5

30. The next prompt is:

- "How much energy do you think it is necessary to introduce into the ground, with the Vibros? EXAMPLE: use HIGH-ENERGY if you suspect volcanics near the surface. LOW-ENERGY HIGH-ENERGY"

* HIGH-ENERGY

With this information EXPSEIS estimates the Vibroseis array for the survey. This is the end of the consultation and at this time EXPSEIS shows on the screen the recommendations for the seismic parameters estimated. (See Figure 16).