univerza v ljubljani
institut "jožef stefan" ljubljana, slovenija

Department for Computer Sciences and Informatics
Artificial Intelligence Laboratory

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Introduction to

D E X

An Expert System Shell

for Multi-Attribute Decision Making

Software Version V1.01ITR

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Contents

1 Introduction

DEX (**D**ecision **EX**pert) is an *expert system shell* for *multi-attribute decision making*. Its main purpose is to *support* the decision maker in solving complex multi-attribute decisions such as selecting an applicant for a job, choosing a kind of technology, buying a house, performance evaluation of complex systems and many more. Such decisions commonly occur in real life and are the decisions where there are many options with their good and bad points that have to be evaluated, analysed and/or compared against each other.

The theory which underlies this program is based on a new approach to multi-attribute decision making, which emphasizes the importance of the decision maker in the decision making process (Bohanec *et al* 1983; Bohanec & Rajkovič 1987; Rajkovič *et al* 1988). The decision maker is encouraged to learn and explore his "decision space" by defining the attributes that seem to be relevant, and the words which describe levels of the attribute. Instead of relying upon arcane mathematical formulae embedded in the program to weight up the options, the program elicits the user's own "decision knowledge". This is expressed simply and naturally as simple facts (also called elementary decision rules), such as:

If the price is high and the quality is low,
then the option is not acceptable.

This method of knowledge representation is used in many expert systems and artificial intelligence programs. When implemented as DEX, this approach to decision-making turns out to be highly flexible. The program is enjoyable and interesting to use. By exploring his decision space, the user gains an insight on the process of making decisions, learning and extending his powers of discrimination to a real expert level.

This document gives some basic information about DEX and the underlying methodology. The text begins with a brief introduction of multi-attribute decision making. Then, the main characteristics of the DEX approach are outlined. Stages of the decision making process are presented together with the functions offered by DEX. The presentation is illustrated by excerpts from an application of DEX in performance evaluation of enterprises (Barrera & Bohanec 1987; Bohanec & Rajkovič 1990). This is followed by some technical and historical data. The document ends with the description of DEX applications, summary of DEX's features and bibliography.

2 Multi-Attribute Decision Making

The *decision making problem* can be, in general terms, defined as follows:

Given a set of options and goals of one or more decision makers, *find* the option that best satisfies the goals or, alternatively, *rank* the options from the best to the worst according to the goals. Here, *options* (also called *alternatives*) are objects or actions of (approximately) the same type, for example different computer systems, different people applying for a particular job, or different investment strategies.

Problems of this kind can be found in almost any field of human activity, ranging from everyday personal decisions to complex problems in economy, management, planning, medicine, etc. The complexity usually originates in

- complex and often incomplete, uncertain or conflicting knowledge of how to define and achieve the goals,
- numerous and/or loosely defined options,
- a large number of parameters that influence the decision,
- the presence of several groups of decision makers with conflicting objectives, and
- limited resources (for example, time constraints).

A number of methods and computer programs have been developed in order to support the decision makers in solving more or less complex problems. They are usually studied within the framework of decision support systems, operations research and management sciences, decision theory or decision analysis. One of the approaches which is widely used in practice (and in DEX, too) is multi-attribute decision making.

The main idea of *multi-attribute* decision making is the decomposition of a decision problem into smaller, less complex subproblems. Options are decomposed onto different dimensions, usually called *attributes*, *performance variables*, *criteria*, etc. These are evaluated independently. The total utility of an option is obtained by some aggregation procedure, commonly referred to as a *utility function*. The utility is then used as a basis for the selection of a particular option or ranking of options.

3 DEX: Basic Approach

In DEX, the multi-attribute approach to decision making is combined with some elements of expert systems and machine learning. In particular, the structure of attributes and aggregation procedures is treated as an explicit *knowledge base* that consists of:

1. one or more trees of attributes,
2. utility functions,
3. descriptions of options.

The structure of the knowledge base is similar to the structure of preference models that can be found in many conventional decision support systems. However, the introduction of expert systems is reflected in the following differences:

1. In conventional systems, attributes are almost exclusively numerical (*quantitative*); DEX, on the other hand, allows only *discrete* (*qualitative*) attributes which take values from discrete and (optionally) ordered domains. The values are usually *words* like "high" or "good", or *intervals* of numerical values, for example "$100–250".
2. Usually, utility functions are specified by a certain formula, most commonly a weighted sum. In DEX, they are defined by simple rules called *elementary decision rules*.
3. DEX emphasizes the transparency, comprehensibility and explainability of the knowledge base and obtained evaluation results. These are the properties that are usually not present in the conventional systems, which are characterized by the so called "black-box" functioning.

In addition, DEX is an expert system shell, meaning that it does not contain any predefined knowledge base. However, it offers various tools that support the users in defining and utilizing knowledge bases for their specific problems.

4 Stages of Decision Making with DEX

With DEX, the decision maker goes through distinct stages. Iteration and amendment to earlier stages are permitted, as the user's decision knowledge progresses.

Stage 0: Identify the problem. The user is assumed to have already identified the problem to be solved, e.g., which car to buy, which investment scenario to implement, whom to employ or how to evaluate the performance of enterprises. In particular, it is assumed that he can provide a few attributes which are relevant to the problem. For example, the attributes that determine the performance of an enterprise can be RETURN, PROFIT, LIQUIDITY, etc. It is important not to be too concerned with producing an exhaustive list of attributes at this stage, just enough to express some of the more important features of the decision.

This stage is usually performed off-line, i.e., without the direct use of DEX.

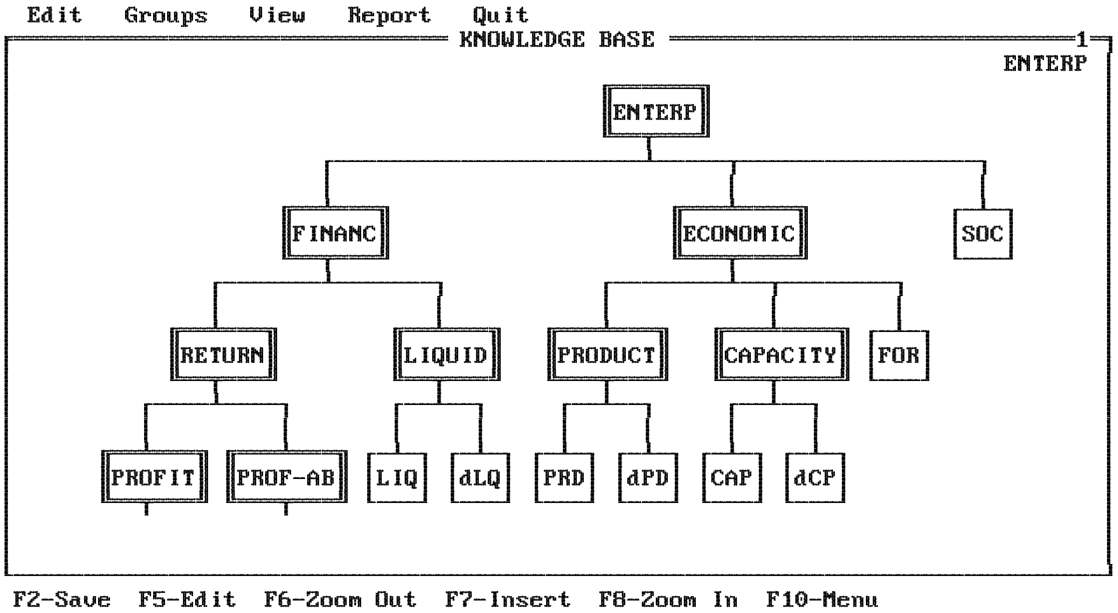

Figure 1: Tree editor of DEX: A part of the tree of attributes for the performance evaluation of enterprises is shown

Stage 1: Attributes and their structure. The starting set of attributes (or "performance variables") is entered into DEX. Each attribute needs to be described in some way. This is done by using a list of words or numbers which the user feels adequately describe his sensitivity to that variable. A typical list of values, known as an attribute *domain*, could be: *small, medium, high*. The variables may be described in purely linguistic terms, but numerical scales may be used where appropriate, e.g., the number of doors on a car, price of machine, profitability as a ratio of assets and liability, etc. Variables are then structured into a tree (Fig. 1).

In this stage, DEX offers a flexible tree editor (Fig. 1). It supports all the functions that are needed for the construction and maintenance of a tree of attributes, such as copying, moving and deletion of (sub)trees, and insertion of new attributes. Trees can be presented at different levels of detail. In addition, there are special windows for editing attributes and their domains.

```
 Edit   View   Report   Settings   Quit
============================== UTILITY FUNCTION ==============================3=
    Attribute: ENTERP   Group: ICPE                                      ENTERP
 Defined rules: 50 of 50 (100%)                           Function determined:100%

       FINANC             ECONOMIC           SOC          ENTERP
    1. bad                bad                unacc        bad
    2. less acc           bad                unacc        bad
    3. acc                bad                unacc        bad
    4. good               bad                unacc        less acc
    5. exc                bad                unacc        less acc
    6. bad                less acc           unacc        bad
    7. less acc           less acc           unacc        bad
    8. acc                less acc           unacc        less acc
    9. good               less acc           unacc        less acc
   10. exc                less acc           unacc        less acc
   11. bad                acc                unacc        bad
   12. less acc           acc                unacc        bad
   13. acc                acc                unacc        less acc
   14. good               acc                unacc        less acc
   15. exc                acc                unacc        acc
   16. bad                good               unacc        bad
1-Bad        2-Less acc   3-Acc        4-Good       5-Exc          *<>. Del ESC

 F2-Save  F4-Status  F6-Ask  F7-Enter  F8-Answer  F10-Menu
```

Figure 2: Utility function editor of DEX: Some elementary rules for the evaluation of public enterprises are shown

Stage 2: Rule elicitation. This and the next stage may be repeated many times as the user proceeds through the learning phase. The decision-maker is required to give some If-Then rules (called *elementary decision rules*) which explain how he feels about particular combinations of attribute values (Fig. 2).

This process is supported by the utility function editor of DEX (Fig. 2). All combinations are prepared by DEX in a tabular form; the user just fills-in the values of some selected combinations. This makes the process of rule elicitation quick and painless. Also, DEX has several commands that suggest combinations of values for the user. The process of rule elicitation is, unless explicitly disabled, continuously monitored against consistency. The user is warned when an inconsistent rule has been entered. There is also a possibility to display the whole set of rules in different forms that show the same knowledge from different viewpoints and at different levels of detail. This is an important feature that improves the transparency, comprehensibility and, implicitly, the quality of the knowledge base (Rajkovič & Bohanec 1990).

```
 Edit   Copy   Delete   Report   Quit
                          OPTION VALUES                                    2
                                                                      ENTERP
                      Options
    Attributes        Enterp.1          Enterp.2          Enterp.3
  1. PRF              pos               pos               pos
  2. dPF              decr              zero              decr
  3. P-A              e                 c                 a
  4. dPA              decr              incr              decr
  5. LIQ              1.25-1.5          1.25-1.5          1.25-1.5
  6. dLQ              decr              decr              incr
  7. PRD              e                 a                 a
  8. dPD              decr              incr              incr
  9. CAP              [.5-.75]          [.5-.75]          gt 0.75
 10. dCP              incr              incr              decr
 11. FOR              acc               acc               acc
 12. SOC              acc               acc               acc



1-Neg                  2-Zero                 3-Pos                * Del ESC
 F2-Save  F3-Load  F4-Status  F5-Edit  F10-Menu
```

Figure 3: Editor of options: Three enterprises are shown

Stage 3: Description and evaluation of options. Some sample options are then selected from the user's experience for evaluation according to the rules just provided. Each option may be assessed according to the attributes defined in Stage 1. Once the values are fed in by means of a spreadsheet-like editor (Fig. 3), DEX evaluates all the options, suggesting how the rules supplied so far rate the options (Fig. 4). Generally, the user will become immediately aware of some attribute that has been overlooked or whose importance depends on how well the other attributes are fulfilled. So, the user can return to Stage 1 or 2, so as to change the tree of attributes or rules.

This stage offers some additional functions for a thorough analysis of options. For example, DEX can explain the results of evaluation by emphasizing the most advantageous and disadvantageous features of each option (Fig. 5). In addition, it is possible to explain the line of reasoning that led to particular evaluation results, to perform "What-If" analysis, etc. An important feature is that options can be evaluated even when some data are missing or uncertain. The analysis is supported by a powerful report generator, that allows the user to choose among various report elements and formats.

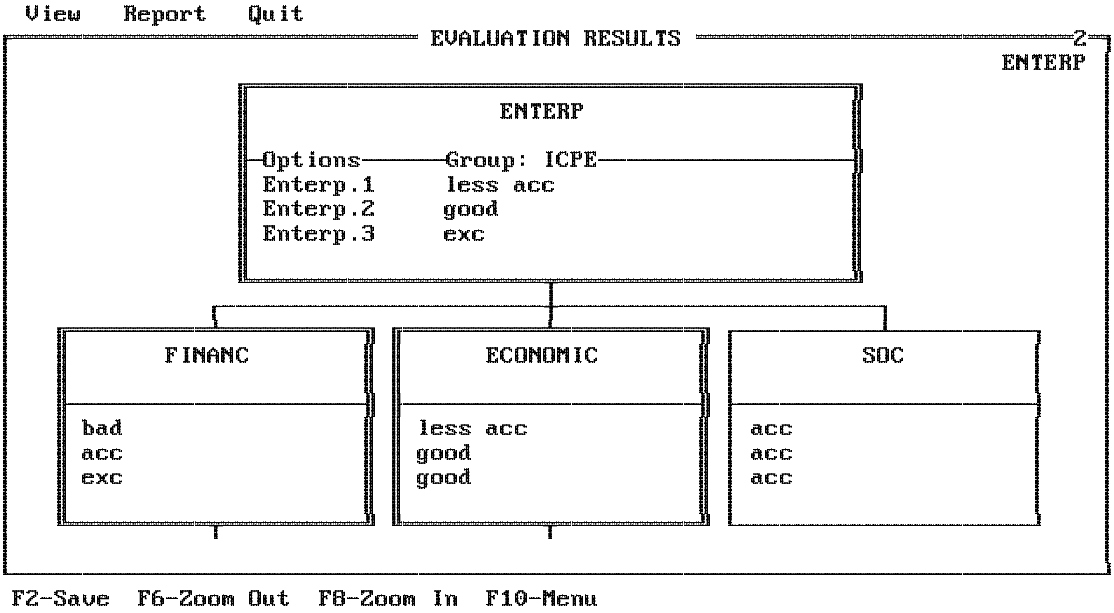

Figure 4: Evaluation results for three enterprises

5 Technical Information and Requirements

DEX is implemented in Turbo Pascal 5.5 for an IBM PC/XT/AT/PS or true compatible computers that run the MS-DOS operating system (version 3.00 or higher).

Requirements:

Computer:	IBM PC/XT/AT/PS or true compatible (AT or PS are recommended)
Operating system:	MS-DOS version 3.00 or higher
Memory:	at least 512KB (recommended 640KB)
Disk:	hard disk is recommended
Monitor:	DEX works with monochrome and colour monitors; no graphic card is required
Extended memory:	not required, but speeds up the execution

```
 Print   Eject   Settings   Quit
═══════════════════════════════ (DIS)ADVANTAGES ══════════════════════ Report ═
SELECTIVE EXPLANATION OF OPTION Enterp.1

ADVANTAGES

Attribute          Value

└─SOC              acc

| └─FOR            acc

| | └─dCP          incr

| | | ├─PRF        pos

DISADVANTAGES

Attribute          Value

├─FINANC           bad
│ ├─RETURN         bad
│ │ └─PROF-AB      bad

F2-Save  F4-Status  F6-Previous  F8-Next  F10-Menu  ESC-Continue  Home  End
```

Figure 5: Report generator: Selective explanation of an enterprise is shown

6 Development History

DEX is based on decision methodology called DECMAK, first published in (Efstathiou & Rajkovič 1979). Since 1979, further research and development of the methodology and supporting software was performed at Jožef Stefan Institute, Ljubljana. DECMAK was gradually extended and tested in practical decision making situations. The main extensions were made in order to support interactive utility knowledge acquisition, explanation of the knowledge and explanation and analysis of evaluation results. For these purposes, DECMAK was combined with artificial intelligence - the approach of expert systems and some machine learning techniques were adapted for decision making. According to the specifics of the field, some new methods and concepts were also developed, for example an interactive question-answer dialogue, the concept of knowledge explanation and methods for analysis of options, e.g., selective explanation and comparison, and an option generator.

This effort resulted in a complex software package which was also called DECMAK. It was first implemented for a PDP-11 computer under RT-11 operating system. Later on, it was ported to VAX (under VMS) and, with major extensions, to IBM PC/XT/AT personal computers under MS-DOS.

In spite of its success in practice (see Section 7), the DECMAK software had two main drawbacks:

- *Complexity*: DECMAK consisted of 19 separate computer programs. This required a well trained user in order to be able to run and combine all these programs. The result of such a complexity was that DECMAK was mainly run by its creators who acted as decision analysts in applications.
- *User interface*: DECMAK was developed as a research prototype software. This resulted in a functionally very rich system, which was, on the other hand, very difficult to run. The user interface was mainly command-driven and rather difficult to learn.

For these reasons, the development of a completely new system, DEX, was initiated at Jožef Stefan Institute in 1988. The main goal was to implement an integrated (single) computer program which would comprise all the most important functions of DECMAK in a meaningful way and which would provide a "user-friendly" man-computer interface.

7 Applications

DEX and its research predecessor, DECMAK, have been applied in about forty complex decision making problems in industry and governmental, educational and research institutions in Yugoslavia, Italy and Peru. The main application areas were the following:

- evaluation of computer systems for enterprises,
- selecting various software for enterprises and schools,
- trading partner selection/evaluation,
- ranking of applications for nursery schools,
- expert team selection,
- matching people to jobs,
- advising children in choosing sports,
- performance evaluation of enterprises,
- evaluation of investment scenarios.

It should be noted that there are two distinct classes of the problems; they differ in the goals which are:

1. to select the best option, for example to buy the best possible computer for a computer center of a company (this is usually a non-repeating decision), or
2. to develop a methodology for the evaluation of options; this is usually a repeating decision (i.e., many times in the future), such as performance evaluation of enterprises, business partners or investment scenarios.

From the experience it follows that DEX is appropriate for both classes provided that:

- the decision problem fits into the multi-attribute decision making schema, i.e., that the quality of options depends on several attributes;
- the decision depends on qualitative judgment and expert rules rather than exact mathematical models (conventional quantitative decision making methods may be more appropriate for the latter case);
- the decision is complex enough, for example it depends on a large number of attributes, say, more than 15 (otherwise, a conventional method —or even none— might be preferable);

Under these conditions, DEX offers some important advantages over the conventional approaches, particularly due to its:

- qualitative knowledge representation and reasoning,
- powerful and flexible tools for knowledge acquisition,
- transparency and explainability of knowledge and evaluation results.

The time needed to develop a knowledge base with DEX varies considerably with the problem. One of the above applications was completed in two days, although it resulted in one of the largest knowledge bases. On the other hand, there was an application where twenty days were spent to develop a relatively small knowledge base. Usually, the stage of developing the tree of attributes is the most demanding one; on average, it takes 1 to 5 working days. The acquisition of rules depends on the size of the tree, but it rarely exceeds two days since it is actively supported by DEX. Usually, it is completed in one day. The last stage, evaluation and analysis of options, may take up to several days. However, DEX is not a limiting factor in this stage, since it evaluates options in the magnitude of seconds. Rather, the consumed time depends mainly on the availability of data, required depth of the analysis and possible conceptual omissions in the knowledge base that require its modification.

8 DEX Summary

Purpose: Interactive expert system shell specialized for multi-attribute decision making.

Stages of problem-solving:
1. problem identification,
2. identification of attributes and their structure,
3. acquisition of elementary decision rules, and
4. evaluation and analysis of options.

Knowledge representation:
1. one or more trees of discrete attributes, and
2. decision rules that describe the impact of attributes to the final decision.

Features of the program:
- interactive acquisition of attributes and trees of attributes,
- interactive acquisition of decision rules,
- consistency checking of decision rules,
- group decision making support,
- treatment of uncertainty and imprecision,
- interactive acquisition, evaluation and analysis of options.

Implementation: IBM PC/XT/AT/PS computers under MS-DOS operating system (version 3.00 or higher) with at least 512 Kbytes of memory.

Applications: DEX and its research predecessor, DECMAK, have been practically applied in about forty complex decision making problems such as:
- evaluation of computer systems for enterprises,
- selecting various software for enterprises and schools,
- trading partner selection/evaluation,
- ranking of applications for nursery schools,
- expert team selection,
- matching people to jobs,
- advising children in choosing sports,
- performance evaluation of enterprises,
- evaluation of investment scenarios.

9 References and Bibliography

Barrera, A., Bohanec, M.: *An experiment with DECMAK in the domain of performance evaluation of public enterprises,* Institut Jožef Stefan, delovno poročilo DP-4723, Ljubljana, 1987.

Bohanec, M., Bratko, I., Rajkovič, V.: An expert system for decision making, *Processes and tools for decision support* (ed. Sol, H.G.), North-Holland, Amsterdam, 1983.

Bohanec, M., Rajkovič, V.: An expert system approach to multi-attribute decision making, Proceedings of IASTED International Conference "Expert Systems" (ed. Hamza, M.H.), *33–37*, Acta Press, 1987.

Bohanec, M., Rajkovič, V.: Knowledge acquisition and explanation for multi-attribute decision making, Proceedings of the 8th International Workshop "Expert Systems and Their Applications AVIGNON 88", Vol. 1, *59–78*, Avignon, 1988.

Bohanec, M., Rajkovič, V.: DEX: An Expert System Shell for Decision Support, *Sistemica* **1**(1), *145–157*, 1990.

Bohanec, M.: *DEX: An Expert System Shell for Multi-Attribute Decision Making, User's Manual (Software version 1.00ITR),* Institut Jožef Stefan, delovno poročilo DP-5896, Ljubljana, 1990.

Efstathiou, J., Rajkovič, V: Multiattribute Decisionmaking Using Fuzzy Heuristic Approach, *IEEE Trans. on Systems, Man and Cybernetics* **SMC-9**(0), 1979.

Olave, M., Rajkovič, V., Bohanec, M.: An application for admission in public school systems, *Expert systems in public administration* (eds. Snellen, I.Th.M., van de Donk, W.B.H.J., Baquiast, J.-P.), Elsevier, 1989.

Rajkovič, V., Bohanec, M., Batagelj, V.: Knowledge engineering techniques for utility identification, *Acta Psychologica* **68**(1-3), *271–286*, 1988,
and
Advances in decision research (eds. Rohrmann, B., Beach, R.L., Vlek, C., Watson, R.S.), North-Holland, 1988.

Rajkovič, V., Bohanec, M.: Quality of decision making: A knowledge engineering approach, Proceedings of International Conference Organization and Information Systems, *389–397*, Bled, 1989.

Rajkovič, V., Bohanec, M.: Decision support by knowledge explanation, IFIP TC-8.3 Conference on Environments for Supporting Decision Processes, *41–53*, Budapest, 1990,
and
Environments for Supporting Decision Processes (eds. Sol, H.G., Vecsenyi, J.), *47–57*, North-Holland, 1991.