Multi-Attribute Decision Modeling: Industrial Applications of DEX

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DEX is an expert system shell for qualitative multi-attribute decision modeling and support. During the last decade, it has been applied over fifty times in complex real-world decision problems. In this article we advocate for the applicability and great potential of this approach for industrial decision-making. The approach is illustrated by a typical industrial application in land use planning, and supplemented by an overview of some other completed industrial applications. The learned lessons indicate the suitability of the qualitative DEX methodology particularly for "soft", i.e., less structured and less formalized, decision problems. Practical experience also indicates the importance of methods that facilitate the analysis, simulation, and explanation of decisions.

1 Introduction

In complex decision-making processes, it is often necessary to deal with the problem of choice (Simon, 1977). Given a set of *options* (or alternatives), which typically represent some objects or actions, the goal is

(1) to *choose* an option that best satisfies the aims or goals of decision maker, or
(2) to *rank* the options from the best to the worst one.

One of the approaches to such problems, which is well known and commonly employed within Decision Support Systems (Andriole, 1989), is based on *evaluation models* (Figure 1). The idea is to develop a model that evaluates options giving an estimate of their worthiness (*utility*) for the decision-maker. Based on this estimate, the options are ranked and/or the best one is identified. Usually, a decision model is designed in an interaction between the decision maker and decision analyst.

An important feature of evaluation models is that they can be, in addition to the sole *evaluation* of options, used for various *analyses* and *simulations*, which may contribute to a better justification and explanation of decisions. For example, a *what-if analysis* can provide a better insight into a causal relation between problem parameters and outcomes. Another example is a *sensitivity analysis* that can assess the sensitivity of model with respect to small changes of options.

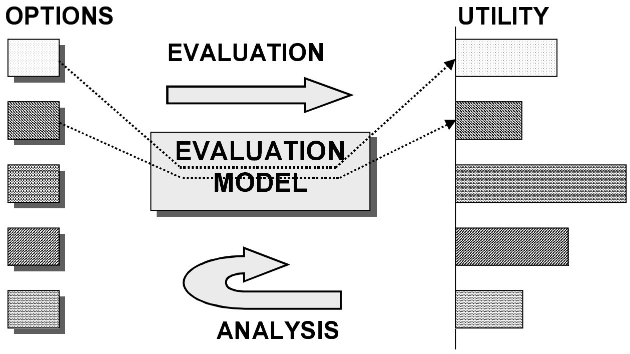

Figure 1: Evaluation-based decision modeling

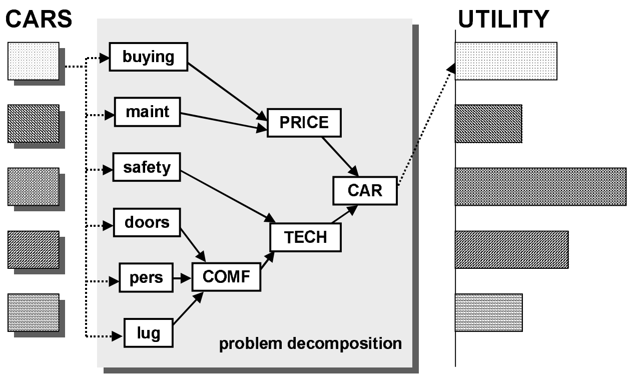

Figure 2: Multi-attribute decision modeling

An evaluation model can be developed in many ways. The approach that prevails in decision practice is based on *multi-attribute decomposition* (Chankong and Haimes, 1983; Saaty, 1993; Buede and Maxwell, 1995): we take a complex decision problem and decompose it into smaller and less complex subproblems. The result of such development is a *decision model* that consists of *attributes*, each of which represents a decision subproblem. Attributes are organized hierarchically and connected by *utility functions* that evaluate them with respect to their immediate descendants in the hierarchy. Figure 2 illustrates this basic principle of multi-attribute modeling by showing a simple hierarchy of attributes for the evaluation of cars.

Real-life applications of multi-attribute methods, which were conducted at Jožef Stefan Institute in Ljubljana, were all based on DEX (Bohanec and Rajkovič, 1990). This is an expert system shell for multi-attribute decision making that combines the "traditional" multi-attribute decision making with some elements of Expert Systems and Machine Learning. The distinguishing characteristic of DEX is its capability to deal with *qualitative* models. Instead of numerical variables, which typically constitute traditional *quantitative* models, DEX uses qualitative variables; their values are usually represented by words rather than numbers, for example “low”, “appropriate”, “unacceptable”, etc. Furthermore, to represent and evaluate utility functions, DEX uses *if-then decision rules*. In contrast, this is traditionally carried out in a numerical way, using weights or similar indicators of attributes’ importance.

An important additional feature of DEX is its capability to deal with inaccurate, uncertain or even missing data about options. In such cases, DEX represents options by distributions of qualitative values, and evaluates them by methods based on probabilistic and/or fuzzy propagation of uncertainty.

During the last decade, DEX was used in more than fifty real-life decision problems. The aim of this article is to advocate for the wide applicability of DEX to complex decision problems that occur in industry. In the next section, we first illustrate the approach by a typical industrial application in land use planning. This is followed by an overview of several other completed industrial applications in performance evaluation of companies, evaluation of products, projects and investments, ecology, and loan allocation. Finally, we summarize the lessons learned in these applications, and propose some future directions for the development of underlying methodology.

2 A Real-World Case

One of the most typical applications of DEX occurred with Goriške opekarne, a company located near the Slovenian city of Nova Gorica. The company is engaged in a very traditional business: production of bricks and tiles. Decades ago, they had built a factory near a suitable clay pit that was then providing raw material for their production. Until 1993, however, the clay pit has become almost completely exhausted, so the company was faced with a critical strategic decision of how to survive and continue with this type of production. Their only option was to find a new appropriate clay-pit location.

An exploratory study revealed three possible candidate locations. Unfortunatelly, none of them was really appropriate as numerous difficult problems were foreseen, ranging from technological, transportational and financial to environmental and socio-psychological. The latter two problems seemed particularly important as the project was inevitably going to affect the environment, leading to a possible rejection of local inhabitants. For these reasons, a group of experts was formed to thorougly analyze the problem and propose alternative solutions (Bohanec, et al., 1993).

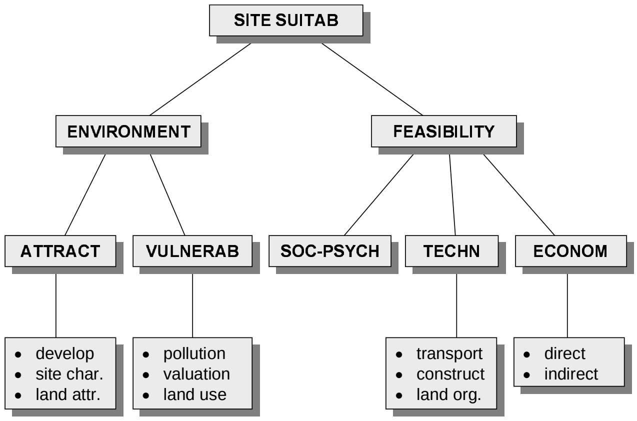

Figure 3: Topmost levels of clay-pit evaluation model

In the first stage, the experts developed the structure of multi-attribute model for the evaluation of clay-pit locations.. Two primary evaluation dimensions were taken into account: Environmental impact and Feasibility of the project. For each of these, the most relevant attributes were identified and organized into a hierarchical structure (Figure 3). Note that only topmost levels of the model are shown in the figure. In total, the model contained 49 attributes: 29 basic (terminal nodes) and 20 aggregate (internal nodes).

Table 1: Decision rules for Site suitability

	ENVIRONMENT	FEASIBILITY	**SITE**
1	*	unacc	unacc
2	unacc	*	unacc
3	less-acc	less-acc	marg-acc
4	≥ acc	less-acc	less-acc
5	less-acc	acc	less-acc
6	acc	acc	acc
7	good	acc	good

The second stage involved the definition of decision rules. Basically, these are simple *if-then* rules that for each of the 20 internal nodes in the model determine its evaluation with respect to its lower-level descendants in the hierarchy. Usually, they are represented in a tabular form. For example, Table 1 shows decision rules that were defined by the experts for the topmost node Site suitability. In the table, an asterisk ‘*’ represents any value, and ‘≥’ means ‘better or equal’.

In the third stage of the decision-making process, the options are identified and described by the values of basic attributes. In our case, there were three clay-pit locations, each of which was represented by 29 data items that corresponded to basic attributes of the model. Furthermore, as some of these items, such as Social-psychological feasibility, were inherently inaccurate or difficult to obtain, several variations of the descriptions were formed, anticipating either an "optimistic" or "pessimistic" development of the project. Effectively, this increased the number of considered options to eight (Figure 4) and provided a foundation for subsequent what-if analysis.

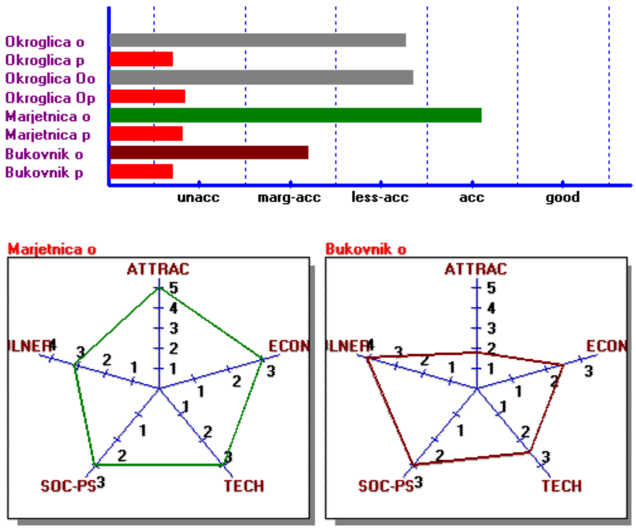

Figure 4: Visualization of clay-pit evaluation results

In the last stage, the model was utilized to evaluate the clay-pit locations. As shown in Figure 4, the best location was the one called Marjetnica, which was evaluated as "acceptable", but only in its "optimistic" instance. On the other hand, all the "pessimistic" instances were unacceptable, indicating the great sensitivity of decision. Therefore, thorough what-if and sensitivity analyses were performed for each location. The most important result was achieved by comparing "optimistic" and "pessimistic" options with respect to basic attributes. The outcome of this comparison was a comprehensive list of possible problems that could occur with each location. On this basis, the expert team not only was able to find the best location, but also to foresee potential pitfalls and suggest how to avoid them.

3 Other Applications

In about ten years time, DEX was used in more than fifty real-life decision problems in various areas. About one half of the problems can be classified as industrial, while the remaining were conducted in the fields such as education or medicine and health care (Bohanec, et al., 1999). Some of the industrial problems were very difficult and involved substantial financial and other risks for decision-making organizations. In what follows we briefly outline five representative application areas, which clearly indicate the wide applicability of DEX for a variety of decision problems. The description of some other early industrial applications can also be found in (Urbančič, et al., 1991).

3.1 Performance Evaluation of Companies

Here, the general task is that a company or agency develops an evaluation model that assesses the performance of some other companies. The aim is, for example, to find a suitable business partner. The work with DEX in this area began in 1987, where a number of such models were developed in collaboration with the International Center for Public Enterprises (Bohanec and Rajkovič, 1990). An example hierarchy of attributes that was used to assess the performance of 54 public enterprises in Pakistan, is shown in Figure 5. This work culminated in 1989 with the development of models that were used in the privatization of Peruvian public enterprises.

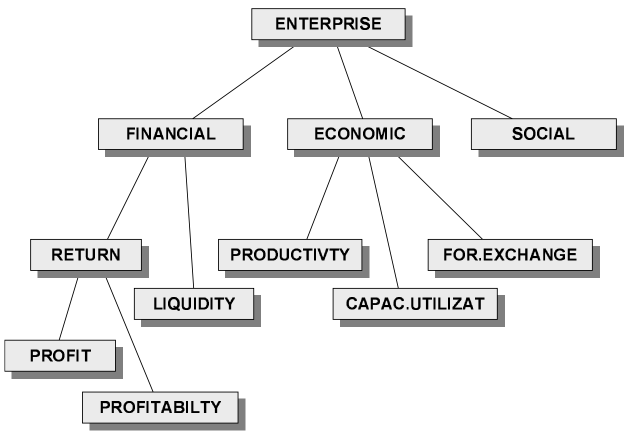

Figure 5: Topmost levels of the model for performance evaluation of public enterprises

3.2 Product portfolio evaluation

The problem is to assess the quality of products made by a company or production unit. This assessment is vital for the formation of strategies. The approach with DEX was based on the so-called portfolio method (Krisper, et al., 1991), which evaluates products using two primary evaluation dimensions: market attractiveness and competitive ability. Several practical cases were analyzed in this way, including the products of some well-known Slovenian companies Fructal, Radenska, SRC, and DZS.

3.3 Evaluation of projects and investments

The evaluation of projects or investment strategies is an industrial application context in which DEX has got the largest number of applications. The most typical investments included various software, hardware and technology, such as data base management systems, production control software, meteorological radar equipment, or a production line. The decision problems were often related to various investment proposals and tenders. An example of such applications, which is documented quite in detail, is a model for the evaluation of research and development projects (Bohanec, et al., 1995).

3.4 Remediation of dumpsites

This is a recent application in the field of environmental care. In order to alleviate the problem of illegal dumpsites in Slovenia, an expert system was developed that assesses the environmental impact of dumpsites and suggests activities for their remediation (Špendl, 1998). The environmental impact of dumpsites is assessed by a qualitative DEX model (Figure 6), which is embedded in the expert system.

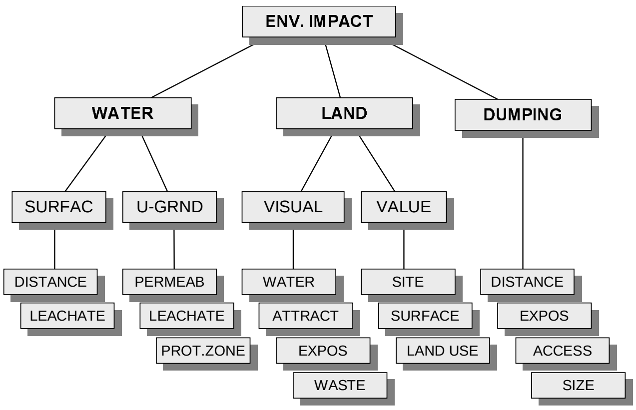

Figure 6: Model for the assessment of dumpsite's environmental impact (topmost levels only)

3.5 Housing loan allocation

This is an example of a repetitive decision-making task being supported by a DEX model. The model is a part of a management decision support system that is used since 1991 by the Housing Fund of the Republic of Slovenia for the allocation of housing loans with favorable terms to citizens (Bohanec, et al., 1996). Until 1999, the Fund has issued 16 floats of loans, i.e., about two per year, and approved almost 20 thousand loans.

The amount requested by applicants in a float typically far exceeds the available funds. Thus, the applicants must be ranked into a priority order. The procedure is required to be fast, reliable, transparent, and fair for all applicants. The request for transparency asks for effective explanations of loan priority order, which have to be provided to both the decision-making committee and a large number (usually, several thousands) of applicants. In the Fund's system, these requirements were fulfilled by a qualitative model that ranks the applications into five priority classes and provides a foundation for various explanations, which are obtained by analyses and simulations of application data and the model itself.

4 Experience

Some important lessons have been learned in the applications of DEX. Here, we present some findings related to the duration of model development processes, difficulty of development stages, and categories of decision problems that seem to be particularly well suited for the application of DEX.

The time needed to develop a DEX model turns out to be extremely problem-dependent: it may take from few hours to several months. Most typically, however, the development requires about two working days for the development of model structure, from one to two days to define decision rules, and from one to several days to collect data about options, to evaluate, and analyze them. Therefore, the process most typically lasts from two to ten working days.

The most difficult stage of the process is its first one, in which the relevant attributes must be identified and appropriately organized into a hierarchical structure. This stage heavily relies on knowledge and experience of decision-makers and experts, and requires a deep understanding of the decision problem. It can still be considered more art than science. The remaining stages have been found much less problematic. Therefore, an appropriate identification of model structure mostly determines the success of the decision-making process.

DEX with its qualitative modeling and ability to handle inaccurate and/or incomplete data about options appears particularly well suited for decision problems that involve qualitative concepts and a great deal of expert judgement. Also, it seems that the usefulness of DEX increases with the increasing difficulty, or "complexity", of the decision problem. So far, the best results were achieved in problems that required large models, consisting of at least 15 attributes, and/or involving a large number of options, i.e., from about 10 to several hundreds of options. On the other hand, DEX turned out to be unsuitable for problems that require exact formal modeling, numerical simulation and/or optimization.

5 Further Work

Currently, there are three limitations of the DEX approach that, we believe, can be greatly improved by appropriate extensions of the methodology. First, the difficult stage of model structure development could be additionally supported by a machine learning method that would develop (or at least suggest) model structure using decision examples taken either from an existing database of past decisions, or provided explicitly by the decision-maker. A considerable progress in this direction has already been made by the development of a learning method called HINT (Zupan, et al., 1999). Given training examples, HINT develops a hierarchical multi-attribute evaluation model that explains and possibly generalizes the examples. The structure of the models developed by HINT is essentially the same as the structure of models developed "manually" using DEX. The HINT's model development is based on function decomposition, an approach that was originally developed for the design of digital circuits.

Another limitation of DEX is that it is strictly limited to qualitative decision models; it cannot use numerical variables nor analytically represented utility functions that are commonly used in traditional quantitative models. This is sometimes advantageous in comparison with other decision modeling systems, which exclusively rely on quantitative models. However, many real-life decision problems require both qualitative and quantitative attributes, so the integration of these two may have a great practical impact: it may increase the flexibility of the method and extend the range of decision problems that can be successfully approached. Methodologically, such integration appears quite difficult and requires more research. In the context of DEX, we consider it a long-term goal.

Last but not least, the major part of DEX software has been developed about ten years ago and currently appears quite outdated. Therefore, an overall redesign and renewal of software is planned for the near future. Currently, we are developing a program called DEXi, an educational subset of DEX to be used by students and teachers in secondary schools and faculties. We plan to follow this by the development of a functionally complete state-of-the-art DEX system.

6 Conclusion

The DEX system effectively integrates two methodologies: multi-attribute decision making and expert systems. To a limited extent, it also includes some elements of machine learning and fuzzy logic. By this, it facilitates a structured and systematic approach to complex decision problems. So far, DEX has been successfully used in over fifty real-life decision problems in industry, medicine, health care and education, which all speak in favor for its wide applicability and flexibility. From the practical viewpoint, the most important characteristics of DEX are:

1. Qualitative (symbolic) decision modeling, which is particularly well suited for "soft" decision problems, i.e., less structured and less formalized problems, which involve a great deal of expert judgement.
2. Focus on the explanation and analysis of options, which lead to better-understood and justified decisions.
3. Active support of the decision-maker in the acquisition of decision rules, which speeds up model development and reduces the number of errors.

The goals of further research and development related to DEX are twofold. First, we wish to improve the support in the difficult stage of model structure development, and propose to use machine learning methods, such as HINT, for that purpose. To further improve the flexibility and general applicability of the approach, we suggest further research towards an integration of qualitative and quantitative decision models.

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