DEX METHODOLOGY: THIRTY THREE YEARS OF QUALITATIVE MULTI-ATTRIBUTE MODELING

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ABSTRACT

DEX is a qualitative multi-attribute decision modeling methodology, which is based on an integration of multi-criteria decision modeling with rule-based expert systems. The method was conceived 33 years ago. In its lifespan, it has been implemented in a wide range of computer programs that have been used in hundreds of practical applications. In this paper we report on its main methodological concepts, contributions to the theory and practice of decision support, and present a history of its development and evolution.

1 INTRODUCTION

DEX is a qualitative decision support methodology aimed at the evaluation and analysis of decision alternatives. Conceived more than thirty years ago, the methodology has a long history of scientific, technical and practical contributions. It represents a pioneering approach of combining the "classical" numerical multi-criteria decision modeling with rule-based expert systems. This approach led to a development of new algorithms and techniques for acquisition and representation of decision knowledge and evaluation and analysis of decision alternatives. DEX was implemented in three generations of software – called DECMAK, DEX and DEXi – and embedded into many other computer programs. It was used in hundreds of practical applications, nationally and internationally. Despite its age, DEX is still very much alive: it is actively used in international projects and cited in international scientific publications, it is taught in schools, there are ongoing new developments and strong plans for future work. Taking all this into account, DEX can be rightly considered an important long-term achievement of Slovenian research in artificial intelligence and decision support.

2 ON ORIGINS AND EVOLUTION OF DEX

The foundations of what eventually became DEX were set up in Durham, UK, by Efstathiou and Rajkovič (1979). In their work, which was heavily influenced by fuzzy sets, they advocated for using words rather than numbers in decision models. They proposed a tabular representation of utility relations, one of the key concepts of DEX methodology. Further development continued in Slovenia, mainly through collaboration of Vladislav Rajkovič and Marko Bohanec. In the 1980's, the methodology was called DECMAK (Bohanec et al., 1983). It was conceptually extended to cope with hierarchies of attributes (Rajkovič, Bohanec, 1980) and to facilitate the acquisition and explanation of decision knowledge (Rajkovič, Bohanec, 1988; Rajkovič et al., 1988). The approach was successfully used in several real-life practical applications, such as evaluation of computer systems (Bohanec et al., 1983) and enrollment into nursery schools (Olave et al., 1989).

The name DEX (Decision EXpert) was coined when the method was implemented in a form of an expert system shell for decision making (Bohanec, Rajkovič, 1990). This was a state-of-the-art implementation of the whole methodology. In the 1990's, DEX was used in a series of complex decision making tasks in industry (Bohanec, Rajkovič, 1999), health-care (Bohanec et al., 2000a), project evaluation (Bohanec et al., 1995), housing (Bohanec et al., 2001), and sports (Bohanec et al., 2000b). An important related achievement was also HINT, a method for automatic problem decomposition (Zupan et al., 1999). Used as a machine learning algorithm, HINT is capable of developing DEX models from data.

The third distinctive period started in 2000 with the implementation of DEXi (Jereb et al., 2003), a somewhat stripped-down, but simple and user-friendly computer program, aimed primarily at education. This paved the DEX's way into Slovenian secondary schools and universities (Krapež, Rajkovič, 2003). In spite of its simplicity, DEXi turned out extremely useful even for most difficult decision-making tasks. Some outstanding international applications included European projects *Sol-Eu-Net* on data mining and decision support integration (Mladenič et al., 2003), *Healthreats* on health threats and crises management (Žnidaršič et al., 2009), *ECOGEN*, *SIGMEA* and *Co-Extra* on genetically modified crops (Bohanec et al., 2008; Žnidaršič et al., 2008), and *e-LICO* on data mining workflows (Žnidaršič et al., 2012). There were countless other applications, for example in public administration (Leben et al., 2006), agronomy (Griffiths et al., 2010; Pavlovič et al., 2011) and tourism (Stubelj Ars, Bohanec, 2010). Methodological advances in this period include a new method for automatic revision of DEX models (Žnidaršič, Bohanec, 2007), a DSS tool for modeling uncertain knowledge called proDEX (Žnidaršič et al., 2006), and new methods for option ranking based on copulas (Mileva-Boshkoska, Bohanec, 2012).

3 PRINCIPLES OF DEX

Intentionally, the basic principles of DEX are kept very simple. The decision maker is requested to define a *qualitative multi-attribute model*, with which decision alternatives are evaluated and analyzed. In principle, the model represents a decomposition of the decision problem into smaller, less complex subproblems The decomposition is represented by a hierarchy of attributes. The DEX model consists of:

- *Attributes*: variables that represent basic features and assessed values of decision alternatives.
- *Scales* of attributes are qualitative and consist of a set of words, such as: 'excellent', 'acceptable', 'inappropriate', etc. Usually, scales are ordered preferentially, i.e., from bad to good values.
- *Hierarchy* of attributes: represents the decomposition of the decision problem and relations between attributes; higher-level attributes depend on lower-level ones.
- *Decision rules*: tabular representation of the mapping from lower-level attributes to the higher-level one. In principle, the table should specify a value of the higher-level attribute for all combinations of values of the lower-level attributes.

Figures 1 and 2 illustrate these components on a simple model for the evaluation of cars (Bohanec, 2011).

Attribute	Scale
CAR	**unacc**; acc; good; ***exc***
├**PRICE**	**high**; medium; ***low***
│ ├BUY.PRICE	**high**; medium; ***low***
│ └MAINT.PRICE	**high**; medium; ***low***
└**TECH.CHAR.**	**bad**; acc; good; ***exc***
├**COMFORT**	**small**; medium; ***high***
│ ├#PERS	**to_2**; 3-4; ***more***
│ ├#DOORS	**2**; 3; 4; ***more***
│ └LUGGAGE	**small**; medium; ***big***
└SAFETY	**small**; medium; ***high***

Figure 1: *DEX model for the evaluation of cars: Hierarchy and scales of attributes*

Decision alternatives are evaluated by an aggregation that is performed from the leaves towards the root of the DEX model hierarchy. Also, the model is typically used for the 'what-if' and sensitivity analysis of alternatives.

Conceptually, DEX is a combination of two approaches: multi-criteria decision analysis (MCDA) and expert systems. From MCDA (Figueira et al., 2005; Bouyssou et al., 2006), DEX takes the idea of evaluation and analysis of alternatives using a hierarchically structured model. DEX departs from using numerical variables and weight-based utility functions by introducing concepts from expert systems: qualitative and linguistic variables, if-then rules, dealing with uncertainty, high emphasis on transparency of models and explanation of evaluation results. DEX has some similarities with two other independently developed approaches: DRSA (Greco et al., 2001) and Doctus (Baracskai, Dörfler, 2003).

	PRICE	TECH.CHAR.	CAR
1	**high**	**bad**	**unacc**
2	**high**	acc	**unacc**
3	**high**	good	**unacc**
4	**high**	***exc***	**unacc**
5	medium	**bad**	**unacc**
6	medium	acc	acc
7	medium	good	good
8	medium	***exc***	***exc***
9	***low***	**bad**	**unacc**
10	***low***	acc	good
11	***low***	good	***exc***
12	***low***	***exc***	***exc***

Figure 2: *Decision rules for PRICE×TECH.CHAR→CAR*

4 IMPORTANT CONCEPTS

Very early in DEX's history it became clear that working directly with model components was not practical; additional tools were needed to acquire and validate model components, as well as to evaluate, analyze and explain the alternatives. Among these, the following were the most important for practical adoption of DEX:

Acquisition of decision rules: Direct definition of tables, such as the one in Figure 2, is tedious and error-prone, and computer-based assistance becomes vital. In its early days, DECMAK offered an interactive ASK/ANSWER dialogue. Now, DEXi supports three strategies for the definition of decision rules: direct, 'use scale orders', and 'use weights' (Bohanec, 2011, p. 35).

Validating rules: In comparison with common expert systems, DEXi rules are simple and restricted by the scales of the corresponding attributes, which makes them suitable for validation of *completeness* (to which extent they define the mapping) and *consistency* (are they in conflict with each other). This improves the overall quality of models.

"The user is always right" principle: In spite of consistency checking, DEX gives precedence to information provided by the decision maker. Thus, any decision rule, even if inconsistent, is taken literally and never modified by DEX. The user is warned, though.

Dynamic aspects of model creation: The model as shown in Figures 1 and 2 is static. However, in practice, such models are continuously modified and improved: parts of the model are created, extended or deleted. There are many such operations, such as deleting or adding an attribute, reordering attributes, removing a scale value, etc. All these operations must be supported by appropriate algorithms so that the information already contained in the model is retained as much as possible after each operation. It is particularly important to properly handle decision rules.

DEX does implement these operations and typically handles them transparently "behind the scenes".

Bridging the gap between qualitative and quantitative MCDA: The traditional MCDA heavily relies on weights to define the importance of attributes. Naturally, there are no weights in decision rules. However, it turned out to be practically important to deal with weights, so these were included into DEX, too. A partial transformation between attribute weights and rules is possible in both ways (Bohanec, 2011): (1) weights are estimated from defined rules by linear approximation, and (2) the values of undefined decision rules are determined on the basis of already defined rules and user-specified weights.

Handling uncertainty in alternatives and rules: An expert system must be able to deal with incomplete and uncertain knowledge. The early DECMAK was already able to evaluate incompletely defined alternatives using fuzzy and probabilistic aggregation (Bohanec et al., 1983). In most of the later software, the uncertainty in rules was only partly modeled by value intervals. Žnidaršič et al. (2008) extended this to using probabilistic distributions.

Transparency and explanation: For practice, it is essential that DEX models appear transparent and comprehensible to the user. DEX always provided mechanisms for presenting decision rules in a user-friendly way, from ID3-based decision tree learning algorithms in the early software, to complex rule generators in the modern DEXi.

Analyses of alternatives: In addition to the mere evaluation of alternatives, the methodology has to provide advanced tools for the analysis of alternatives. For this purpose, DEX includes a number of methods, such as 'what-if' analysis, 'plus-minus-1' analysis and selective explanation.

5 SOFTWARE

Three main generations of qualitative modeling computer programs have been developed so far:

- DECMAK (released in 1981): for operating systems RT-11, VAX/VMS and later MS DOS; command-line interface, supporting a tree of attributes and fuzzy evaluation of alternatives, ASK/ANSWER rule acquisition dialogue, representing rule tables with complex rules and decision trees.
- DEX (1987): for MS DOS, facilitated interactive model creation and editing, probabilistic and fuzzy evaluation of alternatives, report generation, selective explanation of evaluation.
- DEXi (2000): for MS Windows, educational and interactive. Supports model creation and editing, tabular acquisition of rules, value-set-based evaluation of alternatives, "what-if" analysis, "plus-minus-1" analysis, selective explanation and comparison of options, textual and graphical reports. DEXi is publicly available (http://kt.ijs.si/MarkoBohanec/dexi.html) and free for non-commercial applications.

There exists some other supporting software, such as proDEX (implementation of some DEX extensions), JDEXi (an open-source Java library for evaluation of alternatives), DEXiEval (a command-line utility program for evaluation of alternatives), and DEXiTree (a program for pretty drawing of DEXi trees).

Also, DEX was often embedded into other software systems. Typical examples include Talent, a system for advising children into sports (Bohanec et al., 2000b), a system for risk assessment of diabetic foot care (Bohanec et al., 2000a), and traffic management center (Omerčević et al., 2008).

6 APPLICATIONS

Practical applicability is one of the strongest points of DEX. In its early days, we kept records of its applications and counted as many as thirty until 1988 (Bohanec, Rajkovič, 1988). The number of applications continued to grow, but their recording became more and more difficult with the spread of the method and free use of the software. Today, we roughly estimate that there have been hundreds of "serious" real-life applications of DEX. Considering prototypes and student work, the number of all developed DEX models is probably several thousands.

The areas of DEX applications are very diverse. So far, DEX was used to evaluate technologies, companies, projects, and services. Important problem areas include health care, public administration, agronomy, food production, ecology, land use planning, tourism, housing, traffic control, and sports.

Practical experience indicates that DEX is particularly suitable for solving complex decision problems, which require judgment and qualitative knowledge-based reasoning, dealing with inaccurate and/or missing data, as well as the analysis and justification of evaluation results. Typically, these problem require large models (with 15 or more attributes) and/or involve many alternatives (10 or more).

7 FUTURE OF DEX

Currently, the main software for developing DEX models is DEXi. Even after 12 years since its first release, it still seems suitable for education and typical decision making problems, and will – with proper maintenance – serve for these purposes in the future. However, really difficult problems require a more powerful methodology and more advanced software (Žnidaršič et al., 2008). The advances in software engineering require new architectures, such as web-based. There is a need for a DEX library and a set of tools for embedding DEX models into other systems, such as information systems, web pages and mobile devices.

For these reasons, we plan to extend the DEX methodology and implement it in a new generation of software (Trdin, Bohanec, 2012). The most challenging methodological advances are:

- *Introducing numeric attributes*: facilitating the use of both qualitative and quantitative attributes in the same model.

- *Full implementation of probabilistic and fuzzy distributions* for both: decision rules and alternatives.
- *General aggregation functions*: facilitate the use of all types of aggregation functions known in MCDA.
- *Relational models*: extending the methodology from "flat" to relational alternatives, that is, alternatives composed of sets of subcomponents.

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