MULTI-CRITERIA DEX MODELS: AN OVERVIEW AND ANALYSIS

Marko Bohanec
Jožef Stefan Institute, Department of Knowledge Technologies
Jamova cesta 39, SI-1000 Ljubljana, Slovenia
E-mail: marko.bohanec@ijs.si

Abstract: DEX (Decision EXpert) is a hierarchical, qualitative, rule-based, multi-criteria decision modelling method. Since its conception in 1979, it has been used in decision-support applications in various areas, including economy, finance, agriculture and tourism. In this study, we analysed 582 DEX models developed in the period 1979–2015, assessing statistical properties of the main components of DEX models: attribute hierarchies, attribute scales, and decision rules. We also studied the completeness, monotonicity, linearity and symmetricity of the underlying aggregation functions. The results are useful particularly for understanding the boundaries of the decision problems addressed by DEX, and for improving the methodology and the design of the supporting software.

Keywords: Multi-criteria decision model, qualitative model, hierarchical model, method DEX, applications.

1 INTRODUCTION

Multi Criteria Decision Modelling (MCDM) [9] is concerned with structuring and solving decision problems that involve multiple and possibly conflicting criteria. With the aim to support the decision maker, MCDM provides methods and means to obtain preferential information from the decision maker, to represent it in a form of a decision model, and to use the model to perform the intended decision-making tasks: choosing, ranking and/or sorting decision alternatives, and analysing and justifying the results.

In this paper, we focus on one MCDM method, called DEX, and its applications. DEX (Decision EXpert) was conceived in early 1980's [8] under the name DECMAK [1], combining the approach of hierarchical MCDM with rule-based expert systems and fuzzy sets. The name DEX was coined around 1990 [2] together with the method's implementation in a form of an expert system shell for decision support. DEX has three key characteristics:

1. It is *hierarchical*: a DEX model consists of hierarchically structured *attributes* (in MCDM, also called *criteria* or *performance variables*).
2. It is *qualitative*: all attributes are symbolic, taking values that are words rather than numbers, such as "bad", "medium", "excellent", "low", or "high".
3. It is *rule-based*: the hierarchical aggregation of values is defined with *decision rules*, acquired and represented in the form of *decision tables*.

Currently, the DEX method is implemented in a freely available software called DEXi [7]. DEXi supports an interactive construction of the decision model, and evaluation and analysis of alternatives [4]. The decision maker is aided in creating the model structure and defining decision rules. Following the principles of expert systems, DEXi can evaluate alternatives even in the case of incomplete input and preference data. DEXi is a third generation of DEX software; previous generations were called DECMAK [1] and DEX [2].

DEX has been used to support complex decision processes in various problem domains, including health care, project management, quality and risk assessment, environmental management, data mining, and many more. Literally thousands of DEX models have been developed worldwide and used to solve real-life decision problems [3].

The idea explored in this study is that we can learn from DEX models developed in the past. We can analyse their characteristics, such as the size and structure of the attribute hierarchies, types and scales of individual attributes, number and quality of decision rules. On this basis, we may better understand the requirements of the decision-modelling process, and possibly develop better algorithms and tools in the future.

With these goals in mind, we have compiled a research database of DEX models. It contains 582 models developed in 140 decision-making projects conducted in the period 1979–2015. The collection is restricted only to DEX models that were available to the author of this study, who is also a decision analyst and DEX software developer; models developed elsewhere in the world were not included. Nevertheless we believe that the database is highly representative with respect to the addressed decision problems, decision makers involved, covered time period and observed model characteristics. All the included models are “real” in the sense that they were developed by real people with specific decision problems in mind.

In what follows we first present an overview of decision projects included in the database. Then, we describe the key components of the DEX models and their statistical properties: hierarchical structure of attributes, individual attributes and their scales, and decision rules.

2 PROJECTS

The database contains models that were developed in 140 decision-making projects in the period 1979–2015. Here, a “project” denotes a set of related DEX models. In a normal MCDM setting, only one model is expected to be developed per project, aimed at the evaluation of the corresponding decision alternatives. In reality, however, multiple models are often developed for various reasons, such as addressing different decision-making subtasks, different aspects of the problem, different classes of alternatives, or different decision makers.

In the database, the 140 projects actually contain 582 models in total (4.16 models per project). They address very different decision problems and consider the assessment of:

- *Computer technology*: software, hardware, IT tools, programming languages, data base management systems, decision support systems;
- *Projects*: investments, research and R&D projects, tenders;
- *Organisations*: public enterprises, banks, business partners;
- *Schools*: quality of schools, programmes and teachers, school admission, choosing sports for schoolchildren;
- *Management*: production, portfolio management, trade, personnel (employees, jobs, teams), privatization, motorway;
- *Production*: location of facilities, technology, logistics, suppliers, office operations, construction, electric energy production, sustainability;
- *Ecology and Environment*: dumpsite/deposit assessment and remediation, emissions, ecological impacts, soil quality, ecosystem, sustainable development, protected areas;
- *Medicine and Health Care*: risk assessment (breast cancer, diabetes, ski injuries), nursing, technical analysis, knowledge management, healthcare network;
- *Agriculture and Food Production*: economic and ecological effects of using genetically modified crops, crop protection, hop hybrids, garden quality;
- *Tourism*: nature trail, tourism farm facilities, mountain huts;
- *Services*: loans, housing loans, public portals, public services, leasing;
- *Other*: cars, hotels, electric motors, radars, game devices, awards, options, drug addiction, roof covering, data mining.

Among these, 52 projects (38%) are documented in publicly available conference and journal publications. Further 20 (14%) of projects are documented in internal reports. The remaining 67 (48%) of projects are not documented beyond the models themselves. For space limitations, we cannot include the published references here. Please see [3] for a review of some projects and publications. Some recent DEX projects were presented in [6] and [7].

3 MODELS

A DEX model consists of hierarchically structured attributes. Each attribute represents an aspect of considered decision alternatives that is interesting for their assessment in the given decision context. The hierarchy consists of *basic attributes* (terminal nodes), which represent model inputs, and *aggregate attributes* (internal nodes), which represent model outputs and provide assessments of the alternatives. The aggregate attributes depend on their (basic or aggregate) descendants in the hierarchy. The ultimate output of the model (overall assessment of the alternatives) is represented by one or more *root* attributes.

To illustrate these concepts, Figure 1 presents a small, but typical model for the evaluation of cars. This demo model is distributed together with the DEXi software and is also included in the database analysed in this paper. The model assesses cars using the seven basic attributes: BUY.PRICE (buying price), MAINT.PRICE (maintenance price), #PERS (number of persons), #DOORS (number of doors), LUGGAGE (luggage boot size), and SAFETY (car safety). The four aggregate attributes include COMFORT (depends on #PERS, #DOORS and LUGGAGE), TECH.CHAR (technical characteristics, based on COMFORT and SAFETY), PRICE (assessed from the buying and maintenance price), and the root attribute CAR (depends on PRICE and TECH.CHAR). Notice that the *depth* (number of levels excluding the root) of the model is three. The *width* (number of immediate attribute descendants) of CAR is two, and of COMFORT is three.

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: Structure and scales of the car-assessment DEX model

The 582 models in the database are characterised as follows:

- *By category*: 175 (30%) models were developed in various research projects. 129 (22%) are “commercial”, developed in decision-analysis projects for a paying customer. 213 (37%) models were developed as part of various educational activities, such as student assignments. The remaining 65 (11%) are various demonstrational models, such as the one in Figure 1.
- *By language*: 178 (30%) English, 388 (67%) Slovene, 11 (2%) Croatian, and 5 (1%) Spanish.
- *By software*: 53 (9%) of the models were developed by the first generation software DECMAK (mainly 1979–1991), 208 (36%) by the second generation DEX (1989–2001), and 321 (55%) by the third generation DEXi (since 2000).
- *By structure*: the majority of models (554, 95%) have a tree structure, while the remaining 28 (5%) employ a full hierarchy (i.e., a directed acyclic graph, where some attributes affect more than a single higher-level attribute).

Figure 2 (left) shows the histogram of model *sizes* (total number of attributes). Typical models have between 10 and 30 attributes, but there are also very large models containing more than 100 attributes. The average size is 27.8 attributes. The largest model in the database, which is aimed at the evaluation of cropping systems in agronomy, has 383 attributes. The average number of basic and aggregate attributes is 15.8 and 10.3, respectively. The deepest model contains 10 levels, and the average depth is 3.5. The average width of a single node is 2.6, indicating that DEX models are somewhat "thin and deep". This is a consequence of a methodological recommendation to keep the number of immediate descendants low in order to avoid too large decision tables [4].

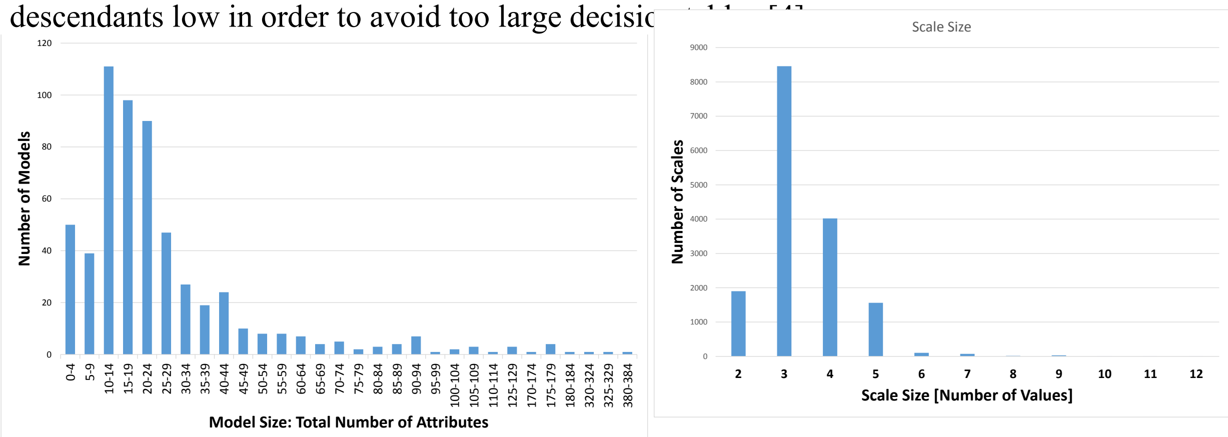

Figure 2: Histograms of model sizes (left) and scale sizes (right)

An additional analysis of models over time (not detailed here) indicated that the average size of models remained almost constant since 1979, however the size of the largest models, which are very few, grew from about 100 in 1980 to almost 400 in the recent years.

4 ATTRIBUTE SCALES

Attributes in DEX models are qualitative: their value scales are discrete and composed of words. Figure 1 shows the scales used in the car-assessment model. It can be seen that they contain only a small number of possible values, three or four in this case. The colours indicate that all the scales are also preferentially ordered from "bad" (printed in red) to "good" (green) values.

This is typical for most DEX models, even though the method permits using more values and having unordered scales. The database contains 16169 scales in total. Figure 2 (right) shows that the vast majority of scales contain 2 to 5 values. The average scale size is 3.4.

The definition of scale ordering has changed over different generations of software and is thus difficult to assess. Roughly, in all the models, 13138 (81%) scales are increasing, 838 (5%) decreasing, and 2192 (14%) unordered.

5 DECISION RULES

In DEX, the aggregation of basic attributes towards the roots of the hierarchy is governed by *decision rules*. These are typically formulated by the decision maker (with the support of software tools) and represented in terms of *decision tables*. Each aggregate attribute in the model has an associated decision table.

For example, Figure 3 shows a screenshot from DEXi in which a decision table for the attribute CAR is being developed. Notice that the table contains all the 12 possible combinations of the values of the descendant attributes PRICE and TECH.CHAR, and that the values of CAR for each combination are given in the rightmost column. Each column represents an *elementary decision rule*. The bold typeface indicates the values entered by the decision maker, while the normal typeface (only at rule number 10) indicates the values suggested by DEXi's decision-support algorithms [4].

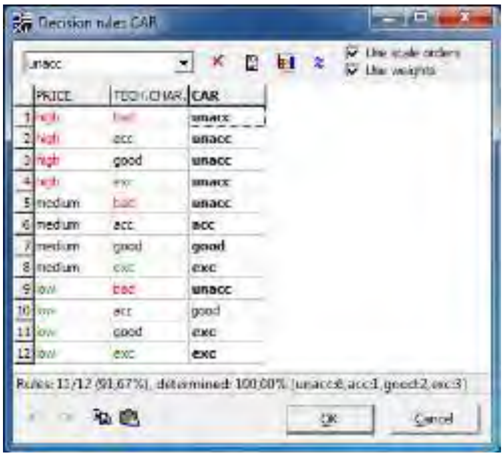

Figure 3: Decision table for the assessment of CAR depending on PRICE and TECH.CHAR

In the following, we define some interesting properties of DEX decision tables and present the actual numbers assessed on the 6362 decision tables contained in the studied database.

- *Number of arguments*: defined as the number of conditional attributes in the decision table (there are 2 in Figure 3: PRICE and TECH.CHAR). The database contains decision tables that have 1 to 8 arguments, the average is 2.5.
- *Number of classes*: denoted $|Y|$, the number of values of the output attribute Y (in Figure 3, the output attribute CAR has 4 values). The observed range of classes is 2 to 11, the average is 3.7.
- *Size*: the total number of decision rules ($3 \times 4 = 12$ in Figure 3). In the database, the size varies greatly between 2 and 15625, but the average and median are only 39.3 and 16, respectively. This indicates that reasonably small tables are preferred by the decision makers and that the "combinatorial explosion" [4], possibly caused by too many attributes and attribute values, is generally kept under control well.
- *Definition*: the proportion of decision rules defined by the decision maker ($^{11}/_{12} = 91{,}67\%$ in Figure 3). The database contains 5034 (79%) completely defined decision tables and 1328 (21%) incompletely defined ones.
- *Determination*: Similar to the above, but also taking into account the values suggested by the software. These suggestions raise the proportion of completely determined decision tables to 5889 (93%); only 473 (7%) decision tables still contain output values that are not fully determined (i.e., specified in terms of unknown or interval values).
- *Monotonicity*: Whether or not the decision table, interpreted as an aggregation function, is monotonically increasing with increased values of its arguments, taking into account the preferential ordering of attribute scales. In other words, whether or not do decision rules conform to the *principle of dominance* [4, 9]. As much as 5993 (93%) decision tables in the database are monotone, and only the remaining 429 (7%) are not. This indicates that the principle of dominance is indeed a powerful mechanism for ensuring the preferential consistency of decision tables, and that the latter has been managed really well.
- *Symmetricity*: Whether or not the decision table is fully symmetric with respect to its all arguments. In the database, 1663 (26%) decision tables are fully symmetric, and 4699 (74%) are not. Partial symmetricity is more abundant, but left out from this presentation.
- *Linearity*: Whether or not it is possible to fully approximate the decision table with a linear function. 1638 (26%) of decision tables are linear in this sense, and 4724 (74%) are not. The proportion of linear decision tables is thus similar to the proportion of symmetric ones.

6 CONCLUSION

The purpose of this study was to make an overview of MCDM DEX models developed since 1979, and to assess basic statistical properties of their primary components: attributes, scales and decision rules. Why is this important? First, it allows us to better understand the DEX models: their dimensions, properties, historical development, trends, possible errors, etc. Second, it facilitates the quality assessment of models and their components, such as the consistency of decision rules. Third, quality assessment may provide a solid basis for quality assurance, for instance, in developing better and more effective decision-support software. Last but not least, the developed database of DEX models provides a reach real-data resource for further research.

This study revealed the average and extreme dimensions of DEX models. An average model consists of roughly 28 attributes (16 of which are basic), 3.5 levels and 2.5 descendants per node. The largest models may span up to 400 attributes and 10 levels. Over time, extreme models were becoming larger, while the average models remained the same. An average scale contains 3.4 values and is ordered by increasing preference. An average decision table has 2.5 arguments, 3.7 classes and 40 decision rules (with the median of 16). Decision tables are mostly monotone (93%), non-symmetric (74%) and non-linear (74%). The overall completeness of decision tables is high (93%). It was also found that the quality of model components depends on implemented features of the supporting software; for instance, the improved handling of scale ordering in subsequent generations of software improved the overall completeness of decision rules. With this in mind, further development of the DEX method and supporting software should address an explicit handling of the symmetricity and linearity of decision tables as means to improve the knowledge acquisition process and the quality of acquired rules.

References

[1] Bohanec, M., Bratko, I., Rajkovič, V. 1983. An expert system for decision making. Processes and Tools for Decision Making (ed. H.G. Sol). North-Holland, 235–248.

[2] Bohanec, M., Rajkovič, V. 1990. DEX: An expert system shell for decision support, Sistemica 1(1): 145–157.

[3] Bohanec, M., Žnidaršič, M., Rajkovič, V., Bratko, I., Zupan, B. 2013. DEX methodology: Three decades of qualitative multi-attribute modeling. Informatica, 37(1), 49–54.

[4] Bohanec, M. 2015. DEXi: Program for Multi-Attribute Decision Making, User's Manual, Version 5.00. IJS Report DP-11897, Ljubljana: Jožef Stefan Institute.

[5] Bohanec, M., Trdin, N., Kontić, B. 2016. A qualitative multi-criteria modelling approach to the assessment of electric energy production technologies in Slovenia. Central European Journal of Operations Research, 1–15.

[6] Bohanec, M., Mileva Boshkoska, B., Prins, T. W., Kok, E. J. 2017. SIGMO: A decision support System for Identification of genetically modified food or feed products. Food Control, 71: 168–177.

[7] DEXi: A Program for Multi-Attribute Decision Making. http://kt.ijs.si/MarkoBohanec/dexi.html [Accessed 2017/06/15].

[8] Efstathiou, J., Rajkovič, V. 1979. Multiattribute decisionmaking using a fuzzy heuristic approach. IEEE Trans. on Systems, Man, and Cybernetics, SMC-9: 326–333.

[9] Greco, S., Ehrgott, M., Figueira, J. 2016. Multiple Criteria Decision Analysis: State of the Art Surveys. International Series in Operations Research & Management Science, Vol. 233. New York: Springer.

SOR '17 Proceedings

The 14th International Symposium on Operational Research in Slovenia

Bled, SLOVENIA, September 27 - 29, 2017

Edited by:

L. Zadnik Stirn, M. Kljajić Borštar, J. Žerovnik and S. Drobne

Slovenian Society INFORMATIKA (SDI)
Section for Operational Research (SOR)

Proceedings of the 14th International Symposium on Operational Research
SOR'17 in Slovenia, Bled, September 27 - 29, 2017.

Organiser : Slovenian Society Informatika – Section for Operational Research, SI-1000 Ljubljana, Litostrojska cesta 54, Slovenia (www.drustvo-informatika.si/sekcije/sor/)

Co-organiser : University of Maribor, Faculty of Organizational Sciences, SI-4000 Kranj, Kidričeva cesta 55a, Slovenia (http://www.fov.um.si/)

First published in Slovenia in 2017 by Slovenian Society Informatika – Section for Operational Research, SI 1000 Ljubljana, Litostrojska cesta 54, Slovenia (www.drustvo-informatika.si/sekcije/sor/)

CIP - Kataložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

519.8(082)
519.8:005.745(082)
519.81:519.233.3/.5(082)

INTERNATIONAL Symposium on Operational Research in Slovenia (14 ; 2017 ; Bled)
SOR '17 proceedings / The 14th International Symposium on Operational Research in Slovenia, Bled, Slovenia, September 27 - 29, 2017 ; [organiser] Slovenian Society Informatika (SDI), Section for Operational Research (SOR), [co-organiser University of Maribor, Faculty of Organizational Sciences, Kranj] ; edited by L. Zadnik Stirn ... [et al.]. - Ljubljana : Slovenian Society Informatika, Section for Operational Research, 2017

ISBN 978-961-6165-50-1
1. Zadnik Stirn, Lidija 2. Slovensko društvo Informatika. Sekcija za operacijske raziskave 3. Fakulteta za organizacijske vede (Kranj)
291596288

Proceedings of the 14th International Symposium on Operational Research in Slovenia (SOR'17) is cited in: ISI (Index to Scientific & Technical Proceedings on CD-ROM and ISI/ISTP&B online database), Current Mathematical Publications, Mathematical Review, MathSci, Zentralblatt für Mathematic / Mathematics Abstracts, MATH on STN International, CompactMath, INSPEC, Journal of Economic Literature

Technical editor : Samo Drobne
Designed by : Samo Drobne
Printed by : BISTISK d.o.o., Ljubljana, Slovenia
Number of copies printed: 160