New Generation Platform for Multi-Criteria Decision Making with Method DEX

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Abstract. DEX is a qualitative multi-criteria decision analysis method. It has been used numerous times in various applications – from everyday decision problems to problems in financial and ecological domains. Based on experience and applications, we identified six methodological extensions to DEX, which form a basis for a thesis in the area of multi-criteria decision support. The extensions are: using full hierarchies, introducing numeric attributes, probabilistic and fuzzy aggregation of values, general aggregation functions, modularization and relational models. The main method DEX with six extensions will be implemented in a library along with a graphical user interface. The performance of the newly developed methods and tools will be empirically evaluated through four real use-cases.

Keywords. Multi-criteria decision making, method DEX, qualitative decision making, relational model, probability, fuzzy set, aggregation function

Introduction

Decision making is a process, in which a decision maker needs to select an alternative among several possible alternatives, which best satisfies his/her goals [1, 2, 3]. Decision analysis [4, 5] is a discipline that provides a framework for analysing decision problems, which typically involves development of some model for the evaluation and analysis of alternatives. In this proposal we are concerned with methods of multi-criteria decision analysis, where alternatives are evaluated using multiple, possibly conflicting, criteria.

This thesis considers a special class of multi-criteria models: qualitative multi-criteria models. These are characterised by using qualitative variables, whose value scales contain a finite predefined set of qualitative (or symbolic) values, in contrast to a more common group of methods that use numerical variables for values and preferences. There are two groups of qualitative MCDA methods, which differ in the way how knowledge is acquired from the decision maker while building a decision model [6, 7]: (1) methods based on interactive questioning procedure for obtaining decision maker's preference, and (2) methods that acquire decision maker's preferences directly.

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Representative methods of the interactive questioning procedure are MACBETH and ZAPROS. MACBETH (Measuring Attractiveness by Categorical Based Evaluation Technique) [8] uses attractiveness and differential judgments between attributes in order to build preferential relations between alternatives. ZAPROS (Russian abbreviation for Closed Procedures near Reference Situations) [9, 10] provides outranking relationships among alternatives by verbal decision making approach.

Typical representatives of the second group are methods DRSA, Doctus and DEX. DRSA (Dominance-based Rough Set Approach) [11] uses rough sets theory with the goal of solving alternative classification and sorting problems represented by decision tables, using the principle of dominance. DRSA has a very strong mathematical foundation [11] and has evolved in many directions, for example considering imprecise evaluations and assignments [12] and dealing with decisions under uncertainty and time preference [13]. Doctus [14] is a Knowledge-Based Expert System Shell used for evaluation of alternatives, supporting three types of alternative evaluation: Rule-Based Reasoning, Case-Based Reasoning, and Case-Based Rule Reasoning. The third method from this group is DEX, which is addressed in this thesis and described in more detail in the next section.

1. Method DEX

DEX (Decision EXpert) method [15, 16, 17, 18, 19] is a qualitative multi-criteria decision modelling method. DEX uses qualitative attribute values, e.g. "bad", "medium", "good", rather than quantitative values. A DEX model has a form of a hierarchy, where lower level attributes are logically combined into higher level attributes. Terminal nodes are called input attributes, whereas all other attributes are called aggregated attributes. Additionally, attributes without hierarchical parents are called roots.

Aggregation of values in the model is facilitated by decision rules. Each of the aggregated attributes has an associated total aggregation function in order to compute a value from its hierarchical children. The mapping is defined by a table that produces a value for every combination of children's input values. Typically such tables are prepared by the decision maker, aided by the software.

Formally, a DEX model M is composed from a set of attributes $X = \{x_1, x_2, \dots, x_n\}$. Attributes are structured hierarchically: each attribute x may have some descendants (children) and/or predecessors (parents) in the model. This relationship is represented by functions $Inputs$ and $Outputs$. Function $Inputs$ maps attribute x to an ordered list of its inputs, $Inputs: X \to X^*$, and function $Outputs$ maps attribute x to an ordered list of its outputs, $Outputs: X \to X^*$. The relations constructed by functions $Inputs$ and $Outputs$ must represent a hierarchy, i.e., directed acyclic graph.

Each attribute x has a corresponding value scale $s \in S$, where s is a set of qualitative values and S the set of all qualitative scales. Scale values are typically represented by words, for example $s = [low, medium\ high]$. D is a function that maps an attribute to the corresponding scale of the attribute,. $D: X \to S$. With respect to decision maker's preferences, scales can be either ordered (increasing or decreasing) or unordered.

Model input attributes are composed of all attributes that have no direct inputs, $ModelInputs = [x_i \in X | Inputs(x_i) = []]$. Similarly, model output attributes are

$ModelOutputs = [x_i \in X | Outputs(x_i) = []]$. Each aggregated attribute $x_i \in X \backslash ModelInputs$ needs a total aggregation function f_i. Suppose $Inputs(x_i) = [x_j, x_k, \ldots, x_l]$, then f_i is a total function $f_i: D(x_j) \times D(x_k) \times \ldots \times D(x_l) \to D(x_i)$.

Decision alternatives are represented by the set $A = \{a_1, a_2, \ldots, a_m\}$, where $ModelInputs = [x_j, x_k, \ldots, x_l]$ and $a_i \in D(x_j) \times D(x_k) \times \ldots \times D(x_l)$. For the evaluation of alternatives, a function $evaluation: ModelInputs \to ModelOutputs$ is defined. Evaluation of alternative a_i on model M is done by computing $Evaluation(a_i)$ – a bottom-up aggregation of model inputs toward its outputs according to the hierarchical structure of the model and using the corresponding aggregation functions.

Currently, the method DEX is implemented in the software package called DEXi [20, 21]. DEXi supports an interactive construction of the decision model and alternatives. The software aids in defining decision rules and checking their completeness and consistency, and provides a number of decision analytical tools.

2. Motivation

Decisions in corporate world, financial institutions, ecology and everyday life are complex, leading to complex decision models and associated data [7, 22, 23, 24, 25, 26, 27, 28, 29, 30]. DEX has been widely used in practice to support complex decision processes in health threats and crises management [28], using genetically modified crops [23, 24, 25, 31], evaluation of data mining work flows [29], evaluation of public administration portals [32], in environmental decision making [30] and many others [18]. Extensive use has clearly indicated a great practical value of the method, but has also revealed the need to extend it in several directions. Also, the current implementation of DEXi has been conceived about 14 years ago and shows its age. Even though it is regularly maintained and upgraded, new generation software is needed.

During the thesis design phase, we identified six main possible extensions to DEX, which are going to be addressed in the thesis:

- Support for native hierarchies of attributes;
- Support for numerical attributes;
- Relational aggregation of alternatives;
- Extended attribute values to fuzzy sets and distributions;
- General aggregation functions, for aggregation of numerical and qualitative values;
- Modularization of model parts.

Extensions were identified by two criteria: (1) need in practice, and (2) providing additional methods for the decision maker. What will be achieved with each extension and how is it going to contribute to the decision process is for each specific extension described in section 4.

As part of the thesis, we wish to reimplement the original method together with all six identified extensions.

3. Research Question and Goals of the Dissertation

We already identified several methodological extensions from which the DEX method could benefit. Extensions cannot be handled only on the conceptual ground, but they must also be implemented and evaluated. The implementation would require a development of algorithms that cannot be provided by any other library. Also, the algorithms and developed software should be empirically evaluated on real-life case studies.

Consequently, the dissertation has three main goals:

1. Develop and analyse extensions to the DEX method;
2. Implement a new library supporting the DEX method and developed extensions;
3. Evaluate the development through real life use-cases.

A description of the six identified extensions is given in the next section. For each extension, we formulate a corresponding research question, namely that the DEX method as well as the decision process itself can be improved by the addition of that extension. The improvements will be measured both qualitatively (e.g., by the ability to model aspects of the decision problem that have not been possible before) and quantitatively (e.g., efficiency of the model development process).

The implementation will provide a new, better and more powerful software architecture for decision making with DEX. Two software layers will be addressed: a library implementing all DEX methods and algorithms, and a graphical user interface for an interactive development of DEX models. The new generation platform will provide an easier access to the developed library to facilitate usage in different applications: standard shell programs, java native computer programs, web sites and web services.

The evaluation of the extended DEX and its new implementation will be empirical. It will involve four real use cases, which all require the methodological extensions developed in this thesis:

- Water outflows: Using modules for the evaluation of different water outflows from a field. This use case in the domain of ecology and agronomy is studied in a bilateral industrial project EVADIFF [33].
- E-portals: Using relational qualitative models for public e-portal evaluations [32].
- Reputational risk: Usage of relational qualitative and quantitative models in reputational risk assessment of a bank. The use case originates in a European project FIRST [34].
- OVJE: Sustainability assessment of electric energy production technologies in Slovenia with emphasis on nuclear technology. This problem is addressed in a national project.

4. Proposed Extensions

In the following subsections we propose ideas for each of the six methodological extensions of DEX.

4.1. Full Hierarchies

Multi-criteria methods often handle multiple attributes by structuring them into a tree or a hierarchy [5, 26, 27]. Many multi-criteria decision making methods already use hierarchies, for instance AHP [26, 27]. The conceptual ideas can be transferred to DEX from such methodologies, but using hierarchies in DEX needs additional caution when modifying an existing model. For instance, when the model structure changes, some inputs or outputs of attributes can change, too, and consequently the aggregation function must adapt or request additional user input.

While DEX fully supports trees, it currently handles hierarchies only indirectly using a symmetric relation $Link$ [21]. Links are problematic to manipulate, because nodes with multiple parents are multiplied through the graph. There is a need to handle hierarchies natively and fully. A sample figure of a developed model hierarchy is seen in Figure 1.

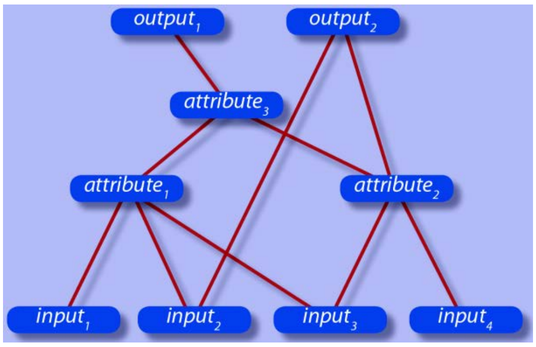

Figure 1. Hierarchical composition of attributes in a model.

Formally, to implement full hierarchies, the $Link$ relation must be eliminated from DEX and replaced by an extended definition of attribute's functions $Inputs$ and $Outputs$. The graph, constructed from the functional values of all attributes, can now formally induce a hierarchy.

With including full hierarchies in DEX, the handling of real relations between attributes will become easier and more "natural". In contrast with tree-based models, the hierarchy is smaller in size, does not include duplicates and is more comprehensible for the user. The model development and validation work is also reduced, since there is no duplication.

4.2. Numeric Attributes

Most of MCDM methods are quantitative, they involve numeric attributes and real-valued utility functions. DEX is in its core a qualitative method and thus all quantitative model values must be transformed into qualitative ones. This approach is not always appropriate and also there are a lot of decision problems where there is a need to support quantitative and qualitative values within the same model [34].

Currently, DEX models can operate only on qualitative attributes. Even though a few quantitative features have already been added to DEX [35, 36], there is a strong need to use and combine both qualitative and quantitative attributes within a model. A model with numeric and qualitative aggregation functions is presented in Figure 2.

Adding numerical attributes requires a number of representational and algorithmic extensions, such as adding numerical aggregation functions and handling transformations between qualitative and numeric values. Attribute value scales have to be extended to include real numbers, integer numbers, finite intervals over real numbers and finite integer intervals over real numbers. Also, while editing, models should be able to transform the data inside them, possibly avoiding excessive user interaction.

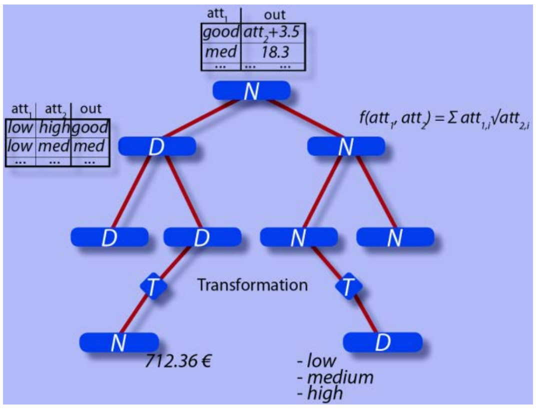

Figure 2. Numeric and qualitative aggregation functions in a model hierarchy.

The introduction of quantitative attribute values is a crucial extension for the modelling process, as it increases the expressiveness of attributes' value scales and aggregation of such quantitative values. The extension introduces a natural way to incorporate numeric values and operations. Nevertheless, there is also a drawback, since the inclusion of numeric values is a complex methodological extension that produces more complex models.

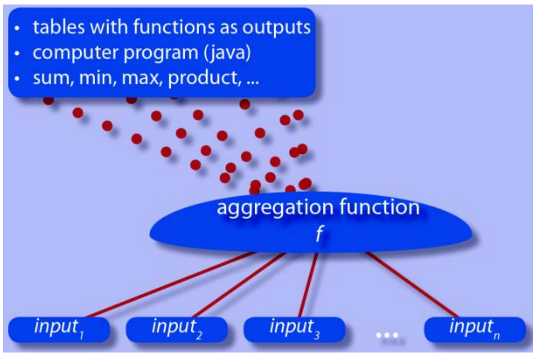

Figure 3. Some general aggregation function types applicable to *n* inputs.

4.3. General Aggregation Functions

DEX in its native form supports aggregation functions in form of a table – decision rules. With the inclusion of numerical attributes, the method has to support a much larger family of functions. Given aggregation function's inputs and its output, the method has to support different possible function definitions according to attribute types. Three attribute type combinations are possible as inputs: qualitative, numeric, and qualitative and numeric. There are also two types of possible outputs: qualitative and numeric. These combinations give six possible function definitions. A general aggregation function types are presented in Figure 3.

This extension will provide more choice and flexibility for a decision maker on formulating aggregation functions. This extension also simplifies definition of common or frequently used functions, such as mathematical functions minimum, maximum, etc.

4.4. Probabilistic and Fuzzy Distributions

The extension of probabilistic and fuzzy distributions incorporates ideas from probabilistic inference methods [37]. This extension will support inclusion of incomplete and uncertain information – values, in the decision making model. Introducing probabilistic and fuzzy distributions in DEX was already included beforehand [30, 31], but as an independent implementation.

Ideally, attribute values are fully determined, that is, the value given to the attribute – computed or supplied by the alternative – is fully determined. Sometimes, this is not the case. Currently, DEX represents attribute values either by single (determined) values or by a set of values (subset of scale values). In this thesis, we wish to extend this towards fuzzy and probabilistic value distributions to associated both with data about alternatives and decision rules. Figure 4 shows a model hierarchy with distributions as inputs and as intermediate computed values. A table-like aggregation using distributions and fuzzy sets as outputs is also presented.

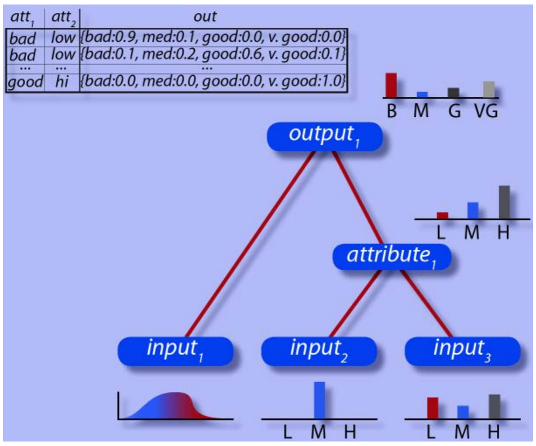

Figure 4. Distributions of values in the inputs and in the intermediate values of evaluating an alternative. A table-like aggregation function is also presented in the upper left, where functional outputs are distributions and fuzzy sets.

To define this extension formally, we need to extend the scales of attributes. We define ES, a space of all fuzzy sets, distributions, sets, intervals and crisp values over all qualitative scales, integers, reals, finite integer intervals and finite intervals over reals. We replace the previously defined space of scales S with ES. This considerably affects the aggregation procedure; when encountering a qualitative distribution of values from some scale, the evaluation must propagate the corresponding probabilities of particular values to construct the final evaluation.

The probabilistic and fuzzy distributions are a major extension to the existing DEX methodology, where uncertain and incomplete information can be introduced as input values, or as values that appear inside the model during evaluation. This greatly enhances the ability of DEX to handle uncertainty, but on the other hand, may affect users understanding and interpretation of the results.

4.5. Relational Models

The data encountered in everyday life are frequently of relational nature in the sense that one entity is composed of several sub-entities. For example, when evaluating a company, a decision maker may want to evaluate all departments of the company. There is a “one-to-many” relationship between company and departments. We propose to extend DEX to handle such situations [38] in the way sketched in Figure 5: we develop two models, one for the evaluation of departments (SM) and one for the evaluation of companies (M). To evaluate a single company, each department is first evaluated by SM. Then, all evaluations are aggregated, providing an input value to M.

Relational data is frequently modelled in relational databases. Several disciplines of machine learning explicitly consider the development of relational models, e.g. inductive logic programming [39]. Relational data is also considered in quantitative multi-criteria decision making methods, but rarely in an explicit way. There, it also rarely causes difficulties because it naturally involves common aggregation operators based on summation and averaging. Such operators are useless in qualitative setting and require special approaches.

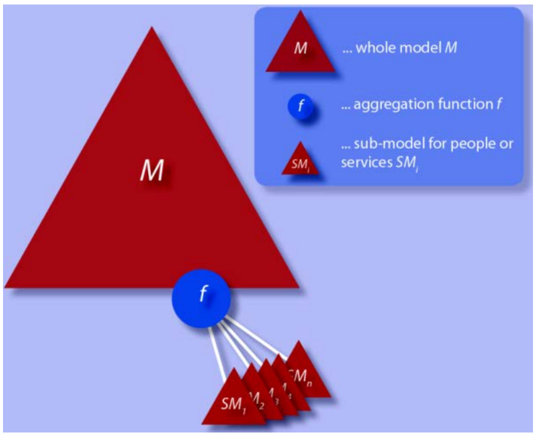

Figure 5. A sample relational model configuration. *M* is the main DEX model, SM_i is a relationally connected sub-model, which is used *n* times (where *n* is the number of relational alternatives) and *f* is the relational aggregation function.

This extension requires an introduction of a new attribute type, the so-called relational attribute rx, which serves as a connection points between the main and subordinate models. The relational attribute’s inputs are attributes from some other (relational) model.

Relational attribute rx has a relational aggregation function f. This is a special type of function, which maps from an arbitrary number of values to $D(rx)$. Formally, suppose $Inputs(rx) = [x_j, x_k, \dots, x_l]$, then f: $D(x_j)^o \times D(x_k)^o \times \dots \times D(x_l)^o \rightarrow$

$D(rx)$, where o is the number of values produced by the inputs. In general, relational aggregation functions are more complex and more difficult to parameterize formally than regular aggregation functions.

Currently, relational models are not supported in DEX. Adding them would be a crucial improvement, which would facilitate addressing a much larger group of decision problems. On the other hand, relational models require complex methodological extensions that affect the representation of decision alternatives and introduce new components, such as relational attributes and relational aggregation functions.

4.6. Modularization

The modularization extension to DEX should support the construction of modules inside of models. This extension is merely practical, as it simplifies the process of model construction and improves the reusability of its components. Figure 6 illustrates using a module in a DEX model.

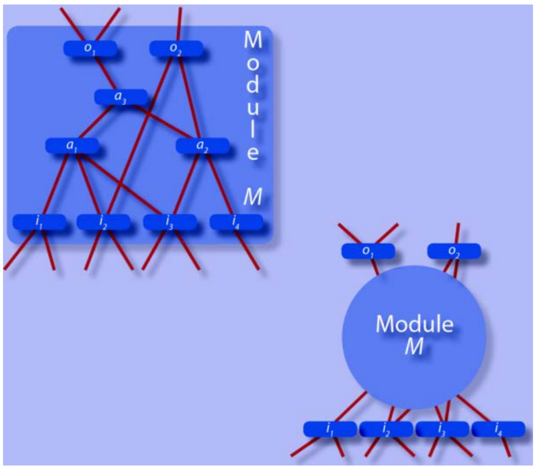

Figure 6. Modularization of model hierarchy. The upper left hierarchy shows the part of the model, which is compacted in to a module – seen in the bottom right. The module inputs and outputs are preserved.

The modularization gives the decision maker the ability to intelligently compress and possibly reuse large parts of models.

5. Methodology

All proposed extensions will be developed through the following procedure:

1. Formal definition of the extension;
2. Specification of functional requirements;
3. Implementation in the library;
4. Empirical evaluation on selected use-cases.

With this procedure, all extensions undergo the design, implementation and evaluation phase.

All the developed methods and tools will be empirically evaluated on real-life use cases. All cases will be difficult in the sense that they cannot be fully modelled by the current method DEX and would require at least one of the extensions developed in this thesis. Evaluation criteria will include: time of development and ease of development of a particular model, coherence with previously acquired results (when available), evaluation time (specifically applicable on models with complex structure and many alternatives) and need of user interaction with the software. Whenever possible, an expert from the problem domain will review the results.

6. Current Status of Research

We have already implemented and tested the majority of new extensions. Fully completed is the support for full hierarchies, numeric attributes, probabilistic and fuzzy distributions, and relational models. General aggregation functions are near completion, while the modularization has not been addressed yet. Currently we are developing the graphical user interface, where the modelling part is near completion.

Decision models for the four use cases have been implemented using the newly developed library:

- Water outflows [33]: The developed library is being actively used by a web-service that is called from a web page. This use case does not use any of six newly implemented extensions, but benefits from the newly developed library.
- E-portals: The developed library was used to reconstruct a previously published example for the evaluation of public administration e-portals [32]. The implemented use case actively uses the relational models extension, including the general aggregation function for relational aggregation. The results of the new model precisely match the previous ones, but the evaluation was highly improved in terms of efficiency and eliminating the need for manual intervention.
- Bank reputational risk assessment model [34] was implemented by a combination of a model developed by DEXi software and an additional implementation of relational models using the library.
- OVJE: Work in progress, where the corresponding relational model is being implemented using the new library.

To date, we have published our research in two international conferences. The overview of the work was published and presented in [19]. There is another accepted presentation at an international conference [38].

7. Expected Contributions

This work is expected to contribute a number of formal and algorithmic extensions of the qualitative modelling method DEX, in particular: supporting full native hierarchies, numeric values, general aggregation functions, probabilistic and fuzzy distributions, handling relational alternatives and models, and modules. Consequently, this will extend the class of decision problems that can be addressed by DEX and improve the decision process by providing additional methods and tools to the decision maker. In addition, this thesis will contribute to practice by implementing a new software library supporting the DEX method and evaluating it on four real life use cases.

8. Completion Plan

To complete the thesis we will firstly complete the library implementation of the methodology with the extensions. Most of the remaining work will be focused on the modularization of DEX models and using general aggregation functions. Further steps include writing documentation of the library, developing the graphical user interface and implementing the bank reputational risk assessment model.

Among the six extensions, special focus will be put on those that extend the class of decision problems that can be addressed by DEX: numerical attributes, general aggregation functions, relational models, and probabilistic and fuzzy distributions.

Regarding publications, we need to publish at least two journal papers. The first journal paper will focus on the methodological part of the thesis, specifically on the extensions. The second journal paper will concentrate on a use-case that is supported by the methodology and the library implementation.

The thesis should be formally completed in one year, but one year extension is allowed by the contract with the Slovenian research agency.

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