SOR '15 Proceedings

The 13th International Symposium on Operational Research in Slovenia

Bled, SLOVENIA, September 23 - 25, 2015

Edited by:

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

Proceedings of the 13th International Symposium on Operational Research
SOR'15 in Slovenia, Bled, September 23 - 25, 2015.

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 2015 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 (13 ; 2015 ; Bled)
SOR '15 proceedings / The 13th International Symposium on Operational Research in Slovenia, Bled, Slovenia, September 23-25, 2015 ; [organiser] Slovenian Society Informatika (SDI), Section for Operational Research (SOR) ; edited by L. Zadnik Stirn ... [et al.]. - Ljubljana : Slovenian Society Informatika, Section for Operational Research, 2015

ISBN 978-961-6165-45-7
1. Slovensko društvo Informatika. Sekcija za operacijske raziskave
281141504

Proceedings of the 13th International Symposium on Operational Research in Slovenia (SOR'15) 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 : Statistical Office of the Republik of Slovenia, Ljubljana, Slovenia

The 13th International Symposium on
Operational Research in Slovenia

SOR '15

Bled, SLOVENIA
September 23 - 25, 2015

Special Session 1:

Qualitative Multiple Criteria Decision Making

A QUALITATIVE MULTI-CRITERIA MODEL FOR THE EVALUATION OF ELECTRIC ENERGY PRODUCTION TECHNOLOGIES IN SLOVENIA

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Abstract: A methodological approach to the strategic evaluation of electric energy production technologies in Slovenia is presented. The aim of this work is to make a transparent and reproducible identification of reliable, rational, and environmentally sound production of electric energy in Slovenia by 2050. The approach is based on a qualitative multi-criteria modelling method DEX and consists of three stages: (1) assessment of individual technologies for electricity production, (2) assessment of mixtures of technologies, and (3) evaluation of scenarios of shutting-down existing old power plants and constructing the new ones until 2050. Technology alternatives include both conventional and renewable energy sources: coal fired, gas fired, biomass fired, oil fired, nuclear, hydro, wind, and photovoltaic. The results indicate that only mixtures of nuclear, hydro, and gas fired technologies can meet expected energy needs in a sufficiently reliable and rational way.

Keywords: Electric energy production technology, power plants, decision analysis, multi-criteria decision modelling, decision rules, qualitative model, method DEX

1 INTRODUCTION

Electric energy is a strategic resource that plays a vital role in the operation and development of every country. Electric energy production is a complex process, which requires strategic management and careful planning years ahead. The selection of appropriate technologies for electric energy production depends on a number of factors: energy needs of a country, availability of fuel and other natural resources, feasibility, efficiency, effectiveness and rationality of production, environmental impacts, and many more. Not only that these factors are multiple, they are often conflicting and influence the decisions in a variety of ways; thus they have to be carefully assessed individually and against each other.

For this kind of problems, Operations Research provides Multi-Criteria Decision Modelling (MCDM) methods [4, 6] that assess decision alternatives using multiple criteria. Each alternative is first assessed according to each criterion. These individual assessments are then aggregated into an overall evaluation of the alternative, which provides a basis for comparison, ranking and analysis of alternatives, and eventual selection of the best one. MCDM methods are commonly employed in the assessment of electric energy production [8], either in a general setting [10], or considering the specifics of countries, such as Germany [5] or Portugal [9].

In Slovenia, almost 13 TWh of electricity is consumed annually (net figure for the year 2014). The electricity is produced by thermal, hydro, and nuclear power plants in approximately equal shares. After a recent introduction of a controversial and expensive Unit 6 of the coal-fired power plant at Šoštanj (TEŠ6), which is expected to produce up to 3.5 TWh of electricity annually, there are important decisions to be taken for the next decades. Slovenia has one nuclear power plant in Krško, which produces around 5 TWh of electricity annually, and which will be according to plans closed down in 2023. However, there is an option to extend its operation until 2043. Another large power plant, coal-fired unit TEŠ5, will be closed down in 2027. There are plans to finalize, by 2025, two hydro power plants on the lower Sava river, which is the last Slovenian water resource available for hydro power plants. There are also plans to introduce gas fired plants, and energy production from renewable sources: wind, biomass and sun.

In order to contribute to strategic planning of electrical energy production in Slovenia, a project called OVJE [7] was conducted with the aim to make a transparent and reproducible identification of reliable, rational, and environmentally sound production of electric energy in Slovenia by 2050. Eight electric energy production technologies were considered: hydro, coal, oil, gas, nuclear, biomass, photovoltaic (PV), and wind. Hereafter we present the methodological approach to this sustainability appraisal and summarize the main results.

2 METHODS

The methodological approach is based on a qualitative MCDM method DEX, which is used in three stages, and involves two MCDM models and one simulation model:

1. *Model T*: Evaluation of eight individual electric energy production technologies.
2. *Model M*: Evaluation of mixtures of technologies, considering the shares of individual technologies in the total installed capacity.
3. *Model S*: Simulation of possible implementations of technology mixtures in the period 2014–2050, taking into account various scenarios of shutting down the existing power plants and constructing new ones.

2.1 Qualitative Multi-Attribute Modelling Method DEX

DEX (Decision EXpert) [1] is a *multi-criteria decision modelling* method. As all other MCDM methods, it is aimed at the evaluation and analysis of a set of decision *alternatives* $A = \{a_1, a_2, \dots, a_m\}$. These alternatives are described with a set of variables $X = \{x_1, x_2, \dots, x_n\}$, called *attributes*. Each attribute represents some observed or evaluated property of alternatives, such as "price", "quality", and "efficiency".

DEX is a *hierarchical* method. This means that the attributes X are organized in a *hierarchy*. Observed in the top-down direction, the hierarchy represents a decomposition of the decision problem into sub-problems. The bottom-up direction denotes dependence, so that higher-level attributes depend on the lower-level, more elementary ones. The most elementary attributes, called *basic attributes*, appear as terminal nodes of the hierarchy and represent the basic observable characteristics of alternatives. Higher-level attributes, which depend on one or more lower-level ones, are called *aggregated attributes*; they represent evaluations of alternatives. The topmost nodes (usually, there is only one such node) are called *roots* and represent the final evaluation(s) of alternatives.

Furthermore, DEX is a *qualitative* method. While most of MCDM methods are quantitative and thus use numeric variables, qualitative methods use symbolic ones. In DEX, each attribute $x_i \in X$ has a *value scale* $D_i = \{v_{i1}, v_{i2}, \dots, v_{ik_i}\}$, where each v_{ij} represents some ordinary word, such as "low", "high", "acceptable", "excellent". Scales are usually small, containing 2 to 5 values. Also, scales are usually preferentially ordered so that $v_{i1} \preccurlyeq v_{i2} \preccurlyeq \cdots \preccurlyeq v_{ik_i}$ (here, $a \preccurlyeq b$ denotes weak preference: the value b is preferred equally or more than a). Attributes that have preferentially ordered scales are called *criteria* [4].

Finally, DEX is a *rule-based* method. The bottom-up aggregation of alternatives' values is defined in terms of *decision rules*, which are specified by the decision maker and usually represented in the form of *decision tables*. Suppose that $x_{(0)} \in X$ is some aggregated attribute and that $x_{(1)}, x_{(2)}, \dots, x_{(r)} \in X$ are its immediate descendants in the hierarchy. Then, the aggregation function $x_{(0)} = f_{(0)}(x_{(1)}, x_{(2)}, \dots, x_{(r)})$ is defined with a set of decision rules of the form

if $x_{(1)} = v_{(1)}$ **and** $x_{(2)} = v_{(2)}$ **and** … **and** $x_{(r)} = v_{(r)}$ **then** $x_{(0)} = v_{(0)}$

Here, $v_{(i)} \in D_{(i)}, i = 0,1, \dots, r$.

The method DEX is implemented as DEXi [2], freely available software that supports both the development of DEX models and their application for the evaluation and analysis of decision alternatives. DEXi checks the quality of decision rules so that its models, when properly developed, are guaranteed to be *complete* (they provide evaluation results for all possible combinations of basic attributes' values) and *consistent* (defined aggregation functions obey the principle of dominance, i.e., they are monotone with respect to all preferentially ordered basic criteria).

For further information of DEX and DEXi, please refer to [1] and [2], respectively.

(a) Model T

Scales

Attribute	Scale
Technology	unsuit; weak; suit; good; exc
Rationality	inapprop; low; med; high
Contribution to development	low; med; high
Economic	low; med; high
Societal	low; med; high
Economic-Technical advancement	low; med; high
Technical level	low; med; high
Expected development	low; med; high
Economy	low; med; high
Financial aspects	less_suit; suit; more_suit
Energy price	high; med; low
Financing	less_suit; suit; more_suit
Financial sources	uncertain; less_certain; certain
Financial shares	less_suit; suit; more_suit
Long-term liabilities	less_suit; suit; more_suit
Efficiency	low; med; high
Energy ratio	low; med; high
Return period	long; med; short
Independence	low; med; high
Dependence	v_high; high; med; low; none
Land use and pollution	unsuit; less_suit; suit; more_suit
Spatial availability	less_suit; suit; more_suit
Land availability	low; med; high
Energy share provision	low; med; high
Resource protection	weak; present; effective
Water protection	weak; present; effective
Land protection	weak; present; effective
Landscape protection	weak; present; effective
Pollution	high; med; low
Health impact	high; med; low
Air pollution	high; med; low
Greenhouse gases	high; med; low
Other pollutants	high; med; low
Public health status	low; med; high
Contribution to development	low; med; high
Feasibility	low; med; high
Technical feasibility	low; med; high
Technological complexity	less_suit; suit; more_suit
Infrastructure availability	low; med; high
Accessibility	low; med; high
Fuel availability	low; med; high
Fuel accessibility	low; med; high
Economic feasibility	low; med; high
Investment feasibility	low; med; high
Return of investment	less_suit; suit; more_suit
Spatial feasibility	low; med; high
Societal feasibility	low; med; high
Social acceptance	low; med; high
Permitting	no; yes
Spatial suitability	low; med; high
Uncertainties	v_high; high; med; low; none
Technological dependence	v_high; high; med; low; none
Foreign dependence	v_high; high; med; low; none
Construction	high; med; low
Licences	strong_restr; moder_restr; no restr
Operation	high; med; low
Licences	strong_restr; moder_restr; no restr
Contracts	strong_restr; moder_restr; no restr
Special materials	strong_restr; moder_restr; no restr
Weather dependence	high; med; low
Fuel supply dependence	high; med; low
Political stability	no; low; high
Possible changes	neg; no; pos
Possible societal changes	neg; no; pos
Possible world changes	neg; no; pos
Perception of risks	v_high; high; med; low; none

(b) Model M

Scales

Attribute	Scale
Technology mix	unsuit; weak; suit; good; exc
Reasonability	unreas; less_reas; reas; desired
Energy demand coverage	low; med; good; high
Reliability of supply	low; med; high; v_high
Availability	low; med; high
Installed capacity	unsuit; suit; exceed
Energy produced	unsuit; suit; exceed
Base load	low; med; high
Peaks	no; yes
Uncertainties	v_high; high; med; low
Health impacts	high; med; low
Possible changes	neg; no; pos
Feasibility and rationality	weak; low; med; high
Feasibility	low; med; high
Economy	low; med; high
Long-term appropriateness	low; med; high
Fulfilment of goals and interests	low; med; high
Environmental goals	low; med; high
Low carbon	low; med; high
Rational land use	low; med; high
Nature protection	low; med; high
National interests	low; med; high
Independence	low; med; high
Energy users capabilities	low; med; high
Energy supply to all	low; med; high
Protection of vulnerable groups	low; med; high
Lifetime of supply	short; med; long

DEXi

(c) Decision rules

	Rationality	Feasibility	Uncertainties	Technology
	43%	29%	28%	
1	inapprop	*	*	unsuit
2	<=low	<=med	v_high	unsuit
3	<=med	low	v_high	unsuit
4	>=low	low	high:med	weak
5	>=low	high	v_high	weak
6	>=med	>=med	v_high	weak
7	high	low	<=med	weak
8	high	*	v_high	weak
9	low:med	low	>=low	suit
10	>=low	low	low	suit
11	>=low	>=med	high	suit
12	low	>=med	>=med	good
13	low:med	med	med:low	good
14	>=low	>=med	med	good
15	high	low	none	good
16	>=med	>=med	none	exc
17	>=med	high	>=low	exc
18	high	>=med	>=low	exc

Figure 1: Hierarchical structure and value scales of (a) Model T and (b) Model M, and (c) example of decision rules that aggregate *Rationality*, *Feasibility* and *Uncertainties* into *Technology*

2.2 Model T: Evaluation of Technologies

The DEX model, used in the first stage of appraisal, is called *Model T* ('T' stands for "Technologies"). It is aimed at the evaluation and comparison of individual energy production technologies: $A = \{$Hydro, Coal, Oil, Gas, Nuclear, Biomass, PV, Wind$\}$. Evaluation criteria X are organised in a hierarchy shown in Figure 1(a). The hierarchy contains 36 basic and 28 aggregated attributes. There are two aggregated attributes that appear twice in Figure 1(a), because they affect more than one higher-level attribute: *Licenses* and *Contribution to development*. Figure 1(a) also shows attributes' value scales; all scales are preferentially ordered increasingly in the direction from left to right.

Model T consists of three main sub-trees of criteria: *Rationality*, *Feasibility*, and *Uncertainty*. *Rationality* assesses how much a particular technology contributes to the overall societal development, the economy, and the prudent use of land with low pollution. Each of these aspects is represented by a corresponding attribute and decomposed further. The sub-tree *Land use and pollution*, for instance, specifically addresses *Spatial availability*, *Pollution*, and *Health impacts*. Similarly, the assessment of *Feasibility* takes into account *Technical*, *Economic* and *Spatial feasibility*. *Uncertainty* evaluation comprises *Technological dependence* (in terms of foreign, uncontrollable factors, operation of supplier, and political stability), *Possible changes* in society and in the world, and *Perception of risks* with respect to technical advancement of a technology and trust into safety management system.

Since Model T contains 28 aggregated attributes, there are also 28 corresponding decision tables, which were defined by experts and decision analysts in the OVJE project. Here, we present only the one that corresponds to the root attribute *Technology*: Figure 1(c) shows a condensed form of decision rules that aggregate intermediate assessments of *Rationality*, *Feasibility* and *Uncertainties* into the overall evaluation of *Technology*. The first rule, for instance, says that whenever *Rationality* is inappropriate, then *Technology* is considered unsuitable, regardless on its *Feasibility* and *Uncertainties* (the symbol '*' denotes any value). The last rule defines *Technology* as excellent when its *Rationality* is high, *Feasibility* at least medium and *Uncertainties* low or better (the symbols '>=' and '<=' denote weak preference). The percentages shown in Figure 1(c) represent the importance of each attribute (determined by linear approximation of decision rules, see [2]). As indicated, *Rationality* is more important (43%) than *Feasibility* and *Uncertainties*, which are of similar importance (29% and 28%, respectively).

2.3 Model M: Evaluation of Technology Mixtures

While Model T evaluates individual technologies, *Model M* evaluates technology mixtures. A *technology mixture* is defined as a collection of technologies, considering a specific share of each technology in the total installed capacity. For example, some technology mixture may employ three technologies, nuclear, coal and hydro, with respective relative installed capacity shares of 0.3, 0.6 and 0.1; this mixture is denoted {nuclear/0.3, coal/0.6, hydro/0.1}.

Model M is structured as shown in Figure 1(b). The two top-level attributes, *Reasonability* and *Long-term appropriateness*, measure the certainty of supply by some mixture, and fulfilment of goals and interests: environmental, social, and national. In total, Model M has 15 basic and 12 aggregated attributes.

Models T and M are connected and used in succession. When evaluating mixtures with Model M, some of its basic attributes receive values from Model T: *Health impacts*, *Possible changes*, *Feasibility*, *Economy*, *Low carbon* (determined from *Greenhouse gasses*), *Rational land use* (from *Spatial availability*), *Nature protection* (from *Resource protection*), and *Independence*. The input values of the remaining basic attributes are determined from scenarios (see section 2.4) for each mixture as a whole. The evaluation of mixtures with Model M takes into account the relative shares of individual technologies and employs an evaluation method based on probabilistic value distributions; see [11] for a detailed description of the method.

2.4 Model S: Simulation of Implementation Scenarios

In contrast with the two Models T and M, which are of multi-attribute type, *Model S* ('S' stands for "Scenarios") is a simulation model. It uses Models T and M, and "runs" them through the years 2014 to 2050. For each year, Model S evaluates technology mixtures that are expected to be in place in Slovenia in that year according to different management scenarios. The following management decisions have been considered:

1. Closing-down of the nuclear power plant (NPP) Krško Unit1 in 2023.
2. Construction of Unit2 at the NPP Krško by 2025.
3. Finalisation of the two hydro power plants on the lower Sava river by 2025.
4. Construction of a gas fired power plant by 2025.
5. Closing-down of Unit5 of the coal fired power plant at Šoštanj in 2027.
6. Construction of the chain of hydro power plants on the mid Sava river by 2035.

Since each of these decisions can be either yes or no, they collectively make $2^6 = 64$ possible scenarios. The simulation of these scenarios is implemented in an on-line decision support system [3].

3 RESULTS

In the first stage, individual electric energy production technologies were evaluated by Model T as shown in Figure 2. In addition to the overall evaluation (second row), Figure 2 displays intermediate evaluation results obtained on two lower levels of the Model T hierarchy. Some evaluation values are presented as intervals, which are due to uncertainties regarding future values of several evaluation criteria. The lower and upper interval bounds correspond to pessimistic and optimistic assessment of evaluation criteria, respectively.

Attribute	Hydro	Coal	Oil	Gas	Nuclear	Bio	PV	Wind	Impor
Technology	suit - ***exc***	**unsuit**	**unsuit**	weak - ***good***	weak - ***exc***	**unsuit**	**unsuit**	**unsuit**	**unsuit**
Rationality	low - ***high***	**inapprop**	**inapprop**	***high***	***high***	**inapprop**	**inapprop** - low	**inapprop**	**inapprop**
Contribution to development	med - ***high***	***high***	med	***high***	***high***	med	**low** - med	**low**	**low**
Economy	med - ***high***	***high***	**low**	med - ***high***	med - ***high***	**low**	**low**	**low**	med
Land use and pollution	**less_suit** - ***more_suit***	**unsuit**	**unsuit**	***more_suit***	***more_suit***	**less_suit**	**unsuit** - ***more_suit***	**unsuit** - **less_suit**	**less_suit**
Feasibility	***high***	***high***	***high***	***high***	**low** - ***high***	**low** - med	**low**	**low**	***high***
Technical feasibility	***high***	***high***	***high***	***high***	***high***	med	med - ***high***	med	med
Economic feasibility	***high***	med	med	med	***high***	**low** - med	**low**	**low**	***high***
Spatial feasibility	***high***	***high***	***high***	***high***	**low** - ***high***	**low** - ***high***	**low** - ***high***	**low** - ***high***	***high***
Uncertainties	high - ***none***	low	**v_high** - low	**v_high** - med	**v_high** - low	low	**v_high**	**v_high**	med
Technological dependence	high - ***none***	low	**v_high** - med	**v_high** - med	**v_high** - low	med	**v_high**	**v_high**	high
Possible changes	***pos***	***pos***	no	no	***pos***	no	no	no	***pos***
Perception of risks	med - ***none***	med - low	***none***	high - med	**v_high** - low	***none***	low	***none***	low

Figure 2: Evaluation results of individual electric energy production technologies with Model T

These results indicate that there are only three technologies of sufficient suitability for Slovenia: Hydro, Gas, and Nuclear. Among these, Hydro is the best. Gas and Nuclear are similar, with Nuclear worse in terms of *Feasibility* and *Perception of risks*, but better in terms of *Economic feasibility* and *Possible changes*. Coal and Oil are unsuitable particularly because of inappropriate *Rationality* due to *Land use and pollution*. All the remaining "green" technologies are unsuitable for a number of reasons, including *Economy*, *Land use*, *Economic feasibility* and *Technological dependence*. See [7] for a more detailed justification of this assessment and its consequences.

Results of simulating the 64 scenarios [7, 3] indicate that only the mixtures that include extension of operation of Unit1 of NPP Krško, construction and operation of Unit2 of NPP

Krško, construction of all planned hydro power plants on the Sava river and construction of the gas fired thermal power plant ensure coverage of energy needs by 2050 in Slovenia. Renewable energy sources – wind and PV – do not constitute a sustainable choice since they are not reliable due to land-use context (almost 40% of the Slovenian territory is under Natura2000 protection regime), and are consequently not capable of meeting a substantial share of energy demands; they may only constitute an option for covering 8% to 15% of energy needs.

4 CONCLUSION

With the aim to contribute to better strategic planning of electrical energy production in Slovenia, this work proposes a systematic, transparent and reproducible sustainability appraisal of technologies and strategic management scenarios. The approach is based on qualitative multi-attribute modelling and simulation, and proceeds in three stages: assessment of (1) individual technologies, (2) technology mixtures and (3) management scenarios in the period 2014–2050. The method is implemented in an on-line decision support system [3].

Evaluation results clearly identify three main technologies that are most suitable for Slovenia: Hydro, Gas, and Nuclear. Only a proper mixture of these technologies is reliable and rational in the context of meeting expected energy needs. Biomass, wind and photovoltaic sources of energy are less sustainable than others and may provide only from 8% to 15% of energy in Slovenia.

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DECISION SUPPORT MODELLING FOR ENVIRONMENTALLY SAFE APPLICATION OF PESTICIDES USED IN AGRICULTURE

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Abstract:
The application of pesticides in agriculture is not always safe for human health and the environment. Despite being officialy approved by authorities in terms of ecological risk, they appear in surface and ground water in concentrations above the official thresholds. To reduce and eliminate water pollution with pesticides, a decision support system (DSS) for ecological risk assessment of pesticide applications and ecological risk management, is proposed. The DSS is built by using the framework proposed by the US Environmental Protection Agency and Multi Criteria Decision Analysis (MCDA) implemented into the DEX (Decision EXpert) integrative methodology was implemented to build qualitative multi-attribute decision models by the DEXi modelling tool. A conceptual solution is demonstrated on an assessment of a proposed crop management plan for winter wheat, where the herbicide Isoproturon is planned to be applied. The DSS identified that the proposed plan is risky, therefore mitigation measures that have to be included in the proposed crop management plan are proposed.

Keywords: pesticides, risk assessment, risk management, mitigation measures, qualitative MCDM, DEX methodology

1 INTRODUCTION

The use of pesticides in agriculture has to be implemented in accordance with safe and environmentally sound agricultural crop management. Their use must be consistent with the European water framework directive [1] and the Directive on the sustainable use of plant protection products [2] in order to provide the most effective protection of surface and ground waters through the implementation of best crop management practices.

Though the crop management uses active substances previously approved for commercial use respecting EU regulations (No 1107/2009) [3] and permitted according to the Commission Implementing Regulation (EU) No 540/2011 [4], they can be still found in surface and ground water in concentrations above the official thresholds. The main reasons for the pollution of waters with pesticides are the inappropriate use and storage of pesticides [5].

Each approved and permitted active substance has passed very rigorous ecological risk assessment during its registration process. The procedure for preregistration risk assessment is described in detail by the respective authorities (e.g., European Food Safety Authority, US Environmental Protection Agency). However, the post-market risk assessment of pesticides used in agriculture is not at that level. To make a progress on this issue, the European Commission (through the environmental program LIFE) and the European plant protection industry association (ECPA) launched the project TOPPS (Train the Operators to Promote best management Practices and Sustainability) [6], which aim is to reduce water pollution due to the improper use of pesticides. The TOPPS project addresses both point and diffuse sources of water pollution by pesticides and it tries to diagnose the level of the pollution risk and give instructions for mitigation measures that would reduce and prevent the pollution of water with pesticides. Though the end-users (agricultural advisers and farmers) benefitted from the TOPPS project, its first results are very difficult to use at the field level and the end-users are not very flexible in terms of selecting a set of proposed mitigation measures.

To overcome these problems and to address the problem of water pollution with pesticides at the field level, the French agricultural institute ARVALIS – Institut du végétal launched a project EVADIFF (EVAluation of existing models and development of new decision-making tools to prevent DIFFuse pollution caused by plant protection products), whose purpose is to upgrade the approach used in the TOPPS project through a combination of existing expert knowledge collected in the framework of the TOPPS project and experiences that ARVALIS experts obtained from the application of different crop management practices on the reduction and elimination of water pollution with pesticides.

The aim of this paper is to combine and structure domain knowledge of risk assessors and risk managers into a decision support system (DSS) comprised of risk assessment and risk management decision modules for pesticides approved for use in the agriculture. The DSS should be applicable on the field level and it should give its end-users (e.g., farm advisers) flexibility regarding the choice of mitigation measures from the list proposed by the decision support system.

2 POST MARKET RISK ASSESSMENT

To propose the methodological solution for post-market assessment of water pollution with pesticides, we used the approach proposed by the US Environmental Protection Agency (EPA). The methodology evaluates the likelihood that adverse ecological effects may occur or are occurring because of an exposure to one or more stressors [7]. The methodology does not rely only on deterministic descriptions of the studied system using empirical data, but it takes into account also expert knowledge accumulated through empirical systematic observations and management experiences.

To evaluate the potential transfer of applied pesticides to the water and to find the appropriate management solutions to reduce or eliminate the pollution if identified in the prior step, the EPA methodology proposes to combine risk assessment and risk management respectively.

The risk assessment is performed in the context of what techniques one should use to objectively describe and evaluate the pollution risk. The results of risk assessment are primarily for providing information and insight to those who make decisions about how that risk should be managed. The process of combining a risk assessment with decisions on how to address that risk is a central task of ecological risk management. This includes decisions about whether to respond to an assessed level of ecological risk and which of the provided alternatives should be selected. As such, both ecological risk assessment and risk management require combining the results from decision modelling for either diagnosis (assessment) or mitigation purposes.

3 METHODOLOGY

To achieve the research objectives, we used two complementary approaches which we implemented in two methodological modules. The first module deals with the assessment of ecological risk of water pollution with pesticides and the second module addresses risk management, which analyses and compares various alternative mitigation measures in order to prevent water pollution by pesticides used in crop management.

To assess the ecological risk, we have focused first on the determination of the prevailing water pathways in a field, and on the assessment of their flow intensities, time in and duration during the crop growing season. Regarding the water flow types, we focused on surface runoff, drainage runoff and infiltration. For individual water pathways we assessed the risk that they could pollute surface and ground water with the transfer of pesticides. The results of the assessment of ecological risk are used as input data in the second module.

The second module deals with risk management. Its goal is to analyse and compare the various alternative mitigation measures to reduce the pollution risk that is assessed in the first module. The result of the risk management module is a list of mitigation measures that the end-user may use to protect water from pesticides applied in the field for crop management purposes.

To integrate the existing expert knowledge, we used a methodology originally developed for Multi Criteria Decision Analysis (MCDA) to generate multi-attribute decision models (MADM) of risk assessment and risk management. The approach is based on a hierarchical integration of subcomponents (e.g., water pathways, used active substance, applied soil management techniques, application time of pesticides, etc.), forming several hierarchical levels beginning with the integration of basic attributes at the lowest hierarchical level.

In general, MADM are built by a quantitative approach using the numeric values of attributes [8], while we generate MADM using a DEX (Decision EXpert) integrative methodology [9], which is based on attributes with a finite set of qualitative (nominal) values instead of attributes with numerical values. The integrative functions in DEX are adjusted for qualitative variables and therefore represented with if-then rules, which are given in a tabular form compared to the more common weight-based integration functions used in quantitative multi-attribute decision modelling. The DEX methodology enables the construction of a transparent and comprehensive models and it provides mechanisms for presenting aggregation rules in a user friendly way, i.e. in the form of decision trees.

In addition to the mere evaluation of alternatives, the DEX methodology provides what-if examination analysis of alternatives. Both possible applications of the DEX methodology were used in our research. The evaluation of alternatives was used for risk assessment (module one), while the what-if analyses were used for selection of mitigation measures in the risk management module (module 2). The decision models were built with the software modelling tool DEXi, which is based on the DEX methodology. DEXi facilitates the development of qualitative MADM [10] and enables an evaluation and analysis of decision options. This is particularly useful for complex decision-making problems, where an option that satisfies the goals of decision makers has to be selected from a set of possible ones (e.g., mitigation measures).

4 THE EXPERT KNOWLEDGE

The expert knowledge that we used to build qualitative multi-criteria decision models for risk assessment and risk management was obtained from experts involved in the TOPPS project and experts for pesticide use from ARVALIS. The decision models were evaluated on data obtained from the experimental station La Jaillière, which is located in western France and managed by ARVALIS. The data are collected on 11 fields from 1987 on. Each field is described with data about water pathways (duration and water quantity) and the concentrations of active substances in water outflows (total 76 active substances). Beside data related to water outflows, meteorological data and data about applying soil and crop management measures were also collected.

5 RESULTS

The decision models for risk assessment and risk management are the central parts of the DSS of plant protection products approved for use in agriculture. The conceptual diagram (Fig.1) shows the structure of the DSS. The input to the DSS is a proposed crop management plan from which several data are extracted and pre-processed for ecological risk assessment. There are two types of input data: the first type consists of data describing the soil hydrological properties of the assessed field (water pathway, flow/drainage period, soil properties) and the second type consists of data describing the crop management plan for that field (crop, pesticide application time, active substance, dosage).

Because the transfer of pesticides to the surface or ground water is made by water flows, the central focus of the risk assessment module is on assessing the prevailing water pathways in a field. In this study, the surface runoff and infiltration were the two general types of water pathways, but due to local soil hydrological specifics, we divided these two categories into a few subcategories. Beside infiltration, we took into account also drainage outflows from the fields with installed tile drainage system that drains the surplus of soil water from the fields. Regarding the surface runoff category, we made a distinction between runoff by saturation, simple surface runoff and runoff on capping soil.

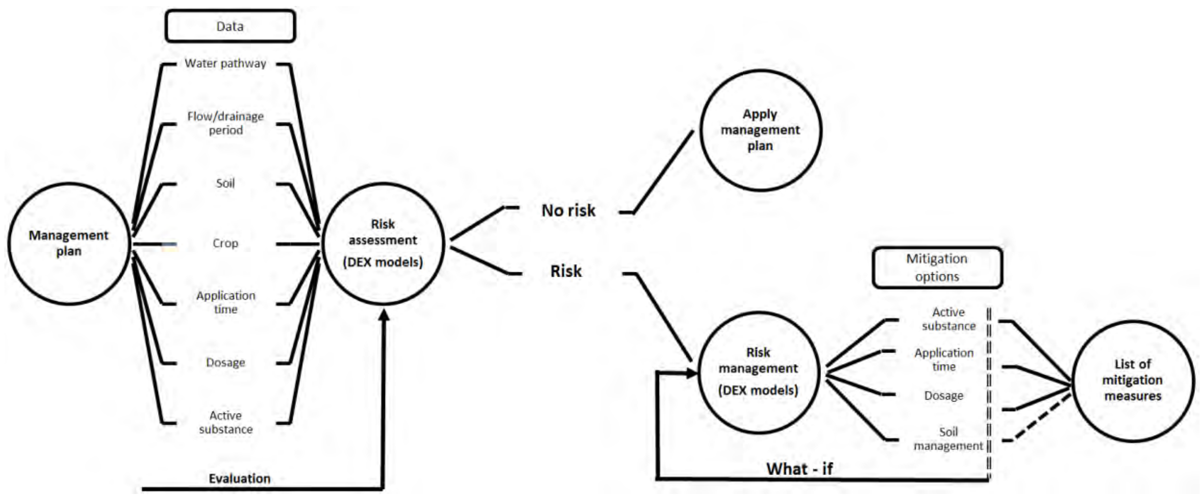

Figure 1: A conceptual diagram of the decision support system for assessing the risk of water pollution by pesticides and for proposing a list of mitigation measures if the risk of pollution exists.

According to the data describing the soil hydrological properties of the assessed field, the DSS first assesses the prevailing water pathway and its intensity. It selects the water pathways with the most intensive flows and in combination with data describing the crop management plan (crop, pesticide, planed application time of pesticide and dosage) makes an assessment of the pollution risk that the prevailing water pathways might cause with the transfer of the pesticides into surface or ground water.

In case the ecological assessment of the proposed crop management plan does not predict any risk for the environment, the management plan can be applied as such. But if the ecological assessment predicts a risk of pollution, the management plan is given as input to the risk management module of the DSS. Its goal is to find which of the planned management measures should be changed in order to avoid the risk of water pollution.

Usually the end-users have technical and financial constraints regarding the selection of mitigation measures. Therefore, they would prefer changes of only a few components of the management plan. In our case, the system can propose mitigation measures with a selection and combination of four suitable mitigation measures to avoid the risk of water pollution: change of the application time of a pesticide depending on the intensity of water pathways; change of dosage; change of the type of active substance; and change of soil management (tillage, no tillage). The risk management module iteratively searches for a combination of suitable mitigation options that would reduce the level of pollution risk to an acceptable level. In order to give the end-users flexibility in terms of their management preferences, the risk management module proposes a list of several possible solutions from which the end-users can choose the one that best fits their management capacity.

To demonstrate how the DSS works for a particular case, we demonstrate its use in the case of maize production in a field with an installed drainage system (Fig. 2). The proposed management plan described in Fig. 2 is assessed as ecologically risky, therefore, the risk management part proposes a list of mitigation measures that the end-user may apply on his field without any risk of water pollution by pesticides.

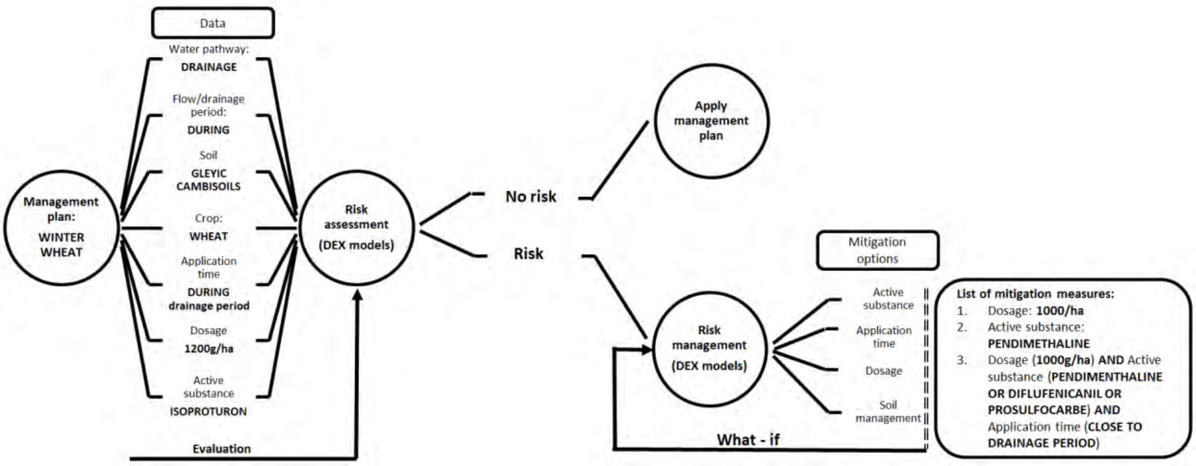

Figure 2: The application of the decision support system to assess the risk of water pollution by isoproturon planned to be applied to winter wheat at a dosage of 1200 g/ha during the winter drainage period. The proposed management plan is assessed as risky, therefore the risk management module proposes a list of mitigation measures.

6 CONCLUSIONS

Since the post market ecological risk assessment of pesticides approved for use in crop management is not as developed as pre-registration assessment, the decision support system presented in this paper makes an important contribution to this very serious environmental issue. The applied MCDA built through the DEX methodology has enabled us to structure the existing expert knowledge according to the approach proposed by the EPA. The applied methodology facilitated the representation of existing domain knowledge about pesticide use and environmental protection crop management measures.

The results have been recognized as very useful because they address different aspects, ranging from the assessment of ecological risk, comparisons of assessed risk under different settings of input data, and what-if analyses of mitigation options that generate a list of mitigation measures for reduction and elimination of assessed pollution risk by pesticides. The results are applicable at the field level and give large flexibility to end-users in terms of their selection of mitigation options.

Since knowledge and practical experiences accumulate through time, the applied methodology enables improvement of the DSS with the latest expert knowledge. The general structure of the DSS presented in Figure 1 can potentially be very widely applicable, given enough knowledge about local soil properties and soil hydrology is available. The presented DSS could be easily implemented as a web application and put into everyday on-site use by advisors.

Acknowledgement

The authors wish to acknowledge the support of the project EVADIFF (Evaluation of existing models and development of new decision-making tools to prevent diffuse pollution caused by phytopharmaceutical products) financed by ARVALIS – Institut du vegetal and Florence Leprince from the Department of Scientific Affairs of ARVALIS.

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ASSESSMENT OF CLOUD HIGH PERFORMANCE COMPUTING POTENTIAL FOR SMES

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Abstract: High Performance Computing (HPC) services offered in cloud are believed to be one of the key competitiveness enablers for companies of all sizes throughout the world. On the EU level several measures, like experiments funding, have been taken to boost adoption among SMEs, particularly manufacturing. However, HPC adoption is in its early stages, and business models are not yet fully explored. In order to support perspective business ideas, and assure transparent and efficient public funds spending, there is a need for assessment of the SMEs potential prior to funding the experiments. Assessment relies on many criteria and stakeholders. Currently, there are some tools developed for selection of the experiments, but they are not complete and rely mostly on individual assessment of designated reviewers. The aim of this paper is to propose a qualitative multi-criteria model for SMEs' cloud HPC potential assessment. Using Decision EXpert methodology (DEX), the model is based on theoretical and practical knowledge, elicited from experts and use cases. The model will be verified on a set of experiments conducted within several EU projects in I4MS initiative.

Keywords: High Performance Computing, Cloud services, Assessment Criteria, Multi-Aattribute Modelling, DEXi

1 INTRODUCTION

High Performance Computing (HPC) refers to computing performance needed for solving complex computing problems that could not easily (or timely) be computed by typical desktop computers. It is generally used for solving large scale problems in science, engineering and business [1]. So far HPC was mainly reserved for the large companies and research institutes, who could afford high costs that are associated with HPC. From the industry perspective the HPC is predominantly used in manufacturing sector with financial sector just behind it [2].

In recent years cloud computing services has reached high adoption rates among companies, also SMEs [3] and so the possibility of hiring HPC services in the cloud became immanent [4]. However, moving HPC to cloud services is the one least exploited, especially among SMEs [5]. The problem lies not merely in high costs but predominantly in the lack of competencies (knowledge, maintenance, proprietary software etc.). One of the promising changes is identified in redefining a business model, which consists not only in hiring HPC services in the cloud, but includes also other services of modelling, maintenance, implementation, and software adaptation. In this way HPC services can become an interesting opportunity for other industries, as well as for the SMEs [6].

Across the EU, there were 21.2 million SMEs (99.8%) in the non-financial business sector in 2013 [6]. The number of manufacturing SMEs, its added value and employment is still below that of the year 2008 and is anticipated to shrink in 2015. However, it is still a very important sector, employing more than 17 million individuals and generating 21% of SME added value in Europe [6]. It is believed that this group particularly can benefit from adopting new technologies, such as HPC, and become successful on the global market, and a leading sector in EU.

On the global level governments are investing in boosting the adoption of cloud HPC [7, 8]. The European initiative ICT Innovation for Manufacturing SMEs (i4MS) is set to support the European leadership in manufacturing through the adoption of ICT technologies. In fact, Europe's competiveness in this sector depends on its capacity to deliver highly innovative products, where the innovation often originates from advances in ICT [9]. Within i4MS initiative four areas are supported: robotics, HPC cloud based simulation services, laser based applications, and intelligent sensor-based equipment. By developing and supporting new business ideas, particularly the use of HPC services in manufacturing SMEs, the initiative aims to foster the new economic growth and competitiveness.

Several projects within i4MS address adoption of HPC cloud services by selecting experiments for showcasing the best practices, develop, test and demonstrate the use of infrastructure and the business model as a one-stop pay-per-use shop. Experiments include all actors (SME, Innovation centres/clusters, experts, code providers) throughout the value chain of an innovation ecosystem. One of the important propositions of the initiative is the "development of a sustainable business model, which is crucial for the successful adoption of these services" [9]. Therefore, general criteria for selection of an experiment are: demonstration of HPC needs for new product development in manufacturing industry; should be end-user driven, address a real use-case, and demonstrate the use of HPC and high potential to benefit from cloud technology [10].

The problem addressed in this paper is the selection of appropriate experiments to facilitate the early adopters and early majority group in order to boost the competitiveness of the European manufacturing SMEs. There are some tools developed, like questionnaires and selection criteria, mostly for the purpose of open call proposals evaluation, that are not complete and are mostly designed to rank the proposals and decide what to fund or not.

1.1 Related work

There are several studies focusing on identifying factors influencing adoption of cloud services in SMEs, mainly through researching adoption factors business perspective, and technology, and security from both vendors and users perspective [11, 12]. There are scarce studies on the topic of decision support and cloud computing services, predominantly from the viewpoint of web-based decision support systems [13] and decision support on migration to the cloud [14, 15].

To address the problem of assessing the potential of cloud HPC services adoption we propose a qualitative multi-attribute decision model based on DEX methodology. The proposed methodology belongs to Multi-Attribute Decision Making (MADM), which is rooted in the decision theory and utility theory, and well accepted in practice.

Multi-attribute decision modelling is a process of evaluation in which we develop the model that supports the alternative evaluation according to the stated goals and preferences. The model is based on a set of criteria, parameters, variables and factors, recognized in the process of decision-making. MADM is a formal basis for model development, where the basic problem is in integrating individual parameters into a final value. Core of the model is based on the methods of expert knowledge modelling of the expert systems, which support the transparent evaluation and reasoning [16]. These methods, however, are not compensating the human decision-maker, but can contribute to more systematically and organized decision-making. Supported by such models, the decision maker is stimulated to understand the problem, to reduce the possibility of error or missing important factors [16].

This research contributes to the discussion of how to identify SMEs with best potential, engage them in public funding schemes and stimulate the adoption of cloud HPC services. Based on literature review on HPC and cloud services adoption, and expert interviews, during several iterations, we propose a qualitative multi-attribute decision model, which can support both vendors of cloud HPC services and SMEs in this decision-making process.

2 METHODOLOGY

The proposed methodological approach is rooted in Design Science Research [17, 18], which dates back as early as 1990 [19, 20] and gained recognition in 2004 by a MISQ paper [17]. Its basic philosophy derives from other engineering disciplines – where development of an artefact was common. The main driver is developing an IT artefact (construct, model, prototype, instantiation) that will demonstrate practical relevance, and is fundamentally rooted in problem-solving paradigm. On the other hand, "the practical relevance of the research result should be valued equally with the rigor of the research performed to achieve the result" [21]. Three basic cycles of DSR are defined [17]: 1) Relevance (definition of environment, application domain, problem or challenge), 2) Design (iterative artefact building process and evaluation method), and 3) Rigor cycle (theory grounding and contribution to theory and practice).

The IT artefact developed in this study is a model, based on a qualitative multi-criteria decision modelling methodology [22, 23]. Figure 1 presents the process of DEX modelling in the context of DSR cycles.

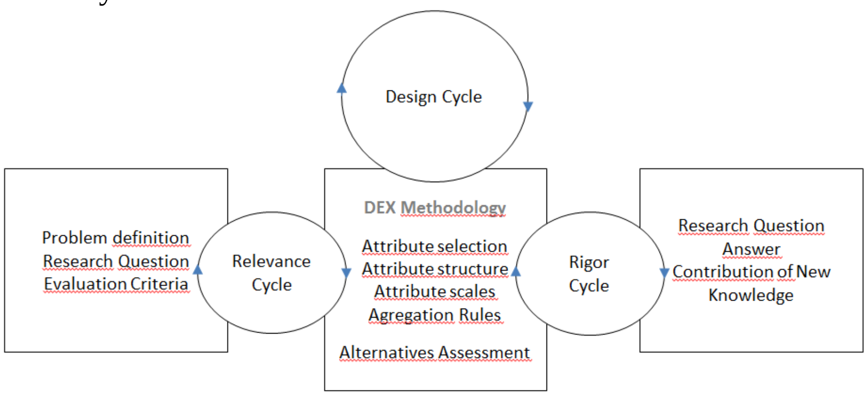


Figure 1: Research design

DEX (Decision EXpert) belongs to a qualitative multi-attribute decision modelling methodology, based on an integration of multicriteria decision modelling with rule-based expert systems [24]. A qualitative multi-attribute model, with which decision alternatives are evaluated and analysed, is developed by a team of decision modelling and domain experts. The model itself represents a decomposition of the decision problem into smaller, less complex sub-problems. The decomposition is represented by a hierarchy of attributes. Attribute scales are qualitative; therefore they are easily understood by the decision-makers. Basic problem represents the aggregation of individual parameter values to a final value (criteria function). Furthermore, the parameter interdependencies, weak determination or ability to measure, and changing influence (weight) make the modelling a complex task. Domain knowledge is modelled by a combination of hierarchical tree of attributes and aggregation based on "if-than" rules. The result is the transparent evaluation, which supports the explanation of the evaluation results and the decision-making process itself [16].

In this paper we model the assessment of SMEs readiness to use the HPC services in cloud as a complex decision-making problem. Our aim, to develop a multi-attribute decision model, is based on the proposition that such a model can be built using DEX methodology and utilized on a set of real-world problems. Two assumptions have to be met: 1) ability to observe and measure criteria in a real-life environment and 2) transparent assessment of SMEs HPC cloud readiness.

3 RESULTS

3.1 Attributes identification

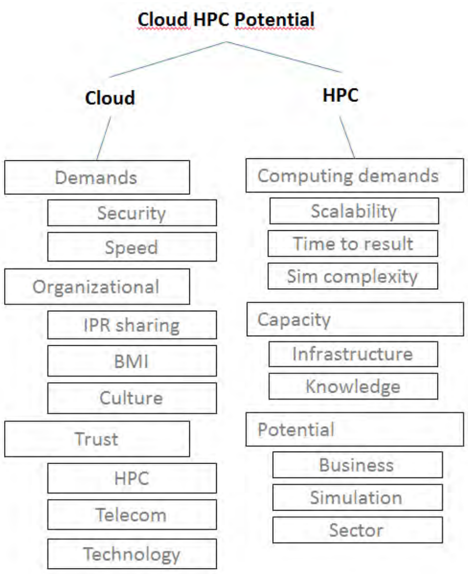
Attributes were defined on the basis of literature review, experiment call for proposals [9, 10], current experiments, 15 experiment proposals, and in a set of group interviews with domain experts (3 rounds of interviews with experts from the fields of HPC, business model innovation, code parallelization). In the first iteration there were 59 attributes identified. In the following iterations the total number of attributes was reduced to 33 basic and 22 aggregate attributes, in total 55 attributes.

3.2 Hierarchical model of decision criteria

From the reviewed documents and interviews we were able to distinct two basic groups of attributes defining the potential of cloud HPC services: Cloud (describing the possibility to use the service in the cloud) and HPC (describing the need for high performance computing). These two groups were further partitioned into subgroups of attributes to the 5th or 6th level Simplified tree of attribute is described in Figure 2.

3.3 Attribute scales

Qualitative attribute scales were defined by domain experts to reflect various phenomenon otherwise difficult to describe numerically (i.e. “Culture”, “BMI”, “trust in HPC provider”). Typically the attribute scales have 3 to 4 values, but the scales of “Cloud” and “HPC” aggregated attributes range from 1 to 4, with final assessment of Cloud HPC potential on a 5 values scale. All scales were ordered from “good” to “bad”.



	Cloud	HPC	Cloud HPC Potential
	47%	53%	
1	not acceptable	<=reassess	No potential
2	not acceptable	>=potential	Low potential
3	reassess	<=reassess	Low potential
4	>=reassess	no potential	Low potential
5	reassess	potential	Medium
6	>=potential	reassess	Medium
7	reassess	*great potential*	*Good potential*
8	>=potential	potential	*Good potential*
9	>=potential	*great potential*	*Great potential*

Figure 2: Hierarchical tree of attributes and a decision table

3.4 Aggregation rules

Values of the basic attributes were determined by the experts, whereas the values of the aggregated attributes are derived by “if-than” rules that are easily understood. These rules in combination with the hierarchical attribute structure provide transparent evaluation and explanation of the evaluation results. A single rule represents a part of domain expert knowledge. DEXi provides an approximation of a linearly weighted sum, but this can be overruled by an expert. This way we can consider non-linearity in the domain knowledge. An example of decision rules, defined by the domain experts, as set in DEXi is presented in Figure 2 on the right.

3.5 Validation of the model

Evaluation of experiments has been conducted in a team of experiment evaluators and proposers. The attribute values were derived mostly from the experiment proposals itself; some information was further elicited from the proposers. In Figure 3 (left) we present two experiments for the purpose of model validation. Results suggest that existing experiments (E1, E2) were evaluated as “acceptable” for the Cloud and “medium” and “reassess” for HPC respectively. Since both experiments were selected for funding, we further analysed E2 (Figure 3). E2* was negotiated in the part, where business model is developed.

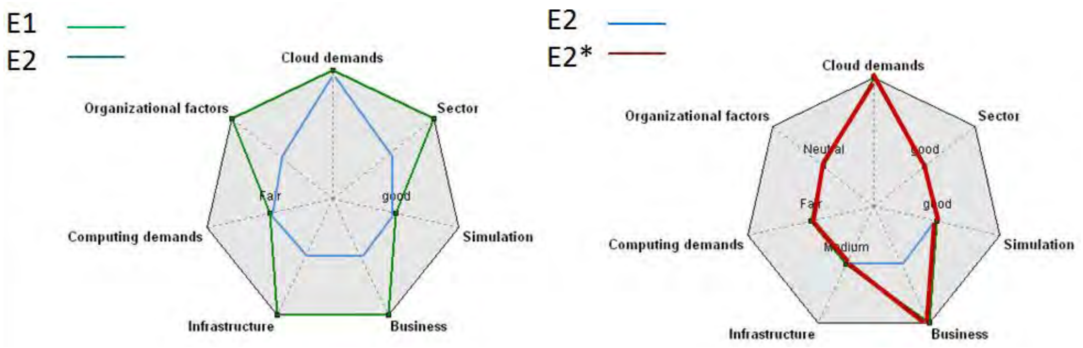


Figure 3: Cloud HPC Potential assessment (left); what if analysis of E2 (right)

4 CONCLUSIONS

HPC offers great potential in new product and services development for the manufacturing SMEs. However, this requires specialized knowledge, infrastructure and software and is as such not available for the SMEs. HPC services offered in the cloud present an important possibility for the SMEs, where other actors in the value chain, such as HPC providers, researchers and other specialists, have an important role in creating new business models.

In order to assess the potential of SMEs, or their proposed experiments, to uptake the cloud HPC services we developed a qualitative multiple-attribute decision model. Together with the domain experts, the attributes were identified, structured in a hierarchical attribute tree, attribute scales were defined and aggregation rules were set. The model was validated by the existing experiments. Based on findings the model will be refined, and further evaluated. Opportunities for using the model in decision and negotiation process were explicated. Preliminary results suggest high usability of the decision model as an assessment tool and the potential to be used in similar set of problems (i.e. business model innovation).

Acknowledgement

This research was funded by Slovenian Research Agency, Grant No. P5-018.

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EMPIRICAL COMPARISON OF THREE METHODS FOR APPROXIMATING DEX UTILITY FUNCTIONS

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Abstract: DEX is a qualitative multi-criteria decision analysis method. It provides support to decision makers in evaluating and choosing decision alternatives, using discrete attributes and rule-based utility functions. This work builds upon our previous attempt of approximating DEX utility functions with methods UTA and ACUTA, aimed at improving the sensitivity of qualitative models and providing an interpretation of DEX utility functions. In this work we empirically compare three methods for approximating qualitative DEX utility functions with piecewise-linear marginal utility functions: Direct marginals, UTADIS and Conjoint analysis. The results show that these methods can accurately approximate complete, monotone DEX utility functions.

Keywords: decision support, multi-criteria decision making, utility function, DEX, UTADIS, conjoint analysis, direct marginals method

1 INTRODUCTION

Multi criteria decision analysis (MCDA) [7] deals with solving decision problems involving multiple, possibly conflicting, criteria. It provides a number of methods to create decision models by using information provided by the decision maker. Provided information can be given in various forms, using different representations. Converting representations from one form to another is often highly desirable, as it can bridge the gap between different methodological approaches and enrich the capabilities of individual ones.

At a general level, this study addresses two types of utility function representations, qualitative and quantitative, and investigates how to convert the former to the latter. At a specific level, we compare three methods of approximating DEX utility functions by piece-wise linear marginal utility functions: the Direct marginals method, UTADIS and the Conjoint analysis method. DEX [5] is a qualitative MCDA method, which employs discrete attributes and discrete utility functions defined in a rule-based point-by-point way (see section 2.1). This makes DEX suitable for classifying decision alternatives into discrete classes. The Direct marginals method (section 2.3) establishes marginal utility functions by a projection of a DEX utility function to individual attributes. UTADIS [6] (section 2.4) is a quantitative method that constructs numerical additive utility functions from a provided subset of alternatives and assigns this alternatives to predefined ordered groups. Conjoint analysis [8] (section 2.5) is a method that constructs numerical additive utility functions through determining attribute importance, the appropriate importance levels and the effects of combining different attributes on the measured variable. The three methods were experimentally assessed on a collection of artificially generated complete monotone DEX utility functions.

All three methods are aimed at providing an approximate quantitative representation of a qualitative DEX function. This extends the capabilities of DEX and is useful for several reasons. First, the newly obtained numerical evaluations facilitate an easy ranking and comparison of decision alternatives, especially those that are assigned the same class by DEX. Consequently, the sensitivity of evaluation is increased. Second, the sheer form of numerical functions may provide additional information about the properties of underlying DEX functions, which is useful in verification, representation and justification of DEX models. In this study, we focus on the accuracy of representation.

There have been several previous attempts to approximate DEX utility functions. A linear approximation method is commonly used in DEX to assess criteria importance [3]. An early method for ranking of alternatives and improving the sensitivity of evaluation called QQ [12] has been proposed in [2]. Recently, extensive research has been carried out to approximate DEX functions with copulas [12]. This paper builds upon our previous work on approximating DEX utility functions by using methods UTA and ACUTA [11]. The methods used in the present study were chosen because they do not have convergence issues when approximating discrete functions as opposed to the methods tried in [11].

2 METHODS

2.1 DEX method

DEX [5] is a qualitative MCDA method for the evaluation and analysis of decision alternatives, and is implemented in the software DEXi [4]. In DEX, all attributes are qualitative and can take values represented by words, such as *low* or *excellent*. Attributes are generally organised in a hierarchy. The evaluation of decision alternatives is carried out by utility functions, which are represented in the form of decision rules.

In the context of this paper, we focus on individual utility functions. For simplicity, we assume that all attributes are ordinal and preferentially ordered, so that a higher ordinal value represents a better preference. In this setting, a DEX utility function f is defined over a set of attributes $\vec{x} = (x_1, x_2, \dots, x_n)$ so that

$$f : X_1 \times X_2 \times \cdots \times X_n \to Y$$

Here, $X_i, i = 1, 2, \dots, n$, denote value scales of the corresponding attributes x_i, and Y is the value scale of the output attribute y:

$$X_i = \{1, 2, \dots, k_i\}, i = 1, 2, \dots, n \quad \text{and} \quad Y = \{1, 2, \dots, c\}$$

The function f is represented by a set of decision rules

$$F = \{(\vec{x}, y) | \vec{x} \in X_1 \times X_2 \times \cdots \times X_n, y \in Y, y = f(\vec{x})\}$$

Each rule $(\vec{x}, y) \in F$ defines the value of f for some combination of argument values $\vec{x}$. In this study, we assume that all functions are *complete* (defined for all combinations of argument values) and *monotone* (when argument values increase, the function value increases or remains constant).

2.2 Approximation of DEX utility functions

All methods assessed in this study are aimed at approximation of some DEX utility function f with marginal utility functions $u_i : X_i \to \mathbb{R}, i = 1, 2, \dots, n$. The functions u_i are assumed to take a piece-wise linear form: the numeric value of $u_i(v)$ is established from f for each $v \in X_i$, while its value for $v \notin X_i$ is linearly interpolated from the closest neighbouring points.

On this basis, f is approximated as a weighted sum of marginal utility functions:

$$u(x) = u(x_1, x_2, \dots, x_n) = \sum_{i=1}^{n} \omega_i u_i(x_i)$$

Here, $\omega_i \in \mathbb{R}, i = 1, 2, \dots, n$, are weights of the corresponding attributes, normalised so that $\sum_{i=1}^{n} \omega_i = 1$.

2.3 Direct marginals method

The direct marginals method establishes the marginal utility function $u_i(v)$ as an average value of target attribute y for decision rule $a \in F$, where $x_i(a) = v$. Let $F_{i,v} \subset F$ denote all decision rules where $x_i(a) = v$. Then

$$u_i(v) = \frac{1}{|F_{i,v}|} \sum_{\{a \in F \ | \ x_i(a)=v\}} y(a), \quad i = 1, 2, \ldots, n, \quad v \in X$$

In the experiments (section 2.6), all functions $u(x)$ were scaled to the $[0,1]$ interval, therefore importance weights for attributes were computed as a percentage of total utility range covered by the range of a particular attribute.

2.4 UTADIS method

The UTADIS method [6] is an extension of UTA (UTilités Additives) method [9] that enables decision maker to assign alternatives to predefined ordered groups. Thus it is very well suited to our problem of approximating discrete DEX functions, assuming that each DEX decision rule $a \in F$ defines some (hypothetical) decision alternative. UTADIS approximates u_i as:

$$u_i(x_i(a)) = u_i(x_i^J) + \frac{x_i(a) - x_i^J}{x_i^{J+1} - x_i^J}[u_i(x_i^{J+1}) - u_i(x_i^J)]$$

It is assumed that each alternative values are divided to $(\alpha_i - 1)$ equally sized intervals $[g_i^J, g_i^{J+1}]$. The alternatives are assigned to groups by using thresholds t_i: $u(x_j) \geq t_1 \Rightarrow a \in C_1,\ t_2 \leq U(g_j) < t_1 \Rightarrow a \in C_2, \ldots, U(g_j) < t_{c-1} \Rightarrow a \in C_c$.

UTADIS searches for marginal utility functions by solving the linear programming problem $min\ E = \sum_{k=1}^{c} \frac{\sum_{a_j \in C_k} \sigma(a)_j^+ + \sigma(a)_j^-}{m_k}$, where σ^+, σ^- denote errors after violation of upper/lower bound of a group C_k and m_k denotes a number of alternatives assigned to the group C_k.

2.5 Conjoint analysis method

Conjoint analysis [8] is designed to explain decision maker's preferences. It outputs attribute importance, their interactions and utility functions for each attribute in a decision making problem. The original decision table is transformed in a binary matrix x_b, that encodes the original attribute values by using a fixed number of bits. This matrix is used to compute a matrix of deviation scores $x = x_b - \mathbb{1}\mathbb{1}^\tau x_b(\frac{1}{n})$. The utility value is computed as $b = (x^\tau x)^{-1} \cdot (x^\tau y)$, where y denotes a vector containing deviation scores of the target variable. Attribute importance is obtained by observing the percentage of total utility range covered by the range of a particular attribute.

2.6 Experimental procedure

The goal of experiments was to assess and compare the performance of the three methods – Direct marginals, UTA, and Conjoint analysis – on artificially generated, complete, and monotone DEX utility functions. For this purpose, we generated all monotone functions for spaces with dimensions $3 \times 3 \to 4$, $3 \times 4 \to 3$, $4 \times 4 \to 3$ and $5 \times 6 \to 7$ (The notation $3 \times 3 \to 4$ denotes the space of all utility functions having two three-valued arguments, that map to 4 values). Evaluation was also performed on several randomly generated function sets of different sizes: $3 \times 4 \times 3 \times 5 \to 6$, $4 \times 5 \times 5 \to 6$, $5 \times 6 \to 7$, $6 \times 7 \to 7$, $8 \times 7 \to 7$ containing 1000 functions, and $3 \times 5 \times 3 \times 4 \to 4$ containing 100 functions.

The experimental procedure consisted of predicting the target utility function for all the generated functions by using three selected methods, and computing evaluation scores for each method's resulting utility function. Two measures were used for evaluation: the Area Under the Curve (AUC) and the Root Mean Squared Error (RMSE). Finally, we computed the average of AUC and RMSE with corresponding standard deviation for sets of functions with given dimensions to compare method performance on the whole function set. Since these methods compute utility values in different ranges, all the functions were scaled to the $[0, 1]$ interval.

All experiments were performed in R programming language by using 'MCDA' [10], 'conjoint' [1] and 'pROC' [13] R packages. In addition, we implemented Direct marginals method, the RMSE measure, monotone function generator that generates all monotone functions in some space with given dimensions, and a random monotone function generator that generates a number of random monotone functions in a space with given dimensions.

3 RESULTS

In this section we present results of approximating DEX utility functions with methods Direct marginals, Conjoint analysis and UTADIS. A thorough evaluation can be seen in Table 1.

method	space dimension	num.	avg. AUC	avg. RMSE	succ.
Direct marginals	$3 \times 3 \to 4$	979	0.996 ± 0.015	0.532 ± 0.246	100%
	$3 \times 4 \to 3$	489	0.998 ± 0.011	0.404 ± 0.162	100%
	$4 \times 4 \to 3$	2014	0.995 ± 0.013	0.416 ± 0.135	100%
	$5 \times 6 \to 7$	1000	0.981 ± 0.021	0.981 ± 0.354	100%
	$6 \times 7 \to 7$	1000	0.978 ± 0.021	1.0 ± 0.327	100%
	$8 \times 7 \to 7$	1000	0.975 ± 0.023	0.980 ± 0.308	100%
	$4 \times 5 \times 5 \to 6$	1000	0.945 ± 0.025	1.056 ± 0.245	100%
	$3 \times 4 \times 3 \times 5 \to 6$	1000	0.921 ± 0.027	1.145 ± 0.225	100%
	$3 \times 4 \times 5 \times 3 \times 4 \to 4$	100	0.928 ± 0.018	0.818 ± 0.101	100%
Conjoint analysis	$3 \times 3 \to 4$	979	0.989 ± 0.026	0.564 ± 0.236	100%
	$3 \times 4 \to 3$	489	0.990 ± 0.026	0.416 ± 0.159	100%
	$4 \times 4 \to 3$	1763	0.987 ± 0.025	0.423 ± 0.132	100%
	$5 \times 6 \to 7$	1000	0.971 ± 0.027	1.014 ± 0.329	100%
	$6 \times 7 \to 7$	1000	0.967 ± 0.028	1.023 ± 0.305	100%
	$8 \times 7 \to 7$	1000	0.964 ± 0.029	0.996 ± 0.291	100%
	$4 \times 5 \times 5 \to 6$	1000	0.925 ± 0.033	1.056 ± 0.233	100%
	$3 \times 4 \times 3 \times 5 \to 6$	1000	0.896 ± 0.035	1.142 ± 0.214	100%
	$3 \times 4 \times 5 \times 3 \times 4 \to 4$	100	0.904 ± 0.028	0.808 ± 0.102	100%
UTADIS	$3 \times 3 \to 4$	979	0.970 ± 0.063	0.722 ± 0.293	99.7%
	$3 \times 4 \to 3$	489	0.976 ± 0.064	0.567 ± 0.215	99.6%
	$4 \times 4 \to 3$	1763	0.972 ± 0.069	0.567 ± 0.212	99.9%
	$5 \times 6 \to 7$	1000	0.931 ± 0.065	1.569 ± 0.688	100%
	$6 \times 7 \to 7$	1000	0.924 ± 0.064	1.574 ± 0.646	100%
	$8 \times 7 \to 7$	1000	0.916 ± 0.068	1.545 ± 0.672	100%
	$4 \times 5 \times 5 \to 6$	1000	0.898 ± 0.054	1.299 ± 0.389	100%
	$3 \times 4 \times 3 \times 5 \to 6$	1000	0.880 ± 0.049	1.292 ± 0.312	100%
	$3 \times 4 \times 5 \times 3 \times 4 \to 4$	100	0.911 ± 0.034	0.875 ± 0.151	100%

Table 1: Comparison results for the Direct marginals, Conjoint analysis and UTADIS method on various generated DEX monotone utility functions. For each method and space dimensions, the columns show the number of utility functions (num.), average AUC and RMSE with standard deviation, and the percentage of successfully approximated functions (succ.).

The results from Table 1 show that all three methods can approximate the majority of artificially created complete monotone DEX utility functions; only UTADIS returns errors when faced with trivial functions (containing equal target value for every alternative), which is likely a problem of implementation. The Direct marginals method achieved the best evaluation score on all tested functions in both AUC and RMSE measures and is closely followed by the Conjoint analysis method. UTADIS method has somewhat lower results and higher standard deviation. The results indicate that the AUC value decreases with the increase of function domain dimensions and the cardinality of attribute value set for all tested methods (see Figure 1). Results for the RMSE measure are little less conclusive. The error rises slowly for the Conjoint analysis and Direct marginals method but drops for UTADIS method. AUC increase and RMSE decrease on the last dataset could be caused by a small generated function sample (100 random functions) and the fact that the target attribute could have only 4 different values.

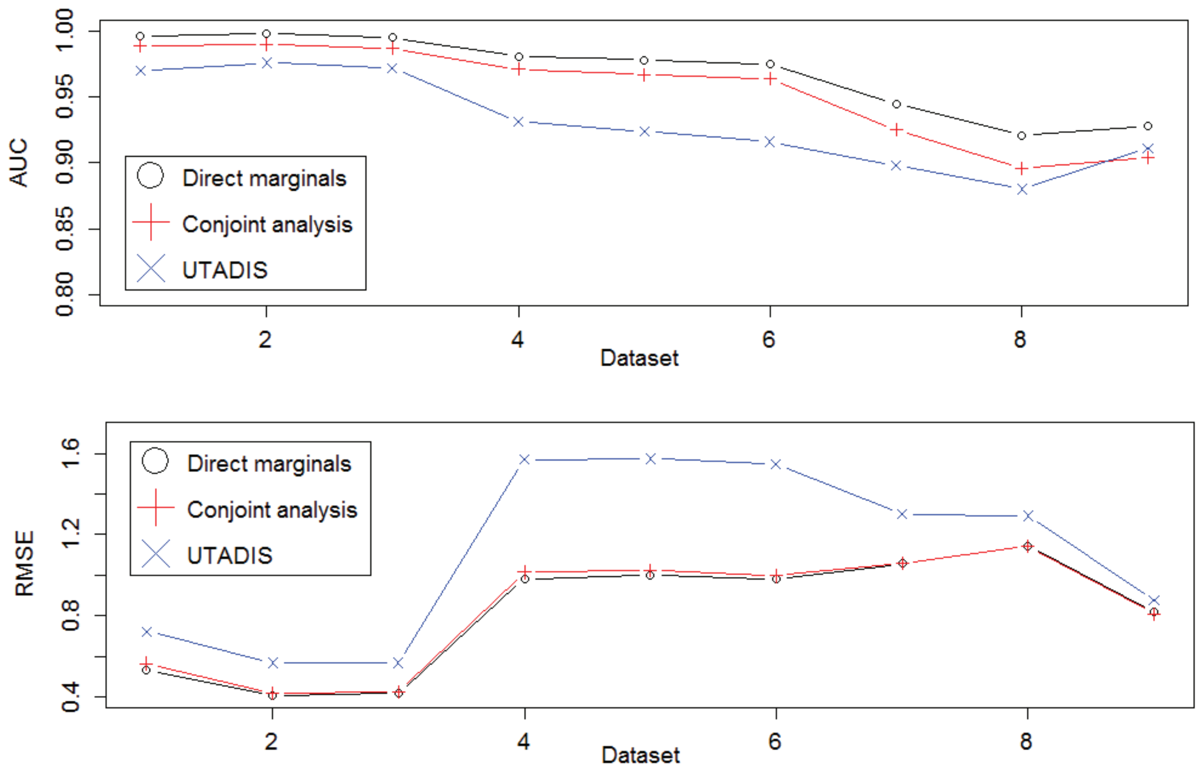

Figure 1: AUC and RMSE comparison for all three methods. Function sets are presented in the same order as in Table 1.

4 CONCLUSION

In this work we presented a new method for approximating monotone DEX utility functions, the Direct marginals method, and compare its performance with two known decision support methods: UTADIS and Conjoint analysis. The methods were evaluated on several sets of randomly generated functions with domains of different dimensions and the resulting utility functions were scaled to the $[0, 1]$ interval, to allow comparative analysis. The overall quality of approximation is assessed by using multi-class AUC and RMSE measures. The Direct marginals method outperformed other approaches on all test functions with respect to the AUC method and on majority of test functions with respect to the RMSE measure. Conjoint analysis follows very closely. All tested methods give fairly good approximations of monotone DEX utility functions and give additional insight into decision makers preferences on attribute level, but also between different attributes. We believe that such insight might be useful for different decision problems, for instance, product manufacturers to evaluate their products and locate important and interesting features that should be improved or changed to satisfy their customers.

In the future work, we would like to address the problem of approximating incompletely defined DEX functions and DEX functions defined with distribution of classes.

5 Acknowledgements

We would like to thank prof. Lavoslav Čaklović for introducing us to Conjoint analysis method.

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MANAGING DIFFERENT INTERESTS IN GROUP DECISION MAKING

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Abstract: The paper discusses group decision making in the frame of multi criteria decision knowledge modelling. Described are pros and cons of group decision making. Special emphasis is given to the leveraging of different interests and possibilities of formulating a joint decision. Available methods and techniques together with a properly organized group work can make a substantial contribution.

Keywords: decision making, multi criteria, knowledge modelling, groups, conflict of interests

1 INTRODUCTION

There is probably no apparent reason for doubting the old proverb »More heads are better than one« in decision making. Still, it is useful to understand the advantages of participating in a group compared to decisions made by an individual. Clearly, such an approach may also be met by certain problems as implies the proverb that »Too many cooks spoil the broth«.

The purpose of this contribution is to present how people work with one another in a decision group through stages of decision knowledge acquisition, processing and use. In other words it deals with *management of decision knowledge*. Special emphasis is on qualitative multi criteria decision making and its added value [6], [13]. Group decision making assumes participation of different people. It is a process in which two or more people influence one another while the decision is being carried out. Usually, the decision in question will affect those participating or their representatives at some point in the future. Participation is furthermore built around the idea of *different interests* that need to be integrated into a *joint decision* [8], [17], [18].

What is the role of operational research methods and techniques in facilitating decision making? Specifically, what can be expected from the information communication technology (ICT) that lies at our disposal? During the decision making as a socio-technological process we can justly count on the *synergy between a human and technology*. According to Dreyfus [10] neither human nor computer can achieve on their own what they can achieve together. It is by far not enough to be aware of existing methods, techniques and technologies. Group decision making has to be appropriately organized. The individual and the group have to be technologically literate. The aim is to harmonize the work among the members of the decision group by using different evaluation and decision making tools [2], [4], [18].

2 HOW TO MANAGE CONFLICTING INTERESTS?

It is completely natural for people to come to different decisions on the same issues. It is due to differences in preferential knowledge what can be attributed to differences in relations to the decision situation, values, principles, understanding of circumstances, knowledge and lack thereof. A decision regarding a new family car is subject to differences in preferences among parents and children, for instance.

On the basis of preferential knowledge a preferential relation between alternatives is established. This way they are listed according to their desirability – utility. An evaluation model can also be used to assess the degree of desirability of a specific alternative, for example by assigning scores on a scale from 0 to 10. Children and parents assess different cars in a different way.

How to merge different scores in order to reach a single decision? First we should check if different scores are not due to insufficient knowledge regarding goals, alternatives and possibilities. Providing arguments for one's different preferences can be helpful. Afterwards we face the different interests.

We differentiate among two basic approaches that are founded on the distinction whether different interest groups are willing to cooperate or not in search of a righteous decision or choice.

Those groups that do not wish to consult one another and cooperate can implement one of the formal methods, for example voting. Again, every method has its advantages and disadvantages. Nobel laureate Arrow (awarded Nobel Prize in 1972) [1] demonstrated and proved through the *impossibility theorem* that an ideal method cannot and does not exist. Still, this does not preclude us from group decision making altogether but rather encourages us to look for the most appropriate method in a given situation.

If we decide that each interest group assigns to each alternative its own degree of utility and if they are willing to look for a *compromise solution*, a few other approaches are available [14]. Let us take the two already mentioned interest groups, namely parents and children deciding on a new family car. Each group assesses each car that matches a point in a system of coordinates, for example V1 (value 1 assigned by parents) and V2 (value 2 assigned by children) as shown in Figure 1.

It is sensible to deal with only non-inferior alternatives which lie on the bolded line depicted in Figure 1. Cars below this line have clear superior alternatives with a higher score given by one group and same or higher score given by the other group. Being aware of this can save us quite some further work.

The remaining question is, which of the alternatives that do not fall among the inferior ones should be chosen as a final group decision? If we choose the approach of »equal satisfaction«, graphically this means deciding for the intersection of a straight line connecting points where V1=V2 with a bolded line in Figure 1. Our imaginary family would thus look for a car that would be similarly assessed by both parents and children. Harsanyi [12] proposes to choose the alternative that maximizes the sum of individual utilities. It is disputed that what can occur are situations in which some groups sacrifice their interest for the common good. Nash (awarded Nobel Prize in 1994) proposed leveraging of interests by maximizing the product of utilities (individual utilities multiplied) [15]. In other words, we consider not only ourselves but also others. It is in the group's best interest not to allow sacrificial lamb.

Examples of leveraging in Figure 1 depict leveraging of interest based on final utilities (scores). Decision knowledge is expressed only with the final utility value. Still, we lack the understanding of the origin of the different scores. The final score is only a consequence.

2.1 Multi-attribute group decision making

When we try to leverage the origins of different scores and not only the consequence, that is the final score, we can apply the hierarchical multi-attribute models [4], [14], [13]. They are structured, have internally devised parameters and are open. This is why they not only produce final scores but also enable us to »look inside« and see how and why the scores came about. We can address specific parameters, their values and relationships among them. All of the evaluation elements are at our hand.

Figure 2 shows an example of a tree of criteria constructed to evaluate a car. The basic criteria or the tree leaves are the following: Purchase price, Maintenance costs, Number of doors, Number of passengers, Luggage space, and Safety. Introduced are also intermediate aggregate criteria. Intermediate criterion Price is composed of two sub-criteria, namely Purchase price and Maintenance costs, while intermediate criterion Comfort consists of three basic criteria: Number of doors, Number of passengers, and Luggage space. Intermediate criterion Technical characteristics combines subordinate intermediate criterion Comfort and basic criterion Safety. The criteria were assigned discrete value domains, which can be observed in Figure 2. For basic criteria were used either descriptive or numerical values (Number of doors). Meaning of descriptive values, such as for instance high Price or acceptable Safety, also had to be defined simultaneously.

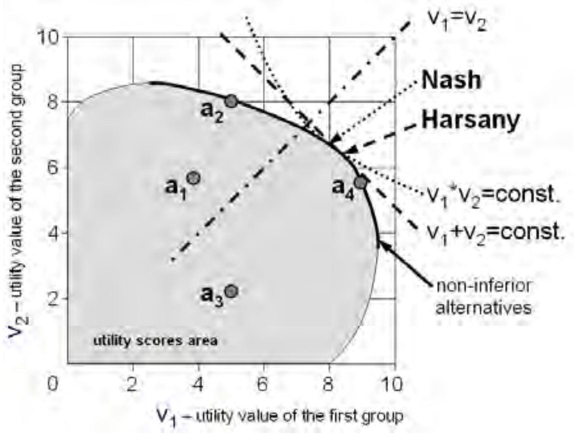

Figure 1: Comparison of alternatives evaluated by two different interest groups

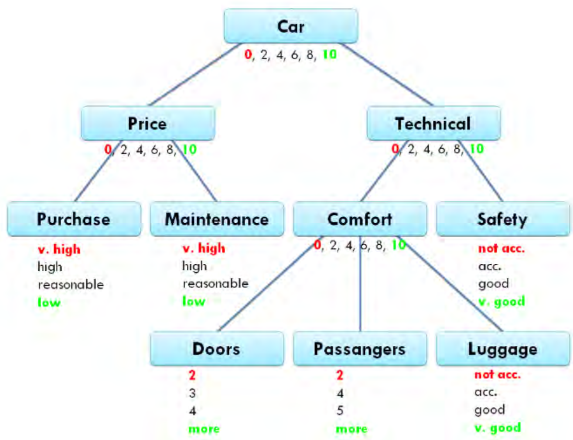

Figure 2: Tree of criteria for car evaluation with value domains

Our experiences [11], [3], [6] show that a unified model structure should be used despite different preferences that may arise due to different interests. Each interest group can however define within this structure its own utility function [16], [13]. The model is then used to evaluate the alternatives for each group separately. Usually, we end up with different scores for the same alternatives. We are not faced with the diversity only when it comes to final scores but can also gain insight into the reasons and origins of the scores provided for specific parameters for each alternative. Instead of leveraging (harmonizing) only the final score, we can investigate at where the differences stem from and what they are like. An explanation helps us realize the key stumbling blocks responsible for disagreements that can serve as a foundation for further interest leveraging among groups.

Figure 3 presents the evaluation score for the alternative Car 3 for parents and children according to all the criteria in the tree structure. Final scores 2 and 4 are inherently different. The difference stems from how the Price and Comfort are perceived. Even though both parents and children consider the Purchase price and Maintenance costs on the same terms, the aggregate score for parents is 6 and for children 8. Let us take a look at the utility functions which are described in table form in Figure 4 and thus establish the source of differences in the scores. Discrepancies are evident in four combinations. Each combination can be interpreted also as a logical rule. For the final score of Car 3 row 14 clearly bears importance. Parents think that low Purchase price and high Maintenance costs yield the value of aggregate score 6, while children think it is 8. Obviously, parents are responsible for financing a car and are far more put off by high Maintenance costs than children. Discussion and negotiations then focus only on the identified differences. Such differences should be discussed and underlying reasons should be made clear. The aim is to reach a decision that is in favour of the decision maker who carries the burden of the discrepancy, in this case the parents providing the financial means.

Attribute	Parents	Children
Car	2	4
— **Price**	6	8
—— Purchase	low	
—— Maintenance	high	
— **Technical**	2	
—— **Comfort**	4	2
——— Doors	3	
——— Passengers	5	
——— Luggage	acc.	
—— Safety	good	

Figure 3: Comparison of different evaluation results for alternative Car 3

	Purchase	Maintenance	Price Parents 58% : 42%	Price Children 64% : 36%
1	v. high	v. high	0	
2	v. high	high	0	
3	v. high	reasonable	0	
4	v. high	low	0	
5	high	v. high	0	
6	high	high	2	
7	high	reasonable	2	
8	high	low	6	4
9	reasonable	v. high	0	
10	reasonable	high	2	
11	reasonable	reasonable	6	
12	reasonable	low	8	
13	low	v. high	4	6
14	low	high	6	8
15	low	reasonable	8	10
16	low	low	10	

Figure 4: Utility functions by parents and children for aggregate criterion Price

3 CONCLUSION

Group decision making is more demanding when differences in preferences of team members are present. Argumentation, why a certain decision was made in a particular way and not the other, increases the probability for a good decision or at least diminishes probability of a bad one. Group decision is more easily understood and can be better justified as we focus only on the differences among team members.

A clear and well justified decision is crucial for a sensible leveraging of different interests. Final score of the alternative is a consequence of numerous factors that appear in the evaluation process. Our decision processes can be and need to be transparent all the way from specific criteria (measures), to their aggregation and final score assigned to an alternative.

Various existing approaches, methods and techniques supported with ICT can be applied [5], [7], [9]. Let us make use of them. We should strive for open and clear models in order to make decision knowledge available to everyone affected. When we are deciding on the most suitable alternative, let us not consider only ourselves but also everyone else involved.

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APPLICATION OF MULTI CRITERIA DEX MODEL IN HOP BREEDING

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Abstract: The planning process in agriculture often requires consideration of many conflicting criteria and participation of multiple stakeholders with conflicting interests. The multi criteria decision method DEX is therefore a viable option for decision support in farm management. This study briefly reviews The DEXi-HOP 1.0 model enables an assessment and ranking of individual hop hybrids' and hop varieties' breeding potentials. The model has 18 attributes, hierarchically grouped within four aggregated attributes: Biology, Chemistry, Morphology and Brewing value. Furthermore, utility functions in the model were defined by sets of elementary decision rules through the entire hierarchy for all aggregated attributes. Four Slovenian hop hybrids, A1/54, A2/104, A3/112, A4/122 and a reference hop variety Hallertauer Magnum with target characteristics in plant resistance and brewing value, were used for the model assessment.

Keywords: multi criteria decision making, DEXi, hop breeding

1 INTRODUCTION

Multi criteria decision analysis can be applied when the evaluation involves several variables that cannot be easily transformed into quantitative units, and the assessment process is likely to be influenced by multiple competing criteria. Such situation often emerges in agriculture and the multi criteria analysis for different kind of assessmets systems has been applied in many cases (Pavlovič et al. 2011; Žnidaršič et al. 2008; Bohanec et al. 2008; Mazetto and Bonera 2003; Griffits et al. 2008, Tiwari et al. 2009; Tojnko et al. 2011).

The most common methods like analytical hierarchical process (AHP) and multi attribute utility theory are based on quantitative assessment. For instance AHP has been used for variety assessment before (Rozman et al., 2015; Srđevićet al., 2004). On the contrary, the method DEXi (Bohanec et al. 2000) is based on discrete values of attributes and utility functions in the form of "if…then" decision rules. In particular, some methods, such as DEXi (Bohanec and Rajkovič 1990; Bohanec et al. 2000), facilitate the design of qualitative (symbolic) decision models. In contrast to conventional quantitative (numeric) models, qualitative models use symbolic variables. These seem to be well-suited for dealing with ‘soft’ decision problems, that is, less-structured and less-formalized problems that involve a great deal of expert judgment and where qualitative scales can be more informative than quantitative scores. The DEXi method has already been successfully used in numerous real life decision and assessment problems such as for the estimation of tourist farm service quality (Rozman et al. 2009) or assessment of multifunctional contributions of “Streuobst” stands.

The aim of this paper is to present the applications of method DEXi in agriculture on real world agricultural decision problem, namely hop breeding.

2 ASSESSMENT OF NEW HOP CULTIVARS

The hop model (Pavlovič et al. 2011) was developed in order to assess new potential hop hybrids. Within the hop breeding research program carried out at the Slovenian Institute of Hop Research and Brewing, thousands of hop hybrids appeared to be perspective according to research objectives (Cerenak 2006). In this research the data from four different Slovenian hop hybrids A1/54, A2/104, A3/112, A4/122 were compared with a reference German variety Hallertauer Magnum, which had the desired characteristics plant resistance and brewing value. The assessment was carried out by a qualitative multi-attribute model based on the DEX methodology (Bohanec et al. 2000). We first developed the model and then applied it to assess the aforementioned perspective hybrids. The model hierarchy is shown in figure 1.

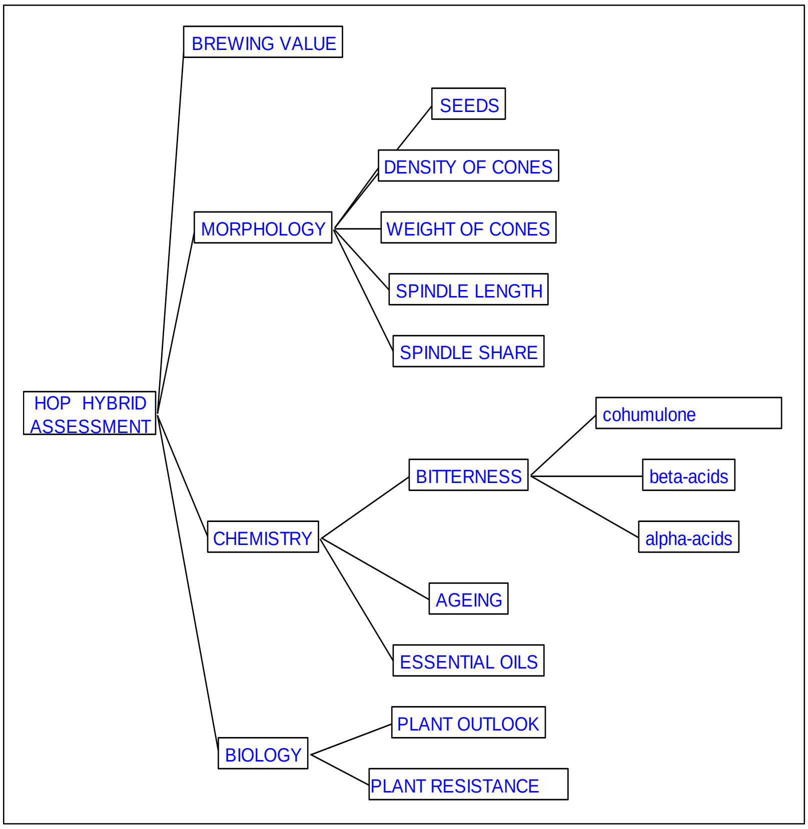

Figure 1: Hop decision model

Among over one thousand of hybrid hop plants analyzed and eliminated stepwise through a selection procedure, the four Slovenian hop hybrids such as A1/54, A2/104, A3/112, A4/122 and a reference variety Hallertauer Magnum were involved into a comparative model assessment. The hop hybrids had been selected through a hop breeding process among sets of seedlings analysed and assessed as highly forthcoming and promising new hop varieties. Numerical data of analyses and measurements of hop cones as well as beer sensory estimation were used to describe hybrids production and brewing quality parameters. They were analyzed and results were additionally discussed. The model enabled a final assessment of hybrids based on defined attributes and decision rules within defined utility functions figures 2).

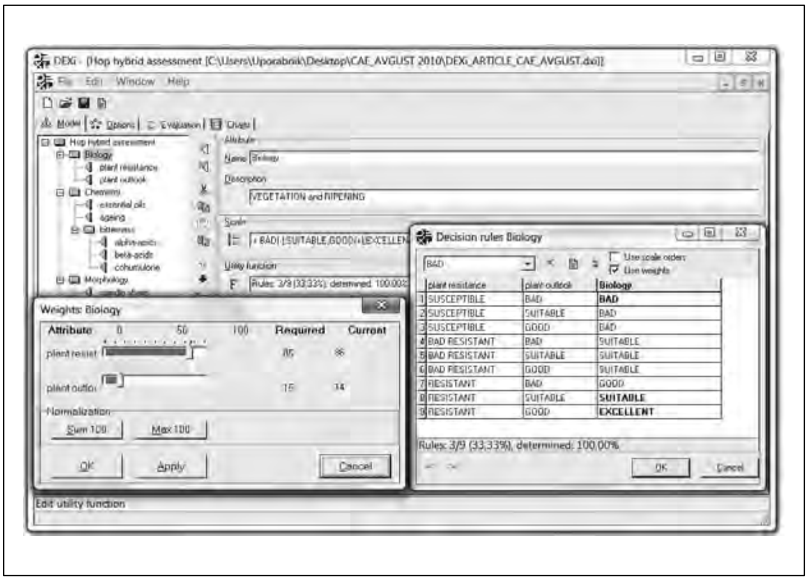

Figure 2: Determination of the DEX-HOP model utility functions for attribute *Biology*.

Based on breeding experiences and the DEXi-HOP 1.0 model results (figure 3), the overall as well as individual (aggregated and derived) attributes assessments were carried out. The results are shown on figures A3/112 and A4/122 reached the overall level of reference and were thus assessed as appropriate for further breeding. On the contrary, A1/54 and A2/104 did not meet expectations in their attributes related to the reference variety. A2/104 was in overall assessed as WORSE, while A1/54 as NON PERSPECTIVE. Therefore, they were considered as hybrids with less breeding potentials. The DEXi model was able to provide additional information on 4 hop hybrids that were initially all considered as perspective by the breeders. We were able to additionally rank them within the group of previously identified hybrids marked as perspective on the basis of breeder’s assessment.

DEXi HOPS.dxi 19.6.2015 Page 1

Evaluation results

Attribute	A1/54	A2/104	A3/112	A4/122	REFERENCE
HOP HYBRID ASSESSMENT	NON PERSPECTIVE	WORSE	REFERENCE	REFERENCE	REFERENCE
├BIOLOGY	BAD	BAD	EXCELLENT	SUITABLE	SUITABLE
│├PLANT RESISTANCE	SUSCEPTIBLE	SUSCEPTIBLE	RESISTANT	BAD RESISTANT	BAD RESISTANT
│└PLANT OUTLOOK	SUITABLE	SUITABLE	GOOD	GOOD	SUITABLE
├CHEMISTRY	GOOD	REFERENCE	REFERENCE	REFERENCE	REFERENCE
│├ESSENTIAL OILS	LESS	REFERENCE	REFERENCE	REFERENCE	REFERENCE
│├AGEING	GOOD	EXCELLENT	EXCELLENT	GOOD	GOOD
│└BITTERNESS	WORSE	REFERENCE	REFERENCE	REFERENCE	REFERENCE
│ ├alpha-acids	LESS	MORE	REFERENCE	MORE	REFERENCE
│ ├beta-acids	LESS	LESS	LESS	LESS	REFERENCE
│ └cohumulone	MORE	REFERENCE	LESS	REFERENCE	REFERENCE
├MORPHOLOGY	BAD	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
│├SPINDLE SHARE	BAD	BAD	ACCEPTABLE	BAD	GOOD
│├SPINDLE LENGTH	BAD	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE	ACCEPTABLE
│├WEIGHT OF CONES	GOOD	GOOD	GOOD	GOOD	GOOD
│├DENSITY OF CONES	BAD	BAD	BAD	BAD	BAD
│└SEEDS	BAD	BAD	BAD	BAD	ACCEPTABLE
└BREWING VALUE	BAD	BAD	GOOD	GOOD	EXCELLENT

Figure 3: DEXi assessment for all four analyzed hop hybrids and the reference

Different kind of analyses can be conducted using DEXi. For instance figure 4 shows a comparison between reference hybrid (Magnum) and hybrid A1/54 that was assessed as NON PERSPECTIVE.

None of the hybrids was able to achieve the same Brewing value as reference cultivar. The chart on figure 5 shows scatter chart for the attribute Brewing value.

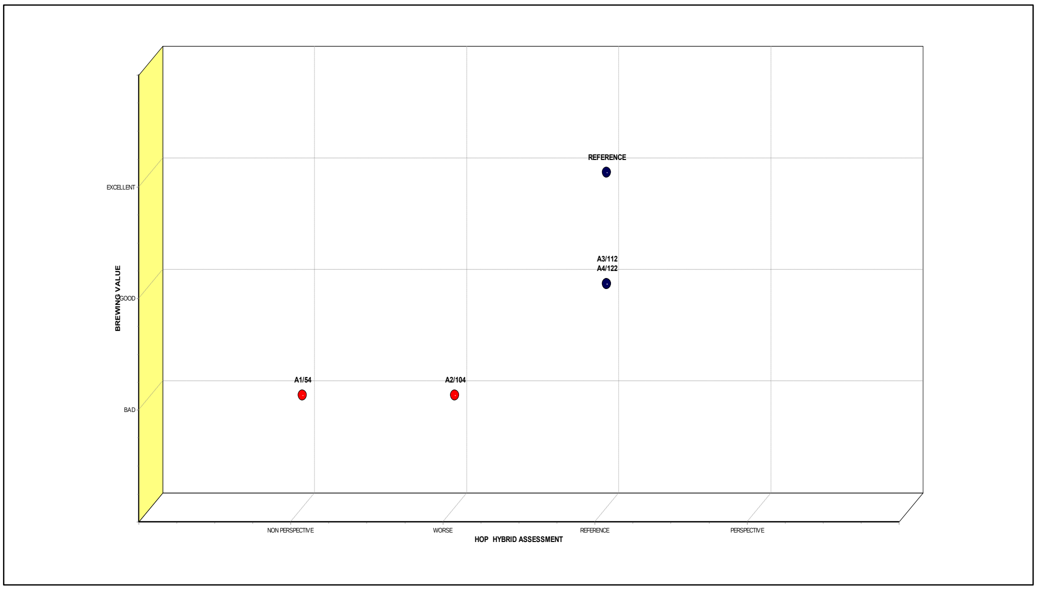

Figure 5: Scatter chart for attribute Brewing value

3 CONCLUSION

In this paper, an attempt was made to present multi-criteria method DEXI, based on qualitative attribute values and utility functions in the form of decision rules, and its possible application in the field of hop breeding.

Despite of the minor deficiencies (such as use of qualitative data only), it was found out that the approach has fulfilled most of the breeders' expectations and revealed considerable advantages in comparison with other approaches. The multi attribute model DEX-HOP 1.0 can therefore be regarded as a useful alternative tool for hop hybrids assessment. We can observe that none of the hybrids is fully equal with the reference cultivar.

This method cannot entirely replace experts, but it can be their additional tool in decision-making, since decisions based on model testing offered much faster results that validate the application of the model for further research. In future, data of new coming hybrids will be added and assessed in comparison to experts' decisions. Furthermore, also new attributes as a response to new goals in hop breeding programs will be included into the model.

Acknowledgement
This research was funded by Slovenia research agency program P4-0022.

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