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INTERACTIVE MULTI-CRITERIA DECISION SUPPORT – NEW TOOLS AND PROCESSES FOR PRACTICAL APPLICATIONS

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Title: Interactive multi-criteria decision support – New tools and processes for practical applications

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Abstract: This thesis studies and develops application procedures of multi-attribute value tree methods and related decision support systems. The objective is to understand the needs of practice for the process support and, through this, to help create user-friendly multi-criteria decision support systems and appropriate ways to use them. The motivation behind this is that the usability of the methods is strongly dependent on the available tools and on their application process. The recent advances on the development of computers and the Internet have also created new opportunities to develop the systems. Consequently, the role of computer support has become very process-oriented instead of only implementing the mathematics of the methods. Specifically, the thesis (i) introduces two new web-based systems, Web-HIPRE and Smart-Swaps, with focus on process support and on adopting the new opportunities of computer support, (ii) reports experiences on the use of these systems in environmental applications to support group decision making processes, and (iii) describes new ways to apply two specific methods, even swaps and preference programming, for various tasks with an aim to improve the practical applicability of these methods.

Keywords: multi-criteria decision analysis, multi-attribute value theory, decision support systems, decision conferencing, even swaps, interval models, preference programming, environmental decision making, nuclear emergency management, public participation

Otsikko: Interaktiivinen monitavotteinen päätöstuki – Uusia työkaluja ja menettelytapoja käytännön sovelluksiin

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Tiivistelmä: Tämä väitöskirja tutkii ja kehittää monitavoitteisen arvopuuanalyysin sovellustapoja sekä analyysia tukevia järjestelmiä. Tavoitteena on ymmärtää päätösanalyysiprosessin käytännön tarpeet ja näiden pohjalta kehittää käyttäjäystävällisiä monitavoitteisia päätöstukijärjestelmiä ja tehokkaita tapoja soveltaa näitä. Perusteena on, että menetelmien käyttökelpoisuus riippuu vahvasti käytetyistä menettelytavoista ja tukijärjestelmistä. Tietokoneiden ja Internetin viimeaikainen kehitys on myös avannut uusia mahdollisuuksia kehittää järjestelmiä. Tietokonetukea käytetäänkin yhä enenevässä määrin menetelmien tukemisen ohella myös prosessin tukemiseen. Tämä väitöskirja (i) esittelee kaksi uutta verkkopohjaisia päätöstukijärjestelmää, Web-HIPRE:n ja Smart-Swaps:in, keskittyen prosessitukeen ja tietokonetuen uusien mahdollisuuksien hyödyntämiseen, (ii) tutkii näiden järjestelmien käyttöä ympäristösovelluksissa tukemassa ryhmäpäätösprosessia ja (iii) esittelee uusia tapoja soveltaa even swaps ja preference programming -menetelmiä tavoitteena lisätä menetelmien soveltuvuutta eri tilanteisiin.

Avainsanat: monitavoitteinen päätösanalyysi, monitavoitteinen arvopuuanalyysi, päätöstukijärjestelmät, päätöskonferenssi, even swaps -menetelmä, intervallimallit, preference programming -menetelmä, ympäristöpäätöksenteko, ydinonnettomuustilanteiden hallinta, osallistava päätöksenteko

Academic dissertation

Systems Analysis Laboratory
Helsinki University of Technology

Interactive multi-criteria decision support – New tools and processes for practical applications

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Official opponent:	Professor Theodor J. Stewart

Publications

The dissertation consists of the present summary article and the following papers:

[I] Mustajoki, J., Hämäläinen, R.P. (2000). Web-HIPRE: Global decision support by value tree and AHP analysis. *INFOR*, 38(3), 208-220.

[II] Mustajoki, J., Hämäläinen, R.P., Marttunen, M. (2004). Participatory multicriteria decision analysis with Web-HIPRE: A case of lake regulation policy. *Environmental Modelling and Software*, 19(6), 537-547.

[III] Mustajoki, J., Hämäläinen, R.P., Sinkko, K. (2006). Interactive computer support in decision conferencing: Two cases on off-site nuclear emergency management. *Decision Support Systems.* (to appear)

[IV] Mustajoki, J., Hämäläinen, R.P. (2005). A preference programming approach to make the even swaps method even easier. *Decision Analysis*, 2(2), 110-123.

[V] Mustajoki, J., Hämäläinen, R.P. (2006). Smart-Swaps – Decision support for the PrOACT process with the even swaps method. *Helsinki University of Technology, Systems Analysis Laboratory, Research Report E20.*

[VI] Mustajoki, J., Hämäläinen, R.P., Salo, A. (2005). Decision support by interval SMART/SWING – Incorporating imprecision in the SMART and SWING methods. *Decision Sciences*, 36(2), 317-339.

[VII] Mustajoki, J., Hämäläinen, R.P., Lindstedt, M. (2006). Using intervals for global sensitivity and worst case analyses in multiattribute value trees. *European Journal of Operational Research*, 174(1), 278-292.

Contribution of the author in the papers

The author was the principal author of all papers. Additionally, he has contributed to the papers as described in the following.

[I] The Web-HIPRE software introduced in the paper was designed by Prof. Raimo P. Hämäläinen and programmed mainly by the author. The earlier MS-DOS based version of the software, HIPRE 3+, was designed by Prof. Hämäläinen and programmed by Hannu Lauri.

[II] The MCDA part of the application was carried out in collaboration with Mika Marttunen from the Finnish Environmental Institute (SYKE). The results of the case studies were collaboratively analyzed by the author and the co-authors.

[III] The MCDA part of the case studies was carried out in collaboration with Kari Sinkko from the Nuclear Safety Authority of Finland (STUK). The results were collaboratively analyzed by the author and the co-authors.

[IV] The author initiated the main ideas of the paper.

[V] The software was designed collaboratively by the author and Prof. Raimo P. Hämäläinen. The author was also one of the programmers of the software.

[VI] The main ideas of the paper were initiated collaboratively by the author and the co-authors. The author was responsible for implementing the simulation model, carrying out the simulations and analyzing the results.

[VII] The main ideas of the paper were initiated collaboratively by the author and the co-authors. The author was responsible for implementing the sample model and analyzing the results.

Preface

The work in this thesis has been carried out in the Systems Analysis Laboratory, Helsinki University of Technology. I am deeply indebted to my supervisor, Professor Raimo P. Hämäläinen for his inspiring and supportive guidance to me during my work in the Lab. I am grateful to him for giving me an opportunity to work in the laboratory and for making me familiar with the scientific world. I would also like to acknowledge my other co-authors, Professor Ahti Salo, Mats Lindstedt, Mika Marttunen and Kari Sinkko, for their contribution to this thesis, and thank them for their cooperation. I appreciate Professor Carlos Bana e Costa and Professor David L. Olson for examining this thesis with great accuracy.

The working atmosphere of the Systems Analysis Laboratory has been great and I want to express my warmest thanks to all the personnel of the Lab. Especially, the daily quiz sessions on coffee breaks have acted as a refreshing counterbalance to the research work. On my conference trips, the lads from room U232 have been very entertaining travelling companions.

All the summers spent at Toiska, the summer home (village) of the Mustajoki family, have been an excellent way to relax and prepare for the work of the coming year. I want to express my thanks to all the Toiska-dwellers for creating this unique and warm atmosphere. I would also like to thank all the members of our student group VC Mekanikot for keeping a balance between studying/work and leisure time activities. I am glad that we still keep actively in touch, even though our student life has been over for years.

Special thanks go to my parents, Arto and Paula, and to my sisters with their families, as well as to my in-laws, for their constant love and support. It's great to have such a big and close family around. Finally, I want to express my very special gratitude to my beloved wife, Anna, and children, Taavi, Tiitus, Villa and Hulda. Your love, smiles and positive attitude towards everything make my life absolutely wonderful.

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Jyri Mustajoki

1. Introduction

Multi-criteria decision analysis (MCDA) is a general term for methods providing a systematic quantitative approach to support decision making in problems involving multiple criteria and alternatives (Clemen, 1996). The aim is to help the decision maker (DM) to make consistent decisions by taking all important objective and subjective factors of the problem into account. Consequently, the decision making process will be transparent and justifiable. A typical decision analysis process involves several steps such as identifying the decision situation, structuring the problem, preference elicitation, decision recommendation and sensitivity analysis (see e.g. Bunn, 1984; Keeney, 1992; Clemen, 1996).

Multi-attribute value theory (MAVT; Keeney and Raiffa, 1976) is an MCDA approach in which the problem is constructed into a form of a value tree. This is a hierarchical structure of objectives in which the overall goal is on the top and the attributes on the lowest level. The alternatives are measured with respect to each attribute, and the attributes are weighted according to their importance. As a result, one attains the overall values of the alternatives. There are various methods for weight elicitation, and for a review of these see, for example, von Winterfeldt and Edwards (1986) or Belton and Stewart (2002).

Decision support systems (DSS) are computer based interactive systems for supporting the decision making process. The aim is that computer support and the judgments of the DM together constitute a human–machine problem solving system (Gorry and Scott Morton, 1971). In a broader scope, the term DSS can be considered to include all the systems that make any contribution to decision making (Sprague, 1980). Multi-criteria+ DSSs (MCDSS), in particular, are model-driven systems that utilize MCDA methods to support the structuring of the problem and the analysis of the results. This thesis deals only with MAVT based MCDSSs but, in practice, the system can employ any other MCDA approach as well, such as multi-attribute utility theory (MAUT; von Neumann and Morgenstern, 1944; Keeney and Raiffa, 1976) or some outranking method (see e.g. Brans and Vincke, 1985; Roy, 1990; Figueira et al., 2005).

This thesis studies application procedures of MAVT methods and the development of related MCDSSs. The focus is on the new opportunities provided by computer technology and the Internet. The objective is to understand the procedural needs originated from practice and, through this, to help create user-friendly MCDSSs and best procedures for the DMs to apply these systems. The rationale for this work is that the practical use of the methods is not just calculating the mathematics of the models but much of it originates from how the methods are applied. With the implementation of the process one can often affect, for example, how effectively and accurately the true preferences of the DM can be elicited with the model. The experiences obtained from the real life applications also play an important role in the MCDSS development. One should, however, note that the DM always needs to understand the logic of the MAVT methods to be able to input his/her preferences consistently in the process.

In group decision making, the use of decision analytical methods makes it possible to analyze the views of various stakeholders in a unified setting with an aim to get a shared understanding of the stakeholders' preferences. This can be useful, in particular, in environmental decision making in which there are typically numerous stakeholders with diverse and even conflicting views. MCDA methods have been successfully applied in numerous environmental applications including those in natural resources management (Hämäläinen, 1992; Gregory and Keeney, 1994; Marttunen and Hämäläinen, 1995; McDaniels et al., 1999; Kangas et al., 2001; Kiker et al., 2005), infrastructure planning (Bana e Costa, 2001; Vo et al., 2002; Bojórquez-Tapia et al., 2005), energy policy evaluation (Hämäläinen, 1988; Hobbs and Meier, 2000; Greening and Bernow, 2004) and nuclear emergency management (Keeney and von Winterfeldt, 1994; French, 1996; Hämäläinen et al., 2000). For surveys of MCDA applications in general, see Corner and Kirkwood (1991) or Keefer et al. (2004), and of DSS applications, see Eom and Lee (1990), Eom et al. (1998) or Eom and Kim (2006).

In particular, this thesis develops MCDSSs with focus on the new opportunities of computer technology to support the process, and reports experiences on the use of these systems in environmental applications. In addition, the thesis studies the practical application of two particular methodologies, i.e. even swaps (Hammond et al., 1998, 1999) and preference programming (see e.g. Arbel, 1989; Salo and Hämäläinen, 1992, 1995, 2001, 2004), in various tasks.

The present summary article is structured as follows. Section 2 discusses the process needs in multi-criteria decision support and Section 3 the requirements for the MCDSSs. The contributions of this thesis to the MCDSS development are described in Section 4, and Section 5 concludes the thesis.

2. Process support in multi-criteria decision analysis

The development of MCDSSs started initially from the methodological needs to carry out the calculations of the models. The first systems in the early 70's were simple and developed using limited information technology available (Siskos and Spyridakos, 1999). Thus, they were able to merely implement the needed calculations. This *method-oriented* approach predominated the first decade or two of the MCDSS development. Since then, computer technology has developed rapidly, which has provided new opportunities to develop MCDSSs. For example, the proliferation of the graphical user interfaces in the late 80's made it possible to create visual and interactive systems, and the invention of the World Wide Web (Berners-Lee et al., 1994) has enhanced the communication possibilities considerably.

The researchers and developers have also become to realize that the MCDSSs can be much more than just calculators, and they can be applied to support the process too (see e.g., Geoffrion, 1987; Pomerol and Brézillon, 1997; Belton and Hodgkin, 1999; Phillips-Wren et al., 2004). Many phases of the process can, indeed, benefit from procedural support. For example, in the preference elicitation phase, such support can reduce the possibility of behavioral biases and procedural mistakes that can exist in the modeling if the methods are used improperly (see, e.g., Stillwell et al., 1987; Weber and Borcherding, 1993; Pöyhönen et al., 2001; Keeney, 2002; Hämäläinen and Alaja, 2003).

Figure 1 presents the evolution from pure method-oriented to *process-oriented MCDA theory and MCDSS development* framework. In the latter framework, the objective of the systems is not to only implement the mathematics of the methods but also to provide support for carrying out the process. In this respect, both the experiences obtained from real life problems and the development of computers have a very important role as initiators of the further method development.

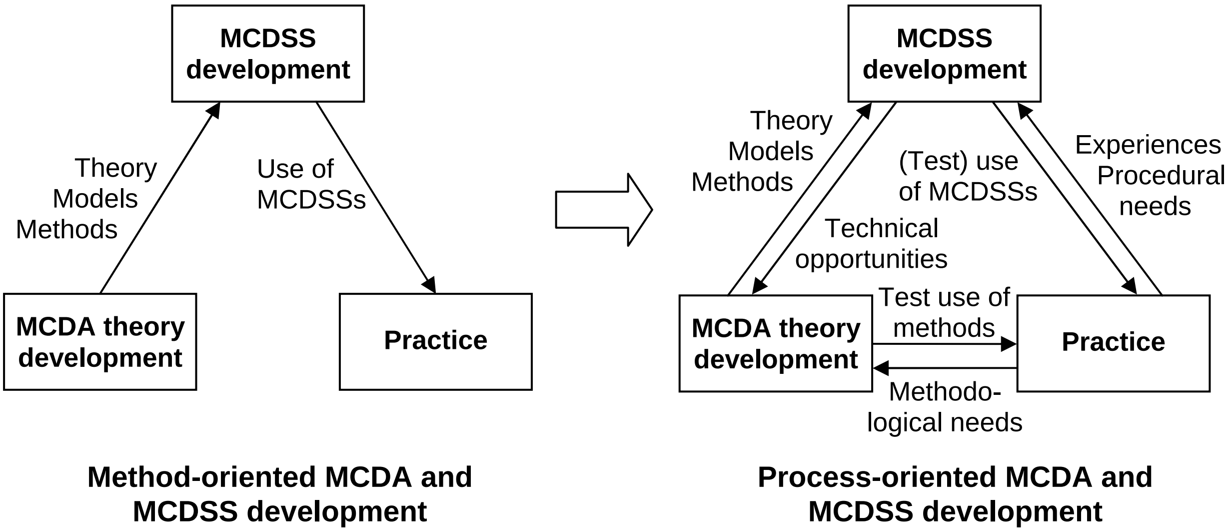

Figure 1. *Evolution from the method-oriented to process-oriented MCDA and MCDSS development.*

In the past two decades, the development of MCDSSs has increasingly taken the needs of practice and the new opportunities of computer support into consideration. The developed systems provide, for example, visual interactive interfaces to help illustrate the MAVT process and the analysis of the results. These tools include HIPRE 3+ (Hämäläinen and Lauri, 1995), Hiview 3 (Catalyze, 2004), Logical Decisions (LD, 2003), M-Macbeth (Bana e Costa et al., 2003, 2005) and V·I·S·A. (Belton, 1994; Belton and Vickers, 1990). The emphasis on different methodologies varies depending on the software, and for comparisons of the software, see, for example, Davey and Olson (1998), Maxwell (2004), Turban et al. (2004) or French and Xu (2004).

In spite of the recent advances, the MCDSS development is still at an early stage. One of the key issues in the future is to provide support for the whole process rather than some particular phase only (Pomerol and Brézillon, 1997; Paschetta and Tsoukiàs, 2000; Liu and Stewart, 2004), and major development is expected in this respect. The opportunities provided by the web are not yet fully utilized, either. As major trends for the next decade of DSS development, Shim et al. (2002) see the increase in the sophistication of the systems and the rise of the web as a platform to support interactivity and collaboration. Although some progress in the development of web-based DSSs can already be seen, a new generation of web-based systems is only beginning to emerge (Bhargava et al., 2006; Power and Sharda, 2006).

Multifaceted research is needed to develop MCDSSs to meet various needs of practice. This thesis focuses on some specific threads of research. Firstly, to meet the need for web-based systems, the thesis studies the use of the web as a platform of the systems and develops two new web-based software. Paper [I] introduces Web-HIPRE (Hämäläinen and Mustajoki, 1998), a successor of HIPRE 3+ with web-based group support facilities, and paper [V] develops the Smart-Swaps (Hämäläinen et al., 2003) software for supporting the even swaps process. Secondly, the need for transparent and justifiable approaches to support group decision making and public participation has also emerged as an important area of development. Papers [II] and [III] focus on this. Thirdly, as one specific area of process needs, papers [IV] and [V] study procedural support for the even swaps method. This is an easy-to-use method but, with appropriate support, we can still provide the DM with substantial help to make the process more efficient. There is a similar situation with preference programming methods, which usually are technically well developed, but appropriate processes to apply them in various tasks are still needed. This is considered in papers [IV], [VI] and [VII].

2.1 Multi-criteria group decision support

Instead of only one DM, the decision is often made by a group of DMs. In group decision making, computer technology can be utilized to support both the use of the MCDA methods and group collaboration. DeSanctis and Gallupe (1987) have classified group decision support into three levels: (1) process support for removing communications barriers (e.g. electronic messaging), (2) decision making support for the modeling and the analysis of the decision problem at hand, and (3) rules of order for controlling the pattern of communication. Of these, MCDSSs can be classified as level 2 support but the systems can also provide, for example, level 1 tools to support communication within the group.

MCDA methods can be used in various ways to support group decision making. The approaches vary from the ones applying a common preference model to the whole group (see, e.g. Quaddus et al., 1992) to ones using some preference aggregation techniques or interval models (see Section 2.4) to include all the different preferences in the model (see e.g. Hämäläinen et al., 1992; Ramanathan and Ganesh, 1994; Salo, 1995; Hämäläinen and Pöyhönen, 1996; Bose et al., 1997; Baucells and Sarin, 2003; Dias and Clímaco, 2005). In terms of reaching a result that satisfies all the DMs, it is important that the approach helps the DMs to understand the other DMs' viewpoints too. This need has led to the development of MCDSSs providing group facilities for this. For example, in the group version of V·I·S·A, the group model shows the spread of the DMs' individual weights obtained from their models through a local area network. Web-HIPRE provides a slightly different approach in which the DMs' models can be studied collaboratively through the web to understand the other DMs' preferences. The individual preferences can also be aggregated to group preferences with a group model in which the effects of individuals can be studied by carrying out sensitivity analyses on the weights of the DMs.

Although the literature on group support systems research in general is wide, the research concentrating, in particular, on group MCDSSs has been rare. For example, Fjermestad and Hiltz (1999, 2001) have evaluated 184 experiments as well as 54 case and field studies on group support systems, of which 109 dealt with the level 2 tools. However, only eight of these made use of MCDA methods. This lack of real life experiences has been one of the motivators behind this thesis to study group decision support with multi-criteria methods. Paper [III] studies the interactive use of the group approach provided by Web-HIPRE in one-day decision conferencing, which is a collaborative and intense way to support group decision making (Phillips, 1984; Phillips and Phillips, 1993; French, 1996; Hämäläinen and Leikola, 1996). The studied two conferences dealt with the planning of later phase countermeasures in nuclear emergency management.

2.2 Public participation

In recent years, the awareness of public possibilities to affect societal decision making processes has increased rapidly. This can be seen especially in environmental issues which typically involve masses of people, and in which the public concern for the state of the environment has also grown. Consequently, this has created a need to include the public in decision making processes.

The objectives of public participation are various. Beierle (1998) has presented a framework based on six objectives: (i) educating the public, (ii) incorporating public values and knowledge into decision making, (iii) improving the substantive quality of decisions, (iv) building trust, (v) reducing conflicts, and (vi) achieving cost-effectiveness. There are also various approaches for public participation. Morgan (1998) classifies these in four categories: (i) methods for primarily seeking public input, (ii) methods for primarily informing and educating, (iii) methods for promoting information exchange and interaction, and (iv) methods for finding commonly agreed upon solutions. For a classification of different approaches with respect to achieving the objectives of participation, see French et al. (2005).

MAVT methods provide a convenient way to model the preferences of different interest groups and, consequently, to help achieve objectives of participation such as improving quality, building trust and reducing conflicts. However, other ways to support public participation are still needed, for example, to communicate the results with the public. In this respect, the World Wide Web provides various new opportunities. It is an easy and cost-efficient way to distribute information, as the information is instantly available to the users and can be accessed at any time by anyone. In addition, the multimedia features provide ways to distribute different types of information. Through the web it is also very easy to collect feedback from the participants. Web-based approaches can be especially useful in environmental processes in which the stakeholders are often geographically distributed.

Paper [II] studies the application of MCDSSs to support participatory processes. The focus is on a setting in which a steering group is set up to represent various stakeholder groups. The preferences of the steering group members are modeled with MAVT, and the results are discussed collaboratively. The public is involved in the process by arranging public meetings in which the results of the steering group meetings are presented and discussed. As an optional element, the paper demonstrates a possibility for the public to use Web-HIPRE through the web to model and analyze their preferences. However, in general this can be considered to be too sophisticated a task to be carried out independently. The approach can be further extended to a full web-based framework for public participation in which web-based tools are also applied to communicate with the public (Hämäläinen et al., 2006).

2.3 The even swaps method

Even swaps is an elimination process in which the DM carries out value trade-offs (see also Keeney and Raiffa, 1976; Keeney, 2002) called even swaps. In an even swap, the consequence of an alternative in one attribute is changed and this change is compensated with a preferentially equal change in the consequence of some other attribute. The new virtual alternative with the revised consequences is equally preferred to the initial one and thus it can be used instead. The aim is to carry out swaps that either make attributes irrelevant or alternatives dominated. These can be eliminated and the process continues until the most preferred alternative is left.

Even swaps is conceptually an easy-to-use method and thus it has potential for a wider interest among practitioners. However, the DM may find it difficult to decide, for example, which swaps he/she should carry out next. With an appropriate selection of the swap, the DM can often considerably affect the number of swaps that have to be carried out to find the most preferred alternative.

Papers [IV] and [V] discuss the application of computer support to facilitate the even swaps process. There seems, indeed, to be a need for this kind of computational help as, so far, only a few applications have been reported (Kajanus et al., 2001; Gregory and Wellman, 2001). This may at least partly originate from the lack of appropriate support and, thus, the proposed approach is expected to be useful.

2.4 Interval modeling with preference programming

The flexibility of the process is often very important and the supporting system should be able to respond to various needs of the DMs. In interval models (see e.g. Sage and White, 1984; White et al., 1984; Weber, 1985, 1987; Arbel, 1989; Salo and Hämäläinen, 1992, 2004), the DM does not have to give precise estimates about his/her preferences over the attributes or about the performance of the alternatives, but he/she can give a range of values on which the 'true' value is. This makes it possible to include imprecision or uncertainties in the modeling, as the information about the alternatives is often incomplete or the DM may be uncertain about his/her preferences (see e.g. French, 1995). The results of interval models can be analyzed with various concepts, such as dominance relations or potential optimality (see e.g. Hazen, 1985; Weber, 1985, 1987; Lee et al., 2001; Eum et al., 2001).

Preference programming (Arbel, 1989; Salo and Hämäläinen, 1992, 1995, 2001, 2004) is a family of interval methods which allows the use of imprecise information in the MAVT framework. There are various preference programming methods available. For example, in the PAIRS method (Preference Assessment by Imprecise Ratio Statements; Salo and Hämäläinen, 1992), the attributes are compared in pairs and the alternatives evaluated with value functions, whereas the RICH method (Rank Inclusion in Criteria Hierarchies; Salo and Punkka, 2005) allows giving imprecise information about the rankings of the attributes and alternatives.

In practice, the implementation of interval models requires solving of linear programming problems. Increase in the computational power of personal computers has made it possible to create interactive software that solves these problems even on-line. This software includes WINPRE (Hämäläinen and Helenius, 1997), PRIME

Decisions (Salo et al., 1999; Gustafsson et al., 2001) and RICH Decisions (Salo et al., 2002). To support the use of MAUT with intervals, software such as MOIRA (Jiménez et al., 2003) has also been developed.

Technically, the interval approaches are well documented but the use of them has not been widely studied. Papers [IV], [VI] and [VII] discuss the application of preference programming in practice with an aim to find efficient and applicable ways to apply the approach in various tasks.

3. Requirements for multi-criteria decision support systems

On MAVT based MCDSSs, proper use of the method is extremely important. This sets requirements both for the method and for the supporting system. For example, according to Stewart (1992), the operational usefulness of the method requires at least ease-of-use by non-experts, transparency of the logic of the method, and freedom from ambiguity of the interpretation of the inputs. Buede (1992) presents a DSS evaluation framework based on several attributes under two main criteria, performance of the software and user friendliness. Naturally, the general requirements for the DSSs also apply to the MCDSSs. For example, Turban et al. (2004) describe a set of ideal characteristics and capabilities of DSSs, which include ease-of-use, flexibility, improving the effectiveness of decision making, allowing humans to control the computer support, etc.

3.1 Independent use of the systems

So far, MCDA software has been typically used with the help of a decision analyst analyzing and interpreting the results to the DMs. Then, the decision analyst can also help the DM to understand the method properly. Today's multi-criteria software provide familiar and easy-to-use user interfaces which also allow non-experts to use the software by themselves. In practice, this independent use of the software is, however, very challenging, as the critical issue is not learning the technology but to adopt the correct use and true understanding of the methods. An inexperienced DM may, for example, relapse into making behavioral biases and procedural mistakes the avoidance of which is essential to obtain reliable results. The recognition of these can be difficult as the DM can get correct looking results, even if he/she had not understood the method correctly.

Computer support can be developed to facilitate the understanding of the methods. In this respect, the design of the user interface is a very important element in delivering the methods to the DM, and consequently in achieving the success of the system (Power and Sharda, 2006). For example, today's multimedia capabilities make it possible to visualize the methods to make the understanding of them easier. The intended user of the software should, however, be taken into account in the software design, as there are a variety of possible users with different skills (see e.g. Belton and Hodgkin, 1999; Hodgkin et al., 2005). One should also note that although this support can be very helpful, it still does not entirely remove the possibility for the improper use of the methods.

Papers [I] and [V] develop new MCDSSs on the web for anyone to use. The Smart-Swaps software focuses on supporting an inexperienced DM to carry out the even swaps process. This is consistent with the original philosophy of the even swaps method which is intended also for DMs without mathematical background. Web-HIPRE is more advanced general purpose software, and thus the DMs may not be able to independently operate with the software. However, in a facilitated environment, this would be possible with certain requirements, which are discussed in paper [III].

As a way to improve the DMs understanding of the methods, eLearning material on the MCDA methods has been developed. For example, the SAL eLearning web site for value tree analysis (Hämäläinen, 2002) provides illustrative demonstrations, video clips and online quizzes about MAVT methods and the Web-HIPRE software. However, more research is needed to study the effectiveness of this material to the learning of the DMs. In addition, we need to study how we can ensure that the DMs understand the methods and commit themselves to the learning process. As another way to improve the understanding of the methods, Papamichail and French (2005) have developed a DSS module that provides the analysis of the results in natural language. For a practical application of this module integrated into Web-HIPRE, see Geldermann et al. (2006).

3.2 Multiple method toolbox

With respect to the flexibility of the software, it is important that there are various approaches available, so that the DM can choose the one he/she prefers. Software providing multiple approaches gives a convenient way to meet this need. Often, there is also a need to easily test and use the approaches to collect experiences about the applicability of different methods. For example, each MAVT method has its own characteristics, which may cause divergence of the results between the methods (see e.g. Schoemaker and Waid, 1989; Borcherding et al., 1991; Pöyhönen and Hämäläinen, 2001). There has also been a lively debate between the applicability of the Analytic Hierarchy Process (AHP) (Saaty, 1980) and MAVT methodologies (see e.g. Belton and Gear, 1982; Belton, 1986; Saaty, 1994; Olson et al., 1995; Salo and Hämäläinen, 1997; Smith and von Winterfeldt, 2004; Gass, 2005). In both cases, a multiple method toolbox will be useful for carrying out experimental comparisons between the methods.

The current MCDSSs typically support some particular methodology. For example, Hiview 3, M-Macbeth and V·I·S·A provide support for MAVT, whereas Expert Choice (EC, 2005) supports the AHP method. To follow the idea of multiple method toolboxes, software supporting several methodologies simultaneously has also been developed. For example, Web-HIPRE and Logical Decisions allow the use of AHP and various MAVT weighting methods in the same model. However, in this respect, the DSS development is still at its early phase, as it would be useful to have, for example, software that implements regular MAVT methods as well as interval approaches in the same software.

Another thread of development has been the creation of portals providing links to different kinds of DSSs. Among such portals are, for example, the DSS resource collection of the Institute for Operations Research and the Management Sciences (INFORMS, 2000) and the Decisionarium site for interactive multi-criteria decision support (Hämäläinen, 2000, 2003) developed in the Systems Analysis Laboratory. However, each software linked to these portals is its own entity providing some specific methodology but, if one wants to use some another methodology, he/she should, consequently, employ some other software. Nevertheless, data exchange between the software is often possible.

One should also note that although multiple method toolboxes make it possible to apply the same software in various problems, more skills are required from the DMs to understand and use the software. At the other end of the scale, there is the application specific software, which provides detailed guidance to the DM through some specific problem type. However, these do not allow much room to apply the procedure to other types of problems and thus they also suits inexperienced DMs. It can be expected that, in the future, the various needs of practice will require the DSS development to produce both kinds of software.

4. This thesis

The main contributions of this thesis to the DSS development are obtained in the following three research areas.

4.1 The development and experiences on a general purpose MAVT software (Papers [I] – [III])

Paper [I] develops a general purpose software called Web-HIPRE that utilizes the new opportunities of the web. Web-HIPRE introduces, for example, a group facility which allows the aggregation of individual MAVT models to a joint group model through the web. It also allows linking the elements of the value tree to web pages having detailed information about the elements. Web-HIPRE is the first general purpose MCDSS available on the web.

The development of Web-HIPRE, as well as its predecessor HIPRE 3+, followed the framework of the process-oriented MCDSS development (Figure 1). In the development of HIPRE 3+, the needs of the energy policy evaluation cases (see, e.g. Hämäläinen, 1988) played a major role, whereas the development of Web-HIPRE started from the needs of the lake regulation projects (see e.g. Marttunen and Hämäläinen, 1995).

Paper [II] studies the application of Web-HIPRE to support environmental decision making in a case of the regulation of Lake Päijänne. The experiences show that a MCDSS applied to model the different views of the steering group members can provide substantial help to support the public decision making process. On the other hand, the study also emphasizes the need to train researchers and practitioners to apply the methods correctly.

Paper [III] studies the independent and interactive use of Web-HIPRE in one-day decision conferences. The participants' individual use of the software in the preference elicitation phase was an essential new feature of the conferences. The results of the study support the applicability of the approach but emphasize the need of simple models and easy-to-use software. The approach is considered especially applicable in preparedness planning but the decision process could include elements of the approach also in a real emergency situation.

4.2 Procedural support for the even swaps method (Papers [IV] and [V])

Paper [IV] presents new techniques to support the even swaps process to facilitate the procedural accomplishment of the method. In the approach, the process is carried out as usual but, in parallel, the evolution of the preferences of the DM is modeled with preference programming. The information obtained with this model is used to help identify practically dominated alternatives (see Hammond et al. 1998, 1999), and to find applicable candidate attributes for the next even swap. As demonstrated in the paper, the proposed approach can provide the DM with substantial help especially in large problems.

Paper [V] introduces the Smart-Swaps (Hämäläinen et al., 2003) software for supporting the even swaps process. Besides implementing the methods developed in paper [IV], it introduces several other ways to facilitate the process. These include the possibility to backtrack the actions that have been made, a process log, and the visualization of the consequences table with different colors indicating the attribute-wise rankings of the alternatives.

4.3 Practical use of the interval models to increase the flexibility of the process (Papers [IV], [VI] and [VII])

Papers [IV], [VI] and [VII] study new ways of applying interval models in various tasks. As mentioned above, technically the use of intervals is straightforward, but procedurally and behaviorally there are many open questions, some of which are addressed in these papers.

Paper [IV] shows how to use intervals to model general bounds for the DMs' preferences in a case where there is no initial information about these but we can assume that the preferences cannot be of any kind. This information is applied to support the accomplishment of the even swaps process as discussed in Section 4.2. The paper also shows how the preference information given in even swaps can be embedded in the interval model to make it more precise.

Paper [VI] describes the application of intervals in the SMART (Edwards, 1977; von Winterfeldt and Edwards, 1986; Edwards and Barron, 1994) and SWING (von Winterfeldt and Edwards, 1986) methods. The generalized interval SMART/SWING method allows interval modeling in the original methods without losing their cognitive simplicity. However, there are practical issues, such as the selection of the reference attribute, which should be addressed. Based on the results of a simulation study, the paper suggests guidelines for efficiently carrying out the weighting process.

Paper [VII] studies the use of intervals in sensitivity analysis to assess the impacts of uncertainties on outcomes of decision models. For an overview of sensitivity analysis approaches in MAVT see, for example, Belton and Stewart (2002), French and Rios Insua (1999) or French (2003). The paper fits into the framework of Rios Insua and French (1991) and Proll et al. (2001) for employing interval constraints on the model parameters. The paper focuses on issues concerning the practical use of this framework in hierarchical multi-attribute value trees and the requirements for this. For example, some related concepts, such as potential optimality (see e.g. Hazen, 1985; Rios Insua and French, 1991), are not applicable in this context.

5. Conclusions and further research

This thesis consists of seven separate papers related to application of MAVT methods and MCDSS development. The emphasis is on process-oriented MCDSS development in which the procedural needs and experiences as well as the new opportunities for computer support are considered as important elements of the system and method development.

The experiences obtained from the case studies strongly support interactive use of advanced MAVT software with group facilities, such as Web-HIPRE, in decision conferences, assuming that these are carefully planned in advance. The experiences also support applying MCDA methods within a steering group representing various stakeholders in a participatory process. However, in both cases, much of the success depends on how well the authorities can implement the different tasks of the process. In this respect, collaboration between decision analysis researchers and policy support administrators is very important.

The studies on the even swap method show that the proposed support can provide considerable help to facilitate the accomplishment of the process. Especially, the applied preference programming model provides a convenient way to model the preferences of the DM in general, and to utilize this preference information further in the process.

Preference programming provides a transparent and easy-to-understand way to model imprecision and incomplete information in MAVT. However, it is not enough to only have the methods available, as the applicability of the method typically originates from their procedural use. This thesis demonstrates procedures for effectively applying these models in various tasks.

In spite of the obtained experiences, more research is still needed especially in studying the opportunities of the web. The future research questions include, for example, how the different ways of presenting information on the web will affect the learning process of the public, and to what extent the use of the web as a communications channel affects the commitment of the participants. Further research is also needed on the use of interval approaches to study their applicability in various tasks. On the MCDSS development, the next step is to create systems that provide comprehensive support for all phases of the process, so that the process could be carried out entirely through the web. Then, we need to also study to what extent inexperienced DMs can be allowed to independently use these systems, and what the requirements are for this.

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