Development of transferable multicriteria decision tools for water resource management

Jaroslav Mysiak (mysiak@alok.ufz.de)
UFZ Centre for Environmental Research, Permoserstraße 15; 04318 Leipzig, Germany

Abstract

The European Water Framework Directive establishes a framework for protecting water resources and prescribes a set of environmental objectives which are to be achieved by 2015. The Directive's implementation will entail decisions which will have to consider multiple, uncertain decision outcomes, and which involve or affect a variety of stakeholders. A raft of methods such as cost benefit analysis, cost effectiveness analysis and multicriteria decision analysis has already been developed to help decision-makers deal with complex decision problems. However, using different methods often leads to different recommendations regarding which of the alternative options to take. The Marie Curie project presented here analyses the success of decision support techniques and tools applied to water resource management. The project's aim is to establish a decision framework helping the most suitable decision support method to be chosen by selecting the programme of measures which can best achieve the Directive's environmental objectives.

1 INTRODUCTION

In the year 2000 the efforts devoted to establishing a common European legislative framework for the protection of water resources finally paid off. After four years of extensive discussions, the EU Council and Parliament adopted Directive 2000/60/EC, also known as the Water Framework Directive (WFD), which lays down a set of environmental objectives and a time schedule for their implementation. The Directive partly replaces and partly augments existing legislation to provide a comprehensive framework. The Directive obliges EU member states to achieve the "good ecological status" of water bodies defined by water quality with respect to the protection of the aquatic ecology, the specific protection of unique and valuable habitats, the protection of drinking water resources, and the protection of bathing water. The WFD places emphasis on transboundary water problems being solved jointly. The need to integrate qualitative and quantitative information and the inclusion of scientifically assessed risk in decision-making pushes planning processes towards including more complex, subjective and complicated choices. The WFD foresees increased public participation in the water resource management process and prescribes the economic assessment of potential measures to achieve good water status.

In order to support the implementation of the WFD, the European Commission has dedicated a key action line under the 5th Program Framework to issues related to the sustainable use of water resources. One of the priorities under this action line is the development of decision-support systems for water resource management.

The Marie Curie project (MC project) presented here is intended to design a transferable structure of decision-making processes suitable for aiding water authorities by selecting programmes of measures suitable for achieving the Directive's environmental objectives. The project analyses water-related conflicts and evaluates different approaches to decision-making aid regarding their ability to integrate conflicting objectives and communicate uncertainty. Emphasis is given to the multiple criteria decision approach (MCA), which allows the expansion and augmentation of the decision makers' learning ability, and helps the other actors' preferences, goals, criteria, intentions and beliefs to be better understood. Based on the characteristics of decision methodologies and the cognitive predisposition of decision makers, the project tries to determine how suitable the decision methods are for catchment-based water management under the conditions created by the implementation of the WFD.

The work presented here is being conducted in conjunction with two EU-funded research and development projects: MULINO and HarmoniRiB. Although the two projects support different tasks imposed by the WFD, they share the aim of improving decision-making in river basin management. The MULINO (MULti-sectoral, INtegrated and Operational Decision Support System for the Sustainable Use of Water Resources at the Catchment Scale) aims to contribute by developing a Decision Support System (DSS) to assist water authorities in the management of conflicting uses of water resources. One of the specific aims of the MULINO DSS, which is completed by combining environmental models, a geographic information system and a multicriteria decision tool, is to achieve a truly integrated approach to river basin management. The HarmoniRiB (Harmonised Techniques and Representative River Basin Data for Assessment and Use of Uncertainty Information in Integrated Water Management) project on the other hand is aimed at developing a practical methodology and a set of tools for assessing and describing uncertainties afflicting the data and models applied by water management planning. The efforts of the two projects are complementary: while the MULINO project is designed to develop a decision support system which helps identify, explore and solve water-related conflicts, the

HarmoniRiB project contributes by analysing how the underlying uncertainties influence the decision outcomes and how robust the decisions are with respect to small changes in the models and/or the preferences elicited.

The goals and achievements of the MC project are discussed here in the light of the WFD implementation process. In the next section the success of formal decision support techniques and tools is addressed and the main reasons for its low acceptance are examined. Then the decision framework developed for the MULINO DSS is described and its suitability discussed with respect to the new concepts for river basin management introduced by the WFD. Finally, the last section introduces the problem of choosing the most appropriate decision methods. The solutions striven for in the context of the HarmoniRiB project are presented.

3 THE SUCCESS OF DECISION-MAKING

Using decision-support techniques and tools to solve real-world decision problems, however theoretically sound and justifiable they may be, is beset by several snags. Despite the variety of scientific papers dealing with theoretical aspects of the now vast array of decision methods available, the solution of real-world problems in water resource management has still not been satisfactorily reported. The overwhelming majority of decision support systems have been developed in an academic environment, which implies limited scope to continue customising the systems and adapting them to changing conditions once the corresponding research project has been completed. Under these conditions, the risk of decision support systems failing to be up to the challenge of real world problems is reported to be high, despite undeniable benefits stemming from their usage as well as the popularity and number of developed decision support systems (DSS) (see 15; 17). According to (18), approximately 80–90% of DSSs do not meet their performance goals and only 10–20% of DSSs meet their success criteria. Some problems with DSS acceptance are related to the general problems generated by information technology such as data availability, the easy of use of graphical user interfaces, etc. Cognitive obstacles, such as an aversion among senior executives to DSS technology, may also have played a significant role. In fact, DSSs still tend to be used by front-line employees and middle management, while integrated decision-making has often been done without any decision support (4).

Nevertheless, one of the main problems related to the low acceptance of the formal approaches to decision-making is the lack of general consensus regarding what constitutes decision quality and, correspondingly, how it should be evaluated. According to (20), the generic problem of any evaluation is the lack of quality definition and assessment. In fact several attempts have been made to evaluate decision support systems (see 3;5-7;11-14;16;17;19;20;23;24) which differ in their chosen approach and the features of a DSS addressed.

The problem of assessing the quality of decision support techniques/tools is partly due to the variety of decision support techniques available which potentially lead to different decisions. Furthermore, the preferences elicited by a decision technique/tool are of a subjective nature and based on the decision maker’s value system. The former issue is addressed by (22) as a paradox of choosing the most appropriate decision methods from all those available. In other words. selecting the best decision method is a decision problem itself which, to be solved, presumes that the best decision method needs to be already known. The second issue refers to the fact that in order to aggregate multiple decision outcomes, subjective preferences and risk attitudes have to be built in. The quality of a decision in such a case can only be assessed with respect to the values and preferences stated by the decision-maker, and this study addresses the quality of preference elicitation.

Normally, the quality of a decision is considered with regard to either the decision process (and its appropriateness) or/and the characteristics of the choice. Neither of them alone is sufficient to predict the acceptance of the solution found by using formal decision techniques/tools. For example, in the case referred to by (17) the DSS became obsolete because the end user (after having used it for a short time) had become familiar with its logic and was able to apply it on his own. Similarly, (1) reports a situation when decision-makers using a DSS were able to obtain detailed insights into the decision problem and then understood their own preferences better, even though the solution eventually adopted was different from the that determined with help of the DSS.

Evaluating the decision process and the decision outcomes separately may omit some important aspects of the decision. An ‘excellent’ decision process (built upon consistent and transparent preference modelling) may end up with a ‘wrong’ decision, while a rather inconsistent decision process may lead to a ‘right’ decision. The decisions made under uncertainty integrate the decision-maker’s attitude towards negative decision outcomes. The decision outcomes in such a case depend on the future conditions, which may prove to be less favourable for the decision-maker. In a group decision situation the expectations of all the parties involved (a ‘win-win’ situation) may sometimes be achieved through the intervention of a ‘dictator’ (a group member who decides for the whole group), while a democratic group decision process, moderated by a non-biased mediator, may end up with no conciliated solution even though most of the group members may be ‘willing’ to compromise their expectations.

Despite the ambiguity of validity concepts developed so far (5) refers to about 50 overlapping concepts for the quality evaluation of decision support systems), some of the success factors (also known as *critical success factors*) are commonly agreed upon. These encompass for example factors referring to (i) the DSS development and/or application process (e.g. the involvement of future users in early development phases, appropriately defined system requirements, evolutionary system development), (ii) the way in which the decision process is structured (e.g. the appropriateness of the logical process followed when using DSS, the number of alternatives explored by DSS, internal communication, correspondence to and appropriateness for decision organisation), (iii) the measurable indicators of the decision outputs achieved (e.g. profit/loss from DSS usage, consensus achieved among decision makers, savings of time or other resources through DSS usage, contribution to organisational efficiency, consistency of solution).

In the next sections the MC project is reviewed in the light of some specific factors addressed to sustain the MULINO and HarmoniRiB objectives.

4 ANALYSING IMPACTS AND PRESSURES

The aim of the MULINO DSS is to support water authorities by implementing the WFD requirements and solving complex; unstructured decision problems resulting from conflicting uses of water resources. The DSS has to rely on an interface which guides users through the decision problems dealt with and which helps users achieve a better understanding of the environmental models implemented in the DSS. The efforts devoted to designing a user-friendly interface were motivated by the fact that the complicated user interface is a common reason for the low acceptance of DSSs. Moreover, the user-friendly interface has reportedly helped at least partly overcome reluctance towards formal ways of decision support, which characterizes some cognitive styles of the decision makers (see 14).

The water authorities in charge of WFD implementation have to analyse the current ecological and chemical status of lakes and rivers and take measures to ensure the objectives set out by the Directive are achieved by 2015. In the first step due to be completed by 2004, the links between the pressures exerted by society and their environmental impact have to be understood and projected to the time frame available for achieving the Directive’s objectives. The main aim of the review of pressure and impacts is to identify water bodies that will not or may not meet the specific objectives. In practice this means identifying the origins of pressure (driving forces) represented by social, demographic and economic developments in societies, modelling the effects caused by the pressures on the water’s state, and finally evaluating the impacts of the water’s changed state. In order to organise the causal relations between these elements, work has been carried out on producing conceptual frameworks which are suitable for structuring, organising and relating the indicators collected to describe and quantify interactions between society and the environment. The DPSIR (driving forces – pressures – state – impacts – response) framework, which has been developed and used by for example the European Environmental Agency (EEA) and EUROSTAT to report on environmental pressures in the EU is one such framework.

The DPSIR is particularly useful because of its ability to represent cause-effect relationships between interacting components of complex social, economic and environmental systems and to organise the flow of information between their parts. It provides a conceptual model that gives the assessor an overview of the problem. It hence structures the assessor’s thinking, helping to provide a good understanding of the system’s dynamics. Combining these two tasks is one of the main objectives of the MULINO project.

In order to provide a conceptual model for the MULINO DSS, the DPSIR was adapted to the water resource planning and decision process prescribed by the WFD. In this context the DPSIR approach was designed to support the DM by introducing a structural system of the catchment in which cause–effect chains are formalised and later modelled to simulate the anticipated effects of the proposed courses of action (responses to water management issues). From the WFD point of view, the Impact highlights the imminent problems, assuming the river’s current characteristics differ from those defined by the WFD. The negative Impact arises since the change of the environmental state reduces the available quantity or quality of the water resource. The Response refers to the decision act, choosing a possible programme of measures – an activity designed to reduce the negative pressures on the state of the environment. The driving forces, pressures and states can be considered as alternative references: a water authority can choose one or more of them combined as a concrete target for the measures.

Then again, following the DPSIR approach during the process of the WFD implementation is not easy. Building cause–effect relations means constructing a simplified representation of reality in the catchment in which the level of abstraction may significantly influence the decisions. Firstly, the identification of the driving forces, pressure and state indicators is not unambiguous since the same indicator may be considered as a driving force or a pressure, or alternatively as a pressure or a state characteristic, according to the specific problem and how it is conceptualised. For example, urban development may be considered as a driving force exerting pressure in the form of water abstraction demand, or alternatively as a pressure resulting from, say, population growth and causing changes to land use patterns. Secondly, the relations between the indicators analysed may be of a much more complex nature than the DPSIR framework would suggest. The driving forces and/or pressures may be interconnected, creating synergy effects which cannot be really understood if they are addressed separately.

Similarly, a specific impact may be caused by simultaneous effects of a number of state conditions. All these ambiguities may result in the framework not being readily understandable for untrained users. For this reason, a training stage has been foreseen for the water authorities before the MULINO-DSS is applied. A set of supporting documentation and exercises is currently being developed.

5 CHOOSING THE DECISION METHOD

In order to select the most appropriate programme of measures, the water authorities often have to consider (i) multiple conflicting objectives (e.g. the economic development of a region vs. conserving water quality), (ii) uncertainty afflicting the measures' predicted outcomes, (iii) a variety of persons involved and their problem views, and (iv) the spatiotemporal distribution of the decision outcomes.

In these situations the holistic (unaided) way to decision making is often beyond the cognitive ability of the decision makers. Decision theory is designed to support decision-makers dealing with such unstructured or semi-structured decision problems. The formal approach of decision theory, which analyses subjective utility and measures goal satisfaction achieved by decision alternatives, makes the decision more transparent and consistent (i.e. rational), and allows multiple decision-makers and stakeholders responsible for or affected by the decision to communicate their positions and compromise their expectations. Decision theory helps decision-makers to organise and synthesise information on a complex and conflicting nature of problems (see 2).

The decision methods developed so far have evolved into a number of divergent schools of thought which differ in their theoretical basis, the type of preferences elicited, the kinds of questions asked, the way in which decision-makers can interact, the type of problems dealt with, etc. Since different methods may lead to different decisions, the variety of different decision support methods leads to the problem of choosing the most appropriate one (1,9,8). The ranks of alternatives yielded by different decision methods can differ significantly, especially when the number of alternatives and criteria increase (9). The variation of results obtained when two or more decision methods are used by a decision-maker may be as large as the variation of rank orders obtained when different people use the same decision method. Moreover, the way a decision situation is structured may be the cause of further disagreements. Different criteria arrangements (e.g. hierarchically and non-hierarchically organised criteria) may lead to different preferences (the "splitting bias" effect, see (8).

The MC project analyses the nature of decisions arising in the process of WFD implementation and facilitates the choice of an appropriate decision support methodology for a specific decision. The project aims at establishing a set of agreed criteria allowing an appropriate MCA method to be chosen for a given decision situation. In particular the economic decision methods such as cost effectiveness analysis (CEA) and cost benefit analysis (CBA), which are foreseen by the WFD for specific situations, are compared with the multicriteria decision methods.

Cost-effectiveness analysis is an analytical technique designed to compare the costs and effectiveness of alternative measures. The aim of using the method is to choose the least expensive alternative which guarantees the given goal is fulfilled. When assessing alternatives, CEA uses a fraction where the denominator is the effectiveness of the measure being evaluated (in achieving a given goal) and the numerator is the measure's cost. The benefits need not be expressed monetarily. In the case of a single objective, goal satisfaction may be directly used to compare the measures. In a different situation when the expected costs of measures are disproportionately high, the WFD provides for the application of cost-benefit analysis (CBA). Unlike cost-effectiveness analysis, cost-benefit analysis requires the benefits or positive impacts of measures to be expressed in monetary terms as well. Several techniques exist for the valuation of environmental costs and benefits such as the travel cost method, the hedonic pricing method and contingent valuation.

Both CEA and CBA methods have been widely used in water management, even though their application is beset by difficulties whenever a broad range of ecological services has to be taken into consideration and where a number of stakeholders with different interests are involved or affected by the decision (21). CEA is popular for its efficiency in comparing two interventions aimed at the same outcome. However, in the case of measures with multiple effects (or outcomes), the effectiveness is not just a single number. Using CEA in such situations requires additional aggregation in order to obtain a single-dimensioned effectiveness of a measure. CBA on the other hand has the difficulty of ecological services like wetland restoration or biodiversity protection being expressed in monetary terms. The approach applies a single-dimension objective function in which all the impacts and preferences are monetarised (10). Moreover, the spatial distribution of decision impacts, which are often of interest in water resource management, may not be adequately considered by CBA. Spatially distributed impacts can emerge for example through the implementation of a particular solution to minimize flood risks in which favourable impacts are produced at one location while negative consequences result at another.

The multiple criteria decision approach (MCA) forms a complement to economic approaches to monetarising externalities and other impacts. MCA explicitly deals with multiple criteria and does not require the monetarisation of ecological services. MCA allows the multiple impacts of alternative actions assessed with respect to multiple criteria to be explicitly considered by (i) examining the trade-offs between conflicting criteria/objectives pushed by one or more decision-makers or stakeholders; and by (ii) helping decision-makers to define and formulate their values. MCA is mainly used in situations where a broad range of ecological services in a multidimensional and community-based watershed approach has to be evaluated (21), which is essentially what is to be anticipated during the WFD implementation. The main advantage of using MCA is the fact that it does not require ecological services to be expressed in monetary terms, thus neatly sidestepping the problems encountered in CEA/CBA.

However, neither monetarisation nor MCA is unambiguously superior to the other; indeed, the two approaches have complementary strengths. The problem of choosing the more appropriate decision support is resolved in the MC project by using several different decision methods which, taken together, help decision-makers better understand the problems and explore trade-offs between options' achievements by reviewing the conclusions they come up with. This tallies with the findings of (1), who showed in an experiment that even if none of the methods tested has a high predictive ability, the final measures ranking changed compared to the initial holistic (unaided) ranking after the decision-makers had explored the problem by applying a number of decision methods. Moreover, the perceived utility of some lower ranked methods to understand one's own position was revealed during the personal interviews. The decision-makers who took part in the experiment stated that even through they would not completely rely on some methods, they are still useful as a way of checking the results derived by other methods. The MC project tests hypotheses regarding whether (i) a set of methods can be specified which are more suitable for a specific situation, without taking into account the decision-makers dealing with the problem; (ii) a set of methods exists which is preferably applied in a successive manner when exploring a given problem; and (iii) how much the usefulness of a method as perceived by decision-makers depends on their understanding of the analytical algorithm underlying the method.

Besides helping water authorities to choose the appropriate programme of measures, the findings of the MCA project support the HarmonRiB project's aim to analyse the various effects uncertainty may have on decisions in river basin management. Although this uncertainty may sometimes be reduced by looking for more precise evidence sustaining the imminent decision, it can never be completely eliminated. Decision support relies on analysis of human behaviour and the elicitation of value judgements – both questions cannot be unambiguously answered and thus transcend science. Human behaviour does not follow precisely known rules and may depend on the conditions specific to a concrete situation. Value judgements on the other hand mean that elicited preferences, which are necessary to compare different measures' outcomes, are of a subjective nature. Differences in value judgements are an inherent feature of the environmental conflicts. In the context of the HarmoniRiB, the MC project compares how uncertainty is dealt with by different CEA/CBA and multiple criteria decision methods, and how suitable these methods are for making uncertainty transparent and communicating it to the decision-makers.

6 CONCLUSIONS

By introducing new concepts such as public participation and the economic analysis of water uses, etc., the WFD has contributed to raising the complexity of river basin planning and decision-making. The efforts undertaken within EC-funded research and development projects towards improving decision-making in water resource management are enormous. The projects funded under the EC 5FP are designed to develop decision support systems, establish methodologies for dealing with uncertainty, and develop integrated models able to represent complex catchment systems, etc.

However, the acceptance of formalized, computerised decision support by the water authorities is often unsatisfactory. This is because the potential of these techniques/tools for solving real-world problems has not been adequately demonstrated and because decision-makers are confused by the variety of methods available. Since different decision methods may lead to different conclusions, water authorities are unsure how to choose the right instrument for a specific situation. The work presented here addresses these problems by analysing the nature of decision problems resulting from the WFD implementation and by examining the factors perceived by the decision-makers as important when applying formalised decision support. The project aims to establish guidelines which help water authorities as they face the increasingly complex decision problems dealt with in river basin management. Close collaboration with two EU R&D projects has permitted the project to benefit from the case studies available for demonstrating the methodology developed.

7 ACKNOWLEDGEMENTS

The present work was carried out within the Marie Curie Fellowship kindly funded by the EC (Contract HPMD-CT-2001-00117) and partly with additional EC funding (Contract EVK1-2000-22089).

8 REFERENCES

[1.] Bell, M. L., Hobbs, B. F., Elliott, E. M., Ellis, H., and Robinson, Z., "An evaluation of multi-criteria methods in integrated assessment of climate policy", Journal of Multi-Criteria Decision Analysis, 10:229-256, (2001).

[2.] Belton, V. and Stewart, T. J., “Multiple criteria decision analysis: An integrated approach” Norwell, Massachusetts: Kluwer Academic Publishers, (2002).

[3.] Brooksbank, K., “Choosing the Right Decision Support Tools”, in: Proceedings of the Forest Extension Working Party Symposium 2001: Assisting Forest Owner, Farmer and Stakeholder Decision-Making, International Union of Forestry Research Organizations, (2001).

[4.] Carlsson, C. and Turban, E., "DSS: directions for the next decade", Decision Support Systems, 33: 105-110, (2002).

[5.] Finlay, P. N. and Wilson, J. M., "Validity of decision support systems: towards a validation methodology", Systems Research and Behavioral Science, 14(3):169-182, (1997).

[6.] Harrison, E. F. and Pelletier, M. A., "Foundation of strategic decision effectiveness", Management Decisions, 36(3):147-159, (1998).

[7.] Harrison, E. F. and Pelletier, M. A., "Revisiting strategic decision success", Management Decisions, 39(3):169-179, (2001).

[8.] Hobbs, B. GF. and Meier, P. M., "Multicriteria methods for resource planning: an experimental comparison", IEEE Transaction on Power Systems, 9(4), (1994).

[9.] Jia, J. and Fischer, G. W, “Evaluating multiattribute decision quality: a simulation study”, in: ORSA/TIMS Joint. Natl. Meeting, (1993).

[10.] Joubert, A. R., Leiman, A., Deklerk, H. M., Katua, S., and Aggenbach, L. C., “Fynbos (Fine Bush) Vegetation and the Supply of Water: a Comparison of Multi-Criteria Decision Analysis and Cost-Benefit Analysis”, 22: 2:123-140, (1997).

[11.] Kanungo, S., Sharma, S., and Jain, P. K., "Evaluation of a decision support system for credit management decisions", Decision Support Systems, 30(4):419-436, (2001).

[12.] Kaplan, B., "Evaluating informatics applications - clinical decision support systems literature review", International Journal of Medical Informatics, 64:15-37, (2001).

[13.] Keil, M., Beranek, P. M., and Konsynski, B. R, "Usefulness and Ease of Use: Field Study Evidence Regarding Task Considerations", Decision Support Systems, 13:75-91, (1995).

[14.] Lu, H. P., Yu, H. J., and Lu, S. S. K., "The effects of cognitive style and model type on DSS acceptance: An empirical study", European Journal of Operational Research, 131:649-663, (2001).

[15.] McBride, N., "The rise and fall of an executive information system: a case study", Information Systems Journal, 7(4):277-288, (1997).

[16.] Mennecke, B. E., Crossland, M. D., and Killingworth, B., “An Experimental Examination of Spatial Decision Support System Effectiveness: The Roles of Task Complexity and Technology, in: Third Americas Conference on Information Systems, (1997).

[17.] Newman, S., Lynch, T., and Plummer A. A., “Success and failure of decision support systems: Learning as we go”., in: Proceedings of the American Society of Animal Science, (1999).

[18.] OASIG, “The performance of information technology and the role of human and organizational factors”, Organisational Aspects of Information Technology Special Interest Group; (1996).

[19.] Poon, P. P. and Wagner, Ch., "Critical success factors revisited: success and failure cases of information systems for senior executives", Decision Support Systems, 30:393-418, (2001).

[20.] Potts, H. W. W., Wyatt, J. C., and Altman, D. G., “Challenges in evaluating complex decision support systems: lessons from design-a-trial”, in: Quaglini, S., Barahona, P., and Andreassen, S.: Artificial Intelligence in Medicine AIME 2001, Lecture notes in computer science, 453-456, (2001).

[21.] Prato, Tony, “Multiple attribute decision analysis for ecosystem management”, 30(2): 207-222, (1999).

[22.] Triantaphyllou, E., “Multi-Criteria Decision Making Methods: A Comparative Study”, Dordrecht, Boston, London: Kluwer academic publishers, (2000).

[23.] Wyatt, R. and Smith, J., "Digital simulation of option-choice behaviour", Computers, Environment and Urban systems, 24: 331-354, (2000).

[24.] Zapatero, E. G., "A quality assessment instrument for multi-criteria decision support software", Benchmarking for Quality Management & Technology, 3(4):17-27, (1996).