International Congress on Environmental Modelling and Software

3rd International Congress on Environmental Modelling and Software - Burlington, Vermont, USA - July 2006

Jul 1st, 12:00 AM

Environmental Policy Aid Under Uncertainty

J. Myšiak

J. D. Brown

Environmental Policy Aid Under Uncertainty

J. Myšiak[1] and J. D. Brown[2]

[1]FEEM Fondazione Eni Enrico Mattei, Castello 5252, 30122 Venice, Italy (jaroslav.mysiak@feem.it)

[2]Institute for Biodiversity and Ecosystem Dynamics, Faculty of Science, University of Amsterdam, Kruislaan, 404, 1098 SM Amsterdam, The Netherlands

Abstract: Uncertainty pervades all aspects of environmental policy making. Numerous typologies and techniques have been developed to conceptualise, classify, assess (qualitatively and quantitatively), propagate, control, reduce and communicate uncertainty. Such assessments are a necessary but insufficient condition for reducing uncertainty in environmental decision making. In this paper we discuss how uncertainty is translated into decisions. Since this entails numerous value judgements and trade-offs which are sensitive to how policy problems are framed, we argue that perceptions of uncertainty cannot be viewed independently of the (quality of) the policy process that it intends to inform. Thus, uncertainty management should not be limited to the elicitation of preferences and value judgements under uncertainty. Rather, it should be embedded within policy making processes more generally, including learning, surfacing tacit assumptions and scrutinising beliefs and knowledge.

Keywords: Integrated Water Resources Management; Uncertainty analysis; Scientific Policy Aid; Policy Analysis

1. INTRODUCTION

Recent emphasis on uncertainty in environmental decision making reflects numerous changes in environmental science and policy making over the past few decades. First, environmental policy problems increasingly involve large, interconnected and complex social choices. For example, climate change, ozone depletion, biodiversity loss, genetically engineered crops, environment-related diseases and health risks involve large scale, long-term impacts, whose precise causes and consequences are often poorly understood. Given these uncertainties and the risk of irreversible environmental changes, different perspectives about the nature, policy implications, or even the existence of a problem are inevitable [Ackoff, 1979; Rittel and Webber, 1973; Rosness, 1998; Sarewitz, 2004].

Secondly, as a consequence, environmental policies[1] have shifted to more precautionary [Dorman, 2005; Dupuy and Grinbaum, 2005; Tallacchini, 2005; van Asselt and Vos, 2005; Vineis, 2005], non-structural [de Loe and Wojtanowski, 2001; Faisal et al., 1999; Hooper and Duggin, 1996; Lu et al., 2001b; Sabino et al., 1999] and demand-led approaches [de Santa Olalla Manas et al., 1999; Froukh, 2001; Gumbo et al., 2004; Mohamed and Savenije, 2000].

Thirdly, and also as a consequence of these new environmental problems, the process of policy making has increasingly favoured interdisciplinary, pluralistic, and inclusive methodologies [Meppem, 2000; Shi, 2004; Tacconi, 1998; van den Bergh et al., 2000b], with scientists participating alongside other stakeholders in deliberative decision making

[1] Relevant examples in the EU include the Sixth Environment Action Programme (EAP); Pollutant Emission Register; Regulatory framework for the Registration, Evaluation and Authorisation of Chemicals (REACH); Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances called also Seveso II Directive; proposal of EU Framework for Community Action in the field of Marine Environmental Policy (Marine Strategy Directive); Strategy for Sustainable Development; Water Framework Directive.

[Baber, 2004; Davies and Burgess, 2004; Renn, 2006], participatory assessment [Argent and Grayson, 2003; Cramb et al., 2004; Kouplevatskaya-Yunusova and Buttoud] or group model building [Sterman, 2002; Stirling, 2006; Vennix, 1999].

These transformations are intertwined with a changing relationship between science and society, favouring greater openness and a dialog between all knowledgeable parties [Fairhead and Scoones, 2005; Johnston and Soulsby; Robertson and McGee, 2003], often laying emphasis on multiple methods and perspectives in tackling these problems.

In this context, 'uncertainty' has become increasingly important in environmental science and policy making. One reason is that policy outcomes are only partly predictable and their associated uncertainties are large enough to sustain persistent conflicts and indecision. Related to this is the tendency for scientists to conceal uncertainty from fear of diminishing their professional credibility and encouraging indecision [Bradshaw and Borchers, 2000]. It is also because uncertainty provides a political resource, which can sustain personal beliefs and self-interest [Stirling, 2006; Weiss, 2002]. Uncertainty poses various philosophical challenges regarding the origin, nature and value of knowledge, ethical challenges regarding acceptable levels of knowledge and risk, its distribution, and who has the mandate to decide, and political challenges regarding how to act when faced with substantial uncertainty. It also poses several practical challenges, in terms of identifying and describing (quantifying, qualifying) uncertainties, propagating them through decisions and communicating the results of an uncertainty analysis.

Recent emphasis on uncertainty within science has led to many perspectives on how risk and uncertainty should be defined and tackled (see for a review [Brown, 2004; Brown et al., 2005; Refsgaard et al., 2005; Rotmans and van Asselt, 2001a; Rotmans and van Asselt, 2001b; van Asselt, 1999; Walker et al., 2003]. Indeed, there is little consensus on how uncertainty should be defined, nor a consistent, interdisciplinary, framework in which to address it (although some attempts have been made, such as Walker *et. al.* 2004). This reflects the complex nature of uncertainty and the diversity of disciplines in which it is a topic of research.

Harmonising these different concepts is not simply an issue of accepting terminology, but an issue of exploring the diversity of words and meanings associated with uncertainty as an "umbrella concept" (e.g. including terms such as imperfect, indeterminate, indecisive, ambiguous, imprecise, inaccurate, vague, and ignorant). The differences between competing understandings of uncertainty (e.g. as a feature of real world systems versus a state of mind or some combination of the two) are deeply rooted in the methodological contexts in which uncertainty is conceptualised and debated. For example, while mathematicians agree on the basic principles of conditional probability, they may disagree on the range of applications in which Bayes' rule (of conditional probabilities) is appropriate, due to important philosophical differences on the nature of probability. In the context of this paper, the lack of a coherent understanding of uncertainty is only significant as far as it frustrates scientific policy advice. Indeed, in scientific research, the variety of competing views and interpretations of uncertainty (and scientific concepts in general) is favourable in the long term for encouraging debate and advancing knowledge. Policy related research on the other hand is action-oriented and competing scientific interpretations prevent shared commitments and make scientific testimony increasingly politicised [Lovbrand and Oberg, 2005; Pielke, 2004; Sarewitz, 2004; Stirling, 2006; Weiss, 2002].

In this paper we discuss the role and value of uncertainty in environmental decision making, informed and aided by science. The paper is complementary to the discussion in Maier and Ascough (2006)[2], which focuses on uncertainties in scientific simulation models. For this reason, a detailed discussion of uncertainty in scientific models is avoided here. In section 2, we briefly outline the nature of uncertainty in policy-related research. This topic is not discussed in detail but aims to place the later arguments in context. In section 3, we discuss cognitive biases and heuristics which influence perceptions of uncertainty. The link between a perceived level of uncertainty or confidence and a number of wider situational and personal factors is illustrated. Finally, in section 4, we focus on uncertainties in decision models and decision frameworks, including their normative assumptions and ability to reduce judgemental biases. We argue that the large number of alternative frameworks can create confusion and encourage indecision, rather than reducing it, if the methodological diversity is not

---

[2] Position paper submitted to workshop "Sensitivity and Uncertainty Assessment of Integrated Environmental Models", organised during the Summit on Environmental Modelling and Software (iMESs) 2006, July 9-12 Burlington, USA.

tackled sensibly. We show that perceptions and assessments of uncertainty are dependent on the formulation of policy problems and the extent to which a decision framework is embraced by policy makers.

2. SCIENTIFIC POLICY AID: BETWEEN SCIENCE AND POLICY

The common distinction between "scientific" (also "statistical", but narrower in meaning) and "political" (also "human reflection") uncertainties has allowed researchers from different disciplines to encapsulate issues which seem tangible from their own disciplinary perspectives. However, due to the flexible boundary between what is perceived as testable (and thus scientific and objective) and what is perceived as untestable (and thus subjective and suspicious), this distinction is often inconsistent. Scientific uncertainty [Gupta et al., 2003; Heazle, 2004; Jamieson, 1996] is typically associated with the quantifiable uncertainties that arise from inadequate methods and instruments or conflicts between what is understood of the environment (e.g. mechanisms) and what is observed (e.g. events). Within this broad understanding, numerous methodologies have emerged for expressing, manipulating and using uncertain quantities. Such expressions range in detail from bounds [Norton, 1996], to set-based approaches [Zadeh, 1973], and probability distribution functions derived from observed frequencies, expert judgements or both [Bernado and Smith, 2001].

Political uncertainty [Brett and Keen, 2000; Hoel, 1998] is frequently conveyed as uncertainty perceived or interpreted outside science. This distinction is misplaced in general (politics exists within science) and specifically in situations when scientists aim to affect policy; first, because implementation is a benchmark of policy-related research and neglecting subjective viewpoints, preferences, or perceptions may significantly reduce the prospect of success; and, secondly, because there are many 'value-laden' choices that are indispensable in policy making, for which science has no special voice. The latter implies that any assumptions and associated judgements must be transparent and subject to debate among all involved parties. Although policy-related decisions often depend on technical advice that is difficult for non-specialists to understand, scientists must be accountable for communicating this advice, and its associated uncertainties, in a way that *is* understandable to non-experts.

Many have argued that policy (or action) related research differs from mainstream science in several ways: it is action oriented (in the sense that the implementation concerns are a part of the research); integrated; value committed (as opposite to 'value-free'); situation specific; operating on long term goals and sensitive to lack of commitment among actors [Meppem, 2000; Shi, 2004]. In practice, however, this distinction obscures the diversity of "policy related research" (policy-relevant research, research on policy etc.) and researchers (e.g. scientists, government advisers, officials) working on environmental policy, as well as the scales of policy considered. In general, these differences are most apparent for large, interdisciplinary, problems, such as sustainable development (SD) and integrated water resource management (IWRM), which engage large numbers of researchers, often from widely different backgrounds. These areas have attracted considerable interest, including both unwarranted enthusiasm and, partly misplaced, criticism in recent years. Although these concepts are arguably vague, elusive, impractical, and susceptible to misinterpretations and hypocrisy [Biswas, 2004; Robinson, 2004; van der Zaag, 2005], they have encouraged wide-ranging discussion and reflection about the values, differences, goals and procedures required to achieve them, leading in turn to a high commitment for their implementation. Of course, such commitments may be partly explained by the vague nature of these concepts, and the consequent scope for re-interpretation and justification of action or inaction by those in power.

Different epistemological frameworks such as post normal science; ecological economics; adaptive management; post-modern science; and mode2 science have been proposed to describe characteristics and 'guiding principles' of policy related research [Meppem, 2000; Norgaard, 2004; Shi, 2004; Tacconi, 1998; van den Bergh and others, 2000b]. However, these frameworks are no more distinct than the problems they address, and partly suffer from overemphasising what is considered "positive" progress while marginalising (caricaturing) others aspects. Nevertheless, they are compelling in other respects, including their re-definition of relations between science and society; release from disciplinary and institutional rigidity; methodological pluralism (embracing ambiguity); surfacing one's own normative assumptions, values, motives, potentials and limits; and a engagement in ongoing dialog [Muller, 2003]. This has several important implications: first, scientists are more likely to facilitate policy processes than to determinate it; secondly, the process of policy making is at least as important as its outcomes; thirdly, the distinction between scientific and 'other' uncertainties is a poor one because they overlap strongly, as is the assertion that scientific uncertainties are somehow 'out there' in the environment.

3. FACTORS INFLUENCING PERCEPTIONS OF UNCERTAINTY

There is a vast body of literature in cognitive sciences, experimental psychology and behavioural decision theory dedicated to the study of inconsistencies underlying judgement and choice. Probably the best known are framing effects [Tversky and Kahnemann, 1974], which refer to changing preferences in normatively equivalent situations. According to Tversky and Kahneman (1981) a decision frame refers to a "decision maker's conception of acts, outcomes, and contingencies associated with a particular choice". In a strict sense, the definition is applied to situations in which the presentation of a problem is slightly manipulated (e.g. half full vs. half empty) but the prospects remain unchanged[3]. In a loose sense the framing effects go beyond a simple semantic manipulation and include substantially different formulations of the 'same' problem (such as positive – gain vs. negative – loss frames), where 'same' is defined in the context of economic theory [Kuhberger, 1998]. Describing identical problems in different frames can elicit different preferences: by highlighting the positive aspects of a problem, risk-aversion is encouraged; whereas negative framing encourages risk-seeking. Others suggested a typology of framing effects with different underlying mechanisms and consequences, distinguishing between risky choice, goal and attribute framing [Levin et al., 1998].

Tversky and Kahnemann [1974] and Kahnemann and Tversky [1996] suggest that intuitive judgement is mediated by a number of distinctive mental operations, called *judgemental heuristics*[4]. Although practical, these heuristics lead to errors and inconsistencies in judgements. Their study is practically motivated (to recognise limitations of intuitive choices) and helps to understand psychological processes underlying perception and judgement. An *Availability* heuristic, for example, refers to the positive weighting of an event that can be easily remembered[5] [Alexander; Greening et al., 1996; Kahneman and Tversky, 1996]. People tend to base their probabilistic assessments on the number of instances they can recall. Judgements are not simply retrieved from memory but are derived from a process that involves recalling memorable information [Carroll, 1978]. *Base-rate neglect* reflects the tendency of people to base intuitive predictions and judgements of probability on similarity or representatives rather than (explicitly stated) base rates of outcomes. *Conjunction fallacy* (see e.g. [Fantino, 1998; Tversky and Kahneman, 1982] refers to the tendency of people to rate the probability of two events more likely to occur than one of them alone. *Confirmation bias* [Fiedler, 2000; Jonas et al., 2001; Patino, 1997] refer to selective information processing, favouring information which confirms rather than contradicts the belief and leads to all but one or two of the most important aspects to be disregarded. *Overconfidence* [Brenner and Koehler, 1996; Tversky and Kahnemann, 1974] refers to the underestimation of uncertainties in some areas compared to the 'average response' whereas *underconfidence* refers to the exaggeration of some uncertainties. A good overview about these and other biases and heuristics can be found in [Berthoz, 2004; Eisenfuehr and Weber, 2003; Kahneman et al., 1982]. Interestingly, despite a rich literature on expert elicitation of probabilities and risks (e.g. [Ayyub, 2001; Moorthy and Fieller, 1998], few studies have attempted to integrate the social-psychological aspects of expert elicitation with the statistical aspects of defining uncertainty, although numerous researchers acknowledge this problem (see [Moorthy and Fieller, 1998].

Opinions on risk and uncertainty are also associated with an individual's character and personality [Chen and Lee, 2003; Hertwig et al., 2005; Larichev, 1992; Lu et al., 2001a; Soane and Chmiel, 2005]. Different cognitive styles[6] have been employed to explain these phenomena [Blais and others, 2005; Lu and others, 2001a],

[3] Tversky and Kahneman (1981) used disease outbreak example in which the prospect of saving 200 (out of 600) people is successively described as sustaining 400 casualties (out of 600).

[4] Heuristic is a subconscious process of evaluation of information (Patt and Dessai, 2005) or a particular technique of directing your attention in learning, discovery, or problem-solving (wikipedia, http://en.wikipedia.org/wiki/Heuristic; accessed on march 13, 2006).

[5] [Kahneman and Tversky, 1996] uses as an examples judgement of the prevalence of suicide being mediated by the easy with which suicide instances come to mind.

[6] Cognitive types are chronic motivations determining the initialisation, course and cessation of information seeking and processing [Blais et al., 2005]

employing different measures of cognitive style, such as the need for enjoyable and challenging cognitive activities; the need to impose structure to dispel doubt and uncertainty; fear of invalidity, information gathering (perception styles) and information evaluation (judgement styles). Numerous researchers [Kowert and Hermann, 1997; Nicholson et al., 2005; Simon et al., 2000] have found a positive association between risk behaviour and a number of distinctive personal characteristics.

Differences in opinion (or 'biases') on risk and uncertainty vary systematically between groups of scientists and policy makers, as well as between individuals. For example, scientists tend to overestimate the uncertainties associated with research from competing groups (e.g. Pinch, 1981). An inability to listen carefully or lack of critical investigation (including its deliberate suppression) may decrease group performance and conviction. [Janis, 1972] identified several symptoms or biases[7] applicable to group performance [Esser, 1998; Turner and Pratkanis, 1998a; Turner and Pratkanis, 1998b]. These symptoms are especially apparent in highly cohesive, isolated, groups with a dominant leader. In such situations, groups tend to perform poorly in terms of surveying alternatives and objectives and appraising uncertainty and risk, leading to poor decision making [McCauley, 1998; Moorhead et al., 1998]. [Hodson and Sorrentino, 1997] suggested that uncertainty-oriented groups are less susceptible to these problems, especially under open-leadership and when a variety of opinions are heard.

Cognitive modelling is used in a number of fields such as system dynamics, DSS and computer science [Barr and Sharda, 1997; Blais and others, 2005; Chen and Lee, 2003; Jiang et al., 2000; Kahai et al., 1998; Lu and others, 2001a]. It attempts to facilitate enrichment and validation of human beliefs and perceptions (mental models) and encourage backward and forward thinking [Chen and Lee, 2003]. Intuitive decision making involves deeply held beliefs and assumptions through which reality is constructed [Chen and Lee, 2003]. Knowledge in human brains is embodied in cognitive structures, referred to as mental models, which are powerful in facilitating learning and qualitative reasoning but less efficient at handling large amounts of data, representing complex phenomena, or capturing non-linear feedback processes. These models are incomplete and imprecisely stated, implicit, intuitive, and often wrong. The term 'mental model' is itself ill defined, being used for a wide variety of mental constructs, but intuitively understandable and thus favoured in a number of scientific disciplines.

A comprehensive discussion of the individual and social factors that govern the quality of intuitive decision making and perceptions of uncertainty is beyond of the scope of this paper. Nevertheless, this short review illustrates how perceptions or beliefs are translated into weight attached to uncertainty or lack of confidence. Furthermore, while it is difficult to assess uncertainty resulting from these biases and heuristics, it is important to acknowledge them in policy processes.

4. UNCERTAINTY IN DECISION MODELS

Choosing one policy measure from a set of mutually exclusive alternatives is limited by our capacity to process all important factors when tackling large environmental problems, such as biodiversity conservation, water and soil degradation, and climate change. In addition to these cognitive limitations, people hold different views about what is important and worthy of pursuit. Competing goals and different underlying values attached to outcomes of policies are yet another source of disagreement and uncertainty in decision making.

Decision analysis[8] helps to avoid biases in judgement and make decisions more compatible with normative axioms of rationality for situations involving multiple, conflicting interests and beliefs. Decision models (DM) result from the systematic exploration and negotiation of a 'problem', including its existence, boundaries and structure. DM comprise alternative courses of actions (policies or policy measures); decision goals - translated into more tangible evaluation criteria - against which the policies are weighed;

[7] These syndromes were called together "groupthink". Merriam-Webster Online Dictionary explains the term as "a pattern of thought characterized by self-deception, forced manufacture of consent, and conformity to group values and ethics" (see http://www.m-w.com/dictionary/groupthink, accessed on March 13, 2006).

[8] For the purpose of this paper we refer to decision analysis as a set of procedures, methods, and tools for identifying, clearly representing, and formally assessing the important aspects of a decision situation. This is different as e.g. in [Raiffa, 1997] where it refers to application of maximum expected utility axioms.

and preferences, which describe how well the policies satisfy the objectives. There are normally several candidate policies; for example, high nitrate pollution can be tackled by introducing financial incentives, changing nutrient management in farms, by protecting littoral vegetation and favouring phytodepuration, or by improving the effectiveness of waste water treatment plants, WWTP). Binary (yes/no) choices, such as whether to adhere to the Kyoto protocol for reducing greenhouse gas emissions[9] are frequently indicative of escalating conflicts due to incommensurable ethical principles, values and interests. Goals may refer to competing targets, e.g. macro-economic developments vs. social impact; favouring different policies so that no single option outperforms all others. In these situations, decision makers may be a priory uncertain (undecided) about what policy action is most appropriate. This *indecisiveness* is a result of the diversity of decision outcomes, which are not uniformly distributed in space and time (e.g. different policy impacts on upstream vs. downstream water users; WWTP extensions may have an earlier impact on nitrate concentration than land use changes) or the values attached to them. Uncertainty in the outcomes of a choice poses yet another challenge for decision making.

The trade-offs or *preferences*[10] are value judgements, which are frequently not observable[11] and must be revealed or approximated. Such uncovered preferences are context specific and depend on the description and framing of a problem, and how the questions are formulated. For example, to assess the environmental costs of irrigation, one must consider the value of wetlands and riverine ecosystems deprived by water abstraction. These values, regardless of whether they are in monetary terms or relative utility, may be difficult to approximate as the results depend on the respondents' prior knowledge or on what they think others would approve. In situations involving uncertainty, preferences are formed over probabilities of possible outcomes of the policies and integrated into the decision model. These preferences embody attitudes towards risk (risk aversion vs. risk seeking vs. risk neutrality), defined according to the value individuals attach to the uncertain outcomes of a decision. This mixing of probability and utility is also found in the formulation and estimation of statistical models in the physical sciences (Moorthy and Fieler, 1998).

DM resemble scientific simulation models (SM) in terms of their structure, and tendency to abstract and simplify phenomena deemed important for a particular case. For this reason, attempts have been made to classify the types and sources of uncertainty that arise in decision models [French and Gabrielli, 2004; French, 1995] in a similar way to SM[12]. Important sources of uncertainty in DM include the extent to which decision criteria approximate the goals and objectives of a study; redundancy within criteria and subsequent overestimation of some aspects; coherence and consistency of preferences; predictability of policy outcomes; representativeness of actors invited to deliberate on policy choices; ambiguity of policies/objectives and expectations about their implementation. Uncertainties can also be classified by the different stages of a decision process, including boundary negotiation; model development; use of models to challenge thinking and interpretation of the results from modelling. Yet there are important differences between DM and SM which limit the practical value of such typologies in DM, as discussed below.

Numerous decision frameworks[13] are available to (more or less explicitly) elicit the preferences of individuals and to aggregate them across different objectives (intra-personal aggregation) and across different actors (inter-personal aggregation). The extent to which specific DM are considered consistent and 'rational' depends on the compliance of the elicited preferences with the

[9] Kyoto protocol is an amendment to the United Nations Framework Convention on Climate Change. Other examples of binary choices are construction of mobile barriers in Venetian lagoon or the Messina's bridge connecting Sicily with the mainland.

[10] Preferences as dealt with in decision theory are real or imagined choices, judgements of merits or degree of (subjectively perceived) satisfaction, about policy options or criteria.

[11] In classical economics market prices are consumer preferences.

[12] For a detailed discussion of uncertainty types/sources in simulation models see [Brown, 2004; Brown and others, 2005; Drechsler et al., 1998; Finkel, 1990; Morgan and Henrion, 1990]

[13] Decision frameworks are referred to as analytic techniques aimed at synthesizing available information from many /narrow or broader) aspect of the problem to assess consequences of different policy options. The concept is sufficiently large to include any normative decision techniques including cost-benefit analysis, cost effectiveness analysis, cost utility analysis, multiple-criteria analysis, game theory, utility theory, risk benefit analysis, operation research, see also [Toth, 2000].

model's assumptions and its ability to outplay cognitive biases. The models differ considerably in terms of (i) the underlying theory and assumptions (e.g. monetary valuation; utility theory; value function approaches; outranking techniques, Bayesian statistics, participatory deliberation); (ii) the approach pursued (e.g. generation of trade-offs versus elicitation of value judgements; a priori methods versus progressive or interactive methods, etc.), (iii) the assumed form of preference function (e.g. non-additive versus additive, linear versus nonlinear), (iv) the way value judgements are elicited (e.g. direct assessment versus elicitation of trade-offs), and (v) the extent to which the method accommodates different perspectives and problem structures.

Although DM vary in purpose, any given decision problem can typically be addressed with more than one DM. As such, DMs act as "lenses" through which the policy problem is viewed, and different DMs may (frequently do) lead to different conclusions. More detailed discussions about the strengths and flaws associated with specific DM can be found in [Bell et al., 2001; Berthoz, 2004; Eisenfuehr and Weber, 2003; French, 1995; Gelso and Peterson, 2005; Hanley, 2001; Kangas and Kangas, 2004; Larichev, 1992; Lienhoop and MacMillan; Liljas and Blumenschein, 2000; Mingers and Rosenhead, 2004; Poyhonen and Hamalainen, 2001; Ryan, 1999; van den Bergh et al., 2000a].

The process of eliciting preferences can also introduce uncertainty into DM. In this context the description and framing of a problem, as well as the formulation of specific questions, can influence the preferences elicited, and hence the reliability of the results. Prior knowledge, preconceived options, levels of understanding of the issues, composition of the interviewed group, levels of income and education and the time spent considering a problem all influence the elicited preferences. Thus, the 'true' beliefs of the individuals may not be elicited, especially if people find value judgements difficult and, in this case, they may adjust their reply to conform with what they believe the interviewer, or the group, finds most acceptable (compliance biases). As a result, the respondents may ultimately feel manipulated by the method or interviewer, and have limited confidence in the results obtained. These problems are greatest when (i) the goods or benefits are unique and cannot be substituted or replaced, or when it is an important component of the respondents endowment; and (ii) too many alternatives/criteria are presented [Jia and Fischer, 1993] or differences in values are high [Bell et al., 2003; Hobbs and Horn, 1997; Hobbs and Meier, 1994].

The variety of different decision frameworks is problematic, as different methods may (normally do) yield different results and hence the decision may depend on the methods selected. Given the large number of methods available, choosing the most appropriate one is difficult and, typically, only a small number of well-known methods are applied. There is no simple criterion for preferring one technique over the others in any given situation; unsurprisingly, most scientific studies show strong partiality for whichever technique conforms best to the world view of the policy adviser. The choice of method is frequently influenced by the beliefs of those identifying policy options, scientists being no exception. The disputes regarding the use of alternative approaches are sometimes based on prejudices, misconceptions or oversimplifications of the criticised methods, while intentionally concealing the weaknesses of the preferred methods. In other cases, alternative decision methods are ignored, and hence the impacts of selecting a specific method are not considered. Clearly, the subjective choices of scientists and decision makers are an important component of decision making, but the impacts of methodological diversity, namely the availability of multiple candidate methods (sometimes referred to as 'equifinality' in the physical sciences), has received relatively little attention in decision making.

In summary, disagreements are inevitable when multiple possible methods are available to address any given decision problem. To overcome this, different methods could be applied in parallel, thereby identifying similarities and highlighting inconsistencies between methods. This could be seen as an educational exercise, whereby the decision maker learns more about their own preferences [Hobbs and Horn, 1997]. Indeed, according to [French, 1995], critical self-reflection is at least as important as the outcome reached through DM. This approach has also been suggested in the physical sciences, where multiple possible explanations of physical data and processes are common (e.g.[Refsgaard and others, 2005]. However, given the practical problems of comparing methods (time, resources, expertise), as well as the problems of selecting an appropriate range of 'candidate methods', further evidence is required on the practicality and value of this approach.

5. CONCLUSIONS AND DISCUSSION

As a result of the previous discussion, it is apparent that perceptions of uncertainty, scientific or otherwise, depend strongly on the context in which they were developed, and that any treatment of uncertainty in policy related research must acknowledge this. If uncertainty is viewed as a level of confidence, and thus dependent on the beliefs of individuals and groups of people, there is a clear correspondence between a decision maker's perceived uncertainty and their level of satisfaction, trust and acceptance of the resulting decisions. However, establishing confidence (reducing uncertainty) is less straightforward, since the main sources of uncertainty are case-specific and vary with the decision problem, levels and access to information, the expertise, interest, and personalities of those involved and the methods used to elicit preferences. In practice, these sources of uncertainty are difficult to specify precisely and cannot be quantified (i.e. numerically) in an operational way. This stems from the inherent difficulty of identifying subtle changes in personal relations, perceptions, and level of trust, all of which are central to decision making. Thus, while it may be possible to develop classifications of uncertainty, such as lists of cognitive biases and heuristics, it is likely that such attempts will improve the qualification of uncertainties in specific cases. This points to an important difference between DM, whose principal aim is to establish values and preferences (which are strongly dependent on the act of observing) and scientific simulation models, where values and preferences are secondary, and results are (presumed) only weakly dependent on the act of observing. These differences are important in understanding the difficulties of communication between scientists and decision makers on issues of uncertainty.

Despite these differences, scientific models and decision models are complementary. The former improve our ability to store and process large volumes of data and analyse complex patterns and non-linear feedbacks, which are beyond our visual and mental capacity. The latter enhance our ability to make coherent choices and comply with assumed axioms of rational behaviour. In both cases, there are strong links between model structures and normative frameworks (defining what is rational and desirable), although they are more apparent in DM. As such, it is difficult to compare models without considering the appropriateness of their normative assumptions.

This paper does not include a deeper reflection about the role of epistemological frameworks in informing environmental policy making or in prompting divergent understandings of uncertainty. Indeed, this is partly because the authors hold different opinions on the extent to which they hamper progress. However, it is clear that particular conceptions of uncertainty are influenced by the wider context in which research is conducted, including its social, political and ethical frameworks.

6. REFERENCES

Ackoff, R. L., The future of operational research is past, *Journal of Operational Research Society*, 30, 93-104, 1979.

Alexander, G., Institutionalized uncertainty, the rule of law, and the sources of democratic stabilities, *Comparative political studies*, 35(10), 1145-1170,

Argent, R. M. and Grayson, R. B., A modelling shell for participatory assessment and management of natural resources, *Environmental Modelling & Software*, 18(6), 541, 2003.

Ayyub, B. *Elicitation of Expert Opinions for Uncertainty and Risks*, CRC Press, pp, New York. 2001.

Baber, W. F., Ecology and democratic governance: toward a deliberative model of environmental politics, *The Social Science Journal*, 41(3), 331, 2004.

Barr, S. H. and Sharda, R., Effectiveness of decision support systems: development or reliance effect? *Decision Support Systems*, 21(2), 133, 1997.

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.

Bell, M. L., Hobbs, B. F. and Ellis, H., The use of multi-criteria decision-making methods in the integrated assessment of climate change: implications for IA practitioners, *Socio-Economic Planning Sciences*, 37(4), 289-316, 2003.

Bernado, J. M. and Smith, A. F. M. *Bayesian Theory*, John Wiley & Sons, pp, Chichester. 2001.

Berthoz, A. *La scienza della decisione*, Codice edizioni, p 386 pp, Torino. 2004.

Biswas, A. K., Integrated water resources management: a reassessment, *Water International*, 29(2), 248-256, 2004.

Blais, A.-R., Thompson, M. M. and Baranski, J. V., Individual differences in decision processing and confidence judgments in comparative judgment tasks: The role of

cognitive styles, *Personality and Individual Differences*, 38(7), 1701, 2005.
Bradshaw, G. A. and Borchers, J. G., Uncertainty as information: narrowing teh science-policy gap, *Conservation ecology*, 4(1), 7, 2000.
Brenner, L. A. and Koehler, D. J., Overconfidence in probability and frequency judgements: a critical examination, *Organisational behaviour and human decision processes*, 65(3), 212-219, 1996.
Brett, C. and Keen, M., Political uncertainty and the earmarking of environmental taxes, *Journal of Public Economics*, 75(3), 315, 2000.
Brown, J. D., Knowledge, uncertainty and physical geography: towards the development of methodologies for questioning belief, *Transactions of the Institute of British Geographers*, 29, 367-381, 2004.
Brown, J. D., Heuvelink, G. B. M. and Refsgaard, J. C., An integrated framework for assessing uncertainties in environmental data, *Water Science and Technology*, 52(6), 153-160, 2005.
Carroll, J. S., The effects of imagining an event on expectations for the event. An interpretation in terms of the availbility heuristic, *Journal of Experimental Social Psychology*, 14, 88-96, 1978.
Chen, J. Q. and Lee, S. M., An exploratory cognitive DSS for strategic decision making, *Decision Support Systems*, 36(2), 147-160, 2003.
Cramb, R. A., Purcell, T. and Ho, T. C. S., Participatory assessment of rural livelihoods in the Central Highlands of Vietnam, *Agricultural Systems*, 81(3), 255, 2004.
Davies, G. and Burgess, J., Challenging the 'view from nowhere': citizen reflections on specialist expertise in a deliberative process, *Health & Place*, 10(4), 349, 2004.
de Loe, R. and Wojtanowski, D., Associated benefits and costs of the Canadian Flood Damage Reduction Program, *Applied Geography*, 21(1), 1, 2001.
de Santa Olalla Manas, F. M., Brasa Ramos, A., Fabeiro Cortes, C., Fernandez Gonzalez, D. and Lopez Corcoles, H., Improvement of irrigation management towards the sustainable use of groundwater in Castilla-La Mancha, Spain, *Agricultural Water Management*, 40(2-3), 195-205, 1999.
Dorman, P., Evolving knowledge and the precautionary principle, *Ecological Economics*, 53(2), 169, 2005.
Drechsler, M., Burgman, M. A. and Menkhorst, P. W., Uncertainty in population dynamics and its consequences for the management of the orange-bellied parrot Neophema chrysogaster, *Biological Conservation*, 84(3), 269, 1998.
Dupuy, J.-P. and Grinbaum, A., Living with uncertainty: from the precautionary principle to the methodology of ongoing normative assessment, *Comptes Rendus Geosciences*, 337(4), 457, 2005.
Eisenfuehr, F. and Weber, M. *Rationales Entscheiden*, Springer Verlag, p 415 pp, Berlin, Heidelberg, New York. 2003.
Esser, J. K., Alive and Well after 25 Years: A Review of Groupthink Research, *Organizational Behavior and Human Decision Processes*, 73(2-3), 116, 1998.
Fairhead, J. and Scoones, I., Local knowledge and the social shaping of soil investments: critical perspectives on the assessment of soil degradation in Africa, *Land Use Policy*, 22(1), 33, 2005.
Faisal, I. M., Kabir, M. R. and Nishat, A., Non-structural flood mitigation measures for Dhaka City, *Urban Water*, 1(2), 145, 1999.
Fantino, E., Behaviour analysis and decision making, *Journal of the Experimental Analysis of Behaviour*, 69(3), 355-364, 1998.
Fiedler, K., Beware of Samples! A Cognitive-Ecological Sampling Approach to Judgment Biases, *Psychological review*, 107(4), 659, 2000.
Finkel, A. M. *Confronting Uncertainty in Risk Management - A Guide for Decision-Makers*, Center for Risk Management, Resources for the Future, pp, Washington DC. 1990.
French, N. and Gabrielli, L., The uncertainty of valuation, *Journal of Property Investment & Finance*, 22 (6), 484-500, 2004.
French, S., Uncertainty and imprecision: modelling and analysis, *The journal of the operational research society*, 46(1), 70-79, 1995.
Froukh, M. L., Decision-Support System for Domestic Water Demand Forecasting and Management, *Water Resources Management*, 15(6), 363-382, 2001.
Gelso, B. R. and Peterson, J. M., The influence of ethical attitudes on the demand for environmental recreation: incorporating lexicographic preferences, *Ecological Economics*, 53(1), 35, 2005.
Greening, L., Dollinger, S. J. and Pitz, G., Adolescents' perceived risk and personal experience with natural disasters: An

evaluation of cognitive heuristics, *Acta Psychologica*, 91(1), 27, 1996.

Gumbo, B., van der Zaag, P., Robinson, P., Jonker, L. and Buckle, H., Training needs for water demand management, *Physics and Chemistry of the Earth, Parts A/B/C*, 29(15-18), 1365, 2004.

Gupta, J., Olsthoorn, X. and Rotenberg, E., The role of scientific uncertainty in compliance with the Kyoto Protocol to the Climate Change Convention, *Environmental Science & Policy*, 6(6), 475, 2003.

Hanley, N., Cost-benefit analysis and environmental policymaking, *Environment and Planning C: Government and Policy*, 19, 103-118, 2001.

Heazle, M., Scientific uncertainty and the International Whaling Commission: an alternative perspective on the use of science in policy making, *Marine Policy*, 28(5), 361, 2004.

Hertwig, R., Pachur, T. and Kurzenhauser, S., Judgments of Risk Frequencies: Tests of Possible Cognitive Mechanisms, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(4), 621, 2005.

Hobbs, B. F. and Horn, G. T. F., Building Public Confidence in Energy Planning: a Multimethod Mcdm Approach to Demand-Side Planning at Bc Gas, *Energy Policy*, 25(3), 357-375, 1997.

Hobbs, B. F. and Meier, P. M., Multicriteria Methods for Resource Planning - an Experimental Comparison, *Ieee Transactions on Power Systems*, 9(4), 1811-1817, 1994.

Hodson, G. and Sorrentino, R. M., Groupthink and Uncertainty Orientation: Personality Differences in Reactivity to the Group Situation, *Group Dynamics*, 1(2), 144, 1997.

Hoel, A. H., Political uncertainty in international fisheries management, *Fisheries Research*, 37(1-3), 239, 1998.

Hooper, B. P. and Duggin, J. A., Ecological riverine floodplain zoning: Its application to rural floodplain management in the Murray--Darling Basin, *Land Use Policy*, 13(2), 87, 1996.

Jamieson, D., Scientific uncertainty: how do we know when to communicate research findings to the public? *Science of The Total Environment*, 184(1-2), 103, 1996.

Janis, I. L. *Victims of groupthink*, Houghton Miffilin, pp, Boston. 1972.

Jiang, J. J., Muhanna, W. A. and Klein, G., User resistance and strategies for promoting acceptance across system types, *Information & Management*, 37(1), 25-36, 2000.

Johnston, E. and Soulsby, C., The role of science in environmental policy: an examination of the local context, *Land Use Policy*, In Press, Corrected Proof,

Jonas, E., Schulz-Hardt, S., Frey, D. and Thelen, N., Confirmation Bias in Sequential Information Search After Preliminary Decisions: An Expansion of Dissonance Theoretical Research on Selective Exposure to Information, *Journal of Personality and Social Psychology*, 80(4), 557, 2001.

Kahai, S. S., Solieri, S. A. and Felo, A. J., Active involvement, familiarity, framing, and the illusion of control during decision support system use, *Decision Support Systems*, 23(2), 133-148, 1998.

Kahneman, D., Slovic, P. and Tversky, A. *Judgement under uncertainty: heuristics and biases*, Cambridge University Press, pp, Cambridge. 1982.

Kahneman, D. and Tversky, A., On the reality of cognitive illusions, *Psychological review*, 103(3), 582-591, 1996.

Kangas, A. S. and Kangas, J., Probability, possibility and evidence: approaches to consider risk and uncertainty in forestry decision analysis, *Forest Policy and Economics*, 6(2), 169, 2004.

Kouplevatskaya-Yunusova, I. and Buttoud, G., Assessment of an iterative process: The double spiral of re-designing participation, *Forest Policy and Economics*, In Press, Corrected Proof,

Kowert, P. A. and Hermann, M. G., Who takes risks? Daring and caution in foreign policy making, *Journal of Conflict Resolution*, 41(5), 611–637, 1997.

Kuhberger, A., The Influence of Framing on Risky Decisions: A Meta-analysis, *Organizational Behavior and Human Decision Processes*, 75(1), 23, 1998.

Larichev, O. I., Cognitive validity in design of decision-aiding techniques, *Journal of multi-criteria decision analysis*, 1, 127-138, 1992.

Levin, I. P., Schneider, S. L. and Gaeth, G. J., All Frames Are Not Created Equal: A Typology and Critical Analysis of Framing Effects, *Organizational Behavior and Human Decision Processes*, 76(2), 149, 1998.

Lienhoop, N. and MacMillan, D., Valuing wilderness in Iceland: Estimation of WTA and WTP using the market stall approach to contingent valuation, *Land Use Policy*, In Press, Corrected Proof, Liljas, B. and Blumenschein, K., On hypothetical bias and calibration in cost-benefit studies, *Health Policy*, 52(1), 53, 2000.

Lovbrand, E. and Oberg, G., Comment on "How science makes environmental controversies worse" by Daniel Sarewitz, Environmental Science and Policy, 7, 385-403 and "When Scientists politicise science: making sense of the controversy over The Skeptical Environmentalist" by Roger A. Pielke Jr., Environmental Science and Policy, 7, 405-417, *Environmental Science & Policy*, 8(2), 195, 2005.

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(3), 649, 2001a.

Lu, S.-Y., Cheng, J. D. and Brooks, K. N., Managing forests for watershed protection in Taiwan, *Forest Ecology and Management*, 143(1-3), 77, 2001b.

McCauley, C., Group Dynamics in Janis's Theory of Groupthink: Backward and Forward, *Organizational Behavior and Human Decision Processes*, 73(2-3), 142, 1998.

Meppem, T., The discursive community: evolving institutional structures for planning sustainability, *Ecological Economics*, 34(1), 47, 2000.

Mingers, J. and Rosenhead, J., Problem structuring methods in action, *European Journal of Operational Research*, 152(3), 530, 2004.

Mohamed, A. S. and Savenije, H. H. G., Water demand management: Positive incentives, negative incentives or quota regulation? *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, 25(3), 251, 2000.

Moorhead, G., Neck, C. P. and West, M. S., The Tendency toward Defective Decision Making within Self-Managing Teams: The Relevance of Groupthink for the 21st Century, *Organizational Behavior and Human Decision Processes*, 73(2-3), 327, 1998.

Moorthy, U. and Fieller, N., Editorial of a special issue on 'Elicitation', *The Statistician*, 47(1), 1-2, 1998.

Morgan, M. G. and Henrion, M. *Uncertainty: A guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge University Press, p 344 pp, NY. 1990.

Muller, A., A flower in full blossom? Ecological economics at the crossroads between normal and post-normal science, *Ecological Economics*, 45(1), 19-27, 2003.

Nicholson, N., Soane, E., Fenton-O'Creevy, M. and Willman, P., Domain specific risk taking and personality., *Journal ofRisk Research.*, 8(2), 157–176, 2005.

Norgaard, R. B., Learning and knowing collectively, *Ecological Economics*, 49(2), 231, 2004.

Norton, J. P., Roles for deterministic bounding in environmental modelling, *Ecological Modelling*, 6, 157-161, 1996.

Patino, H., Reducing confirmation bias in clinical decision-making: Eli I. J Dent Educ 60:831, 1996, *Journal of Oral and Maxillofacial Surgery*, 55(6), 651, 1997.

Pielke, J. R. A., When scientists politicize science: making sense of controversy over The Skeptical Environmentalist, *Environmental Science & Policy*, 7(5), 405, 2004.

Poyhonen, M. and Hamalainen, R. P., On the Convergence of Multiattribute Weighting Methods, *European Journal of Operational Research*, 129(3), 569-585, 2001.

Raiffa, H. *Decision Analysis: Introductory Readings on Choices Under Uncertainty*, McGraw Hill, pp. 1997.

Refsgaard, J. C., Nilsson, B., Brown, J., Klauer, B., Moore, R., Bech, T., Vurro, M., Blind, M., Castilla, G., Tsanis, I. and Biza, P., Harmonised techniques and representative river basin data for assessment and use of uncertainty information in integrated water management (HarmoniRiB), *Environmental Science & Policy*, 8(3), 267, 2005.

Renn, O., Participatory processes for designing environmental policies, *Land Use Policy*, 23(1), 34, 2006.

Rittel, H. W. J. and Webber, M. M., Dilemmas in a general theory of planning, *Policy Science*(4), 155 -169, 1973.

Robertson, H. A. and McGee, T. K., Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia, *Journal of Environmental Management*, 69(3), 275, 2003.

Robinson, J., Squaring the circle? Some thoughts on the idea of sustainable development, *Ecological Economics*, 48(4), 369-384, 2004.

Rosness, R., Risk Influence Analysis A methodology for identification and assessment of risk reduction strategies, *Reliability Engineering & System Safety*, 60(2), 153, 1998.

Rotmans, J. and van Asselt, M. B. A., Uncertainty in Integrated Assessment Modelling: A Labyrintic Path, *Integrated Assessment*, 43-55, 2001a.

Rotmans, J. and van Asselt, M. B. A., Uncertainty Management in Integrated Assessment Modeling: Towards a Pluralistic Approach, *Environmental Monitoring and Assessment*, 69(2), 101, 2001b.

Ryan, M., The role of social process in participative decision making in an international context, *Participation and Empowerment: An internation Journal*, 7(2), 33-42, 1999.

Sabino, A. A., Querido, A. L. and Sousa, M. I., Flood management in Cape Verde. The case study of Praia, *Urban Water*, 1(2), 161, 1999.

Sarewitz, D., How science makes environmental controversies worse, *Environmental Science & Policy*, 7(5), 385, 2004.

Shi, T., Ecological economics as a policy science: rhetoric or commitment towards an improved decision-making process on sustainability, *Ecological Economics*, 48(1), 23, 2004.

Simon, M., Houghton, S. M. and Aquino, K., Cognitive biases, risk perception, and venture formation: How individuals decide to start companies, *Journal of Business Venturing*, 15(2), 113, 2000.

Soane, E. and Chmiel, N., Are risk preferences consistent? The influence of decision domain and personality, *Personality and Individual Differences*, 38(8), 1781, 2005.

Sterman, J. D., All models are wrong: reflections on becoming a system scientist, *System dynamic review*, 18(4), 501-531, 2002.

Stirling, A., Analysis, participation and power: justification and closure in participatory multi-criteria analysis, *Land Use Policy*, 23(1), 95-107, 2006.

Tacconi, L., Scientific methodology for ecological economics, *Ecological Economics*, 27(1), 91-105, 1998.

Tallacchini, M., Before and beyond the precautionary principle: Epistemology of uncertainty in science and law, *Toxicology and Applied Pharmacology*, 207(2, Supplement 1), 645, 2005.

Toth, F. L., 2000, Decision analyis frameworks in TAR, in Pachauri, R., Taniguchi, T. and Tanaka, K. eds.) Guidance papers on the cross cutting issues of the third aasessement report of the IPCC, World Meteorolog. Org., Geneva, p^pp.

Turner, M. E. and Pratkanis, A. R., Theoretical Perspectives on Groupthink: A Twenty-Fifth Anniversary Appraisal, *Organizational Behavior and Human Decision Processes*, 73(2-3), 103, 1998a.

Turner, M. E. and Pratkanis, A. R., Twenty-Five Years of Groupthink Theory and Research: Lessons from the Evaluation of a Theory, *Organizational Behavior and Human Decision Processes*, 73(2-3), 105, 1998b.

Tversky, A. and Kahneman, D., 1982, Evidential impact of base rates., in Kahneman, D., Slovic, P. and Tversky, A. eds.) Judgement under uncertainty: heuristics and biases, Cambridge University Press, Cambridge, p^pp 153-160.

Tversky, A. and Kahnemann, D., Judgment under uncertainty: Heuristics and biases, *Science*, 185, 1124-1131, 1974.

van Asselt, M. B. and Vos, E., The precautionary principle in times of intermingled uncertainty and risk: some regulatory complexities, *Water Sci Technol.*, 52(6), 35-41, 2005.

van den Bergh, J. C. J. M., Ferrer-i-Carbonell, A. and Munda, G., Alternative models of individual behaviour and implications for environmental policy, *Ecological Economics*, 32(1), 43, 2000a.

van den Bergh, J. C. J. M., Ferrer-i-Carbonell, A. and Munda, G., Alternative models of individual behaviour and implications for environmental policy, *Ecological Economics*, 32(1), 43-61, 2000b.

van der Zaag, P., Integrated Water Resources Management: Relevant concept or irrelevant buzzword? A capacity building and research agenda for Southern Africa, *Physics and Chemistry of the Earth, Parts A/B/C*, 30(11-16), 867-871, 2005.

Vennix, J. A. M., Group model-building: tackling messy problems, *System Dynamics Review*, 15(4), 379-401, 1999.

Vineis, P., Scientific basis for the Precautionary Principle, *Toxicology and Applied Pharmacology*, 207(2, Supplement 1), 658, 2005.

Walker, W., Harremoes, P., Rotmans, J., van der Sluijs, J., van Asselt, M., Janssen, P. and Krayer von Krauss, M., Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support, *Integrated Assessment*, 4(1), 5–18, 2003.

Weiss, C., Scientific uncertainty in advising and advocacy, *Technology in Society*, 24(4), 375, 2002.

Zadeh, L. A., Outline of a new approach to the analysis of complex systems and decision processes, *IEEE Trans. on Systems, Man & Cybernetics SMC-3*, 28-34, 1973.