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Transferable Decision-making Procedure for Integrated Flood Management

A theoretical approach to the micro studies of human decision-making and decision makers heuristics

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Preface

Since September 2003, the Institute of Forestry Economics has been involving in the EU Interreg IIIB NWE project 'WaReLa' (Water Retention by Land-Use). The transnational project aims at developing a transnational decision support instrument for spatial planning to decrease flood disasters, which caused by small and medium-sized rivers, by precautionary land-use in meso-scale catchment areas. As one of the 11 partners, who have been assigned different roles and responsibilities, the Institute contributes to the evaluation of the economic, ecological and water retention efficiency at the micro-scale areas through the development of an Eco-Efficiency Analysis (EEA) concept. The EEA complements the physical process based Decision Support Systems (DSS), and thus called EEA-DSS. The EEA-DSS aims at assisting decision makers in evaluating the impacts and feasibility of potential water retention measures through spatial planning in forestry, agriculture and urban sectors.

At a larger scale, the tool is intended to be applied to meso-scale catchment areas as well as transnational catchments. This intention was stated in one of the objectives – development of an internationally-applicable 'Eco-Efficient Decision Support System (DSS)' as a steering tool for transnational river basin management. However, the study on decision-making process with regards to the inclusion of the soft systems in the tool, i.e. the social processes, has not been the focal point of the project. It is generally recognised that an applicable and transferable decision-making instrument is not merely about generating information about physical processes using DSS to facilitate decision-making, but also a mechanism to address the uptake of information by decision makers.

Following up on this issue, the current PhD research project emphasises on the analysis of decision-making process with an ultimate aim of proposing a mechanism for integrating both hard and soft systems in an applicable and transferable decision-making procedure for integrated flood management.

This working paper unveils the overall analysis of the decision-making process including the interfacing and integration problems between science and management arenas, which has been conceptualised as the 'paradigm lock'. In this conjunction, it presents the theoretical framework addressing the interfacing problems and outlines a conceptual framework showing the interaction between these arenas involved in the knowledge production and use cycle in a decision-making system. In addition, the complexity and uncertainty in the decision-making environment will also be taken into account in addressing this issue. This working paper serves as a stepping stone leading towards a more comprehensive theoretical analysis of knowledge management and rationality in decision-making in a complex and uncertain decision-making environment.

On the other hand, this research project will also ultimately be submitted to the College of Forest and Environmental Science for the fulfilment of the requirement for the attainment of the qualification of a doctorate degree.

Freiburg, in January 2008 Tuck Fatt Siew

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Abstract

The development and implementation of a transferable decision support system (DSS) for environmental or natural resources management has been a great challenge. The management problems dealing with both natural and social processes are fundamentally bound with complexity and uncertainty. This has resulted in the much recognised interfacing and integration problems of scientific outputs into decision-making process and these problems have been subjected to contradictory debates too. In this conjunction, holistic and integrated approaches are still required for the understanding of the elements that underlie the complex situations and subsequently for addressing the interfacing and integration problems in order to improve the applicability and transferability of DSS. The main purpose of this working paper is to primarily compile and analyse literature and the state-of-the-art pertaining to these issues, so as to provide a setting and framework for the research project. The ultimate aim of the research project is to develop a transferable decision-making procedure through the integration of knowledge production and use (or soft and hard systems) in the field of integrated flood management and thus to promote cooperation and consensus between different actors. A theoretical approach is adopted in this study. The concept of systems thinking is used for the understanding of the complex decision-making system that underlies the complex situations. Complex decision problems are analysed based on the concept of unstructured problems proposed by Kolkman et al. (2005). Whilst, the integration problems are addressed based on different concepts and theories, namely the paradigm lock, epistemic community and bounded rationality. Subsequently, a conceptual framework addressing the problems through the broad perspective of organisation knowledge management is proposed. The framework illustrates an organisation of scientists and decision-makers getting involved in the knowledge management process. It provides for guidance or stepping stone to further take on micro studies of human decision-making as well as decision makers heuristics.

Abstract (in German)

Die Entwicklung und Durchführung eines übertragbaren Entscheidungshilfesystems (DSS) für das Umweltmanagement oder das Management von natürlichen Ressourcen ist eine große Herausforderung, da die komplexen Fragestellungen sowohl Naturprozesse als auch soziale Prozesse betreffen. Dies macht die Übertragung der wissenschaftlichen Ergebnisse auf die Entscheidungsprozesse schwierig und führte unter Umständen auch zu widersprüchlichen Resultaten. Daher werden holistische und integrierte Ansätze sowohl für das Verständnis der Elemente, die den komplexen Situationen zu Grunde liegen, als auch für die Bearbeitung der Schnittstellen und Integrationsprobleme benötigt, um die Anwendbarkeit und Übertragbarkeit des DSS zu verbessern. Die Zielsetzung dieses Arbeitsberichts ist es in erster Linie die relevante Literatur und den aktuellen Wissensstand zusammenzustellen und zu analysieren, damit der Forschungshintergrund und der Rahmen für das Forschungsprojekt eingerichtet werden können. Das endgültige Ziel des Forschungsprojekts ist es ein übertragbares Entscheidungsfindungsverfahren, das die Integration von Wissensdarstellung und Nutzen (oder ‚soft' und ‚hard' Systeme) in Bezug auf ein integriertes Hochwassermanagement enthält, zu entwickeln. Dadurch soll die Zusammenarbeit und die Koordination verschiedener Akteuren gefördert werden. Ein theoretischer Ansatz wird in dieser Untersuchung eingesetzt. Das Konzept des „Systemischen Denkens" wird für das Verständnis des komplexen Entscheidungsfindungssystems, das den komplexen Situationen zu Grunde liegt, verwendet. Die komplexen Entscheidungsprobleme werden auf Grundlage des Konzepts der unstrukturierten Probleme, das auf Kolkman et al. (2005) zurückgeht, analysiert. Dabei werden die Integrationsprobleme nach verschiedenen Konzepten und Theorien, nämlich dem ‚paradigm lock', der ‚epistemic community' und dem ‚bounded rationality' angesprochen. Anschließend wird ein Konzeptionsrahmen vorgeschlagen, der die Probleme durch das Konzept des Organisationswissensmanagements angeht. Dieser Rahmen erläutert die Organisation von Wissenschaftern und Entscheidungsträgern, die am Wissensmanagementprozess beteiligt sind. Er dient als eine Basis für weitere Detailstudien über Entscheidungsfindungsprozesse und Entscheidungsträgerheuristik.

1 INTRODUCTION

Environmental or natural resources management demands interdisciplinary cooperation as well as planning and decision-making across different levels and scales. Nature-based flood mitigation through spatial land use planning, for instance, requires coherent relationships between science, politics, public administration and public opinions. In addition, such approaches also have precipitated interest in seeking spatial land use planning and water management solutions at diverse geographic and temporal scales, so that the impacts of actions at any one level of operation in the hierarchy of spatial and temporal scales can be managed at other levels (Walker et al., 2001). However, the management problems dealing with both natural and social processes are fundamentally bound with complexity and uncertainty. As a result, the development and implementation of a transferable decision support system (DSS) or a decision-making procedure in order to facilitate decision-making have been a great challenge. In this conjunction, holistic and integrated approaches, which include micro studies of human decision-making and the improvement of decision-making heuristics, are still required to address the complex situations and the problems of integrating scientific outputs into decision-making process.

According to Verdenius and Broeze (1999), the application of complex environmental models has become an important part in decision- and policy-making processes. Decision support systems (DSS), which constitute of a combination of environmental modelling modules, provide a means for decision makers to deal with increasingly complex decisions, increased information, and to professionalise their activities (Walker, 2002). In other words, they are relied on to enhance the capacity of human mind in formulating and solving complex problems. In order to better facilitate group discussion and to increase user satisfaction and compromise so as to obtain an inclusive, equitable and defendable decision, decision evaluation have also been explicitly included in DSS (Bell et al., 2003). Despite these efforts and endeavours, making DSS transferable and integrating them into decision-making process remain great challenges.

The intriguing and foremost questions are:

- Is the development of transferable decision support systems (or scientific outputs in general term) a myth?
- How should the underlying integration problems be addressed in the complex and uncertain decision-making environment?

First and foremost, the challenge of transferring and integrating is attributed to the complexity and uncertainty of the management problems. Then, it was recognised that a more technical approach to the issues of integrating scientific outputs to facilitate decision-making does not fit well with the policy or decision-making process. Instead, a more socially induced problem solving mechanism is necessary to address the integration problems (Slob et al., 2007).

In order to address the issues, positive contributions are expected from a broader education in systems thinking and in multidisciplinary perspectives and methods (Jakeman et al., 2006).

In this respect, the decision-making system needs to be analysed from a broad perspective that underlies the complex situations. Subsequently, the problems of transferring and integrating scientific outputs into decision-making process shall be considered based on various concepts and theories, especially with respect to cognitive and institutional aspects.

1.1 Problem Statement and Objectives

The solutions to environmental and natural resources management problems are challenging because the problems dealing with natural and human environments are bound with complexity and uncertainty across multiple spatial and temporal scales. In this conjunction, the development and implementation of a transferable decision-making procedure that incorporate both soft and hard systems for facilitating rational decision-making about environmental management generally and integrated flood management specifically across different scales also remain a challenging task.

With regard to decision-making, a rational decision could only be made in an ideal world, where reliable information about the consequences of available alternatives and consistent preferences to evaluate their outcomes are available (Choo, 1996). In the real world, however, the state of nature is unclear, possibly incommensurable, and continuously changing (Godard, 1992). Consequently, despite enormous endeavours, including the improvement of DSS by explicitly inclusion of decision evaluation techniques in DSS in order to take into account the preferences of stakeholders and decision makers in alternative evaluation process, the problems of producing credible scientific outputs and their integration into decision-making process are still being subjected to contradictory debates.

Kolkman et al. (2005) explained that the construction of knowledge within different paradigm groups, which leads to different interpretations of the problem situations, contributes to the difficulties in the decision-making process. Whilst, Ballantine (2005) indicated that there was evidence of limitations affecting the uptake of scientific information, such as the different cultures, contexts, and languages of researchers and policy makers (Slob et al., 2007).

Consequently, a gap emerged between knowledge production and use (or between science and management). The gap is termed in the HELP[1] programme, which is a joint initiative of the UNESCO[2] and WMO[3], as interfacing problems or the

[1] Website: http://www.unesco.org/water/ihp/help
[2] United Nations Educational Scientific Organization
[3] World Meteorological Organization

'paradigm lock'. At the European level, the need for more research on and analysis of existing experience with science-policy interfaces was recognised notably in the Sixth Framework Programme for Research and Technological Development of the European Union (FP6) (quoted by van den Hove, 2007). Whilst, research on decision-making process about integrated flood management including interfaces between science and decision-making at the local level have been scarce.

It is clear that adaptive mechanisms for decision support, which encompass the design of methods, tools, and structures for the synthesis of information (including data and knowledge about system function) is much desired (Walker et al., 2001). On the other hand, the challenge for integration is to develop approaches by which data, knowledge and scientific judgements of that data and knowledge can all be made available for integration into a negotiation process that attempts to deal with inherent uncertainty through communication of the principles, values and assumptions underlying analysis (Walker et al., 2001). In this respect, strategic intelligence provides insight into the potential, application and implementation of new technologies and the development of instruments to support players in innovation processes with regard to the analysis and support of decision-making processes (Smits, 2002).

Based on these notions, the main questions of this study are:

- What are the contributing factors in the development and implementation of a transferable decision-making procedure with regard to knowledge management?
- How should knowledge production and use be integrated in the decision-making procedure considering both soft and hard systems?

The main objective of this project is to propose an innovative and transferable decision-making procedure for integrated flood management combining both soft and hard systems. Towards achieving this objective, understanding of the decision-making system from the broad perspective of knowledge management and the integration between science and management within the complex decision-making environment will be primarily focused on.

Therefore, the specific objectives of the study are:

1) To understand the decision-making system from the broad perspective of knowledge management;
2) To identify contributing factors or components underlying integration problems between science and management (or soft and hard systems) in the complex decision-making environment pertaining to knowledge management;
3) To identify interconnecting components and mechanism needed for the integration of soft and hard systems in the decision-making procedure;
4) To identify features of an innovative and transferable decision-making procedure for integrated flood management.

1.2 Scope of the Study

The development of an innovative and transferable decision-making procedure should require a holistic and integrated approach. Slob et al., (2007) recognised that the limited or unstructured understanding of the system is a source of dispute and controversy. Based on this notion, this study attempts to first clarify the complex decision-making system, i.e. the decision-making environment and the decision problems using systems thinking. The analysis of the whole system tries to understand the cause-effect relations between the subsystems as well as externalities that influence the behaviour of the system, and hence the rationality in decision-making in a complex and uncertain environment. Subsequently, the components and factors contributing to the integration of scientific outputs (i.e. results from the study of the natural processes – hard system) into decision-making process (i.e. involves social processes – soft system) will be identified and analysed (Figure 1).

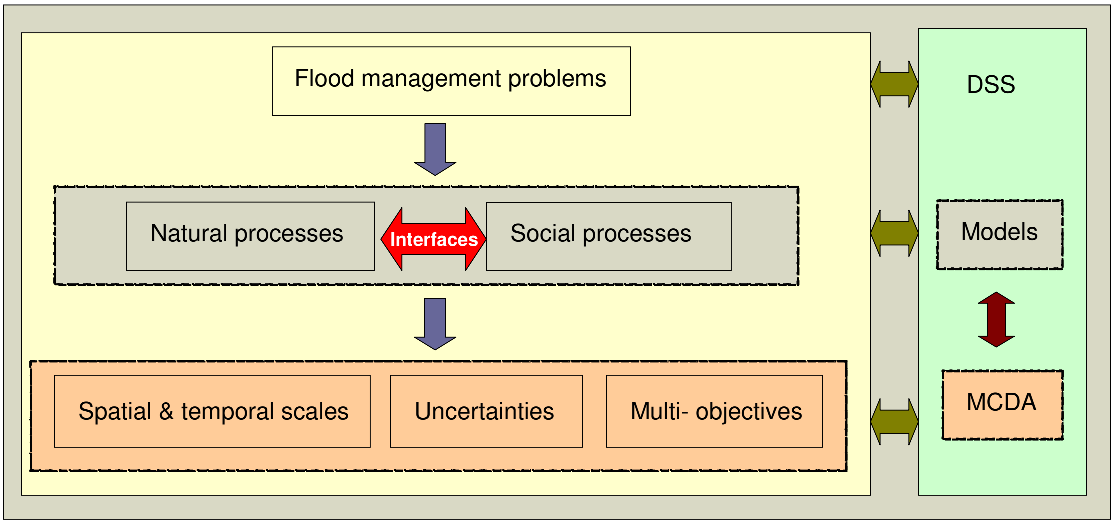

Figure 1: Scope of study within the context of management of decision problems through DSS.

The study adopts both soft and hard approaches for the analysis of the respective soft and hard systems in the decision-making system. The soft approach includes critical analyses and elaboration on the decision-making system and the contributing factors and constraints in decision-making, which underlie the complex situations pertaining to the integration problems in the decision-making process. In this respect, the issues of organisation knowledge management within the context of science and management at different scales and levels will be addressed. A conceptual framework illustrating the interaction between scientists and decision makers, who are involved in knowledge management, serves as a base for further analyses of the micro studies of human decision-making within the networks of epistemic community under complex and uncertain situations.

On the other hand, the hard approach includes the identification and analyses of decision evaluation technique with regard to problem definition and design in the effort of managing complexity and uncertainty issues. As noted by Janssen (2001), the support of problem definition and design is more important than the development of more sophisticated, for instance, multi-criteria decision analysis (MCDA) methods.

Problem structuring approach will then be explored to integrate both soft and hard systems in the decision-making procedure.

1.3 State-of-the-Art: Interfacing and Integration between Science and Management

1.3.1 Overview

In the recent years, the numbers of studies addressing the interfacing problems between science and management (or decision-making) with the ultimate aim of achieving integration have been increasing. Most recently, the study conducted by van den Hove (2007) aimed at a better understanding of the justification for science-policy interfaces, of the reasons for their growing importance in environmental governance, and of the theoretical and epistemological challenges they pose. In her opinion, a series of methodological issues pertaining to the design, implementation and assessment of science-policy interfaces will need to be considered from the perspective of theoretical investigation, practical experimentation and critical debates.

On top of that, other studies also provide different perspectives on the generation of credible scientific outputs by scientists and the uptake of information by decision makers (e.g. Kolkman et al., 2005; Slob et al., 2007). At the same time, different approaches have also been attempted to address the problems in the field of water resources management as well as from the perspective of an organisation. These studies focused on the understanding of the roles of scientists and decision makers (Mills and Clark, 2001; Walker et al., 2001), the forces dividing science and water management arenas (Acreman, 2005), the role of decision support systems (Walker, 2002), and the requirements of models or decision support systems development (Biswas, 1975; Westmacott, 2001). In this conjunction, their debates related to the effective communication between scientists and decision makers as well as between decision makers and stakeholders, the inclusion of social dimension in the development of decision support systems, capacity building through learning, the understanding of cultures, contexts and languages of the researchers and policy makers (especially in transboundary river basin management), as well as the accountability of risks and uncertainties in a complex decision-making environment.

The focus of these studies can be analysed based on different dimensions, namely the actor, institutional and technology innovation dimensions.

1.3.2 Actor Dimension

Mills and Clark (2001) highlighted the interfaces between science and decision-making from the perspective of the roles of research scientists and decision makers. Their study was related to the questions of what credible scientific information is and how such information is used in often emotionally or politically laden natural resource management decisions. In this regards, they proposed the roles that research scientists and decision makers could play. Using the experience with the Interior Columbia Basin Ecosystem Management Project, the question of how research scientists can be successful in bringing their skills and knowledge to bear on controversial natural resource management policies were also discussed.

Likewise, Walker et al. (2001) also took a pragmatic view on the roles of managers, planners and scientists with regards to the integration of research results into decision-making in natural resource management at catchment scale. They proposed a particular and emerging role in designing approaches to adaptive decision support.

Challenges of linking science and decision-making in water resource management were also exemplified by case study conducted by Acreman (2005). In the case study pertaining to the setting of environmental river flow, he explored the forces dividing scientists and water managers, and examined trends in thinking and how risk and uncertainty need to be handled constructively when applying results.

On the other hand, Slob et al. (2007) explored the use and ignorance of scientific knowledge in decision-making in river basin management in the EU project AquaTerra based on a theoretical review. They elaborated on the ‘two communities theory’, which explains the problems of the policy-science interface by relating and comparing the different cultures, contexts, and languages of researchers and policy makers. They concluded that there is a clear need for new models describing the factors, which influence the uptake of scientific information by policy makers, more adequately than the two communities theory.

1.3.3 Institutional Dimension

In his paper, Norgaard (1992) examined how the difficulties in finding sustainable environmental interactions may be rooted in the institutionalised thinking and organising from which these attempts emerge. The major question addressed was why agencies and organisations support special interests better than collective ones.

On the other hand, Cinquegrani (2002) analysed the concept of epistemic community from the perspective of knowledge and capacity of acting under the conditions of uncertainty. He also explored the possibility of considering some organisations and institutions as future epistemic communities.

Concerning organisational knowledge management, Choo (1996) analysed how an organisation uses information to make sense of change in its environment; to create new knowledge for innovation; and to make decisions about courses of action. Based on the principle of bounded rationality founded by Herbert Simon, Choo proposed the concept of 'the Knowing Organization' for holistically managing its sense-making, knowledge building and decision-making processes in order to gain the necessary understanding and knowledge to act wisely and decisively. According to him, without a firm grasp of how an organisation creates, transforms and uses information, an organisation would lack the coherent vision to manage and integrate its information processes, information resources and information technology.

1.3.4 Technology Innovation Dimension

In the effort of developing usable and useful decision support systems, Westmacott (2001) used an example in integrated coastal management to describe the components of the decision-making environment and criteria need to be considered. He also explored various techniques available to deal with different modelling needs, the constraints of inadequate data and the multi-objective decision-making environment. Three examples of DSS were selected for their different structures and approaches to the development of the DSS and were critically evaluated. Whilst, Walker reappraised the role of decision support and proposed a generic framework for the implementation of decision support as a broader initiative than the development of a decision support output, and one that aims to foster learning and co-learning.

Biswas (1975) maintained that it is necessary to reduce the proliferation of unvalidated, untested and unuseful models. In this respect, there are basic rules for realistic model development and remedies for improving the image of modelling in the eyes of decision makers. Likewise, Jakeman et al. (2006) also stated that developers of decision support systems should be less focussed on developing 'one-off' visualization and interface tools for specific applications, and more focused on extracting generic features which are common to many applications. They further stated that development of DSS should be an investment in learning what is frequently useful, not in generating software that has little capacity for reuse. In addition, DSS are also desired to be adaptive under different institutional and political frameworks with the inclusion of public participation aspects.

Courtney (2001) suggested that organisations and their DSS must embrace procedures that can deal with the complexity of organisational decisions of future and go beyond the technical orientation of previous decision support systems. He discussed DSS and knowledge management in Singerian organisations and called for a new decision-making paradigm for DSS.

Based on the framework proposed by Courtney (2001), Kolkman et al. (2005) presented a theoretical framework that uses mental model mapping techniques to analyse the difficulties in finding a solution for complex and unstructured problems considering the fundamental cognitive level, which can reveal experiences, perceptions, assumptions, knowledge and subjective beliefs of stakeholders, experts and other actors, and can stimulate communication and learning. The framework consists of problem solving or policy design cycle, knowledge production or modelling cycle, and (computer) model as interface between these cycles.

Using a different approach, Willems and de Lange (2007) described the concept of using bi-directional linking of various types of information sources identified as potential means to technically support science-policy interfacing for enhancing the interfacing mechanism. It is based on a combination of activity-based and contextual keywords as central element to describe specific activities related to policy implementation, and to link these activities with supporting tools and other RTD (Research and Technology Development) results, as well as to experiences from existing practical implementations and implementation guidance.

Being innovative, Petkov et al. (2007) demonstrated how the combination of multiple criteria decision-making (MCDM) [or multi-criteria decision analysis (MCDA)] and separate techniques from systems thinking (soft systems) approaches for decision support at particular stages of complex problem solving may support multiple perspective representations of complex managerial problems. The justifications of the methodologies and lessons learned were discussed using case studies within the information and communications technology sector.

On the other hand, there is no general consensus pertaining to the choice of specific multi-criteria decision analysis (MCDA) method, i.e. as decision rule, to apply to a specific management problem. The application of MCDA methods to water management and water resource related problems were reviewed by Myšiak (2006) and Hajkowicz and Higgins (2007, 2008). Hobbs et al. (1992) argued that it is not only the technical aspect of the method that influences the choice of methods, the users have also some instinctive influences in adopting a particular method. Likewise, Myšiak (2006) stated that the choice of MCDA methods is a multi-criteria decision problem in itself and the suitability of MCDA methods is subjected to the evaluation of the complexity of the methods, the confidence they inspire in decision maker, the difficulty of interacting with them, the ability to deal with a decision problem, and the ability to designate a solution. Srdjevic et al. (2004) suggested that several standard methods are used to generate results, which are then analysed using an unbiased method in order to come up with a final solution. In this conjunction, Myšiak (2006) maintained that the application of multi-method MCDA for unstructured decision problems may be regarded as a type of validation, which is more extensive than standard sensitivity analysis, and which enables the decision maker to review the preferences and judgements previously elicited by a single method. However, as concluded by Janssen (2001), the support of problem definition and design is more important than the development of more sophisticated MCDA methods. Likewise, Myšiak (2006) also commented that structuring the problems and the issues encountered by implementing the alternatives eventually chosen is addressed in insufficient detail in applying MCDA methods.

1.3.5 Summary

The applicability and transferability of decision support systems and the effective integration of the tools into decision-making process have been debated since decades. Scientific outputs provided by scientists have not been convincing to the decision makers, who demand for credible scientific information and knowledge for decision-making. In this respect, a multitude research effort and resources have been invested in developing new sophisticated decision support tools as well as in improving the tools by including decision evaluation techniques, which account for preferences and judgement of stakeholders and decision makers, to facilitate more effective decision-making. However, such efforts have not been able to provide for satisfying solutions.

The interfacing and integration problems emerged between science and management indicate that the decision problems are fundamentally bound with complexity and uncertainty in both natural and social systems. Apart from addressing the problems technically, more theoretical investigation from the broad perspective of micro studies of human decision-making should also be required. In this respect, addressing the complex decision problems should revolve around actor, institutional, and technology innovation dimensions, which shall then be critically analysed based on the concepts and theories of bounded rationality, epistemic community and the paradigm lock, respectively. These dimensions shall subsequently framed in the knowledge production and use process (i.e. knowledge management process) in a decision-making system.

2 THEORETICAL FRAMEWORK

2.1 Systems Thinking

The understanding of the nature of complex situations requires a number of different perspectives at different scales of investigation (Kay, 2003) as well as a paradigm shift from fragmented to holistic science (Hjorth and Bagheri, 2006). In order to achieve such a shift, linear and mechanistic thinking (or linear causal thinking, which is also called ‘command and control’ by Holling and Meffe (1996) must give way to non-linear and organic thinking, more commonly referred to as systems thinking (Hjorth and Bagheri, 2006).

Systems thinking is the antithesis of prevalent reductionist thinking (Kay, 2003). It offers some insights and approaches for dealing with complexity by providing a way of framing our investigations and a language for discussing our understanding. The theory applied leads us to view system from a broad perspective that underlies complex situations, including seeing overall structures, patterns and cycles in the system as well as its various subsystems and the recurring patterns in the relationships between the subsystems, rather than seeing only specific events in the system. By focusing on the entire system, solutions that address as many problems as possible in the system can be identified.

Therefore, systems thinking is the art and science of linking structure to performance, and vice-versa – often for purposes of changing structure (relationships) so as to improve performance (Richmond, 1994). Systems thinking focuses on the causes in the system rather than people. It lets one designs high-leverage interventions for problematic system behaviour (Hjorth and Bagheri, 2006). In systems terms, changing structure means changing of the information links in a system: the content and timeliness of the data that actors in the system have to work with, and the goals, incentives, costs, and feedbacks that motivate or constrain behaviour (Hjorth and Bagheri, 2006).

A branch of systems thinking called system dynamics is a thinking model and simulation methodology that was specifically developed to support the study of dynamic behaviour in complex systems (Hjorth and Bagheri, 2006). It draws on a wide variety of disciplines to provide a common foundation for understanding and influencing how things change over time. System dynamics modelling is about discovering and representing the feedback process, which determines the dynamics of a system as well as a method to enhance learning in complex systems (Sterman, 2000). Besides, system dynamics can also be applied in building and running simulation models to analyse system performance under different scenarios, which offer a good decision support tool for choice of appropriate strategies or policies for a system (Hjorth and Bagheri, 2006).

On the other hand, the notion of everything is connected, at least weakly, to everything else raises fundamental systems' questions regarding the scope of a study as well as the scale and extent of the study. The rules of a system define its scope, boundaries, and its degrees of freedom (Hjorth and Bagheri, 2006). Any analyst must make decisions about what to include and what to leave out of the system to be studied (Kay, 2003). These decisions are done in a systematic, consistent and necessarily subjective way.

2.2 Decision-making Process

2.2.1 Decision-making

Decision-making shares equivalent meaning with problem solving and management. As suggested by Kolkman et al. (2005), decision-making can be characterized as a process of systematic problem solving concerning possible alternative solutions (e.g. using effect forecasting and decision methods). Herbert Simon and his associates maintained that management is decision-making (quoted by Choo, 1996) and the decision-making process consists of three phases: intelligence, design and choice (quoted by Malczewski, 1999) (Figure 2a). Whilst, Biswas (1975) defined management as the process of converting information into action (Figure 2b).

Consequently, decision-making involves the process of problems definition, choosing and evaluating available alternatives for a specific course of action through the assessment of the criteria values of each alternative based on the preferences of the decision makers taking into account available resources and the constraints present in the decision-making environment.

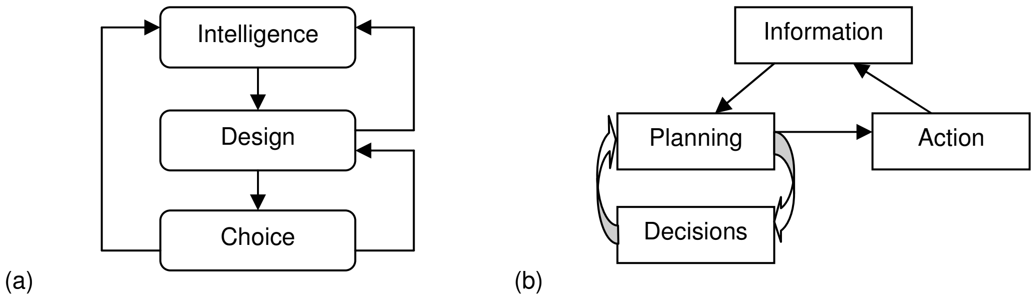

Figure 2: Processes in decision-making: (a) Three-phase decision-making process (adapted from Malczewski, 1999); (b) Management process illustrating the basic components and sequence of events (Biswas, 1975).

2.2.2 Complexity of Decision Problems

Decision problems, particularly in the field of environmental management or natural resources management, are bound with complexity, uncertainty and disagreement and are, therefore, termed as unstructured problems (Figure 3) (Kolkman et al., 2005). Such unstructured situations are also referred to as messes or wicked problems (Mackenzie et al., 2006). For a system, complexity means more entities having more properties and more relationships, i.e. the interaction of social, economic, and institutional dimensions with the natural dimension, which relationships can also be more complicated; for knowledge, complexity equals uncertainty in disciplinary knowledge (due to limited knowledge and/or disagreement on analysis methods) and in the coupling of knowledge from different disciplines; and for society, complexity means uncertainty and disagreement about values and norms of stakeholders (Kolkman et al., 2005).

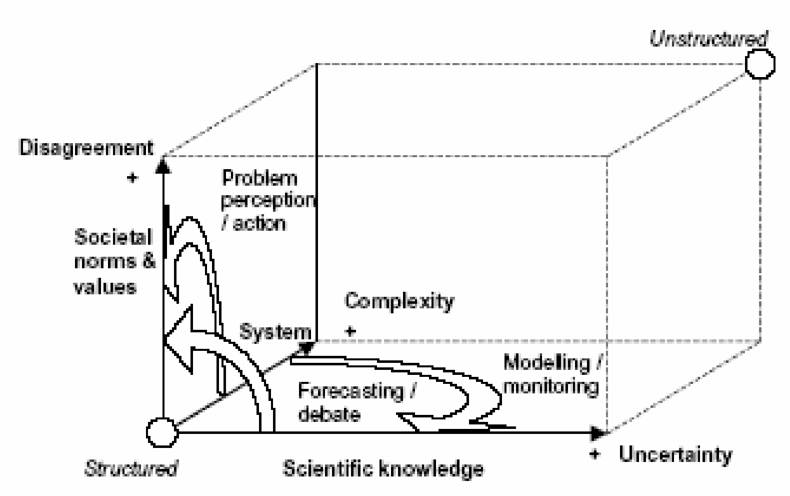

Figure 3: The three dimensions of complex unstructured problems (Kolkman et al., 2005).

In a decision-making environment, information available, cooperation and communication among different decision makers and stakeholders, expertise and education level, availability of financial resources, and acceptability of the strategies to those affected contribute to the decision-making capacity (Westmacott, 2001). At the same time, the multiple fields and disciplines are also influenced by other factors (Figure 4). In this respect, the changing characteristics and interactions of physical environment, various social needs and available technology across spatial and temporal spaces in the decision-making environment result in the complexity and uncertainty in the decision-making process.

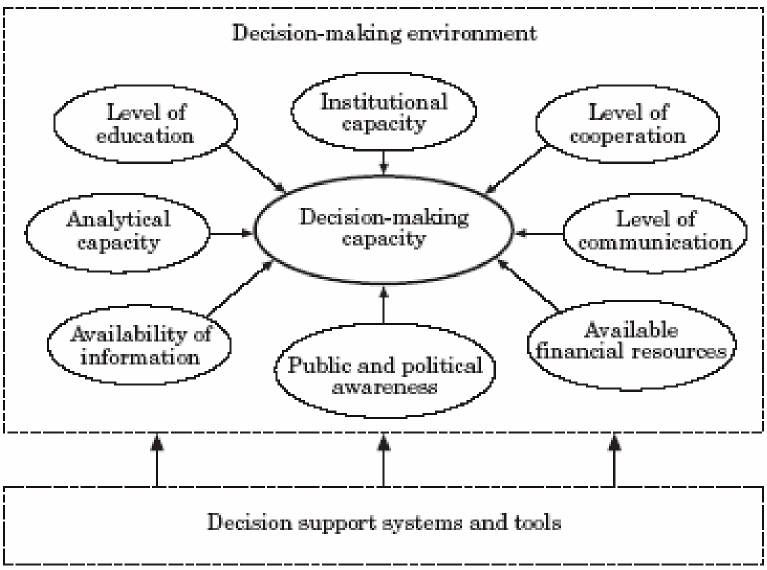

Figure 4: Decision-making environment (Westmacott, 2001).

2.2.3 Decision Support Systems

Decision support technologies (e.g. decision support systems) and paradigms have been developed by scientists as a means to deal with the complexity of decision problems through the enhancement of the limited capacity of human mind in formulating and solving complex problems. Mowrer (2000) defined decision support systems (DSS) as computer-based systems that integrate data sources with modelling and analytical tools; facilitate development, analysis, and ranking of alternatives; assist in management of uncertainty; and enhance overall problem comprehension. Whilst, Gorry and Scott Morton defined DSS as a computer system that deals with a problem at least at some stage of which is semi-structured or unstructured (quoted by Courtney, 2001).

According to Walker (2002), DSS have their origins in management and information sciences and have in return been widely proposed as providing a basis for improving management. Likewise, Nevo and Chan (2007) mentioned that together with executive information systems and expert systems, DSS are the predecessors of knowledge management systems. DSS can be used for assisting in systematic thinking and deepening mutual understanding (Kainuma et al., 1991), strengthening the decision-making capacity (Westmacott, 2001), and transferring of disciplinary knowledge (Kolkman et al., 2005). They are needed as operational tools to put the broadest context of methodologies into practice (Giupponi et al., 2006). In other words, they provide useable knowledge at an appropriate point of decision-making process, and at an appropriate level of precision. As mentioned by Te'eni and Ginzberg (1991) and Fabbri (1998), DSS are developed under the belief that these systems are able to improve our understanding of the interrelationships between natural and socio-economic variables and hence result in improved decision-making.

As DSS play an useful role in connecting the interface between science and policy or decision-making, the functional design (as opposed to the implementation) of decision support tools, the design and facilitation of capacity building exercises, and the design and implementation of evaluative strategies for assessing the impact of the process of decision support systems, represents an increasingly important activity in natural resource management (Walker et al., 2001). Westmacott (2001) explained that decision support systems should be designed in such a way as to support the components within the decision-making environment by providing additional information, analytical tools and management tools that would not otherwise be available. In addition, model concept and regimes, scales issues, common data definitions and software environment (on which various models can be linked) need to be considered in developing DSS (Jakeman et al., 2006). Besides, sensitivity, risk and uncertainty assessment of DSS are also important.

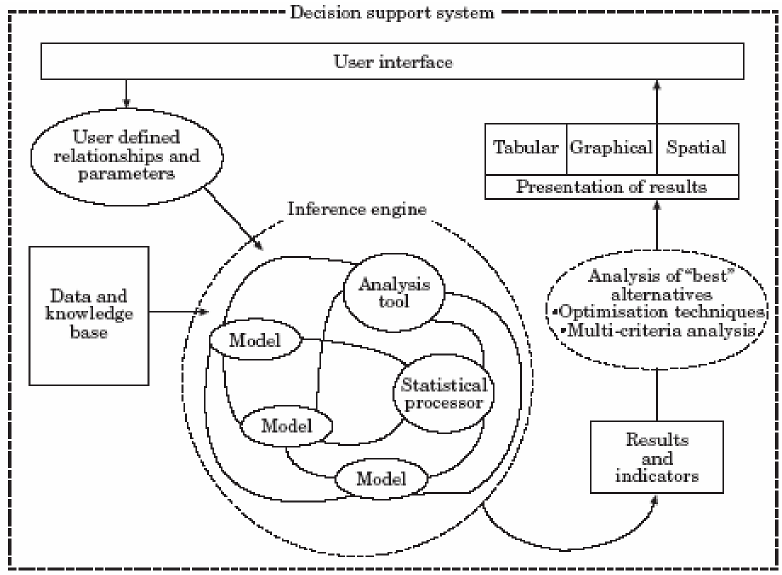

Figure 5: Components of decision support systems (Westmacott, 2001).

Structurally, each DSS typically consists of a user interface, a knowledge base or database and a series of models (Figure 5). The contents and design of DSS are determined by the purpose of the systems, whether they are used as screening tools to assess the environmental impacts of individual projects (Geraghty, 1993) or planning tools for developing and analysing alternative management strategies (Westmacott and Rijsberman, 1995).

On the other hand, DSS have evolved to become group decision support systems and knowledge-based decision support systems (Courtney, 2001), as well as to integrate and operate in a spatial environment using geographic information systems (GIS).

2.2.4 Evaluation Technique

As indicated by Bell et al. (2003), DSS that explicitly include decision evaluation increase user satisfaction and better facilitate group discussion and compromise. Multi-criteria decision analysis (MCDA) has become a frequently used approach in water resource management decision-making, as it provides an effective tool by adding structure, auditability, transparency and rigour to decisions (quoted by Hajkowicz and Higgins, 2008).

Multi-criteria decision analysis (MCDA) is defined as an umbrella term to describe a collection of formal approaches, which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton and Stewart, 2002). According to Mendoza and Martins (2006), the inherent properties and desirable features of MCDA techniques are appealing and practically useful as well as an appropriate tool for analysing complex problems such as those typically found in natural resource management. MCDA helps to structure problem, evaluate a set of alternatives in MCDA problems based on conflicting and incommensurate criteria, and deliver a rational, justifiable and explainable decision. In other words, MCDA methods help decision makers process data, understand policy tradeoffs and learn how their value judgements affect decisions (Bell et al., 2003). However, MCDA is not meant for calculating the right decision, but to help improve understanding for decisions involving risks, multiple criteria, and multiple interests (Bell et al., 2003).

MCDA has been moving from optimising methods to more interactive decision support tools (Bender and Simonovic, 2000). It offers a collaborative, flexible and open structure framework that can deal with quantitative (hard system) and qualitative (soft system) data. This provides for a participatory environment that accommodates the involvement and participation of multiple experts and stakeholders (Mendoza and Prabhu, 2003). In addition, MCDA techniques have been evolving to incorporate methods for analysing uncertainty aspects of multi-objectives environmental problems in a spatial environment since conventional MCDA techniques are not sufficient to deal with complex decision problems.

2.3 Interfacing and Integration Problems

Varieties of methods and tools, such as modelling, environmental impact assessment and decision support can provide rational insight into the system's behaviour and the problems addressed, but integration and use of DSS to facilitate decision-making remains a difficult issue (Giupponi et al., 2006). According to Walker (2002), the failures of DSS can be attributed to non-delivery, non-adoption and unexpected negative impacts of DSS where they are adopted. On one hand, DSS must be able to implement rigorous scientific approaches as well as be simple and easy-to-use for stakeholders. On the other hand, there is also concern about misapplication of models and tools, which can lead to unrealistic and misleading outputs (Parker et al., 1995).

The integration problems are primarily attributed to the complex decision-making environment. In this conjunction, the challenge for integration is to develop approaches by which data, knowledge and scientific judgements of that data and knowledge can all be made available for integration into a negotiation process that attempts to deal with inherent uncertainty through communication of the principles, values and assumptions underlying analysis (Walker et al., 2001).

System uncertainties convey the notion that the problem is not concerned with the discovery of a particular fact, but with the comprehension or management of an inherently complex reality (Kolkman et al., 2005). Hence, the understanding of cognitive and institutional aspects based on various concepts and theories is necessary in order to address the complex problems and thereafter integration problems. These concepts and theories include the paradigm lock, epistemic community and bounded rationality.

2.3.1 The Paradigm Lock

A dramatic gap in the knowledge, the aims, the way of thinking and the language exists between those who analyse and provide disciplinary expertise and those who decide (Luiten, 1999). This mismatch between science and management is generally termed as the 'paradigm lock' (Figure 6). The gap signifies that scientists and water managers are locked into separate vicious circles, which are also driven by different forces, for instance legislation, transparency, consistency, funding and operation time scale (Acreman, 2005).

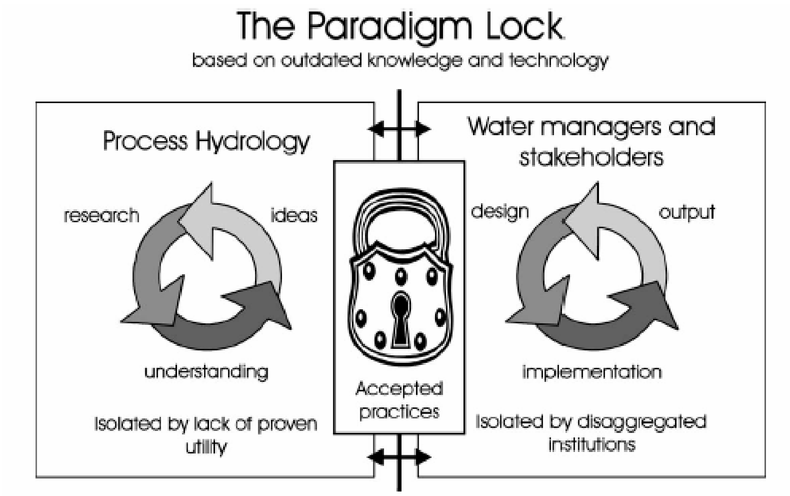

Figure 6: The paradigm lock illustrated by UNESCO (adapted from Acreman, 2005).

According to Biswas (1975), the mismatch problems relate to the purpose of the DSS developed, which have been classified somewhere between dilettantism and academic exercises. Willems and de Lange (2007) pointed out that the operation use of newly developed tools from the research community is most often limited because the needs of decision or policy makers are not taken into account at sufficient level. Scientists are driven by innovation and understanding of the problem of a study to come up with methods that can be replicated by their peers (Acreman, 2005). As a result, in the opinion of the water managers, the results of the scientific studies are not compatible to the form required. Likewise, Mills and Clark (2001) also explained that scientists in routine science are driven by questions of importance requiring basic and/or applied research as well as to fill basic gaps in scientific knowledge, while critics are constructive allies in the scientific process and understand the 'language of science' and the results are subjected to rigorous peer review. Similarly, Acreman (2005) maintained that scientists seek the best theory to explain the data that are available, are driven by innovation and understanding, are concerned more with technical integrity, and their main performance indicator is publications that have been peer-reviewed by other scientists. Whilst, water managers seek consistent methods and decision support tools to support decision-making.

Furthermore, Willems and de Lange (2007) argued that scientists view the end-user in the research project as the client for their research results, but on the ground there is a significant lack of transfer mechanisms that would allow passing the relevant information on to other stakeholders including policy makers and implementers. Boehmer-Christiansen (1994) also noted that science is often more comfortable in providing advice on what ought to be done and why, rather than practical advice on how it might be achieved.

Although the use of scientific evidence within policy is a key input to improve legislation and decision-making, there are also evidences of limitations affecting the uptake of scientific information, (Ballantine, 2005). According to Slob et al. (2007), a lack of public confidence in scientific information, the difficulty of obtaining high-quality science at short notice and a lack of universal support for scientific input into policy making are the results of both contradictory science and a lack of certainty surrounding the available results.

On the other hand, Slob et al. (2007) maintained that some policy makers are unable to make use of highly technical advice, while discrediting science and even the scientist is a strategy sometimes used by antagonists on both sides of the issues because science applications to natural resource issues are usually done in the glare of public conflict and controversy (Mills and Clark, 2001). In the opinion of scientists, DSS should be seen as support systems but not decision makers (Westmacott, 2001; Courtney, 2001).

The debates indicate that the science-policy interrelationship is inefficient at this moment as it should/could be (Willems and de Lange, 2007). Although there is evidence that they are sometimes well connected, the opposite is also apparent (Slob et al., 2007).

2.3.2 Epistemic Communities

On the contrary, Acreman (2005) concluded that there is no real gap between science and decision-making, but rather a continuum of expertise from basic to applied scientists through to water managers, with individual scientists producing research results along the spectrum from fundamental understanding to very applied. The continuum is, however, bound to complexity, which introduces risk and uncertainty in the decision environment.

Moreover, the continuum of expertise also forms different epistemic communities, (which are similar to agencies and organisations,) who support special interests better than collective ones (Norgaard, 1992). According to the concept of epistemic community, members of an epistemic community share inter-subjective understandings; have a shared way of knowing; have shared patterns of reasoning; have a policy project drawing on shared causal beliefs, and the use of shared discursive practices and have a shared commitment to the application and production of knowledge (Haas, 1992).

An epistemic community as defined by Haas (1992) is a network of professionals from a variety of disciplines and backgrounds, who have (1) a shared set of normative and principled beliefs, which provide a value-based rationale for the social action of community members; (2) shared causal beliefs, which are derived from their analysis of practices leading or contributing to a central set of problems in their domain and which then serve as the basis for elucidating the multiple linkages between possible policy actions and desired outcomes; and (3) shared notions of validity – that is a set of common practices associated with a set of problems to which their professional competence is directed, presumably out of the conviction that human welfare will be enhanced as a consequence. In a similar context, Godard (1992) defined an epistemic community as a network of experts who share beliefs about cause-and-effect relationships – even if such beliefs turn out to be wrong – and who holds common values about preferred public action.

Kolkman et al. (2005) explained that the construction of knowledge within different paradigm groups leads to different interpretations of the problem situations and contributes to the difficulties in the decision-making process. Besides, there are not only different paradigms and methods between biophysical scientists and social scientists, but also gaps in shared understanding between some of the major quantitative sciences (Jakeman et al., 2006). Norgaard (1992) suggested that discipline boundaries have impeded true implementation of interdisciplinary methodologies and the development of generalised models because the assumptions, cultures, and paradigms within the disciplines have not been overcome. He further explained that different organisations also have not overcome the differences in the way they transform data into information.

In short, epistemic community indicates a 'new' and in some aspects, atypical political actor, which constitutes of networks of the experts coming with different experiences, from different backgrounds, a common interest, a shared task and diversity of knowledge (Cinquegrani, 2002).

2.3.3 Bounded Rationality

According to Biswas (1975), management success depends not only on the quality and extent of the information available but also what information is selected for use and ultimately channelled into the decision-making process. Likewise, Haas (1992) also maintained that the information desired is not so much based on purely technical knowledge but rather is the product of human interpretation. In this respect, cognitive level, cultures and paradigms play an important role in influencing the rationality of a decision maker and hence the choice of information to facilitate decision-making.

Based on a rationalist approach to decision-making, procedures for policy and decision-making usually require the collection of information to support the selection of a policy option, assuming that a rational and therefore legitimate choice can be made (e.g. environmental impact assessment) (Slob et al., 2007). This means that rational choice or rational decision-making in an ideal world would require a complete search of available alternatives, reliable information about their consequences, and consistent preferences to evaluate these outcomes (Choo, 1996).

However, this is not realistic in the real world because any system in which humans are involved is characterized by the following essential system properties: bounded rationality, limited certainty, limited predictability, indeterminate causality, and evolutionary change (Hjorth and Bagheri, 2006). Bounded rationality as defined by Herbert Simon (quoted by Choo, 1996): The capacity of the human for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behaviour in the real world – or even for a reasonable approximation to such objective rationality. Therefore, decision-making is constrained by the bounded rationality, i.e. the human way of thinking is not normative or rational but conditional, meaning that humans use their whole life experiences to reach a decision (Kainuma et al., 1991). Consequently, a right decision can only be made if decision makers could get hold of available information and knowledge, knowing probably the outcomes as well as the values of the outcomes to the individual affected, within time constraint (Biswas, 1975).

2.4 Managing Complex Decision Problems

2.4.1 Paradigm Shift in Science

According to Feynman (1998), science in layman language means a special method of finding things out, a body of knowledge, the new things one can do with what has been found out (i.e. technology), or a mixture of these meanings. Philosophy of science, as understood by most social scientists, has given us an image of the scientific enterprise as a large hypothesis testing machine, where individual scientist is the key unit of this enterprise (Blankenship, 1974). Blankenship (1974) argued that individual scientist has learned or intuitively understands a set of logical rules, which he brings to bear in ordering his thinking about a problem by creating a model, theory or hypothesis, specify the data he needs to check out his thinking, collect the data, analyse and report the results. In this knowledge generating system, human intervention in terms of politics and management are unnecessary as well as out of place (Blankenship, 1974).

As shown in Figure 7, science has undergone a major shift from mode 1 science, the traditional methods of production of scientific knowledge, to mode 2 science, which is regarded in its social and political context (Gibbons et al., 1994). van den Hove (2007) defined science as a social process, set in a social context, and involving actors and institutions and it is often called upon to provide solutions to societal problems.

Characteristics	Mode 1	Mode 2
Knowledge developed in	Academic context	Context of application
Knowledge production	(Mono)disciplinary	Transdisciplinary
Place and way of knowledge production	Homogeneous (one place, a certain time)	Heterogeneous (knowledge developed close to the place of application)
Organization	Hierarchical, preserves form	Heterarchical, transient
Quality control	Academic, peer review	Socially accountable, reflexive

Figure 7: Characteristics of mode 1 and mode 2 science (Gibbons et al., 1994).

In the mode 2 science, knowledge is developed in the context of application. The context of application describes the total environment in which scientific problems arise, methodologies are developed, outcomes are disseminated and uses are defined (Nowotny et al., 2003). In this respect, objective scientific knowledge (i.e. explanation and predictions) intertwined with subjective knowledge is a very common ingredient of policy making in the context of application.

Interdisciplinary research community of modellers focuses on applying existing scientific knowledge to management problems, and on communicating this knowledge through models, assessments and decision support systems (Jakeman et al., 2006). Therefore, when properly generated, presented and accountably used, science facilitates discussion among competing interests by helping to define the range of available choice and focusing discussions on consequences of social choice (Mills and Clark, 2001).

As exemplified by the study conducted by Petkov et al. (2007), a systemic multimethodology mix of methods is a way forward to address the complexity of a problem situation, which involves multiple stakeholders and needs for multiple perspectives on the problem situation.

2.4.2 Organisation Knowledge Management

Solving complex problems may require knowledge from any source and those knowledgeable in any discipline or profession as the Singerian inquirer views the world as a holistic system, in which everything is connected to everything else (Courtney, 2001). Knowledge of all types, namely tacit and explicit, deep and shallow, declarative and procedural, exoteric and esoteric, must be supported in this environment (Courtney, 2001). In other words, social, economic, technical, legal and political aspects need to be considered in the multi-dimensional problems as knowledge for obtaining multi-dimensional optimal solutions is desired.

An organisation is a distinct entity, which can be viewed as an open system that takes in resources from its environment, processes them in some way, and produces products. Open systems model recognise not only the interaction between subsystems and their environment within the organisation, but also the relationships and reciprocal influence between the organisations and the external environment. As knowledge has long been considered an important organizational resource, its effective management is therefore crucial to success (Nevo and Chan, 2007).

Knowledge management is the process through which firms create and use their institutional or collective knowledge, and includes three sub-processes: organizational learning, knowledge production and knowledge distribution (Sarvary, 1999). Whilst, Courtney (2001) noted that the knowledge management perspective in the Singerian approach is a combination of functional, interpretive and critical views. Sousa and Hendriks (2006) stated that knowledge management addresses policies, strategies, and techniques aimed at supporting an organization's competitiveness by optimising the conditions needed for efficiency improvement, innovation, and collaboration among employees. Therefore, economic competitiveness is based more and more on the capacity to develop and apply knowledge (Florida, 1995).

Figure 8 shows the knowledge management cycle model that describes the key aspects of knowledge management (King et al., 2008). With regard to construction of knowledge, it may refer to knowledge creation and knowledge acquisition. Knowledge creation involves developing new knowledge or replacing existing knowledge with new content, while knowledge acquisition involves the search for, recognition of, and assimilation of potentially valuable knowledge, often from outside the organization (King et al., 2008). Choo (1996) stated that knowledge creation is achieved through a recognition of synergistic relationship between tacit and explicit knowledge in the organization, and through the design of social process that creates new knowledge by converting tacit knowledge into explicit knowledge.

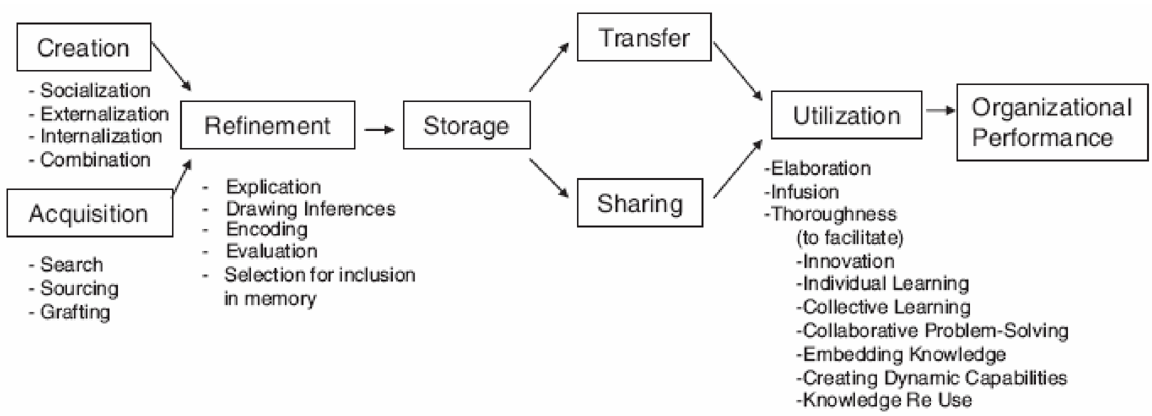

Figure 8: Knowledge management cycle model (King et al., 2008).

On the other hand, knowledge may be used or applied through a process of elaboration (the development of different interpretations), infusion (the identification of underlying issues), and thoroughness (the development of multiple understandings by different individuals or groups) (quoted by King et al., 2008). According to Choo

(1996), an organization uses information to make sense of change in its environment, to create knowledge for innovation, and to make decisions about courses of action. The unified view of the principal ways an organization can make use of information strategically is represented in Figure 9 - the Knowing Organization proposed by Choo (1996). He further concluded that by holistically managing its sense-making, knowledge building and decision-making processes, the knowing organization will have the necessary understanding to act wisely and decisively.

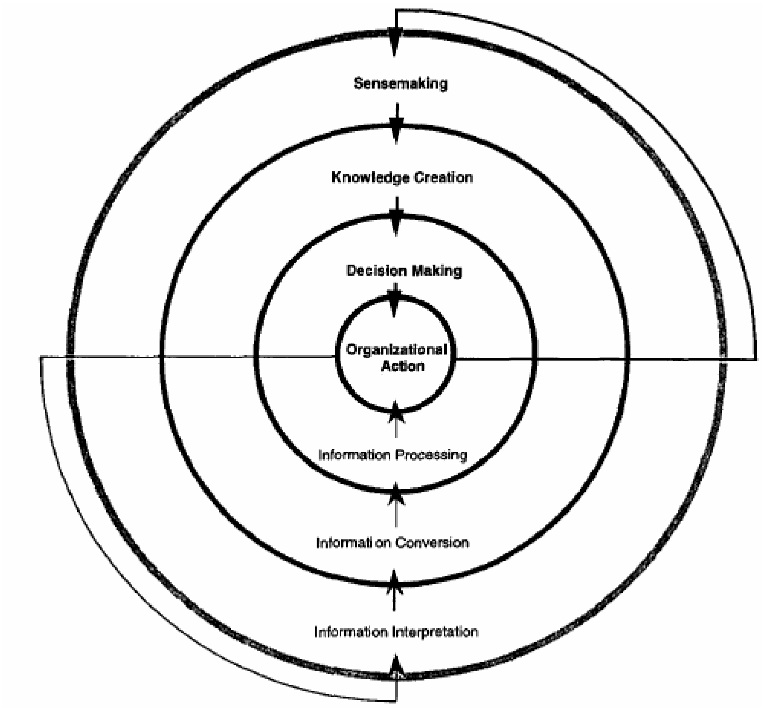

Figure 9: The Knowing Organization (Choo, 1996).

Slob et al. (2007) explained that knowledge production and use are separated and the challenge is to communicate scientific results to the policy community in such a way that the results can be taken up and used appropriately. Therefore, knowledge production and use is regarded as a social process and the interaction between different involved communities (scientists, stakeholders, researchers) should be emphasized (Slob et al., 2007). Nonetheless, the practice of knowledge management is commonly degraded to implementation of new IT-based systems, neglecting important organizational aspects particularly human and social issues (Kjærgaard and Kautz, 2008). The study of knowledge management is therefore a way to determine its contribution in managing and leveraging organisational knowledge.

2.4.3 Mental Model

Dealing with bounded rationality, mental model is used in problem solving in the selective search processes (e.g. search algorithms) (Schwartz, 2001). In the real world, choices are made in all steps of the decision-making process and are driven by the frames of perception of actors, which are influenced by mental models (Kolkman et al., 2005) (Figure 10). These frames determine the types of data the actor perceives in the real world, and the types of knowledge the actor derives from the data (Courtney, 2001; Kolkman et al., 2005).

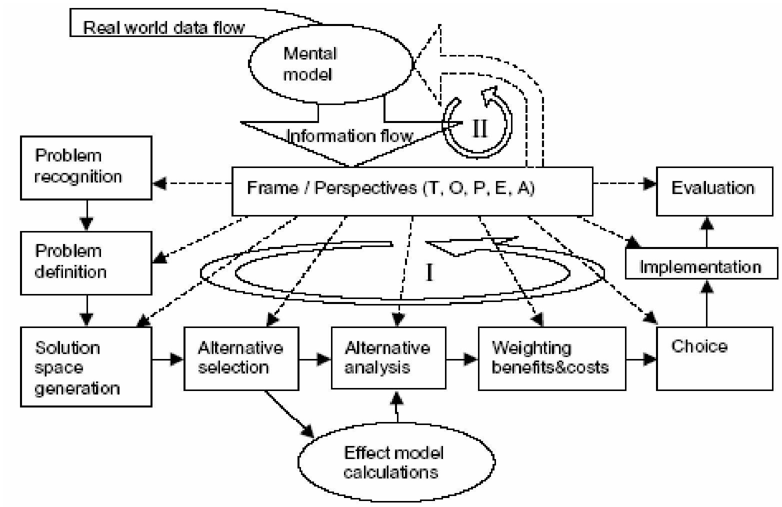

Figure 10: The direct and indirect influences of frame of perception and mental model, respectively, on the steps of problem solving cycle (Kolkman et al., 2005).

van der Zaag (2001) pointed out that decision-making should involve the integration of different perspectives and objectives, and be prepared to manage trade-offs or priority setting between these objectives where necessary, by carefully assessing them in an informed and transparent manner, according to societal objectives and constraints.

3 ANALYSIS FRAMEWORK

The conceptual framework shown in Figure 11 illustrates the relevant interfacing aspects and the simplified interaction between different entities, i.e. scientists and decision makers, who are involved in the knowledge production and use process (i.e. knowledge management) in a decision-making system. The rationale driving behind this framework is that decision-making process involves technology innovations, the use of knowledge and information which is influenced by the bounded rationality of the mental framework of each actor, as well as the relations within and between paradigm groups.

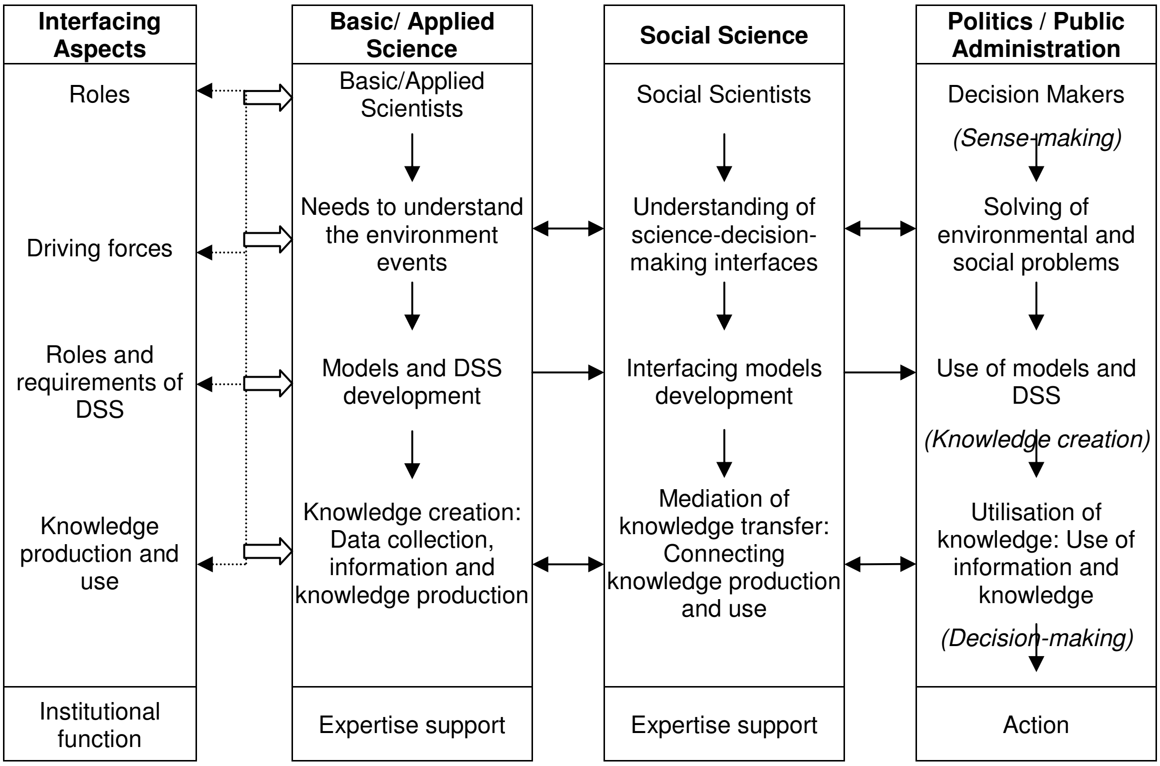

Figure 11: Framework for the evaluation of decision-making system with regard to interfacing aspects.

The common interfacing aspects are the roles of each entity, driving forces that boost or constrain the interests of each entity, roles and requirements of models and DSS, capacity of each entity in knowledge management process, and the institutional functions of each entity.

The capacity of scientists and decision makers in knowledge management are fundamentally determined by their respective roles, which need to be clearly and effectively defined and communicated as this will also determine their respective institutional functions in a decision-making system. Often, scientists provide expertise support to the decision or policy makers, who have to make decision to come to an action. They contribute to the decision-making process through facilitation of sense-making and knowledge creation stages. As explained by Cinquegrani (2002), the demand for the expert advice is a common phenomenon in policy-making processes, at local, national and international level.

Under the similar institutional function, social scientists also play an important active role as mediators to address the science-decision-making interfacing problems. Their contributions to the development of conceptual models and problem structuring techniques, for instance, signify their endeavours to deal with complex management problems. Therefore, rather than being a passive analyst of the situations, social scientist has been added into this schema to strengthen the integration between science and decision-making.

Even though each entity is driven by different forces in pursuing respective aims and interests, they are interconnected by certain implicit forces or components in a multi-disciplinary environment as they attempt to solve common problems. Models and decision support tools are commonly used as technical tool that serve as a common platform to operationalise method into practice, i.e. for information and knowledge production and use, in which scales, uncertainty and risk need to be taken into account.

In this framework, feedbacks or responses through effective vertical and horizontal communication among organizations and between stages in the decision-making system are represented by ‘double-ended arrow’ and ‘dotted-line arrow’. The need for suitable feedback is important in cognitive learning that deals with insights, reasoning and imagination, and emphasises retrieval and extraction, association, repetition, recognition and the solution of problems (Schwartz, 2001). In addition, Schwartz (2001) also noted that networks learn by changing the strengths of their interconnections in response to feedback and adaptive production systems.

Furthermore, it may be necessary to represent and clarify the relation between knowledge management, ICT usage and experts as mediators between the complexity of political decision and the tendency of institutions to become advanced learning organisation (Lovering, 1999; Lagendijk and Cornford, 2000). Corresponding to the view of Haas (1992), this relationship may result in the formation of an epistemic community, who is a network of professionals and experts, who are from a variety of disciplines and backgrounds and have a shared set of normative and principled beliefs. In the ideal situation, the multi-person actor, who work within the framework of complexity and uncertainty, try to re-define problems in broader context and attempt to comprehend ‘change’, and able to ‘anticipate’ using knowledge, various backgrounds and expertise (Cinquegrani, 2002).

This conceptual framework serves as a base for the understanding of the micro studies of human decision-making and hence their behaviour and rationality in decision-making under complex and uncertain situations.

4 CONCLUSIONS

Decision support systems (DSS) have been an important tool to facilitate decision-making in the field of environmental and natural resources management by providing scientific knowledge and information through modelling and simulation about the natural system. However, the development of a transferable DSS remains a great challenge because the management problems are bound with complexity and uncertainty. The complexity of the problems has been a constraint to the adoption of scientific outputs for supporting decision-making and resulted in the emergence of an interfacing gap between science and management. Different actors are locked into the ‘paradigm lock’, which is signified by the gap in knowledge, the aims, the way of thinking and the language.

The conceptual framework proposed in this paper illustrates the interaction between science and management, who are involved in the knowledge production and use process as well as decision-making process. The framework takes the approach of organisation knowledge management to address the complex interfacing problems from the perspectives of technology innovation, institution and actor dimensions. It is recognised that cognitive and institutional aspects, which are related to the rationality and behaviour of each actor, coupled with technology innovations play a central role in organisation knowledge management. Although it was not comprehensively analysed, the framework provides for guidance or stepping stone to take on further in-depth micro studies of human decision-making as well as decision makers heuristics in the effort of addressing complex decision problems and the problems of integrating science and decision-making.

In the next step, the concepts of bounded rationality and epistemic community will be further focused on in elaborating organisation knowledge management in the decision-making system. The gap between human decision-making and technology innovation shall also be bridged, possibly through problem structuring interface.

Ultimately, a transferable decision-making procedure, which operates across temporal and spatial scales and which promotes consensus and cooperation between actors, shall be proposed for integrated flood management.

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6 APPENDIX

Integrated Flood Management

Flood is a natural event that is caused by extreme weather condition, in combination with weather constellations. In addition, it is also significantly aggravated by anthropogenic activities, which alter the hydrological condition locally and regionally. Exploitation of land resource, for instance, for the purpose of agricultural, housing and industry as well as infrastructure development often involve clearance of natural vegetation covers or modification of landscapes in a river catchment.

In view of the critical problem, a holistic approach, i.e. integrated flood management, has been adopted for flood (risk) management. Integrated flood management sits within the broad context of integrated water resources management. Therefore it is of multidisciplinary nature and includes multiple perspectives as in river basin management. These perspectives are shown in Figure 12 and are elaborated in Mostert (1999)[1].

Perspective	Starting point	Descriptive or normative character	Attention to (inter)national character?
Natural Science	Basin	Descriptive	No
Engineering	Measures	Descriptive	No
Social optimisation	Measures	Normative	Yes/No
Law	Actors	Normative	Yes
Decision-making	Actors	Descriptive	Yes
Ethics	Actors	Normative	Yes/No

Figure 12: Perspectives on river basin management (adapted from Mostert, 1999).

WMO (2006)[2] stated that integrated flood management seeks to integrate land and water resources development in a river basin within the context of IWRM, and manage floods based on risk management principles in order to optimise the net benefits from flood plains while minimizing the loss of life from flooding. According to the International Flood Initiative (UNESCO, 2007)[3], “integrated flood management (IFM) is a process that promotes a holistic risk-based approach to flood management. It aims to reduce human and socio-economic losses from flooding and use of flood plains while increasing social, economic and ecological benefits. IFM

[1] Mostert, E. (1999). Perspectives on river basin management. *Pyhsics and Chemistry of the Earth* 24(6):563-569.
[2] WMO. (2006). Legal and Institutional Aspects of Integrated Flood Management. World Meteorological Organization No. 997, Geneva.
[3] UNESCO. (2007). International Flood Initiative. International Hydrological Programme (IHP), Division of Water Science.

sits with land and water resources management in the broader context of integrated water resources management (IWRM). It includes institutional actors at all levels of flood management and recognizes the critical importance of stakeholder participation and cultural diversity in planning and implementation."

The five essential elements of integrated flood management identified by WMO (2006) are: (1) to manage the water cycle insofar as it relates to land, as a whole; (2) to integrate land and water management; (3) to adopt a best mix of strategies; (4) to ensure a participatory approach; and (5) to adopt integrated hazard management approaches. Therefore, flood management is not only about modification of river morphology or construction of engineering structures to contain water surplus, but also includes all operational activities to be taken from pre through post flood event including political and administrative decisions at different levels or scales that aim at preventing or mitigating a flood event or a flood disaster.

Conventional flood mitigation measures are about building engineering structures in or near rivers (e.g. dam, dikes) to retain water or on existing buildings to protect against flood damage on properties. Realising that making space for water is more sustainable in managing flood risk, minimising amount of water flows over land surfaces has become an alternative flood mitigation option within a river catchment. For example, water retention by land use through spatial land use planning and management is one of the sustainable solutions to improve water retention capacity on-site. Besides, developing innovative insurance strategies and instilling awareness of shared responsibility among the people are also part of flood mitigation strategies.

Integrated flood management approach calls for participation and interaction among various disciplines, government departments and various actors to ensure coordination and cooperation across institutional boundaries. In this respect, a legal framework should provide for the following specific issues: (1) coordination and cooperation between the various organizations, institution, sectors and users; (2) availability and accessibility of the basic data and information for informed decision-making; and (3) building an enabling environment for all stakeholders to participate and make collective decisions (WMO, 2006).

In Germany, the general conditions for flood control measures through various new legislative regulations at the federal and state level have been improved. These legislative regulations include Federal Regional Planning Act, Water Management Act, [Flood Control Act] and superordinate guidelines (principles, objectives and guidelines of land use and regional development) (Friesecke, 2004)[4].

With respect to the development of decision support systems for local and transnational river catchments management, a number of EU-funded projects have been commissioned in Germany, for example ELLA (Elbe-Labe Spatial Planning Flood Management Strategy), NOFDP (Nature-oriented Flood Damage Prevention), FLOWS (Floodplain Landuse Optimising Workable Sustainability), WARELA

[4] Friesecke, F. (2004). Precautionary and sustainable flood protection in Germany – strategies and instruments of spatial planning. 3rd FIG Regional Conference, Jakarta, Indonesia, October 3-7, 2004.

(Water Retention by Landuse) and AMEWAM (Agricultural Measures for Water Management and their Integration into Spatial Planning).

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