Decision Support Systems for Sustainable Development:Experience and Potential — a Position Paper

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UNU/IIST, Macau

March 1996
UNU/IIST, Macau

Abstract

We present the findings of an expert group workshop help under the auspices of the Canadian Government's IDRC and UNU/IIST in Macau on the subject of Decision Support Systems for Sustainable Development — Software Technology for Agenda'21. The findings are summarised in the form of a set of recommendations for further action with respect to research, development, training and awareness building on the subject of the expert group workshop (see title of this report).

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The people listed above actually took part in the Expert Group Workshop and thereby contributed to the content of this position paper. Where this position paper directly derives from their work, they are cited as a footnote 'See reference [19]'. In many cases there were co-authors who contributed indirectly through the joint authorship of papers contributed to the workshop, and through comments on the draft versions of this position paper. These persons are shown in the author lists of the position papers, at the end, associated with the person who was present.

1 Introduction

This paper has arisen from a workshop held at the UNU/IIST in Macau, sponsored by IDRC. The workshop was organised in response to the Agenda 21 report from the Rio Earth Summit, and particularly to its Chapter 40 on Information for Decision Making. See reference [43]. It has been written for policy makers concerned with the development and decisions about development. . The process of development requires the making of decisions, selecting from among several possible alternative development paths the line of action that will return the most perceived benefits. Development should be sustainable and decisions directing its path should be made with sustainability in mind. In this context, the definition of sustainable development provided in the Brundtland Commission (1987) (See reference [18]) report, namely "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", offers both a guiding principle and an objective for the decision process.

It is important that development decisions are made well and that they use the best information, methods and tools available. For development to be sustainable we need to make decisions that do not have long-term negative impacts and to assess both impacts and benefits prior to undertaking implementation actions. Because predictions of impacts, especially in the long term, can ever only be approximate, we can only make select development paths of limited duration. Each decisions need to be revisited and revised as their consequences are revealed in practice.

In this paper we formulate a basis for study and application of decision support systems (DSS) for the purpose of sustainable development. Our objective is to provide a broad position on issues related to DSS and their implementation. We provide researchers and practitioners with a perspective on current issues and future needs. We establish a basis for discussion of the unique requirements of developing countries in and their sustainable development.

In this position paper we characterise in section 2 the essential features of sustainability that will be significant in our consideration of decision support systems. We start by a short review of the evolution of the concept of sustainable development from Malthus through to Brundtland. This is a particularly western view of the history, and we also argue that sustainable practices have been widespread across communities and through the ages. We focus on the need for equity and the use of indigenous knowledge, and emphasise that it is essential that the decision making processes themselves should also be sustainable.

In section 3, we review the process of decision making and its underpinning theory, noting recent trends away from rational decision theory to decision support theory and the need to be able to accommodate uncertainty and risk in decision making. The importance of people in the decision making process is emphasised.

In section 4 the roles of computer-based decision support technologies are described, working through the process from information gathering and storage, through knowledge bases, the support for decision making, to visualisation and the support for group decision making. We end by discussing the need for solutions which integrate many tools, with existing KBS and GIS systems giving partial solutions: we conclude by outlining an agenda for developing a domain specific architecture for decision support systems for sustainable development.

Section 5 considers the wider issues of deploying decision support systems in developing countries. Decisions require high quality data, trained personnel, up to date computer systems, and a continued commitment to maintaining the data and computer systems.

The paper is concluded in section 6 with a list of recommendations arising from this position paper and the experience of the authors.

2 The Need for Development that is Sustainable

"Development" is assumed to be desirable, but what it means exactly is problematic. It is generally assumed to align with "progress", to mean improvements in living standards, health and welfare, and the achievement of other goals agreed by the community concerned. What is considered to be development depends upon those intended to benefit from that development, and no universal definition is possible. The nearest we might come would be the World Bank's "Reducing poverty is the fundamental objective of economic development". See reference [17].

Development has always been with us, as societies have evolved and adapted to their environment, migrated to new environments, learning to use the resources available, and discovering new resources that they could use. These developmental economic activities are inevitably associated with the consumption of natural resources. This consumption then raises questions about sustainability. Again, this concern has always been with us, and societies have always responded to the concern by selecting appropriate forms of economic activity. But as we move to a global society aware of the disparities around the world, this issue of sustainable development has taken on a new force.

2.1 The Need for Sustainability

Publication of the Brundtland Report in 1987 (World Commission on Environment and Development, 1987) (See reference [18]) has led to world-wide interest in the concept of sustainable development. However, this concept is by no means new.

Concern for the sustainability of life on our planet can be traced back two thousand years to Greek culture. Here it appeared first in the Greek vision of Ge or Gaia as the Goddess of the Earth, the mother figure of natural replenishment. Guided by the concept of sustainability, the Greeks practised a system whereby local governors were rewarded or punished according to the appearance of their land.

More recently, major concern with the limited productivity of land and natural resources appeared with the publication of Malthus's essay on population in 1789 and Ricardo's Principles of Political Economy and Taxation in 1817. These thinkers worried that economic growth might be constrained by population growth and limited available resources.

Then came the Industrial Revolution and colonial expansion. Towards the end of last century and the beginning of this century, an optimistic view arose that the prosperity of Western economies could continue unabated. Natural resources were no longer regarded as posing severe restriction on economic growth as new technologies for making better use of resources and new resources were discovered. However, the fragility of our economic growth was soon revealed by the depression of the 1920 and 1930s, and more recently the world oil crisis and economic recession in the 1970's. Neo-Malthusians began to have doubts about unlimited growth, stressing once again the importance of natural resources in setting limits to economic growth.

In April 1968, the Club of Rome which consisted of a group of thirty individuals including scientists, educators, economists, humanists, and industrialists gathered to discuss the present and future predicament of mankind published the book "The Limits to Growth" (Meadows et al, 1972). See reference [9]. The book predicted the limits of growth of the earth would be reached sometime within the next one hundred years if the present trend of growth remained unchanged. The predicament came from the exponential growth in global population, resource depletion, and industrial pollution, in the context of our finite resources. In 1992, 20 years after the controversial "The Limits to Growth" was published, the same authors published a successor book, "Beyond the Limits", which re-examined the situation of the earth (Meadows et al., 1992). See reference [9]. With new evidences from global data, the book shows that there is still an exponential growth in global population, economic growth, resource consumption and pollution emissions. In 1971 they concluded that the physical limits to human use of materials and energy were just a few decades ahead. In 1991, after re-running the computer model with new compiled data and analysing the lately development pattern, they realised that in spite of the world's improvement policies, many resource and pollution had grown beyond their sustainable limits. The earth may be approaching its limit faster than what we would have thought.

The concept of sustainability is evident, albeit implicitly, in several related concepts. For example, the notion of a carrying capacity is defined in wildlife ecology and management as "the maximum number of animals of a given species and quality that can, in a given ecosystem, survive through the least favourable conditions occurring within a stated time period" and in fisheries management as "the maximum biomass of fish that various water bodies can support". Most recent interpretations of sustainable development are modified derivatives of the concepts of the limits of growth and carrying capacity. They not only stress the importance of resource availability in limiting economic growth but also draw attention to the need to develop methods that facilitate growth in harmony with the environment, emphasising the potential complementarity between growth and environmental improvement. Hence the Brundtland definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and the IUCN definition as "a process of social and economic betterment that satisfies the needs and values of all interest groups, while maintaining future options and conserving natural resources and diversity" (International Union for the Conservation of Nature, 1980, p.2). See reference [6]

Population is a key factor to be considered in the implementation of sustainable development. Sustainable development can only be pursued if population size and growth are in harmony with the changing productive potential of the ecosystem. An example is the ECCO (Enhancement of population Carrying Capacity Options) computer model developed at the Centre for Human Ecology, University of Edinburgh (Loening, 1991). Reference [8] has tried to identify the trade-offs between population growth and standard of living, and between intensification of agriculture and soil conservation.

2.2 The Need for Equity

The above discussion focuses to a large extent on economic development. However, development must also help overcome the lack of equity between rich and poor, developed and underdeveloped, north and south. The concept of equity in the use of Earth's resources cannot be overlooked. Equitable resource use requires that everyone gets a fair share of the planet's resource base and that this principle holds equally within a country, between countries, between genders, and from generation to generation. The intergenerational transmission of equity in resource use clearly is key to a sustainable future and this underscores the importance of the temporal dimension in the Bruntland Commission's definition of sustainable development.

There is also a need for equity in the consideration of expertise deployed in development. While the expertise that the various communities around the world may be very different, none is necessarily superior to the other. Indigenous peoples have lived in harmony and stability with their environment for generations, and this knowledge must be incorporated into the decision making process. For example, a network for the sharing of indigenous knowledge has been established in India. See reference [28]. Methods of development must be appropriate to the people and the environment in which they are applied.

Decision that are made, and the rationale underpinning those decisions, must be acceptable to the people concerned. Decisions cannot be made by proxy by outside agencies, they must be made by the people in the communities themselves. It is the involvement of the people themselves at all levels that is absolutely critical in making development sustainable.

2.3 Implementing Sustainable Development

Although the term sustainable development is now widely used, there is, in general, no widely accepted operational framework though which to practice sustainability. Sustainable development does not mean no development. It means improving methods for resource management in the context of increasing demand for resources. Sustainable development must facilitate economic development while fostering environmental protection.

In order to systematise the concept of sustainable development it is useful to utilise Barbier's (1987) (See reference [2]) model of interaction between three complementary systems — (a) the biological (and other natural resource) system; (b) the economic system; and (c) the social system. For these three systems, the goals of sustainable development may be expressed respectively as maintenance of genetic diversity, resilience, and biological productivity; satisfaction of basic needs (reduction of poverty), equity-enhancement, increasing useful goods and services; and ensuring cultural diversity, institutional sustainability, social justice, and participation.

Within this framework there is scope for different communities to seek different balances between these. Some interests may place high value on obtaining high environmental quality, while others may prefer to have improved living standards. Income, education, social structure and ideology are factors that determine the definition of sustainable development in a community. However, no community lives in isolation and the environmental impact of one community can affect everybody. Some rules need to be designed to guide people's behaviour for sustainable development:

1. A given renewable resource cannot be used at a rate which is greater than its reproductive rate, otherwise complete depletion would occur.

2. Strict controls on the use of non-renewable resources are necessary to prevent their early depletion. Substitutes and new technologies are helpful in reducing the use of scarce resources.

3. The amount of pollution emission cannot exceed the assimilative capacity of the environment. Abatement measures should be taken to reduce the influences of the pollution.

4. We need biodiversity in the ecosystem because there may be unknown genes of high value to be found in some species. Species extinction can also introduce imbalance in

the ecosystem. Some species can improve the human living environment by generating soil, regulating fresh water supplies, decomposing waste and cleaning the ocean.

Different countries have different perceptions and thus different approaches to sustainable development. It is not possible to design universal measurements and indicators of sustainable development because of different weights that are given to different components by different communities. What we are concerned with is enabling communities to make their own decisions about sustainable development, using the theoretical frameworks and tools that they themselves believe to be appropriate and can continue to use. Not only must the methods of economic activity and resource utilisation be sustainable, but the decision methods must also be.

3 Decision Making and Decision Support Systems

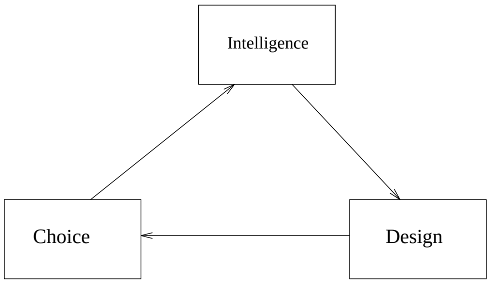
Development involves making decisions as to the choice of a desired path to follow. Decision theory is, in and of itself, a highly complex field. Here, we take a very broad view of decision making as any situation where a decision taker has a choice between alternatives. In the simplest case there may be only one alternative and the decision is to take this or not. However, in reality there are usually numerous competing options or alternatives available in any course of action and thus the decision is correspondingly more complex. In contexts where decision making involves action it is important to evaluate also the implementation and results of decisions. When a deliberate course of action is laid out and subsequently implemented this constitutes planning. Decision making and planning may be at the group or individual level and in the former case reconciliation of different value systems is likely to be required. This may involve negotiation or trade-offs before a course of action that is acceptable to all groups is agreed upon.

3.1 Rational Decision Making

At the basic level, decision making involves a few simple stages. Simon (1960) (See reference [15]) captures these in his decision model shown in Figure 1. During the Intelligence phase information is gathered to understand the problem for which a decision is required, the various assumptions that have to be made are made explicit, and information on which to base the decision. Then during Design, various alternatives are explored through building models and making appropriate calculations to predict the consequences that would arise from the particular alternatives. Finally in the Choice phase a best or satisfactory decision is sought, and selected, some final verification is undertaken. In addition to the three stages identified by Simon, a post-decision stage of monitoring and evaluation should be included to follow-up the outcome of a decision.

In decision science we identify a number of decision variables, numerical values or other values which can be represented by numbers, which will form the basis for our decision. In order to make choices we need to do three things. Firstly they must be standardised, which involves scaling all the various values so that their numerical ranges are comparable and that they have a common interpretation, perhaps as a probability. Then the standardised values are aggregated by combining various elements to form the basis for a judgement, as in factor analysis, multiple criteria analysis, and so on. Finally the aggregated value or values are thresholded to produce a binary result or decision.

Figure 1: Simon's Decision Model.



These rational decision methods are widely applied, supported by suitable mathematical models:

- the location of primary health care services in the Central Valley of Costa Rica to maximise accessibility was decided using a location-allocation model. See reference [25].
- land use in the rapidly developing areas of Dongguan in south east China, adjacent to Hong Kong was modelled using an equity function. See reference [40].
- recovery from the Chernobyl nuclear disaster in the Ukraine. See reference [26].
- decisions about sources of energy in Nepal was modelled using multiple objective programming. See reference [46].

The above processes are grounded in statistics and mathematics, and implicitly assume that the various values required can be obtained and are accurate. It assumes that the relationships between the variables is known. It assumes that there is a basis for a decision through a utility function or functions, involved in the aggregation step, and that these utility values have an agreed interpretation. These utility values encapsulate within the value system of the decision takers. The processes postulate that an optimal solution exists and is meaningful. In the development context, all of these assumptions are questionable. Two simple examples are:

- the absence of hydrological data to guide well location in Cameroon. See reference [54].
- the importance of powerful people in influencing decisions in rural India. See reference [23].

3.2 Uncertainty and Risk

Data is never precise, its acquisition may lead to estimations and error, survey populations may be very small. This fuzziness needs to be taken into account, and a number of theoretical approaches are available to us from rational decision theory. The values may be given a probabilistic interpretation, or may be taken as deriving from the fuzzy sets of Zadeh, or Dempster-Schaffer belief theory might be used, and there are other approaches that could be taken. The particular approach to uncertainty will depend upon the needs of the decision maker and the information that he/she is using. This uncertainty can itself lead to uncertainty in any calculations concerning the outcome of the decision making process. This means that any decision has an attendant risk, and this risk should be calculated to make it explicit, and it should then be used in the decision making.

Examples addressing uncertainty and risk presented to the workshop were:

- normal survey data carried out by local administrators was found to be up to 30% inaccurate, attributed to lack of stake in the results of the survey by the administrator concerned. See reference [23].
- variables used in planning in a variety of sectors within Goa were treated as fuzzy variables. See reference [39].
- predictions of flood arising from rises in sea-level in Vietnam have to be treated probabilistically. See reference [29] .
- water supply uncertainty in Zaire was treated using fuzzy sets. See reference [42].

Often decisions cannot be made on the basis of the theory outlined above. The theory assumes that you can be objective in measurement and in calculation, and this may not be possible. It assumes that the formulae and equations can be solved, and this may not be possible. This realisation has led to Decision Aid theory (Roy 1993). It may not be possible to find the best solution, and instead we should aim for a feasible solution, one that is good or at least satisfactory. We should aim to satisfy rather than optimise. See reference [42].

3.3 Human-based Decisions

Where we are unable to model the decision process, and as we have argued above this is usually the case for development, we must rely on humans to make the judgements necessary. People can weigh a number of alternatives and arrive at a decisions, recognising a good outcome when they see it, even if they are unable to articulate the reasons for the choice sufficiently precisely for it to be automatable. Where the people involved are drawn from the communities for whom the decisions are being made, they embody the value systems that are important for making a an appropriate and sustainable decision. Where groups of people are involved, the possibly conflicting needs and values must be reconciled using appropriate processes.

In making sustainable development decisions in British Columbia, Canada, there were the conflicting interests of Salmon Fisheries, Forestry, Oil, and indigenous peoples, with significantly different value systems, which needed to be balanced. See reference [21].

Where sustainability objectives need to be pursued with sparse and incomplete data/information, these limitations can partially be bridged by tapping into extensive experiential local knowledge. For conditions where quantitative cause effect relationships are absent or scarce, particularly across bio-physical and socio-economic domains, qualitative local knowledge can be essential to fill the gaps and correct inaccuracies. Local knowledge encompasses implicitly aggregated facts and information, incorporates uncertainty, and draws from experience, resulting in intuitive, general relationships or correlations between different factors affecting sustainability. The depth of such knowledge can be considerable. See reference [31]. An examples the capturing of the knowledge of agricultural extension workers in Egypt, later planning to use this knowledge base to train farmers and new extension workers. See reference [48].

4 DSS — Support for Decision Making

In order to render complex decision making manageable and reasonable in terms of the underlying goal of sustainable development, the decision making process as described above can be supported systematically by a variety of computer-based software tools. Kersten and Meister (1995) (See reference [7]) have undertaken a comprehensive survey of the tools available, concentrating on geographical and demographic information systems, and the more basic database and knowledge based systems.

We will describe the tools required in terms of their general type, focusing on the stage in the decision process being supported, from information gathering through storage to exploring alternatives to helping people make the decision.

4.1 Information Collection and Management

Decision making requires information, and this needs to be collected. One important source of social data is the governmental census, and other governmental and non-governmental sources of things like opinion polls, natural resource inventories and commercial registers may be useful. These will need to be extracted and transferred from their current databases to the decision maker's database. An important concern here may be the preservation of confidentiality, typically achieved through aggregation the removal of names to make the data anonymous. For a particular study it may be possible to obtain the data unaggregated, but this use should be restricted, and it must guarantee that the aggregation that is part of the decision making process will protect confidentiality. Data interchange formats need to be agreed and any special converters produced. See reference [47].

Existing data would typically need to be supplemented by surveys focused on the needs of the decision problem at hand. Computer aids, particularly the use of the Internet, may help here, though with communications infrastructures in their current undeveloped state this may not be possible in developing countries.

Another important source of information that is now readily available is remote sensing from satellites. Here information providers may make data available to local communities to help in their decision making. This data would typically feed into geographic information systems.

An example of the way remote sensing data might be distributed is given by India. Remote sensing data from satellites is collected centrally, then distributed to states who further distribute this data to districts; in parallel with this there is a second line of distribution via regions to projects See reference [50].

While the storage of most data can be achieved using standard database products, the storage of geographic data usually requires special methods. There are two methods for doing this — as "vectors" in which the geographical area is represented by a number of point, line, and polygon objects whose co-ordinates are stored; and as "rasters" in which the geographical area is divided into many small uniformly sized rectangles or "pixels". Over these can be laid further networks of roads, rivers, boundaries and so on, as well as the locations of towns and similar features. Features can be divided along thematic lines, "layering" the area according to certain criteria and displaying thematic maps to highlight the different layers. These two representations are equivalent and can be converted one to the other, but the representations favour different calculations. Examples of the vector approach are TheMaps (See reference [39]) and winR+ See reference [32], and of the raster approach is IDRISI. See reference [29].

Large amounts of raw data from different sources and in different formats must be verified and often converted into formats suitable for other components of a decision support system. This is the well known problem of inter-operability and data interchange. One solution suggested is to use Federated Database Systems See references [20,24].

Data integrity is critical for computer-based modelling and knowledge-based systems. A computerised DSS should provide facilities for verification of information integrity, and for discovery of discrepancies in received information. Statistical methods and rule-based systems provide some tools for the analysis and preprocessing of data used for generation and evaluation of alternative decisions.

4.2 Modelling and Rational Decision Support

It is important to explore the consequences of particular courses of action. To do this we need to build models, and facilities for this are important. Models enable manipulation and experimentation with variables representing characteristics of real systems within a predefined time scale. Long-term effects of suggested decisions can be analysed in a short computer session.

The most common modelling tool is the spreadsheet, but equally important here are simulation modelling techniques. A complex DSS requires a collection of models. The software architecture should include facilities for model repository, selection of appropriate models and composition of subsets of models to solve complex problems.

The many methods used in rational decision making, such as multi-criteria analysis and linear programming, are all supported by computer using mature software packages. The uncertainty prevalent in development decision problems makes it necessary that these packages can handle the uncertainty and risk.

These have become standard capabilities of off-the-shelf software, and nothing special is required for decision making in developing countries.

4.3 Visualisation and the Human Interface

When people need to participate in the decision making process, they find it helpful to have pictures and diagrams to help them visualise the situation about which they must make a decision. Routine facilities for these are the so-called business graphics of pie and bar charts and graphs which show the relationships between numerical data. Also of great usefulness is the display of a network of dependencies between parts of the problem and their influence on the solution.

Of more recent origin is the ability to display the rich and complex maps in multiple colours with a fine level of detail. These maps can display the spatial relationships between the elements of interest, and the geographical distribution of those elements through theme-maps under user control . Humans have very powerful spatial reasoning capability, and the display of geographic data can tap into that reasoning power.

A range of visualisation methods are possible to help the people involved in the decision making process:

- simple diagrams helped users understand the financial planning methods proposed for them in the Philippines. See reference [30].
- simple graphs helped explain the trade-offs in making decisions in Canada. See reference [21].
- theme maps helped decision making in Chinese disaster planning. See references [58,34].
- anamorphic maps of the world to show countries gross-national product, and population represented by size on the map. See reference [52].

As with all computing systems, it is important that the systems are easy to use by the persons concerned. It is important that technical expertise is not necessary. General usability analysis is applicable here.

Of particular importance in decision support systems is the ability for the decision makers to work in their own natural language. While PCs and Unix systems support the translation of software to other languages, some deeper cultural issues will need to be addressed which are not catered for by these basic approaches. An example of a cultural dimension is the choice of colours in theme maps, where, for example, red signifies danger in Europe but joy in China. See reference [33].

4.4 Group Decision Making

Often decision making is a group process. The various stake-holders need to reach agreement. Visualisation methods where alternative representation of the choices open to the decision makers is one important method, but tools for group working and work-flow may also be important. This may be particularly important where the stake-holders are geographically dispersed and communication networks need to be exploited.

Simple computer conferencing methods may suffice, but more structured systems which enable the development of a debate by widely separated people over a period of time may also help. Systems are commercially available us "group-ware" to support collaborative working, the holding of meetings, and so on. The recent rapid growth of the Internet will be important in making this support widely useful.

There needs to be trial application within development decision making.

4.5 Knowledge Capture and Representation

It is important to be able to capture local knowledge about the decision problem. One important way of doing this is through Knowledge Based Systems (KBS) and expert systems.

Knowledge Base Systems generally contain a knowledge base and a problem solving method or inference method. The term expert system is sometimes used as a synonym for KBS. The first generation of expert systems represented knowledge as "production rules" of the form "it this situation is found in the data then undertake this action or add to the data in this way"; the inference engine applied these rules using "forward and/or backward chaining" to control the sequence in which rules were applied. Since the beginning of the 1980's commercial products (shells) have been produced to support this approach. Later on, frames and objects have also been included in the commercial products as a second method for knowledge representation. Inference methods for frames and objects are supported by “methods” attached to them, and “inheritance”. Although successful applications have been implemented using rules, the number of rules in these applications is small (25 to 50 rules).

In the mid 1980’s, some scientists noted the disadvantages of using production rules and a new trend has appeared emphasising inference at the “knowledge level” of human problem solving. This new wave of KBS was called second generation expert systems. In the USA, the Generic Task (GT) methodology and Role Limiting Method have appeared, while the Knowledge Analysis and Design Structuring (KADS) has appeared in Europe. The main idea of these second generation expert systems was to characterise the system as a task that performs a specific function such as diagnosis, planning, scheduling, and others. The task structure consists of one or more subtasks, and/or primitive problem solving methods (PSM). In the GT methodology the granularity of the PSM is coarse whereas in the KADS methodology the granularity is fine. Each PSM uses its appropriate knowledge representation scheme. Unfortunately, few commercial products have appeared to implement second generation expert systems, though some tools have appeared to help in using the KADS methodology in the design phase.

Capturing the rules of an expert system can itself require great expertise, and a promising technology here is that of rule induction — the system ’learns’ the decision rules from examples of the correct decisions. See reference [35]. Another learning method that is promising is Neural Networks.

Case based reasoning is a promising approach, if a record of successful decisions is available, and if the context of the decision can be characterised by a number of attributes which can be used to assess the similarity or otherwise of a new situation to past cases. An example of the application of Case Based Reasoning is the determination of the equivalence of educational qualifications. See reference [51].

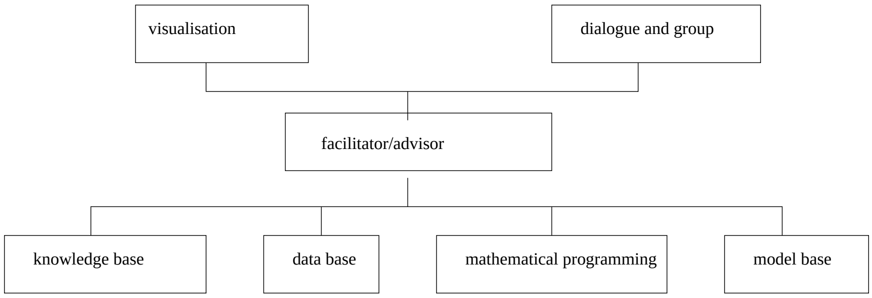
If possible the KBS being used should provide advanced facilities such as generating explanations on how and why particular conclusions have been drawn. Built-in uncertainty factors should be available to allow analysis using incomplete and unreliable data in decision-making procedures and evaluation of the probability of results. Collaboration between KBS systems could be useful in solving some problems in a way similar to decision-making by an interdisciplinary group of experts.

The application of KBS to capture expertise in sustainable development falls into two main categories: where the KBS is the core of the DSS, and where the KBS is an auxiliary to some other system. The first category is where there is human expertise in an area related to SD such as crop management, pollution handling, and so on. See reference [48]. The second category is where there is a need for expertise in handling the results from a certain model and/or software package in order to let the results of that system comprehensible by the decision makers — examples are the output from a sophisticated simulation model for economical growth, or the reports generated from large data base.

4.6 DSS Integration

It is agreed that a key capability must be the inter-operation of tools obtained from different sources. We must be able to choose the appropriate tool for a particular job and transfer information into it and out of it as we explore the alternative decisions available to us. This transfer of information is difficult at present, though there is a move towards more open systems — data interchange is already well established in manufacturing and publishing, and standards for GIS are being developed.

Figure 2: An architecture for a Next Generation Decision Support System.



There is an emerging trend of data standardisation for GIS in the developed countries. The National Committee for Digital Cartographic Data Standard (NCDCDS) and the Federal Inter-agency Coordination Committee on Digital Cartography (FICCDC) tries to establish standards to ensure compatibility among digital spatial data gathered by different agencies (Digital Cartographic Data Standards Task Force, 1988). A similar effort is also being made in the United Kingdom and Canada. Attempts have been made in the People's Republic of China to arrive at a national standard of geographic co-ordinate system for GIS, classification system for resources and environmental information, and the boundaries of administrative, natural, and drainage area regions. See reference [56].

An alternative to this openness mediated by standards is to have a set of facilities already integrated from a single supplier. Many program development systems aimed at a particular class of problems may also have integrated with them many of the other facilities that we have listed above. Two of these are important for us.

Off-the-shelf knowledge based systems may include not only mechanisms for knowledge representation and inference, as described in section 4.5, but may also have all the visualisation and user interface development facilities that we described in sections 4.3. See reference [30]. Further, it is possible to use the rule based systems in a more general manner as a programming tool that does not require the level of technical expertise that conventional programming requires, as we see in the effective us of KBS systems in China. See reference [40].

Off-the-shelf geographic information systems are capable of integrating geographical data with other data from various sources to provide the information necessary for effective decision making in planning sustainable development. Typically a GIS systems serves both as a tool box and a database. As a tool box, GIS allows planners to perform spatial analysis using its geo-processing or cartographic modelling functions such as data retrieval, topological map overlay and network analysis. Of all the geo-processing functions, map overlay is probably the most useful tool for planning and decision making — there is a long tradition of using map overlays in land suitability analysis. Decision makers can also extract data from the database of GIS and input it into other modelling and analysis programs together with data from other database or specially conducted surveys. It has been used in information retrieval, development control, mapping, site selection, land use planning, land suitability analysis, and programming and monitoring. GIS can be seen as one form of spatial decision support systems. GIS has been applied in many decision situation, from land usage in west Africa (Ramachandran) to tourism in the Cayman Islands. See reference [32].

4.7 A Reference Architecture for DDSfSD

The current state of technology means that systems developed in different places do not connect together well. We believe that the time is ripe now to move on to the next generation of technology to support decision making. We need to define a high level reference architecture like that shown in Figure 2, derived from approaches being developed in federated database systems.

A set of DSS "product lines" should be identified (e.g., land, water, energy, health-care, etc.) where each one has its users and stake-holders clearly identified AND the inter-operability issues have been addressed (e.g., land and water models can be analysed together). Each product line should be configurable, extendible, and designed to "reuse" a common set of capabilities shared by other product lines. We will need to identify the major software components and the interfaces through which they will exchange data. We must support the integration of software tools from wherever they are available.

Bjørner (See reference [24]) presents a one domain-specific architecture, but we will here outline the one presented by Tracz. See reference [53].

To achieve this we would need to undertake the following process, based upon the experience of NASA in their work on domain specific architectures .See reference [53].

4.7.1 Analysis Phase

1. Create a list of DSS domains.
2. Rank the domains according to impact.
3. Gather several (dozen?) scenarios that reveal how DSSs will/can be used.
4. Establish a common vocabulary describing DSS systems.
5. Create a thesaurus, if necessary.
6. Create a list of "capabilities" DSS systems should/could provide.
7. Classify these capabilities as being "common", "required", "optional" and "alternative" across DSS systems.
8. List the design and implementation constraints on current and anticipated hardware platforms, operating systems, data bases to be supported, etc. This includes inter-operability with legacy systems and the data formats they would impose.
9. Review the scenarios, attributed capability list, and design/implementation constraint list with the various stake-holders (e.g., end users, developers, funders, etc.).
10. Update this information (called a domain model in some circles) and iterate again, adding more detail until some form of consensus has been achieved.

4.7.2 Design Phase

1. Develop a "layered", "configurable" architecture that provides the identified capabilities while satisfying the certain design and implementation constraints. The layering will allow common functionality/capabilities to be used across product lines as well as provide for common technology insertion point.

2. Specify/Modify/Adopt data standards for use by the system.
3. Design a configuration mechanism, whereby the architecture can be specialised to meet end-user application-specific requirements.
4. Evaluate the architecture for non-functional requirements such as concurrency, reliability, fault tolerance, security, performance, throughput, inter-operability, configurability, extendibility, scalability, etc. (One technique is to identify a set of scenarios that address each of these requirements).
5. Define interfaces of components that make up the architecture.
6. Define the communication protocols used between components.
7. Publicise the architecture/data standard.

4.7.3 Implementation Phase

1. Fund the implementation of the configuration mechanism (or modify an existing one).
2. Prioritise the set of components.
3. Incrementally fund the development the components according to the prioritised list. Hopefully, the marketplace will respond and develop "plug compatible" components.
4. Pick one or two DSS domains and use the existing artifacts to "deliver" a DSS system.
5. Verify implementation and calibrate. Ideally we should patent the architecture and offer a no-cost license to maintain control over it. As a minimum we should copyright the interfaces. In addition the approach needs to be disseminated, through a series of workshops, tutorials, videos, and so on.

5 Decision Support Systems in Sustainable Development

The authors of this position paper have between them carried out studies in Decision Support in most sectors of Sustainable Development in most regions of the world. From all these case studies we have learnt a number of lessons. Some of these lessons concerning the decision making processes and their support in tools have already been indicated in sections 3 and 4. Other lessons concerning the deployment of decision making processes in developing countries are given here.

5.1 Lack of Quality Data

The lack of available data is one of the major hindrances in the use of DSSfSD. Data is vital. In developed countries, most data needed is readily available thus making the establishment of a DSS relatively easy, but data is not so readily available in the developing countries.

The most readily available data are those from remote sensing, but these are mainly limited to land cover information from which a very limited amount of information can be extracted. Base maps are often lacking or outdated, compiled by different agencies with different accuracy and map scales and geo-coding systems making them difficult to be integrated into the system.

Nevertheless much useful planning can be undertaken, as for example in China where satellite remote sensing data has been used in planning for disasters and changes in land use at the national level (See references [34,58]) and even at the local level. See references [27,40].

Socio-economic data, are generally lacking and are often limited mainly to census data, though this can be very useful. See references [25,47]. Socio-economic data requires field surveys which are expensive and time consuming. However, the main obstacle still lies in government recognition of the need for statistical information for planning and the willingness to mobilise resources in collecting it.

It is not only the availability of data which is a problem but the quality too. In India (See reference [23]) it was found that locally collected data could be up to 30% in error: the solution seemed to lie in making the collectors of the data also the beneficiaries, so that they had a stake in the quality of the data collected.

The currency of data is very important in decision making and there need to be institutional arrangements to determine, co-ordinate, and monitor the frequency of data updating, and verifying the quality of the data collected.

The centrality of data to the adoption of DSS and the high costs and lead time to acquire data make if highly desirable to ensure that data is seen as a national asset serving multiple purposes.

A first step towards acquiring this asset is co-ordination. Early and relatively cheap measures would include a national register of available data, to forestall repeated and duplicated acquisition. It might also be possible to encourage projects to extend their activities to acquire, at low incremental cost, additional data which is highly likely to be used by other projects. A second step is encouragement of adoption of standards for the content and representation of data, to provide a formal guarantee that the data will be applicable to other projects.

5.2 Current Decision Making Practice; Need for Education & Training

The current practice of decision making in developing countries has not advanced much in comparison to the tools available to help. The skills of planners and the planning system may not be ready to utilise the data and functions available, and may not yet be aware of the benefits and potential applications of technology. Little effort has been spent on transforming data into information for making decisions. The result of this is that decision making could be made in the interests of a few dominant stake holders.

There is a general shortage of trained manpower even in the developed countries. This shortage is more severe in the developing countries both in absolute numbers and relative terms. The problem of training is more severe in the developing countries because of the lack of expertise and shortage of funds in universities who do not lead in the teaching and research of DSS. Very often, it is the government agencies which buy and use the latest systems through funding from international agencies

Training programmes are needed for five major groups of users — policy makers, decision takers, programmers, technicians, and educators. Policy makers should be made aware of the uses and limitations of DSS. Decision takers in the field should have a general understanding of data, models, and relational data structures, and the use of DSS functions in different stages of urban and regional planning process. A higher level of technological competence is needed for the training of programmers. They need to be trained to manage the system and to develop application modules to meet local needs. Technicians are need to be trained for data collection and entry, particularly the technical process involved and the likely types of errors. Educators should be kept informed of the latest development of DSS. Universities and higher educational institutions should put more investment in DSS training and research in order to develop local expertise.

In the Philippines we have found (See reference [30]) that developing human resources is a slow process, requiring many years during which the relevant data would also be gathered and decision support systems developed to fit local needs.

It will not necessarily be possible to transport training programmes from developed countries, since the decision making processes may be different. This has been discussed above in sections 3 and 4. It arises partly from the need to handle uncertainty and risk, but also arises from cultural differences — how decisions are made and agreement reached may be very different.

5.3 Leadership and Organisation

The strong influence of leadership and organisational setting on the effective use and introduction of computers is very well documented. A few key individuals interested in computers become instrumental in the initial acquisition of equipment and guide its applications. The function of the leadership is to set clear goals and objectives, to win acceptance among information system users for such goals and objectives, and to provide commitment to achieve project goals and tasks. Another critical function of leadership is co-ordination of different departments sharing the information system.

Lack of prior computer use can also be critical, both in ensuring awareness of their potential, and for the infrastructure to support their use. DSS projects are very often initiated by international assistance agencies and there is a general failure to take account of the organisational setting and personal motivations of those involved. There is evidence of large investments having been made to acquire technology, but there is less evidence that the systems are functioning satisfactorily and contributing to national development efforts. Moreover, problems often arise in the transfer of expertise as well as in maintenance costs when the international assistance left the project.

5.4 Software Development

Software for large scale systems is mainly purchased from the developed countries. It is expensive and consumes much foreign currency which is often in short supply. There is a general lack of locally developed software. Attempts have been made to use low cost commercial software to perform DSS tasks, the most popular are the combinations of commercial CAD packages such as AutoCAD with commercial database packages such as dBASE III. These systems, although limited, can make decision support available to departments and agencies with little funding. However, these low cost software systems still need to be purchased from the developed countries.

There have been quite a number of software developments in the developing countries. However, their developments are fragmented and most involve one to two researchers. They do not have the manpower and institutional set up to develop and maintain software like the commercial packages from the developed countries. See reference [39].

There may be a need for different researchers in a country or the region to pool their manpower and resource together to develop a package that can have good documentation, manuals, and support, similar to the commercial packages in the developed countries. Networks need to be established within the developing world and with the developed world. Already there are initiatives to do this in same regions (See reference [45]), and this workshop has lead to further trans-national networking.

Usability, and particularly the natural language of the interface, is a barrier to the adoption of technology. Most of the imported programs and manuals are written in English, but most of the users, and particularly the decision-makers, have limited understanding of English. User-friendly application programs which hide the technology form the users, with instructions or pull-down menu written in local languages need to be developed in order to enable local planners and decision-makers to use decision support systems. See reference [33].

One next-generation software architecture for a Decision Support System — and also one that could be based on federated GIS and Demographic Information Systems has been put forward by Bjørner. See reference [24].

5.5 Maintenance

Most of the DSS hardware and software used currently is imported from developed countries. It often takes a long time to repair a piece of hardware, particularly when the necessary components are not readily available locally. Equally, it is difficult to consult software companies when problems arise. Most of the service and expertise are also mainly concentrated in the large cities, especially primary cities, making hardware and software maintenance more problematic for sites located elsewhere. Systems must be available on low-end platforms like PCs, and must be fully serviceable in country, as would arise with locally produced software. Large countries with a substantial requirement for DSS and GIS systems should be encouraged to develop suitable software locally.

Funding to acquire the system is mainly available through central government funding or international assistance, but little is available to maintain the system. Very often, the system cannot be in full operation because one or two terminals and peripherals are out of order and the agency responsible does not have funds to repair them. More serious is that there may not be funding and institutional arrangement to update the data after they are created. As decision making needs up-to-date information, the system will be useless if its data are not updated. The development of DSS should be considered as a continuous process and not just a one-off project. The sustainability of the DSSs themselves is important.

6 Conclusions and Recommendations

The workshop has established a shared understanding of the current state of development and application of Decision Support Systems for Sustainable Development. The papers written for the workshop will be available through the IDRC and the UNU/IIST libraries, and a book will be produced documenting a comprehensive range of case studies of decision making for sustainable development and the methods and tools that were used there.

This has left us with a very strong foundation from which to move forward. We recommend that financial and organisational support is found for the following actions.

6.1 DSSfSD Practitioner Community Building

The network established at this workshop should be strengthened and enlarged through

- establishment of an Internet list service through which experience can be shared, using for example the established devices of FAQs (frequently asked questions), newsletter, and WWW home page.
- within this focused interest groups within the DSSfSD should be established, like the application of expert systems and GIS.
- the establishment of a journal on DSSfSD should be investigated.
- a follow-up workshop or conference should be arranged, possibly coupled with some other event like the forthcoming CARI conference in Africa.
- this communication should be extended to take place in languages other than English, ideally all the official languages of the UN.

It is through this community and the communication channels established that results of the other actions proposed will be disseminated.

6.2 Database of Existing DSSfSD Projects

Many studies of DSSfSD have been undertaken, but most of these have been in research laboratories. A database of theoretical and operational DSSfSD in the developed and developing countries is needed to find out how DSSfSD is developed in the research laboratory and how they are actually used in the real world environment. It should record:

- theoretical and actual use of the DSSfSD
- planning and implementation stages covered
- sectors within the developing country
- type of decision addressed
- software, model, and data used
- organisational structure for using DSSfSD

This database will help us understand the current state of the art and practice, and help identify areas for further development. 6.3 Focused DSSfSD projects should be established Leverage can be taken from the sharing of experiences and results. Suitable projects could be in the following areas:

- land management
- tourism
- planning
- disaster reduction
- use of local level solutions to development problems

which should build upon groups of existing projects, such as regional planning in the Philippines and India, agriculture in Egypt and Thailand, and the Indian honey-bee network.

6.3 DSSfSD Software Development and Distribution

It is important that appropriate software is readily available from whatever sources are appropriate. Work should be put in hand to: define reference architecture for DSS which identifies major components and their interfaces

- develop a workbench for DSS including KBS, GIS, modelling
- identify and distribute free software for this architecture and workbench
- ensure that the DSS is appropriately multi-lingual and multi-cultural.
- promote international standards and processes for DSS and GIS

The proposal by Bjørner (et al.) (See reference [24]) may serve as inspiration for such a workbench.

6.4 Training and Awareness Raising

Substantial programmes of training and education in decision making and the use of tools in this process needs to be made available to development planners at all levels. In order to bring this about we recommend projects to:

- identify and make available free training and educational materials
- develop further materials as necessary
- assess need for follow up awareness raising events and organise these as needed
- establish sharing networks for planners and decision makers in the area of sustainable development
- compile reports of case studies as an aid to this

The provision of free software will be important in facilitating this.

6.5 Advancing the Foundation for DSSfSD

To support the improvement and enhancement of decision making in sustainable development, studies of the underpinning foundations need to be carried out. Projects should be established to:

- characterise the decision making process formally
- establish new approaches to decision making appropriate to the different environment in which these decisions need to be made
- undertake social studies of the decision making process in the different regions of the world

7 References and Bibliography

A comprehensive bibliography of the area is available from IDRC. Here is a selected bibliography.

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19. **Papers presented at the Macau Expert Group Workshop**

A wide range papers were presented to the workshop and through discussions have led to this position paper. The papers are listed here with full authorship and in alphabetical order by the author who presented the work.

20. Abel: D.J. Abel, K.L. Taylor, G.C. Walker and G. Williams "The Design of Decision Support Systems as Federated Information Systems".

21. Adams: Blair L. Adams "A Value Based System for the Creation and Evaluation of Forest Ecosystem Network"

22. Audroing: Chris Audroing "Satellite Images and Geographical Information Systems: the Tools of the Future"

23. Bhatnagar: Subhash Bhatnagar "Building DSS Planning in India: Some Lessons"

24. D. Bjørner and Mohd Rais: Federated GIS- & DIS-based Decision Support Systems for Sustainable Development — a Conceptual Architecture, UNU/IIST Report # 61

25. Bowerman: Robert L. Bowerman, G. Brent Hall and Paul H. Calamai, "Improving Accessibility to Primary Health Care Services"

26. Chabanyuk: Victor S. Chabanyuk, "Problems of Creation of Decision Support Systems for Environmental Management in Ukraine (DSS in Chernobyl)"

27. Chen: Chen Shijing "Guandong Flood Protection and Disaster Reduction Auxiliary Decision Support System – A Study of DSS for SD"

28. Chokkakula: Srinivas Chokkakula, "Decision Making in Rain Water Harvesting Technology: For the People and By the People"

29. Eastman: J Ronald Eastman, "Uncertainty and Decision Risk in Multi-Criteria Evaluation: Implication for GIS Software Design"

30. Gamboa: Eduardo D. Gamboa, "Using EcoKnowMICS Object Models to Build and Understand Decision-Support for Economic Planners"

31. Gameda: S. Gameda and J. Dumanski, "Decision Support System Integrating Scientific Research and Local Knowledge for Sustainable Development"

32. Hall, Brent: Robert D. Feick and G. Brent Hall, "Spatial Decision Support and Tourism Planning" (presentation only)

33. Hall, Pat: Patrick A.V. Hall, "Software Internationalisation Architectures for Decision Support Systems"

34. He Jianbang: He Jianbang and Tian Guoliang "Monitoring and Evaluation Information System of Major Natural Disasters in China"

35. Ho TuBao: TuBao Ho, "Finding Decision Rules in Data for Knowledge-Based Decision Support Systems"

36. Kersten: Gregory E. Kersten and Wojtek Michalowski, "The DSS Phenomenon: Decision, Functions and Management Support"

37. Kersten: Gregory E. Kersten and Sunil Noronha, "The Cognitive and Organisation Paradigms: Implication for DSS Designs"

38. Koussoube: Souleymane Koussoube, James L. Ndoutoume, Roger Noussi, "On an Interactive System to Support the Management of Industrial Rubber Tree (HEVEA) Plantations"

39. Krishnayya: J. G. Krishnayya, "Development of Decision Support Systems module, and Integration with locally developed GIS software'

40. Li: Li Xia and Anthony Gar-On Yeh "A Decision Support System for Sustainable Land Development in China Using Remote Sensing and GIS - A Case Study in Dongguan"

41. Luhandjula: M. K. Luhandjula "From Decision Theory to Decision-Aid Theory and Decision Support Systems"

42. Luhandjula: M. K. Luhandjula, "Handling Uncertain Information in a Decision Support System for Planning: Application to Water Supply Problems"

43. Mikolajuk: Zbigniew Mikolajuk, "A Framework for Research on DSS for Sustainable Development"

44. Mulvey: Michael Mulvey and Clement Dzidonu "An Evaluation Model for Configuring Computer-based Decision Support System Architecture"

45. Noussi: S. Koussoube, J. L. Ndoutoume, R. Noussi, "A Succinct Presentation of Research Theme in the Project Initiated by the CARI for the Creation of An African Regional Group of Research on DSS"

46. Pokharel: Shaligram Pokharel and Muthu Chandrashekar "Integrated Rural Energy Decision Support System"

47. Poulard: Serge Poulard and Brent Hall "Access to Population Data for Local Planning and Decision Making"

48. Rafea: Ahmed Rafea, "Natural Resources Conservation and Crop Management Expert Systems"

49. Rais: Mohammad Rais "Land Use Planing in India: DSS Requirements"

50. Rao: Mukand Rao, V Jayaraman, M G Chanderashekar, "GIS Based DSS for Sustainable Development"

51. Smith: F.V. Burstein, H.G.Smith, R. Sharma, A. Sowunmi, "Organizational Memory Information Systems: a Case-Based Approach"

52. Tikunov: Vladimir Tikunov, "Environmental Impact Assessment and Information Systems: Russian Experience"

53. Tracz: Will Tracz, "DSSA-ADAGE: Decision Support Capabilities"

54. Weti: Jean-Pierre Weti "Computer Assisted Programmng of Rural Water in Cameroon"

55. Wu: Jian Kang Wu, "DSS: State of the Art"

56. Yeh: Anthony Gar-On Yeh, "GIS in Decision Support Systems for Sustainable Development"

57. Ykhanbai: H. Ykhanbai, "Various Data Collecting Systems and Their Role as DSS for SD in Mongolia"

58. Zhu Honglei "Knowledge Based Method Application in Remote Sensing Image Classification for Environment Monitoring"