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1. Introduction

This chapter has arisen from a workshop held at the United Nation University International Institute for Software Technology in Macau in 1996, and sponsored by the International Development Research Centre, Canada. The workshop was organized in response to the Agenda 21 report from the Rio Earth Summit, and particularly to its Chapter 40 on Information for Decision Making. The paper 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) 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

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The editors of this volume revised the chapter and added references to its chapters and other published papers.

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. Decisions need to be revisited and revised as their consequences are revealed in practice.

We formulate a basis for the 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 and their sustainable development.

We characterize, in Section 2, the essential features of sustainability that will be significant in our consideration of DSS. 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 emphasize 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 emphasized.

The roles of computer-based decision support technologies are described in Section 4, working through the process from information gathering and storage, through knowledge bases, the support for decision making, to visualization and the support for group decision making. We then discuss the need for solutions which integrate many tools, with existing knowledge-based and geographic information systems giving partial solutions, and conclude by outlining an agenda for developing a domain-specific architecture for decision support systems for sustainable development (DSSfSD).

Section 5 considers the wider issues of deploying DSS 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 conclusions are given in Section 6 with a list of recommendations arising from this chapter 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 to 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" (World Development Report 1990).

Development has always been with us, as societies have evolved and adapted to their environment, migrated to new environments, learned to use the resources available and discovered 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, the issue of sustainable development has taken on a new force.

2.1 The need for sustainability

Publication of the Brundtland Report in 1987 (WECD, 1987) 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 practiced 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' 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 the 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 restrictions 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 1920s and 1930s, and more recently by the world oil crisis and economic recession of the 1970s. 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). The book predicted that the limits of growth of the earth would be reached some time 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). 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 analyzing the lately developed pattern, they realized that in spite of the world's improvement policies, many resources and pollution had grown beyond 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 favorable 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, emphasizing 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". 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" (IUCN, 1980, p. 2).

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 which has tried to identify the trade-offs between population growth and standard of living, and between intensification of agriculture and soil conservation (Loening, 1991).

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 Brundtland 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 various communities around the world have 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 (Gupta, 1995). Methods of development must be appropriate to the people and the environment in which they are applied.

Decisions 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 this involvement of people 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 through which to practice sustainability. Sustainable development does not mean no development. It means improving methods for resources management in the context of an increasing demand for resources. Sustainable development must facilitate economic development while fostering environmental protection.

In order to systematize the concept of sustainable development it is useful to utilize Barbier's (1987) model of interaction between three complementary systems - (a) the biological (and other natural resources) 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 systems. 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 behavior for sustainable development:

1. A given renewable resource cannot be used at a rate that 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 emissions cannot exceed the assimilative capacity of the environment. Abatement measures should be taken to reduce the influences of 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 the 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 resources utilization be sustainable, but the decision methods too must be sustainable.

3. Decision making and DSS

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): intelligence, design and choice. Simon's decision model is discussed in Chapter 2. 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 the values must be standardized. This 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 standardized values are aggregated by combining various elements to form the basis for a judgment, 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.

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

- seeking to maximize accessibility, the location of primary health care services in the Central Valley of Costa Rica was decided using a location-allocation model (REDATAM, 1996);
- land use in the rapidly developing areas of Dongguan in south east China, adjacent to Hong Kong was modeled using an equity function (see Chapter 5);
- incentive strategies in rural development were formulated with a two-level multi-criteria model (see Chapter 7);
- decisions about sources of energy in Nepal were modeled using multiple objective programming (see Chapter 9); and
- recovery actions from the Chernobyl nuclear disaster in the Ukraine used modeling of radioactive contamination dispersion (see Chapter 17).

The above processes are grounded in statistics and mathematics, and implicitly assume that the various values required can be obtained and are accurate. There is an assumption that the relationships between the variables are known. Another assumption lies in the existence of a basis for decision through a utility function or functions involved in the aggregation step, and that these utility values have an agreed interpretation. These utility values are encapsulated within the value system of 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; and
- the importance of powerful people in influencing decisions in rural India (Bhatnagar, 1991).

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. Then again, the 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 can itself lead to uncertainty in any calculations concerning the outcome of the decision making process. Therefore any decision has an attendant risk, and this risk should be calculated to make it explicit. Only then should it be used in decision making.

Examples addressing uncertainty and risk presented to the workshop were:

- normal data from surveys 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 (Bhatnagar et al., 1994);

- variables used in planning in a variety of sectors within Goa were treated as fuzzy variables (Krishnayya,1995);
- predictions of floods from rises in the sea level in Vietnam have to be treated probabilistically (Eastman et al.,1996); and
- water supply uncertainty in Zaire was treated using fuzzy sets.

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 formulae and equations can be solved, and this may not be possible either. This realization 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 to optimize.

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 judgments necessary. People can weigh a number of alternatives and arrive at decisions, recognizing 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 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 (Kenney et al., 1990).

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 (see Chapters 10 and 11). 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 Chapter 10). Capturing the knowledge of agricultural extension workers in Egypt, and later planning to use this knowledge base to train farmers and new extension workers is an example of this (see Chapter 13).

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) 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 (KBS).

We will describe the tools required in terms of their general type, focussing 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. Other governmental and non-governmental sources of things like opinion polls, natural resources 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 the aggregation of names to make the data anonymous. For a particular study it may be possible to obtain the raw data, but this process should be restricted, and must guarantee that the aggregation that is part of the decision making process will protect confidentiality. Data interchange formats and any special converters produced need to be discussed and accepted by the research community (REDATAM+, 1996).

Existing data would typically need to be supplemented by surveys focussed 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 (GIS).

An example of the way remote sensing data might be distributed can be seen in India. Remote sensing data from satellites is collected centrally, then distributed to states who further distribute this data to districts; in parallel with this is a second line of distribution via the regions to the projects (Rao et al., 1994).

While the storage of most data can be achieved using standard database products, the storage of geographic data usually requires special methods. Geographic data can be stored as (1) "vectors" in which the geographical area is represented by a number of point, line and polygon objects whose coordinates are stored, and as (2) "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 favor different calculations. Examples of the vector approach are Themaps (Krishnayya, 1995) and *win*R+ (REDATAM+, 1996). IDRISI is an example of the raster approach (Eastman, 1992).

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 DSS. This exemplifies the well known problem of interoperability and data interchange. One solution suggested is to use Federated Database Systems (see Chapter 18).

Data integrity is critical for computer-based modeling and KBS. A computerized 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 Modeling 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. 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 analyzed in a short computer session.

The most common modeling tool is the spreadsheet, but equally important here are simulation modeling 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 computers using mature software packages. The uncertainty prevalent in development decision problems makes it necessary that these packages can handle uncertainty and risk.

These have become standard capabilities of off-the-shelf software, and no other special features are required for decision making in developing countries.

4.3 Visualization 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 visualize 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 colors 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 capabilities, and the display of geographic data can tap into that reasoning power.

A range of visualization methods are possible to help those involved in the decision making process:

- simple diagrams helped users understand the financial planning methods proposed for them in the Philippines (see Chapter 6);
- simple graphs helped explain the trade-offs in making decisions in Canada;
- theme maps helped decision making in Chinese disaster planning (Yufeng et al., 1995); and
- anamorphic maps of the world show countries' gross national product, and population represented by size on the map.

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 not be necessary. General usability analysis is applicable here.

Of particular importance in DSS is the ability of decision makers to work in their own natural language. While personal computers (PC) and Unix systems support the translation of software to other languages, some deeper cultural issues will need to be addressed which are not taken into account through these basic approaches. One example of a cultural dimension to be addressed is the choice of colors in theme maps, where for example, red signifies danger in Europe but joy in China (see Chapter 16).

4.4 Group decision making

Often decision making is a group process through which various stakeholders need to reach agreement. One important approach is the visualization method, where the representation of alternative choices is available to decision makers. Tools for group working and workflow may also be important and particularly so when the stakeholders involved 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 using "groupware" 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 decision making for development.

4.5 Knowledge capture and representation

It is important to be able to capture local knowledge about a decision problem. One important way of doing this is through KBS and expert systems.

KBS generally contain a knowledge base and a problem solving or inference method. "Expert systems" is sometimes used as a synonym for KBS. The first generation of expert systems represented knowledge as "production rules" of the form "if 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 1980s 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 1980s, some scientists noted the disadvantages of using production rules and a new trend has appeared emphasizing 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 methodology (KADS) has appeared in Europe.

The main idea of these second generation expert systems was to characterize 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 sub-tasks, and/or of 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 correct decisions (see Chapter 14). Another learning method that is promising is Neural Networks.

Case Based Reasoning (CBR) is a promising approach, if a record of successful decisions is available, and if the context of the decision can be characterized by a number of attributes which then can be used to assess the similarity or otherwise of a new situation to past cases. An example of the application of CBR is the determination of the equivalence of educational qualifications (see Chapter 15).

If possible the KBS being used should provide advanced facilities (e.g. 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 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 sustainable development such as crop management, pollution handling and so on (see Chapter 13).

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 be comprehensible to the decision makers. Examples are the output from a sophisticated simulation model for economic growth, or the reports generated from large databases.

4.6 DSS Integration

It is agreed that a key capability of DSS must be the interoperation 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.

There is an emerging trend of data standardization for GIS in developed countries. The National Committee for Digital Cartographic Data Standards (NCDCDS) and the Federal Interagency Coordination Committee on Digital Cartography (FICCDC) try 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 delineation of boundaries of administrative, natural, and drainage area regions (see Chapter 5).

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 KBS may include not only mechanisms for knowledge representation and inference, as described in section 4.5, but may also have all of the visualization and user interface development facilities that we described in section 4.3 (see Chapter 6). Further, it is possible to use rule based systems in a more general manner, i.e. as a programming tool that does not require the level of technical expertise that conventional programming requires, as we see in the effective use of KBS in China (see Chapter 5).

Off-the-shelf GIS 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 serves both as a tool box and a database. As a tool box, a GIS allows planners to perform spatial analysis using its geoprocessing or cartographic modeling functions such as data retrieval, topological map overlay and network analysis. Of all the geoprocessing 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 different modeling 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 DSS. GIS have been applied in many decision situations, from land usage in West Africa (Eastman, 1992) to tourism in the Cayman Islands (REDATAM, 1996).

4.7 A reference architecture for decision support systems for sustainable development

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 derived from approaches being developed in Federated Database Systems (Tracz, 1993).

A set of DSS "product lines" should be identified (eg. land, water, energy, healthcare, etc.) where each one has its users and stakeholders clearly identified AND the interoperability issues have been addressed (eg. land and water models can be analyzed 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. To achieve this we would need to undertake the following process, based upon the experience of NASA in their work on domain-specific architectures (Tracz, 1993).

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 DSS will/can be used.
4. Establish a common vocabulary describing DSS.
5. Create a thesaurus, if necessary.
6. Create a list of "capabilities" DSS should/could provide.
7. Classify these capabilities as being "common", "required", "optional" or "alternative" across DSS.
8. List the design and implementation constraints on current and anticipated hardware platforms, operating systems, databases to be supported, etc. This includes interoperability 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 stakeholders (eg. 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 certain design and implementation constraints. The layering will allow common functionality/capabilities to be used across product lines as well as provide for a 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 specialized to meet end user application-specific requirements.
4. Evaluate the architecture for non-functional requirements such as concurrency, reliability, fault tolerance, security, performance, throughput, interoperability, 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. Publicize the architecture/data standards.

4.7.3 Implementation phase

1. Fund the implementation of the configuration mechanism (or modify an existing one).
2. Prioritize the set of components.
3. Incrementally fund the development of the components according to the prioritized 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.
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. DSS for sustainable development

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 developing countries.

The most readily available data is that from remote sensing, but this data is mainly limited to land cover information from which a very limited amount of information can be extracted. Base maps are often lacking or are outdated, compiled by different agencies with different accuracy and map scales, and geocoding 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 (Chen et al., 1994) and even at the local level (Wu, 1995).

Socio-economic data is generally lacking and is often limited mainly to census data, though this can be very useful. The capturing of socio-economic data requires field surveys which are expensive and time consuming.

However, the main obstacle still lies in government's recognition of the need for statistical information for planning and its willingness to mobilize resources in collecting data.

It is not only the availability of data that is a problem, but the quality too. In India it was found that locally collected data could be up to 30% in error (Bhatnagar et al., 1994). 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 is a need for institutional arrangements to determine, coordinate 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 needed to acquire data make it highly desirable to ensure that data is seen as a national asset serving multiple purposes.

A first step towards acquiring this asset is coordination. 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 highly likely to be used by other projects. A second step would center on encouraging the 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 Need for Education and 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 itself may not be ready to utilize the data and functions available. Planners 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. Consequently decision making in the interests of a few dominant stakeholders results.

There is a general shortage of human resources even in developed countries. This shortage is more severe in developing countries both in absolute numbers and in relative terms, where training can be made difficult due to a lack of expertise and a shortage of funds in universities that do not lead in DSS education and research. Very often, it is government agencies that buy and use the latest systems through funding from international agencies

Training programs 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 processes. A higher level of technological competence is needed for the training of programmers. They must acquire skills to manage the system and to develop application modules to meet local needs. Technicians need to be trained in data collection and entry, particularly the technical process involved and the likely types of errors encountered. Educators should be kept informed of the latest developments in DSS. Universities and higher educational institutions should invest more in DSS training and research in order to develop local expertise.

In the Philippines we have found (see Chapter 6) that developing human resources is a slow process, requiring many years during which relevant data is gathered and DSS are developed to fit local needs.

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

5.3 Leadership and organization

The strong influence of leadership and organizational 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 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 coordination of the different departments sharing the information system.

Prior computer experience can also be critical, both in ensuring awareness of the computer's 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 organizational 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 due to maintenance costs and in the transfer of expertise arise when the international assistance ceases.

5.4 Software development

Software for large scale systems is purchased mainly from 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, most often using combinations of commercial CAD (Computer Aided Design) packages such as AutoCAD with commercial database packages such as Microsoft Access. 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 developed countries.

There have been quite a number of software developments in developing countries. However, these developments are fragmented and most involve one to two researchers. Developing countries do not have the human resources and institutional setup to develop and maintain software like the commercial packages available in developed countries (Krishnayya, 1995).

There may be a need for different researchers in a country or region to pool their human and other resources to develop a package that can have good documentation, manuals and support, similar to commercial packages in developed countries. Networks need to be established both within the developing world and with the developed world. Already there are initiatives under way to do this in some regions (AfricaGIS'95, 1995), and this workshop has lead to further transnational networking.

Usability, and particularly the natural language of the interface, is a barrier to the adoption of technology. Most imported programs and manuals are written in English, but most users, decision makers especially, have a limited understanding of English. User-friendly application programs, which hide the technology from users by providing instructions or pull-down menus written in local languages, need to be developed so that local planners and decision makers can use DSS (see Chapter 16).

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. Also, most of the service and expertise is concentrated mainly in 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 be the case for 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 the funds to repair them. More serious is the fact that there may not be funding and institutional arrangements to update the data once it is created. Decision making requires up-to-date information: the system will be rendered useless without it. The development of DSS should be considered as a continuous process and not just a one-off project. The sustainability of DSS themselves is important.

6. Conclusions and secommendations

The workshop has established a shared understanding of the current state of development and application of DSSfSD. The papers written for the workshop will be available through the IDRC library, 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.
This has left us with a very strong foundation from which to move forward. We recommend that financial and organizational support be found for the following actions:

6.1 DSSfSD practitioner community building

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

- the establishment of an Internet list service through which experience can be shared, using for example the established devices of FAQs (frequently asked questions), newsletters, and WWW home pages;
- the establishment of focussed interest groups within DSSfSD (eg. groups looking at the application of expert systems and GIS);
- the establishment of a journal on DSSfSD;
- the arrangement of a follow-up workshop or conference, possibly coupled with some other event like the forthcoming CARI conference in Africa; and
- the sharing of this communication in languages other than English, ideally in all official languages of the UN.

It is through this community and the communication channels established that results of the other actions proposed 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 developed and developing countries is needed to find out how DSSfSD are developed in the research laboratory and how they are actually used in the real world environment. It should record:

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

- organizational 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 Focussed DSSfSD projects

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; and

In all these areas it is important to secure that local level solutions are used to development problems. This 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.

6.4 DSSfSD software development and distribution

It is important that appropriate software is readily available from whatever sources are suitable. Work should be initiated to:

- define reference architecture for DSS which identifies major components and their interfaces;
- develop a workbench for DSS including KBS, GIS and modelling;
- identify and distribute free software for this architecture and workbench;
- ensure that DSS are appropriately multi-lingual and multi-cultural; and
- promote international standards and processes for DSS and GIS.

6.5 Training and awareness raising

Substantial programs for training and education in decision making and the use of tools in this process need 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 the need for follow-up awareness raising events and organize these as needed;

- establish sharing networks for planners and decision makers in the area of sustainable development; and
- compile reports of case studies as an aid to this.

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

6.6 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 initiated to:

- characterize the decision making process formally;
- establish new approaches to decision making appropriate to the different environments in which these decisions need to be made; and
- undertake social studies of the decision making process in different regions of the world.

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Editors

Kluwer Academic Publishers
Boston/Dordrecht/London