Decision Support Systems for Sustainability: Beyond the State of the Art

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Your honor President Pastrana, Mr. Clarke, Dr. Borrero, friends, and colleagues, thank you for the opportunity to share some of my thoughts with you today.

When Santiago Borrero asked me if I would give the first keynote address for this conference I enthusiastically accepted. It was later, as I began preparing my talk, that I was struck with the awesome importance of this meeting.

The tenth anniversary of the signing of Agenda 21 is just over a year away. The Earth Summit in Rio in 1992 was a time of optimism. Nations outlined the ambitious Agenda 21with the belief that we could overcome our differences and work together to improve the lot of mankind, the environment, and the economy simultaneously. Everyone knew it would be difficult. Perhaps no one knew how difficult.

The Earth Summit, which will take place in Johannesburg, South Africa in 2002, will be a time for the nations of the world to reflect on our accomplishments or shortcomings. It will be a time to reaffirm our dedication to solve complex problems. It will be a time to demonstrate to ourselves and each other that nations can overcome political, ideological, cultural, and economic differences to work for the common good of mankind.

What has happened since the Rio conference? Clearly population has grown. In less than ten years it has climbed by 13 percent, from 5.45 billions to 6.l6 billions of people (U.S. Census Bureau 2001). The compounding effects of population growth and the rightful desire for improved living standards for everyone have placed increased stresses on the environment. They have increased our demands for energy and food. They have caused the demand for luxury items to grow as well as the demand for basic necessities. They have caused our cities to swell and grow beyond our expectations. This, in turn, has put more people in harm's way due to their proximity to natural and human-induced hazards.

Technology has changed as well. The Internet grew from 376,000 hosts in 1991 to 109,574,429 hosts in 2001 (Zakon 2001). Now over 450 million people are connected to the Internet. Many more use it. Not since the invention of the telephone has our ability to communicate changed so drastically. The World Wide Web was introduced in 1991. It has rapidly changed the way we conduct business and make information available.

Computer capacity and speed have grown as well. In 1992 a top of the line personal computer had a hard drive of 100 megabytes, 4 megabytes of random access memory (RAM), and a 486 chip with a speed of 25 to 50 megahertz. Today a top of the line personal computer has a hard drive with 30 gigabytes, 512 megabytes of RAM, and a Pentium IV chip with a speed of 1 gigahertz.

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According to the Intergovernmental Panel on Climate Change (IPCC), human activities are destabilizing the global climate (IPCC 2001) and the effects are measurable. As Kofi Annan, Secretary-General of the United Nations, pointed out (Annan 2001) "environmental problems build up over time, and take an equally long time to remedy." If that is the case, and I believe it is, we must work on at least two fronts.

We must work to remedy or mitigate the environmental problems, such as climate change, land degradation, depletion of natural resources, and others that we have caused over the years and continue to cause. We must also work to adapt to the current and changing situation. We must live in the best way possible while we attempt to correct the unintended consequences of our previous actions.

All sectors of our society must bring their capabilities to bear to establish a more sustainable future. The sectors represented in this room are dominated by information technology and the environmental sciences. Of course, we all represent other sectors as well, but those two predominate. They can help the people of the world remediate and mitigate as well as adapt.

At the Commission on Sustainable Development's 9^{th} meeting at the United Nations in New York this past month there was a reaffirmation of the importance of information technology and scientific information as foundations of sustainable development. Yet, the digital divide widens. Not because some societies are going backwards, although a few are, but because the technological advances are taking place at such a rapid pace that some societies are advancing much more rapidly than others.

To make the progress needed for sustainable development in the first half of the 21^{st} century, a time that by some estimates will see the population grow by fifty percent (U.S. Census 2001), we must ensure that all societies have access to the best decision-making technologies and underlying scientific information possible. And that, must be better than anything any of us has today.

Decision support systems (DSS) are not a new concept. Computerized decision support systems were used in business during the 1960's (Shuford 1964, Zannetos 1965) and industry by the 1970's (Morton 1971). They have advanced considerably since then.

By the early 1990's a standard model had evolved (Carter and others 1992). It consisted of six main parts. The first part is an interface between the human and the computer. Second, a model base is needed. That is where models of phenomena, rules, and other analytical capabilities reside. Data are needed to run the models. These data form the third component, the database. A system must exist so the various components can communicate with each other. An analytical engine must also exist. That is the assembled models and data in an actionable form. One more piece of technology completes the package. That is the output and visualization capability. This is how the DSS communicates results back to the user. The smallest decision support systems reside on one computer with the models and data residing on the hard drive and the operating system and programming provide the communication between the various components of the DSS.

The DSS model worked for locally-held systems as well as enterprise-wide systems. Surprisingly, this very simple model also functions quite well for increasingly complex computerized decision support systems. For instance, during the 1990's there has been an increasing effort to modularize models of biological, physical, and economic processes. Often a number of models reside in a model base. Some of these models perform the same functions but are valid under specific conditions. For instance, a number of hydrologic models may be in the model base. One may work well in steep terrain. Another may work better in fairly level terrain. One may work better in humid regions, another in arid regions. And so on. The user can select the appropriate snow-melt model to link to the appropriate hydrologic model to link with the appropriate water demand model. These models can be used to help determine optimal water release from a reservoir. The modular approach gives considerable flexibility (Leavesley and others 1997).

A few large vertically and horizontally integrated digital geo-spatial databases were available on the Internet by the early to mid-1990's (Scientific Assessment and Strategy Team 1994, Kelmelis 1995). Now, ten years after the World Wide Web was introduced, it is common practice for organizations to plan their digital databases for access and distribution on the World Wide Web or on some more restricted network. Still, much of the data are not vertically integrated. Often additional work is required to make one data set compatible with another to do meaningful analysis. In addition, needed data are limited or not available for many parts of the world.

In this environment, a more collaborative method of systems development is taking place. For instance, the Open GIS Consortium (OGC) is made up of government, private industry, academic, and independent organizations. The OGC works to develop open specifications that can be used by industry to ensure operability of hardware and software.

The International Standards Organization (ISO) is another vital part of the puzzle. New capabilities like g.net, the new GIS architecture ESRI has unveiled, are a major step in the right direction (Dangermond 2001) as well. There are many pieces of this puzzle such as the Global Mapping Project, individual national and commercial databases, the e-government effort in the United States. The list could go on.

Of course, the Global Spatial Data Infrastructure and the many regional and national spatial data infrastructures of which it is composed are being developed to make it easier to access the interoperable tools and data to help solve critical problems of sustainability.

With all of this technology, we must be nearing a solution to the data and information problems. It must be easy for people to do spatial and process analysis wherever and whenever they want. We must be nearing an available decision support system to address the problems outlined in Agenda 21. Of course, we all know that is not the case.

The changes that are taking place on the Earth are huge. There are unintended consequences of previous decisions we must deal with. If that was not enough, there is that pesky digital divide that was mentioned earlier. Can we go beyond the current state of the art to help cross that digital divide and use science and technology to help all of us make critical decisions?

The model we are currently using has merit. It can be extended to go beyond the state of the art. Assume you are in a country with very limited access to data, models, geographic information systems (GIS), computer capacity, in situ monitoring, or communications infrastructure. This is the case for most people and many governments at all levels throughout the world.

It would be a great advance if we could get onto the web and describe our problem in natural language and get an intelligent broker to help us find the GIS or process models we need, biophysical, socioeconomic, engineering, etc.; identify and get the data needed to run those models, whether historic or new from satellites, field teams, or whatever monitoring systems exist; find and access the computer capacity to assemble the models into a DSS then run it; communicate the results back to us in a timely and usable manner; rerun it so we could see the results with a variety of options; and maintain a history of all actions and sources so the process can be repeated in case verification is necessary. In an environment of limited resources as I described above, a vision like this would be of great value. The user might only need a portable computer and a link to a communications satellite.

Some of the key technological, scientific, and social concepts needed to develop this have been discussed in the literature (Dangermond 2001, Holland 2001, Johnson 2001, Kelmelis 1998, Kelmelis and Gunther 1998). They include:

- Searchable, interoperable, linkable modular models whose inputs and outputs meet standards that allow quick and easy assembly into larger systems; the models must also be intelligent enough to know what kind of data they need, for what domain they are appropriate, and what computer processing demands they will have;
- Interoperable, horizontally and vertically integratable data with searchable, analyzable metadata;
- A brokering capability to share computer capacity;
- Search engines sufficiently sophisticated to analyze natural language user queries and find the models, data, and computer capacity that are suitable to the task at hand;
- Sufficient bandwidth, whether hard lines or via satellite, to communicate the necessary information anywhere in the world;
- Methods to visualize and present the results in ways that are meaningful to the particular individuals and cultures using the system;
- Improved understanding of the way biophysical, socioeconomic, engineering, and other processes work, interact, and feed back upon each other; models must be built of the processes so they may be incorporated into systems;
- Improved education of all societies so they may use the information provided by the systems; and
- Understanding by us all that people make the decisions, not the systems; that there are more variables that affect the decisions than scientific information; and that whatever decisions are made, they are experiments, the results of which must be monitored; and that the decisions may need to be changed in the future.

What does all of this mean to us here? It is simple. We should be prepared to demonstrate the great things that have been accomplished in the past decade. We should also be prepared to lay out an agenda for the next decade that will move us far closer to realizing the goals of Agenda 21. We should use our knowledge of science and technology to find ways to bridge the digital divide and make knowledge that is useful for decisions available to everyone.

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