Visualization of Sustainability Indicators: A Conceptual Framework

Ray Quay[1], Khanin Hutanuwatr [1], and David Pijawka [2,3]

Abstract

As sustainability becomes integrated into public policy decision making, comprehensive and easily accessible sustainability information will be needed to assist policy analysis. As visual analytics emerges as a major tool of policy analysis, sustainability information, particularly sustainability indicators, will need to be structured to work with visualization methods and tools. Numerous models for defining and organizing sustainability indicators have been published but there is limited literature on defining a theoretical framework for organization of such data so that it can be easily analyzed using visual analytic tools. This project is developing a framework for organizing and visualizing hierarchical based sustainability indicators within three scales, topical, spatial, and temporal. This will include quantitative and qualitative concepts and methods for analyzing large sets of sustainable data. Desktop and Internet based Visual Analytic

Introduction

Sustainability concepts now span such a broad range of topical areas that few, if any, individuals can be experts in all aspects of sustainability. Most sustainability researchers and advocates either focus on a broad context of sustainability, environment, economy, etc, or they focus on a one particular area of sustainability, such LEEDS. These approaches are useful when the focus of decision making is sustainability itself, however such opportunities in public policy making are rare. If sustainability is to be successfully inserted into public decision it will need to be one of many factors that may be of importance to policy makers (EUROCITIES, 2004) and sustainability information will have to be relevant to a wide range of specific economic, social or rights issues (Clark, 2003; Nyerges, 2002). Given the complexity of these issues and sustainability, decisions makers will need sustainability information simplified to a manageable level so that they can be considered along with the other factors of importance to the decision at hand (Forester, 1989.; Lindblom, 1995). Indicators are one tool that can be used to help simplify the understanding of sustainability issues (Gudmundsson, 2003). Across most topics of sustainability there are a variety of measures that can be used as indicators of sustainability and a variety of models for organizing these measures and indicators have been proposed (See Table 1).

In general most sustainability indicator models report or summarize information across three basic scales: topical, spatial, and temporal. The interests and needs of decision makers can vary across these scales based on the nature of the various issues they are evaluating. (Prescott-Allen, 2001) Effectively delivering sustainability information to decision makers will require visualization techniques that allow decision makers to easily explore simple sustainability indicators at these various topical, spatial and temporal scales (Clark, 2003; Gallopín, 2004; Nyerges, 2001). This project is exploring the two key factors in providing this level of flexibility: 1) the method used to organize the indicators and 2) the techniques used to visualize the indicators.

Table1: Sustainability Indicator Models

Canada Sustainability Report (SRP, 2004)
Central Texas Sustainability Indicators Project (Central Texas Sustainability Indicators Project, 2004)
Ecological Foot Print (Venetoulis, Chazan, & Gaudet, 2004; Wackernagel et al., 1997)
Interagency Working Group on Sustainable Development Indicators (Sustainable Measures, 2002)
Neighborhood Plans (Crossroads Resource Center, 1999; Manglani & Pijawka, 2003)
Oregon Benchmarks (Sustainable Measures, 2002)
Sustainability Counts (SDU, 1998)
Sustainable Seattle (Best, Dusen, & Conlin, 1998; Sustainable Measures, 2002)
The Montreal Process (MPO, 1995)
The Natural Step Process (Natural Step, 1997)
The State of the Nation's Ecosystems (Heinz Center, 2002)
UN Indicators of Sustainable Development (Sustainable Measures, 2002)
UNCHS (Habitat) indicators program (Auclair, 1997)
Yale Environmental Performance Index (Esty et al., 2006; Heinz Center, 2002)

Current Concepts

Organization

Most models for sustainability indicators use two basic concepts for organization. First environmental, social, and / or economic measures are used directly or in some normalized fashion to create indicators or a trend analysis. For example different types of crimes for an area may be reported, and then combined to create a crime index, such as total crimes per capita. Second these indicators are organized into categories, usually hierarchical, based on some topical or systems classification scheme. For example a Crime index may be combined with Health index under the category of Human Welfare. In some cases, these indices for each of the topics may be combined to create an index for the category as a whole. Table 2 shows the organization structure for Prescott-Allen's The Well Being of Nations Sustainability Indicators.(Prescott-Allen, 2001)

Generally, there is little consistency among these indicator models in how indicators are developed or aggregated functionally, spatially, or temporally. Some indicators system just focus on natural environmental indicators(Esty et al., 2006; Heinz Center, 2002; Venetoulis et al., 2004), while most others include some human condition indicators. Generally at the highest topical hierarchical level

Table 2: Sample Hierarchial Structure for Indicators

Level 1	Level 2	Level 3	Level 4	Measures
Human Wellbeing				
	Heath and Population			
	Wealth			
	Knowledge			
	Equity			
	Community			
		Freedom & Governance		
			Political rights	
			Civil liberties	
			Press freedom	
			Corruption perception	
			Peace & Order	
			Armed conflicts	
			% defense expenditure of GDP	
			Peace	
			Crime	
				Homicides (Number and Rate)
				Rapes (Number and Rate)
				Robberies (Number and Rate)
				Assaults (Number and Rate)
				Other violence (Number and Rate)
Eco Wellbeing				
	Land			
	Water			
	Species & Genes			
	Resource			
	Air			
		Global Air Quality		
		Local Air Quality		
		CO2 Per Person		
				CO2
				CO2/ha
				CO2/person
		Ozone Depletion		
				Ozone depleting substance metric ton
				ODS/ha (a)
				ODS/person (a)

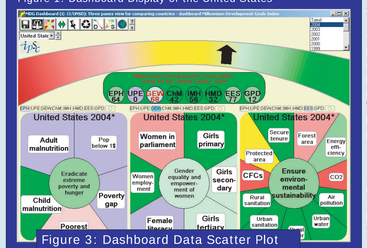
The Well Being of Nations Sustainability Indicators (Prescott-Allen, 2001)

these indicators models have two main indicators, Human and Ecological. Below this level what data is used and how it is aggregated to different levels varies widely. Each model creates its own standard classification, weighting, and aggregation standards but the rules for such aggregation or weighting are seldom presented. For example, in The Wellbeing of Nations Prescott-Allen does provide rules for topical aggregation of the indicators but not rules for spatial aggregation. In the presentation of the data, tables of country indicators indices are grouped by region, however, no method is provided to create an aggregated index for a region. There has been some work on the methods that could be used for weighting and aggregation of data and indicators to create composite indicators for different hierarchical indicator levels (Nardo, Saisana, Saltelli, & Tarantola, 2005)

Visual

Though there is a rich set of systems for defining sustainability indicators, there has been less work on general methods of organization and visualization of these indicators (Williams, 2004). Each model is typically presented with one method of reporting its indicators. This may vary from a simple table such as used in the LEED system to maps that show index values for varies geographic units such as those used in The Wellbeing of Nations. None of the models utilize advanced methods for displaying and analytically exploring hierarchical data.

Figure 1: Dashboard Display of the United States



Currently the only published tool for visually displaying and exploring sustainability data is The Dashboard of Sustainability developed by International Institute for Sustainable Development (Consultative Group on Sustainable Development Indicators, 2006) (http://www.iisd.org/cgsdi/dashboard.asp). This tool uses the motif of a vehicle dash board to display sustainability status information as various gauges and allows amore in depth and interactive exploration. The tool is a windows based stand alone application that allows the user to interact with a hierarchical structured database of indicator data. Dashboard is able to display indicators for various topical, spatial, and temporal scale data in a variety of ways including the

Figure 3: Dashboard Data Scatter Plot

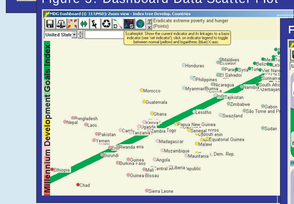


Figure 2: Dashboard Map View

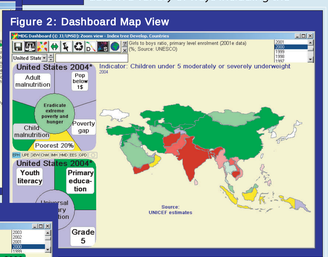
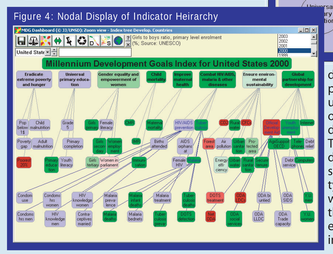


Figure 4: Nodal Display of Indicator Heirarchy



dashboard guage, maps, scatter plots and value plots by spatial unit. The tool does allow the user to view data summarized at different levels of the topical hierarchy and does aggregate the data internally for each grouping of indicators. Three levels of hierarchy are supported, lower data level, group data indicator level, and then a single aggregated indicator. Figure 1 shows the typical Dashboard display of the United States with the indicator gauges. Each colored part of the gauge corresponds to a data indicator, with each center being the group aggregated indicator value. Different gauges can be selected for viewing. Figure 2 Shows a similar data display but in map view. In this view the map is interactive and data from any country can be displayed in the dashboard by clicking on the map and data values for any country can be displayed by clicking on the dash board gauge. Dashboard gauges can also be displayed side by side with other countries (up to eight). Other views include a scatter plot of all countries (figure 3) based on values for two indicators, and a nodal view (figure 4) of the hierarchy itself for one country.

Though Dashboard provides a rich interactive environment, it structure around the dashboard concept is limiting when try to explore the hierarchical data within the three scales, topical, spatial, and temporal is difficult and no tools (visual or otherwise) are provide for doing analytical analysis nor is any method to produce a report at any selected topical, spatial, or temporal level

Visual Analytics Conceptual Framework

Organization

The calculation of an indicator is typically based on some rule which defines what data is used, what the calculation is (if any) to create a metric, and what normalization is done (if any) to create a numeric index or indicator. In addition to this numeric, these indicators have attributes of scope: topic, space, and time. These other attributes are not static and can describe as a hierarchical structure. Space can be defined as a single parcel of land, or aggregated into a single block, or to a square mile, or to a city, state, nation, hemisphere and planet. Topic can be described as a single measurement, such as CO2 levels, combined with others to describe green house gases, combined with other measures (Particulates etc) to describe air quality, or as part of a summary of environmental health or general global well being. Time can be described as now, or the day, or the month, year, decade, century or as the difference between two points in time.

These hierarchy schemes of scope can be described independent of the data with in a a nodal network. Each node may be linked to one or more other nodes which can be described in XML (which is well structured to represent nodal hierarchies See Table 3). Measured data can then be described where it lies within these scope hierarchies. This is more than just a hierarchical classification scheme. In this case, each level of the hierarchy represents a summary of all the values below this level.

This data summarization of indicators from one level to another is based on rules of how the indicators or data from lower levels is aggregated at the higher level. These rules will be different for different hierarchical schemes and indicators. Toipcal Air quality may be simply be done by averaging while spatial aggregation may be weighted by size of the country. Thus within the hierarchical indicator scheme, rules must be developed for how each indicator is aggregated These rules can either be defined as part of the hierarchy, or simply calculated and included in the data and associated with the aggregated node. Averaging and weighted averaging would be the most common rules. Such simple methods could be reflected in XML scope hierarchies.

Table 3: Scope Heirarchy Definition

TOPICAL HIERARCHY XML

```
<HIERARCHY NAME="TOPICAL">
    <GLOBAL NAME="Global Wellbeing Index">
        <HUMAN NAME="Human Well Being Index">
            <WEALTH NAME="Wealth Index"> </WEALTH>
            <FREEDOM NAME="Freedom Index">
                <VOTE NAME="Voting Rights Index></VOTE>
            </FREEDOM>
        </HUMAN>
        <ECOSYSTEM NAME="Ecosystem Wellbeing Index">
            <AIR NAME="Air Quality Index">
                <CO2 NAME="CO2 Levels"></CO2>
                <OZ NAME="Ozone Levels"></OZ>
            </AIR>
        </ECOSYSTEM
    </GLOBAL>
</HIERARCHY>
```

SPATIAL HIERARCHY XML

```
<HIERARCHY NAME="SPATIAL">
    <GLOBAL NAME="World Wide">
        <NHEMISPHERE NAME="Northern Hemisphere">
            <NAMERICA NAME="North America">
            <US NAME="United States">
                <TEXAS NAME="State of Texas">
                    <BEXAR NAME="Bexar County">
                        <SA NAME="City of San Antonio"></SA>
                    </BEXAR>
                </TEXAS>
            </US>
            </NAMERICA>
        </NHEMISPHERE>
    </GLOBAL>
</HIERARCHY>
```

TEMPORAL HIERARCHY XML

```
<HIERARCHY NAME="TEMPORAL">
    <1900CENT NAME="20th Century">
        <1990DEC NAME="Decade 1990-1999">
            <1990 NAME="1990"></1990>
            <1991 NAME="1991"></1991>
            ...
            <1999 NAME="1999"></1999>
        </1990DEC>
    </1900CENT>
</HIERARCHY>
```

Visualization and Interaction

The conceptual framework of sustainability indicator organization and visualization includes five components.

1) A data organizational system that defines indicator data based on hierarchies of topical, spatial, and temporal attributes;
2) Methods for aggregation of indicator indices at various levels of topical, spatial, and temporal hierarchies,
3) Visual techniques to display indicator data in views that either are topically, spatially, or temporally focused,
4) Visual Analytic techniques to analytically assess indicator data, and
5) A simple and intuitive visual interface that allows the decision maker to explore sustainability indicators and analysis to find information relevant to their needs and interests.

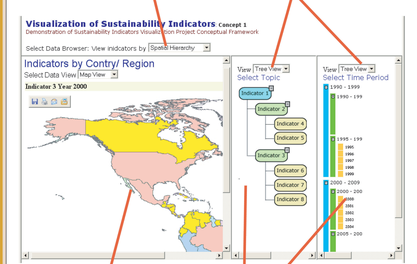
Public policy decision makers must are faced with a wide range of complex issues for which sustainability will be only one of many factors that will be considered. The environment of public decision making can be chaotic, and the focus on what aspects of sustainability are important to an issue may shift over the course of discussion of an issue. Thus there is a need for tools with high degree of flexibility providing both summarized and details in a variety of levels of place and time. A simple and intuitive visual interface that allows the decision maker to explore sustainability indicators and analysis to find information relevant to their needs and interests is proposed. Using this proposed framework of topical, spatial and temporal hierarchical data organization, an interface that allows the user to browse the data based on each hierarchy could be constructed. Such an interface would provide a main display frame, in which the user would browse data based on one of the hierarchies, based on single or multiple attributes selected from the other hierarchies. Figure 5 provides an overview of such and interface. Also conceptual frameworks and prototypes are being developed on this basis and are located at www.public.asu.edu/~mcquay/sivp

Visualization research is rich in methods to display hierarchical and nodal based data. Visual analytics research is also rich in methods to analyze hierarchical and network data. However, use of these techniques will require that that sustainability indicator data be organized to facilitate visualization, interactive exploration, and analytical assessment.

Figure 5: Interface Concepts

Select an Indicator Browser: Topical, Spatial or Time. Each allows the user to explore the indicator data based on a Topical, Spatial, or Timeline classification heirarchy.

Attribute selectors can display the attributes based on different' views of the heirarchy: List, Map, Tree



Indicator Data Browser Display
Various Views of Heirarchy
Lists
Maps
Trees
Graphs

Indicator Attribute Selection
Select what attributes are displayed by the indicator browser
Topic, Spatial, Time

Further Research Needed

1) Some sustainability schemes are not hierarchical, organizing indicators in hierarchical structures needs to be researched. (Gallopín, 2004; Nyerges, 2002)
2) Most indicators are not normalized making comparison of indicators from different units of measure difficult. (Allard, Cherqui, Wurtz, & Mora, 2004; Nyerges, 2001)
3) Most indicator system define indicators one geographic scale because of the inconsistent availability of data for all indicators at all geographic scales, (N.L.Leake, Adamowicz, & Boxall, 2002)
4) Most indicators do not provide rules for summation of indicators to higher topical and spatial levels. (Nyerges, 2001)
5) There is general lack of historical indicator data.
6) There currently appears to be little research into the use of sustainability indicators with futures analysis.

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[1] College of Design, PhD Program, Arizona State University, PO Box 871905, Tempe, AZ 85287-1905;
[2] College of Design, School of Planning, Arizona State University, PO Box 871905, Tempe, AZ 85287-1905;
and School of Sustainability, Arizona State University, PO Box 872511, Tempe, AZ 85287-2511

References

Auclair, C. (1997). The uncha (habitat) indicators program. In K. Meilden & et al (Eds.), Sustainable Indicators: A report on the project on indicators of sustainable development New York: John Wiliyah Sons.

Best, A., Dusen, H. V., & Conlin, B. (1998). Indicators of sustainable community: Sustainable Seattle.

Central Texas Sustainability Indicators Project. (2004). Fifth annual report. Austin, Texas: Central Texas Sustainability Indicators Project.

Clark, W. C. (2003). Sustainability science: Challenges for the new millennium. University of East Anglia, Norwich UK: An address at the official opening of the Zackerman Institute for Connective Environmental Research, September 4, 2003.

Consultative Group on Sustainable Development Indicators. (2006). The dashboard of sustainability. Retrieved 3/17/2006, 2006, from http://www.iisd.org/cgsdi/dashboard.asp

Crossroads Resource Center. (1999). Neighborhood sustainability Indicators guidebook Minnesota: Urban Ecology Coalition (Minneapolis).

Esty, D. C., Emdyntyak, T., Kim, C. H., Levy, M. A., Sherbinin, A. d., & Anderson, B. (2006). Pilot 2006 environmental performance Index. New Haven: Yale Center for Environmental Law & Policy.

EUROCITIES. (2004). Towards a strategy on the urban environment: Eurocities statement. In E. T. N. o. M. E. Cities (Ed.): European Union.

Forester, J. (1989.). Planning in the face of power: University of California Press.

Gallopín, G. (2004). Sustainable development: Epistemological challenges to science and technology. Workshop on Sustainable Development: Epistemological Challenges to Science and Technology. ECLAC, Santiago de Chile: ECLAC.

Gudmundsson, H. (2003). Making concepts matter: Sustainable mobility and indicator systems in transport policy. International Social Science Journal, 55(177), 199-217.

Heinz Center, T. (2002). The state of the nation's ecosystems: Washington, DC: The H. John Heinz III Center For Science, Economics, and the Environment.

Lindblom, C. E. (1995). Science of muddling through. In D. C. McCool (Ed.): Public policy theories, models, and concepts (pp. 142-157).

Manglani, R. & Pijawka, K. D. (2003, November 9 - 12, 2003). Measuring environmental impacts of sustainable neighbood plans. Paper presented at the PLEA 2003 - The 20th Conference on Passive and Low Energy Architecture, Cobe.

MPO, T. M. P. O. (1995). Criteria and Indicators for the conservation and sustainable management of temperate and boreal forests.

N. L. Leake, Adamowicz, W. L., & Boxall, P. C. (2002). An examination of economic sustainability Indicators in forest dependent communities in canada: Sustainable Forest Management Network.

Nardo, M., Saisana, M., Saltelli, A., & Tarantola, S. (2005). Tools for composite Indicators building. Ispra, Italy: European Commission, Directorate General, Joint Research Center.

Natural Step, T. (1997). The natural step.

Nyerges, T. (2002). Visualizations in sustainability modeling: An approach using participatory gis for decision support. Los Angeles: Association of American Geographers.

Nyerges, T. L. (2001, October 1 - 2, 2001). Research needs for participatory geospatial decision support: Linked representations for sustainability

Prescott-Allen, R. (2001). The wellbeing of nations: A country-by-country Index of quality of life and the environment. Washington Island Press.

SDU, S. D. U. (1998). Sustainability counts. In F. o. B. A. Department for Environment (Ed.). United Kingdom.

SRP, S. R. P. (2004). Canada sustainability reports: Institute for Research and Innovation in Sustainability.

Sustainable Measures, J. (2002, 6/25/02). Comparative summary of existing Indicator sets - part 1. Retrieved 9/15/05, 2005, from http://www.sustainablemeasures.com/Projects/ComparativeSummaryPart1.pdf

Sustainable Measures, J. (2002, 6/25/02). Comparative summary of existing Indicator sets - part 2. Retrieved 9/15/05, 2005, from http://www.sustainablemeasures.com/Projects/ComparativeSummaryPart2.pdf

Venetoulis, D. J., Chazan, D., & Gaudet, C. (2004). Ecological footprint of nations: Redefining Progress.

Wackernagel, M., Onisto, L., Linares, A. C., Falfán, I. S. L., Garcia, J. M., Guerrero, A. I. S., et al. (1997, 9/12/2005). Ecological footprints of nations. Retrieved 9/15/05, 2005

More Info? Contact
ray.quay@asu.edu