Development of Spatial Decision Support Systems to Support Long-term, Integrated Planning

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EXTENDED ABSTRACT

Spatial decisions support systems (SDSS) are integrated frameworks designed to help explore weakly-structured or unstructured problems characterised by many actors, many possibilities, and high uncertainty. In principle an SDSS represents an ideal tool to support long-term integrated planning for sustainable development In practice SDSS development requires addressing organisational, scientific, and technological challenges within typical project management constraints, i.e. limited time, limited resources, and to desired specifications.

We discuss these challenges in the context of developing an SDSS for the Choosing Regional Futures project in New Zealand. The project aims to develop new methods and tools to support integrated, long-term planning by 1) developing processes to evaluate, deliberate, and choose futures through scenario analysis and multi-criteria evaluation frameworks and 2) developing an SDSS to support those deliberation processes. Together these tools will help councils evaluate links and trade-offs between economic, environmental and social/cultural outcomes and the cumulative effects of many decisions over space and time and help them achieve long-term outcomes desired by their community.

Organisationally the project is a deliberate attempt on behalf of a key end user (a regional council) and several research organisations to actively co-develop an SDSS to support new council planning processes. Project development required the formation of new organisational networks that did not exist before. Scientifically the SDSS will consist of a spatially-explicit dynamic systems model incorporating different economic, environmental, and social aspects. Technically it will be based on a common software framework to facilitate use and uptake by the key end-user and possible transfer to other organisations in the future.

Three key information sources have informed initial SDSS design: regional community outcomes and associated indicators, qualitative scenarios, and community outcomes from 4 other regions. The draft SDSS is a multi-scale, spatially explicit operating at four scales: New Zealand & Global (climate change, external drivers), regional (hydrology, water quality, economy-environment), district (zoning, demographics, dairying), and local (land use, biodiversity, spatial Indicators). Initial assessments indicate that the draft SDSS will best address economic and environmental themes and outcomes, some aspects of quality of life but will not address most outcomes related to participation and equity or culture and identify.

Initial observations include 1) successful development requires active and on-going organisational commitment, 2) tension exists between design flexibility and prioritisation, 3) a spatially-explicit systems model approach can adequately unite different models, and 4) technical integration offers adaptive potential but generates additional overheads and requires willingness of researchers to relinquish some control.

1. INTRODUCTION

New Zealand, like many countries, has adopted policies to promote sustainable development (DPMC 2003). This includes recognising the links and interactions among cultural, economic, environmental, and social activities and outcomes when making decisions, understanding the trade-offs among those outcomes, identifying the drivers of change at various scales and anticipating the potential effects of actions. Such effects may range from the consequences of single large events (e.g., volcanic eruptions) to the cumulative effects of many small decisions: what the New Zealand Parliamentary Commissioner for the Environment called "death by a thousand cuts." (PCE 2002).

While laudable in principle, sustainable development in practice presents a significant challenge because it involves difficult societal choices about allocating and distributing resources to benefit both current and future generations. In that sense, sustainable development represents a type of unstructured problem. Whereas structured problems are tractable and understandable and often have a single and optimal solution, weakly- or unstructured problems are characterised by high levels of uncertainty, potential conflicts, or both (Figure 1). Ludwig (2001) called them "wicked" problems with no definitive formulation, no stopping rule, and no tests for a solution. Functowicz and Ravetz (1991) called them "post-normal" problems that involve many actors (some or most of whom have not yet been born), with legitimate perspectives and high uncertainty.

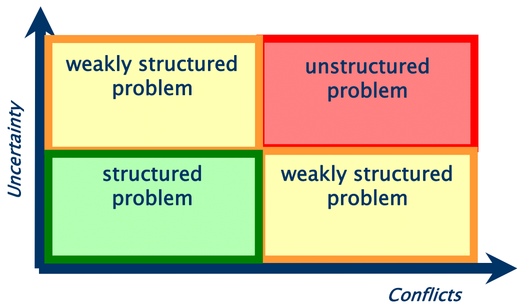

Figure 1: Conceptual categorisation of problems (after van Delden 2000).

Spatial decision support systems (SDSS) help deal with weakly- and unstructured problems by helping users explore alternative scenarios by combining knowledge, data, and models in a flexible and easy-to-use manner (Engelen et al. 1997). A good SDSS will support different decision making styles and adapt over time to the needs of the particular user through interactive and iterative processes. An SDSS has the advantage over a non-spatial DSS by being able to store and manipulate complex spatial data structures, conduct analyses within the domain of spatial analysis, and provide spatially-explicit output (i.e. maps) and other reporting tools. This provides a robust framework for exploring resource management issues by highlighting potential limits to resources use (e.g., only so much land, water, energy, etc.) and the consequences of different allocation schemes.

Effective design, development, delivery and use of an SDSS presents inter-related organisational, scientific, and technical considerations including, but not limited to, how to decide what issues or questions to address (i.e. scope), how general or detailed to make the overall SDSS and/or individual components, what technologies are most appropriate, and who will use the SDSS and how will they use it? Overlayed on those are the typical constraints of time, resources, and performance associated with any finite, resource-limited project (i.e. "reality") (Figure 2).

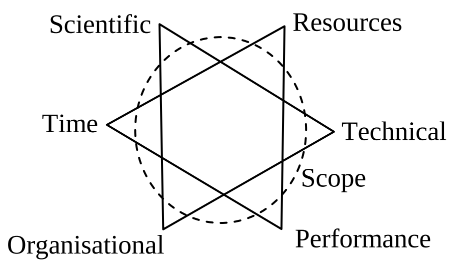

Figure 2: Key considerations and constraints in SDSS development.

Our paper explores these related considerations in the context of developing an SDSS for the Choosing Regional Futures project. Our 4-year project (2006-2010) aims to develop methods and tools to support long-term integrated planning at regional and local government levels within New Zealand. The project has two objectives. The first focuses on developing processes to evaluate and deliberate plausible futures through scenario analysis and multi-criteria evaluation frameworks. The second involves developing an SDSS to support those deliberation processes. SDSS development is occurring in four stages: 1) design, integration, calibration, and validation. This paper focuses on SDSS design. The challenges that we have faced and choices we have made and are making, while particular to our project, may provide broader insights that would benefit similar efforts to develop tools such as an SDSS to promote better long-term, integrated planning and help foster truly sustainable development.

2. POLICY CONTEXT

In New Zealand two pieces of legislation, the Resource Management Act 1991 (RMA) and the Local Government Act 2002 (LGA), establish the basic governance structures for deciding how to manage the allocation and use of New Zealand's natural resources and attempt to operationalise the broader principles of sustainable development.

The RMA sets out the overall framework for planning and managing natural resources within New Zealand (Harris 2004). Its purpose is "to promote the sustainable management of natural and physical resources", where sustainable management means "the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems, and c) avoiding, remedying, or mitigating any adverse effects of activities on the environment." (Section 5). The RMA establishes mechanisms for the governance of natural resource use at several levels. They range from national policy statements intended to provide consistent national guidelines on resource use, through regional policy statements, to regional and district plans, and finally to consents issued for specific projects or activities (Harris 2004).

The RMA is effects-based, meaning that activities are evaluated and regulated on a case-by-case basis based on their overall effect (Harris 2004). It does not prescribe absolute limits on resource use but instead requires evaluating whether intended activities cause significant effects, which can be "positive or adverse; temporary or permanent; in the past, present, or future; singular or cumulative; high probability; or low probability but with high potential impacts" (Section 3).

The LGA created the system of territorial local authorities (TLAs) comprised of 12 larger regional councils, 69 smaller district and city councils, and 4 unitary authorities with combined regional and district powers and authorities. The LGA established the framework under which TLAs decide what activities to undertake, how they will undertake them, and promotes the accountability of TLAs to their communities.

Recent (2002) changes to the LGA broadened TLA responsibilities by providing for them "to play a broad role in promoting the social, economic, environmental, and cultural well-being of their communities, taking a sustainable development approach." (Section 3). TLAs must now prepare a long-term council community plan (LTCCP) that 1) identifies, prioritises and integrates economic, social, cultural and environmental outcomes that the community wants to achieve in the long term, 2) describes councils actions to help achieve those outcomes, 3) must be for at least 10 consecutive years, and 4) provides "integrated decision-making and co-ordination" of council resources (Section 93). Every 3 years councils must report on progress towards achieving community outcomes and inform the community about important issues so that stakeholders and the public can effectively participate in community planning processes and councils can make informed decisions. In essence, the LGA promotes a holistic, integrated method of planning that is essential for sustainable development.

The shift to more integrated, long-term planning required by the LGA presents new and complex challenges to the 85 TLAs. The LTCCP planning process demands more information including the development of integrated datasets, new integrated models and decision support systems to evaluate general or specific (i.e. sectoral) issues, an understanding of knowledge and capabilities (e.g., systems analysis) that many councils lack, and the ability to use the new knowledge, tools, and methods effectively in community consultation processes. The breadth and complexity of the task at hand extends beyond the ability of any single TLA to develop and/or implement.

3. SDSS DESIGN: KEY CONSIDERATIONS

As discussed above, development of an SDSS presents key organisational, scientific, and technical considerations. In this section we outline some of the considerations that have guided SDSS design to date in the Choosing Regional Futures project.

3.1. Organisational Considerations

A fundamental consideration in developing any model such as an SDSS is its intended use. In a pure research context, the goal of generating new knowledge and information usually outweighs questions of application and on-going use. In a more applied context such as the Choosing Regional Futures project, consideration of users, their requirements, and longer-term support and development become essential.

Via the LTCCP process, councils (i.e. TLAs) within New Zealand can play a potentially important role as key enablers of sustainable development. In fulfilling their duties under the RMA and LGA, they uptake new policy and research findings and apply them directly to resource management and community development. They would benefit from better integrated assessment frameworks to help consult with their communities in setting goals, exploring scenarios of the future, evaluating possible consequences of resource management decisions, and monitoring actual versus anticipated progress in truly adaptive management cycle. Therefore the project has targeted councils and the LTCCP process as a logical pathway for developing and trialling an SDSS in support of long-term integrated planning in New Zealand.

A fundamental consideration or perhaps prerequisite was recognition of and importance placed on building new organisational links by both researchers and end-users. The key end-user (Environment Waikato, a regional council) and research organisations came together to share and develop ideas during a 2-year period prior to the start of the project, which included developing the project proposal. The process included a series of sessions where researchers outlined the need for and potential benefits of the methods and tools that the project might deliver and where council staff outlined their processes for policy development and resource management and related needs. This process required patience and understanding by all participants as new relationships developed and trust was gained. It also required organisational support including targeted funding to allow staff the time to co-develop new ideas and relationships.

A key aspect to emerge from this new partnership was the project management structure. The key end user holds the main contract with the funding agency, acts as overall project manager, and contracts the research partners to deliver contracted outputs and achieve contract outcomes. Science leadership remains vested with the research organisations. Several factors influenced the decision to structure the project in this manner. First having the end user as lead agency, rather as simply a member of a governance body, maximises the opportunity for them to participate actively in the research process and fosters their ability to learn and interact with researchers during SDSS design and development. Second it fosters buy-in and ownership of the project and its outcomes with council staff. Third it builds familiarity and knowledge between end-users and researchers. Fourth, having the end-user lead the project may have helped facilitate the formation of the interdisciplinary research team by relieving competitive tensions because no one research organisation was "top dog."

Another reason to use this structure was to leverage existing council LTCCP consultation processes rather than create an entirely new consultation process for the project. Ultimately the decision to structure the project in this manner was intended to increase the chance for a successful outcome, namely that we develop an SDSS that the end user can and wants to use successfully in their LTCCP process.

3.2. Scientific Considerations

Scientifically our aim was to focus on integration of existing knowledge and models, rather than develop entirely new sets of models or components. Given the focus on the LTCCP process, we wanted to design an SDSS that addressed of range of issues chosen in conjunction with our end-user partners, was spatially-explicit, was multi-scale, and explored issues over relatively long time horizons, i.e. 25-50 years as compared to 3-5 year cycles or even the 10-year LTCCP planning required by the LGA.

We decided to adopt a spatially-explicit systems approach that represented aspects of the economy, environment, and society as a set of stocks. The SDSS would track the stocks and flows among those aspects over time and in space. While not wanting to be completely prescriptive, we did seek out research partners capable of addressing key economic, environmental, and social issues. Lastly the Waikato region bounds our system. Anything occurring outside will be exogenous to the SDSS.

3.3. Technological Considerations

Main technical considerations related to aspects of integration, adaptability/transferability, and usability. Project goals and objectives clearly guided the choices that we are making, and SDSS development to meet other goals or objectives would likely follow quite a different path.

While designing the project, we decided to develop a truly integrated SDSS that incorporated all data, models, etc. into one software framework. While not strictly essential, we felt that producing a "packaged" SDSS would more likely facilitate integration rather than hinder it. From a research standpoint standardisation offers the benefits of creating direct links among SDSS components, sharing of a common database, and generation of standardised outputs with the same "look and feel." From an end-users standpoint the "package" concept appears quite appealing, as they get a single, integrated SDSS rather than a more complicated system of interconnected but separate models. This should facilitate the ability of council staff to learn how to operate the SDSS and interpret and use its outputs for integrated long-term planning, although success will likely depend less on the SDSS itself and more on the process that we develop to educate staff in its use.

The drawbacks of the integrated primarily arise from trying to integrate models and components from different scientific disciplines. Different researchers have different philosophical, methodological, and technical approaches to their work and their corresponding models can operate under a variety of frameworks and paradigms and at a variety of spatial and temporal scales. A simpler and likely cheaper (although less elegant solution) would have involved developing interoperability standards and simply passing data and forth among models, perhaps via the web. In the medium- to long-term, such distributed, perhaps web-based systems may become the norm rather than the exception.

Consideration of end-user needs and capabilities significantly affected the choice of the software platform for the SDSS. The research team faced three basic options: 1) design and programme a new SDSS framework from scratch based on a particular software platform (C++, C Sharp, Java), 2) use an existing platform, e.g., a GIS package given the need to process spatial data, or 3) work with an integrator who could build the SDSS within a particular framework. Project constraints (resources, time) precluded Option #1. Option #2 was initially appealing because many research team members possessed the requisite skills to make such a solution feasible. However issues related to organisational and software capabilities made this option less attractive. Environment Waikato has staff with significant skills in the GIS package that we could have used. Conversely other TLAs within New Zealand employ different GIS packages, which would compromise our long-term goal of trying to adapt and transfer the SDSS outside the Waikato region. Lastly from a pure technical standpoint, current GIS packages that we considered do not readily support dynamic spatially-explicit systems modelling at the level of execution and sophistication that we desire.

Ultimately we decided to partner with an integrator (Research Institute for Knowledge Systems) who provides services in SDSS design and development, with a particular emphasis on policy applications. The advantages of partnering with them included 1) the ability to develop a truly integrated, compact, and stand-alone SDSS (i.e. does not depend on GIS software), 2) leveraging their extensive experience in SDSS development over the past 15 years, and 3) having a partner who is philosophically aligned with the other project partners. The main disadvantage or perhaps risk is the reliance on a third party to provide the technological solution, although similar risks exist regardless of the chosen solution, although perhaps not to the same magnitude.

4. SDSS DESIGN TO DATE

In our project a single issue or set of issues or objectives does not drive SDSS design. Instead end-users and researchers are working in an iterative process to identify and explore key issues and questions that the SDSS could address and then prioritise what it will address given the organisational, scientific, technological, and project management constraints. For most involved, this process represents a significant shift from a standard purchaser-provider model to a co-developer model, whereby end-users and researchers work and learn actively together.

Within the Waikato Region, each council has developed a first-generation LTCCP that identifies desired community outcomes. The councils within the region also ran a coordinated community consultation process to develop a shared set of regional community outcomes[1]. In addition each council has a number of other policy and planning documents addressing a range of related issues.

Faced with such overwhelming choice of outcomes and issues, we began the design process by examining three key sources of information to identify important recurring issues and themes. Those sources were: 1) a set of 5 community themes and associated outcomes developed through the coordinated regional process, 2) key drivers and issues identified in 4 qualitative scenarios developed in Objective 1, and 3) community outcomes from 4 other regions in New Zealand (Auckland, Bay of Plenty, Horizons, and Canterbury) for comparative purposes. The Waikato community themes and outcomes and the key drivers/issues from the qualitative scenarios provided information from within the Waikato region. Community outcomes from other regions provided comparative information of the generality or uniqueness of different outcomes or issues to the Waikato versus other regions within New Zealand. The latter is important because we aim to develop an SDSS suitable for application throughout New Zealand.

[1] Available at http://www.choosingfutures.co.nz/

We quickly learned that the high-level themes and outcomes were too broad and difficult to characterise in terms of SDSS design. We instead focused on our ability to directly or indirectly address an associated set of 75 indicators developed to inform the community/themes outcomes. We held a workshop involving researchers and key end-users to develop a draft SDSS system design. In that workshop we identified and discussed which indicators, and by extension themes/outcomes, and which issues we could potentially address and worked collaboratively and organically to produce a first draft of SDSS system specifications.

4.1. Draft SDSS System Specifications

Draft SDSS specifications consisted of an overall systems design that includes integrated components operating at four spatial scales: NZ & the World, the Waikato region, districts, and local i.e. 200m x 200m grid cells.

The New Zealand and the World scale contained climate scenarios and external drivers. The climate scenarios consisted of IPCC climate change scenarios down-scaled for relevant use in New Zealand. External drivers will consist of key factors that may strongly influence New Zealand and/or the Waikato region, such as foreign exchange rates, world commodity prices, or interest rates.

The Waikato regional scale includes 1) a regional dynamic economy-environment model adapted from a model Auckland region based model and consisting of consists of six sub-models: population, labour force, growth, economics, economic physical flow, and environment-economic physical flow (McDonald 2007); 2) a hydrology model that simulates surface and shallow groundwater hydrology to generate hourly time series of river flow and soil moisture (Bandaragoda et al. 2004), and 3) a water quality model that estimates pollution loads, (e.g., total nitrogen) at selected points in a river network as a function of upstream catchment characteristics including land use (Elliott et al. 2005).

The District scale contains 1) zoning information from district councils (i.e. TLAs), 2) a demographic project model for each district within the region that projects population over time, expressed as 1-year male and female age cohorts, and 3) a dairying that will model the effects of dairying intensity aggregated by district based on a combination of physical attributes or suitability, production targets (i.e. kg/milk solids/ha desired), and management practices.

The Local Scale consists of 1) a cellular automata land use model that dynamically models land use change over time based on total demand (area) over time, zoning, biophysical suitability, accessibility, and local influence (Engelen et al. 1997); 2) a biodiversity component that tracks changes in indigenous and exotic land cover over time to provide information on biodiversity status across a range of scales (Rutledge et al. 2004), and 3) a set of spatial indicators generated by different components of the SDSS.

5. INITIAL ASSESSMENT OF SDSS ABILITY TO INFORM POLICY AND PLANNING

5.1. Community Outcomes and Indicators

We undertook a simple evaluation to test the “goodness of fit” of the draft SDSS design to inform key community themes and outcomes. The draft SDSS would provide the most information about sustainable economy and sustainable environment outcomes. It would provide some information on quality of life and very little and no information on culture and identify and participation and equity, respectively (Table 1).

Table 1: Community outcome indicators directly or indirectly informed by the draft SDSS.

Waikato Region Community Theme	Indicators (#) Total	Informed Direct	Indirect	Gap
Sustainable Environment	22	16	5	1
Quality of Life	23	3	6	14
Sustainable Economy	17	9	4	4
Culture and Identity	10	-	3	7
Participation and Equity	4	-	-	4

5.2. Key Drivers from Qualitative Scenarios

Key drivers from the qualitative scenarios included climate change, population, market changes, and globalisation (World); demographic trends, lifestyles, economy, energy, and housing affordability (New Zealand); and land use, Auckland urbanisation pressure, economy, and governance (Waikato region, districts, local). Overall the SDSS would provide good coverage of economic and demographic issues. Some issues are covered by other components, while housing and affordability would be least well addressed.

5.3. Community Outcomes – Other Regions

Assessing the ability of an SDSS to address key drivers or issues from other regions was the most problematic and subjective given the range of issues identified across those regions and the different approaches to identifying and articulating community outcomes. The draft SDSS design addresses several common issues (economy, land use, demographics, water quality, climate change, biodiversity). The Dairying component has less relevance to other regions, but otherwise the SDSS appeared sufficiently basic and robust enough that it could be adapted to other regions within New Zealand without the need for major design modifications. Various model relationships and parameters would definitely require re-estimation or recalibration if transferred to another region.

6. CONCLUSIONS (SO FAR)

While it is too early to say if our project will achieve its goals in the long-term, we can make several observations based on organisational, scientific, and technological choices made to date. First success will require commitment from both end-users and researchers. Fortunately our team members bring a similar philosophy and belief in the importance of the project. Second emphasizing process rather than particular issues offers flexibility but creates challenges for prioritising what to address and to what extent from end-user and research perspectives. Third a spatially-explicit systems modelling approach appears to be a good solution for uniting different models/approaches, although many issues remain to be resolved. Fourth integrating models into a common framework offers advantages in terms of portability but adaptation of components generates additional overheads and requires research partners to relinquish some control of their individual contributions. Despite these challenges, end-user researcher partnerships to design and develop tools like an SDSS should become more common as we all strive to achieve more integrated, long-term planning to support sustainable development.

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