Chapter 23
Building Decision Support Systems for Sustainable Transitions

Dina Margrethe Aspen and Christina Carrozzo Hellevik

Abstract Developing decision support systems for sustainable transitions at the societal level is a complex undertaking due to the high number of stakeholders involved, the urgency of problems that needs to be addressed, and the uncertainty of information linked to decisions. A mismatch between the technological tools offered for decision support and the real needs of practitioners and society at large has been observed. In order to address these challenges, several approaches are explored under the theoretical framework of post-normal science, including co-creative developmental design, soft systems thinking and models for technology integration.

23.1 Introduction

Capacity building for environmental and sustainability management (CapSEM) to achieve sustainable transitions requires generating, structuring, storing, retrieving, communicating, and acting upon information and knowledge. Transitions are achieved through decisions, individual or in series, as instances or processes, made based on relevant information and knowledge, to trigger small or large-scale change from one state to another. Decision support systems (DSSs) help facilitate these transitions by offering actionable information to decision-makers and other stakeholders. DSSs may be defined as interactive computer-based systems that aid decision-makers utilize data and models to solve problems (Sprague Jr, 1980). Since the 1960s, these systems have evolved in scope and complexity to help address tasks at multiple organizational levels across several sectors. As the toolbox for sustainability transitions has grown, so has associated DSSs. While there exist several DSSs to address challenges at the process, product and organisational level, few DSSs currently are currently in use to support broader system change.

D. M. Aspen (✉) · C. C. Hellevik
Department of International Business, NTNU, Ålesund, Norway
e-mail: dina.aspen@ntnu.no; christina.hellevik@ntnu.no

A. M. Fet (ed.), *Business Transitions: A Path to Sustainability*,
https://doi.org/10.1007/978-3-031-22245-0_23

In this chapter, the basic structures and features of DSSs are introduced and explored in the context of the CapSEM framework. The chapter discusses problem complexity as a barrier to developing DSSs for system change and explores pathways for creating DSSs for sustainable transitions at systems level. The case of Planning-Support Systems, i.e. DSSs for urban development and planning, is discussed drawing on experience from development projects in Norway.

23.2 Decision Support Systems for Sustainable Transitions

23.2.1 Structure and Components of Decision Support Systems

Arnott and Pervan (2005) define Decision Support Systems (DSSs) as "… the area of the information systems discipline that is focused on supporting and improving managerial decision-making". The concept emerged during the 1950s and 1960s when organizations started automating business operations such as order processing, billing, and inventory control using computers (Arnott and Pervan, 2005). Early DSS developers aimed to provide an environment where the decision-maker and the information system worked interactively to solve problems. Humans would deal with the complex and unstructured parts of the problem, while the information system would assist by automating the structured elements of the decision context (Arnott and Pervan 2005). Since their advent in the 1950s, DSSs have become prolific in several fields, such as business, agriculture, and clinical decision-making.

While several types of DSSs and problem domain applications exist, they all have in common some basic components. Figure 23.1 shows a generic structure of a DSS (based on Sprague Jr 1980). DSS users initiate computational procedures in the DSS through their queries and commands via the interface. Users may be decision-makers, i.e., the individual or group that faces the problem or decision and needs to act and hold responsibility for the consequences. Users may also involve intermediaries or other actors that have access to the system via their stakeholder role.

The interface offers functionalities tailored to the DSS with parameters the users may specify for the query or command. The interface displays query outputs, which may be unprocessed data or information derived from the model base. In some decision support systems, users may also enter commands (decisions) based on this information to record or activate a change in another system controlled by the DSS.

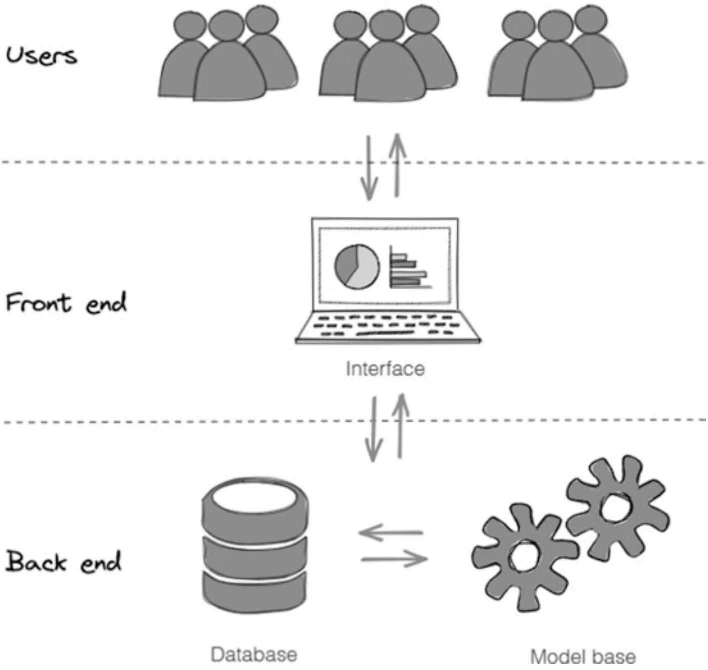

Fig. 23.1 Basic components of decision support systems (DSSs). (Modified from Sprague Jr 1980)

23.2.2 Decision Support Systems for Supporting Transitions to Sustainability

While DSSs have been prolific in nearly all industries and domains, systems dedicated to supporting sustainability have become more popular during the last few decades. Following the four Levels of the CapSEM Model, as shown in Fig. 23.2, DSSs that support decision-makers at each level currently exist.

For Level 1, multiple process optimization systems exist, such as e.g., marine fuel optimization to reduce fuel costs and emissions or maintenance optimization models to determine efficient intervals for machinery maintenance. These may be expert systems that are either integrated with wider enterprise management software or stand-alone applications.

For Level 2, a range of decision support systems also exists, such as e.g., life cycle assessment software to help decision-makers identify environmental hotspots and improvement potential across a product life cycle. SimaPro, GaBi, and OpenLCA are examples of tools that permit life cycle inventory modeling, environmental impact assessment, and sensitivity analyses. These tools may also contain features such as environmental product declaration generators or enterprise reporting functions to link product information to the wider organizational reporting.

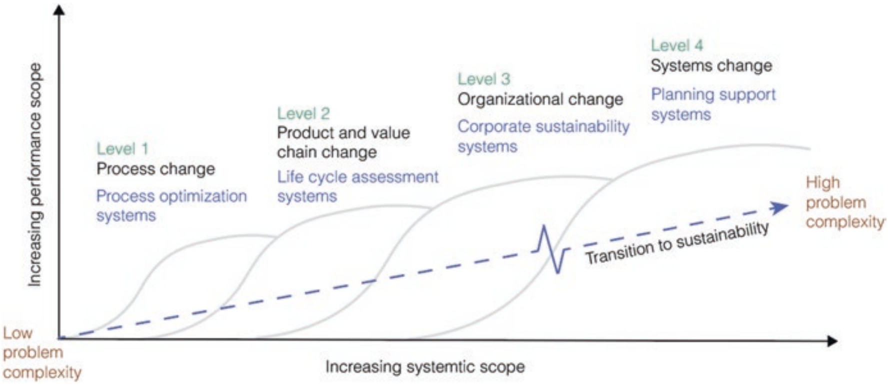

Fig. 23.2 Example of DSSs at various CapSEM levels

For Level 3, there are also numerous corporate sustainability systems for management, reporting, and communication. These range from simple dashboards that keep track of company performance across selected sustainability performance indicators to more advanced systems for managing sustainability performance, such as SoFi.

The types of problems exemplified above, all have a relatively simple, objective answer, which, assuming that the user makes the rational choice according to the priorities of the company, can truly optimize operations. However, moving from the organisational to the systems or societal level (level 4) in the CapSEM framework entails a great increase in complexity from a decision analytical viewpoint (Fig. 23.2). System change requires planning and policy-making at higher organizational levels, involving decision-makers from industry, government, and the wider public sphere.

An example of an attempt to build DSSs for Level 4 may be found in the planning support tools. These DSSs aim to support planning across multiple organizational entities and may be designed for addressing decisions concerning land-use and transportation, tourism, and public health-services, to name a few examples.

Decisions related to system level transitions typically involve a wide range of stakeholders with potentially conflicting values, a strong urgency to address the problem at hand, and high levels of uncertainty in the scientific information necessary to fully appraise alternative courses of action. These elements are synthesized as Post-Normal Science (henceforth PNS) by Funtowicz and Ravetz (1993). In PNS theory, we are reminded that any information and choice of presentation is value-laden, that worthwhile knowledge exists in the community, and that uncertainty should be accepted in decision-making (Ravetz 1999) rather than rejected or hidden.

23.3 Discussion

23.3.1 Developing Decision Support Systems for Systems Change: Challenges

In searching for an explanation as to why few DSSs for societal transition are in use, it is necessary to understand the activities of problem-solving and decision-making. Herbert A. Simon (1960), considered a pioneer in DSS science, distinguished three phases of decision-making processes. In the first phase, *intelligence activity* is performed to search the environment for conditions calling for a decision. In operations research, this refers to problem structuring activities, which entails identifying stakeholders and their problems, goals, and values. This also involves creating an understanding of the external environment and constraints to potential solutions (Belton and Stewart 2002). Simon's second decision-making phase involves *design activity*, where possible courses of action are developed and analyzed. This relates to the model building phase in operations research, where alternatives and values are specified in models (Belton and Stewart 2002). Lastly, the *choice activity* takes place, where a particular course of action among those identified is selected. In operations research, this involves the application of models to discern preferable courses of action. Simon underlined that these steps are sequential and iterative, and that all phases occur within each phase (Simon 1960). Since Simon, authors such as Witte (1972) have challenged the established idea of sequential phases, favouring a model where actions are made in parallel.

While dividing the decision-making process into distinctive phases may support the design of a DSS to drive sustainable transitions, the complexity in both problem structuring (intelligence) and model building (design) activities greatly increases between Level 3 and Level 4, i.e. from the organizational to the systems level. This is partly due to the number of stakeholders potentially involved as well as the variety of system types to address, which may diminish the hopes of achieving agreement on defining a problem and how it may be solved. According to Pidd (2003), decision situations where there is stakeholder agreement on both these dimensions may be considered puzzles – the challenge is merely to select a best course of action. Next, there are problems – decision situations where a unified understanding of the problem and solution is achievable, but requires effort to formulate and select promising solutions. Lastly, there are messes, where there is no consensus on the problem itself, nor the solutions to potentially solve them. This links back to the PNS theory where a high number of stakeholders with conflicting values interact to reach decisions. Moving from lower to higher Levels in the CapSEM Model implies greater problem complexity as there are more degrees of freedom and more stakeholders whose (potentially conflicting) perspectives need to be addressed to define the purpose and scope of the DSS.

Rittel and Webber (1973) famously coined problems of planning and policy-making as "wicked problems". In their seminal article "Dilemmas in a general theory of planning", the abstract succinctly states their viewpoint:

> The search for scientific bases for confronting problems of social policy is bound to fail, because of the nature of these problems. They are "wicked" problems, whereas science has developed to deal with "tame" problems. Policy problems cannot be definitively described. Moreover, in a pluralistic society there is nothing like the undisputable public good; there is no objective definition of equity; policies that respond to social problems cannot be meaningfully correct or false; and it makes no sense to talk about "optimal solutions" to social problems unless severe qualifications are imposed first. Even worse, there are no "solutions" in the sense of definitive and objective answers.

23.4 Pathways to Developing Decision Support Systems for Systems Change

Against this backdrop, it is worth asking whether it is possible to develop useful DSSs for system change or if the logic underpinning DSSs makes its shortcomings too big. While the shortcomings are seemingly clear, some remediation may exist. The following sections aim to explore potential pathways to address this question in the research and practice of DSSs through rethinking the *who*, *how* and *what* of DSS development.

23.4.1 Who: Exploring Co-creative Developmental Design

Several scholars have explored the existing implementation gap of decision support systems at the planning and policy-making level. A key finding from this research is that many systems seem to be developed *for* users, rather than *with* them (Te Brömmelstroet 2010). Another problem is that they are technology-driven as opposed to user-driven and thereby end up representing state-of-the-art without consideration to state-of-the-practice (Te Brömmelstroet 2010; Geertman and Stillwell 2020). This mismatch between research and practice is also observed for DSSs in general (Arnott and Pervan 2008). These challenges call for new methods to engage users and problem-owners in the research and development of DSSs. One way that PNS theory advocates effective problem-solving in these circumstances is by ensuring the quality control of the scientific information and policy recommendations through the extended peer community. Scientific data and models may hide important details of how changes may be felt "on the ground", and valuable insights held in the local community may be lost (Funtowicz and Ravetz 1993). In addition, these types of decisions can have serious consequences on a wide range of stakeholders, beyond the decision makers. DSSs should support decisions on issues that are relevant to practitioners and therefore include their knowledge as well as that of the local community.

Engaging users in the research and development of DSSs may be done in several ways. At the most basic level is the traditional involvement where input from users is added to an existing arrangement. In these types of development projects, a team of researchers/developers facilitate user engagement, e.g., through pre-designed input and feedback activities. Next, there is collaborative research where users and researchers/developers initiate, perform and control projects together. Lastly, there is user-controlled research where users both initiate and control the research and development.

While these forms of engagement are relatively well known from public health research, it is still unclear how they translate to decision science and other disciplines involved in creating DSSs. While basic user feedback is relatively commonplace in a DSS development, involving users more profoundly throughout the entire development process calls for new ways of designing development projects and engagement methods. What are the potential roles of users beyond offering information about their needs and requirements and feedback to subsequent mockups and prototypes? How do these potential new roles change the interaction between researchers/developers and users in DSS development? How to generate ownership and participation in the design phase without creating fatigue among the user group? While some of these stronger user engagement approaches may pose new challenges to developmental design, they may also open up for increased literacy among users in the DSS technology itself and the problem context in which it exists in addition to securing improved relevance once it has been developed.

23.4.2 How: Exploring Soft System Thinking and Methodologies

While known rules and procedures from operations research and "hard sciences" have apparent shortcomings in the face of wicked problems in planning and policymaking at the systems level, soft systems methodologies may offer valuable approaches to address them. Checkland's soft systems methodology (Checkland 1999) has, in fact, been deployed in operations research exercises to expand on conventional problem structuring efforts (see e.g. Belton and Stewart 2002). Checkland argues that while solving problems in hard systems is possible through offering models of the world, soft systems problem solving requires developing models relevant to arguing about the world. Essentially, soft systems models can at most represent a particular view of the world (Checkland 1985). These models, achieved through soft systems methods, may occasionally condense to formulate clear objectives necessary in hard systems thinking. This linkage between soft and hard systems thinking offers a pathway to explore (and potentially expand) models and elements of the messy, wicked soft systems that may be translated to and managed in the structured environment of a DSS.

In PNS, the usual domination of "hard facts" over "soft values" is inverted. Due to the high level of uncertainty, and the high decision stakes, some policies with life-changing consequences for high numbers of people will be decided on very uncertain information. Value commitments and trust will determine the acceptance of these policies rather than scientific certainty. Therefore, as pointed out by Funtowicz and Ravetz (1993), the traditional scientific inputs become "soft" in the context of "hard" decisions.

23.4.3 What: Exploring the Potential Transformative Role of DSSs

Up until this point, there has been little debate about the DSS's role in supporting sustainable transformation at the system level. A critical question is what such a DSS can do, beyond offering new sustainability-related information or knowledge to decision-makers at various system levels. To explore this potential, the SAMR model may be helpful (Puentedura 2013). Robert R. Puentedura developed the model as part of his work in the Maine Learning Technologies initiative (Puentedura 2006). The model was initially developed, and is still primarily deployed, for educators to rethink the role of technology in learning. The model provides a ladder where the role of technology in learning moves from enhancement to transformation. What is intriguing with the model in DSSs is the ability to consider the potential impact on both cognitive and social processes brought about by its use. Table 23.1 shows the basic achievements at each step of the ladder.

While DSSs offer computational capacities far beyond the abilities of the human mind, a system that merely performs calculations to alleviate the cognitive burden to decision-makers will only *substitute* this part of the decision-making process. As an example, a process optimization software that helps tune operational parameters in a physical system (e.g., a ship, building, or production plant) to reduce energy consumption may be said to act in a pure substitutive manner. The role of the decision-maker is to act upon this information without necessarily rethinking the entire design and functioning of the (physical) system of study. The same may be said about a planning support tool that offers more precise and/or comprehensive information about a transportation system. As long as the information is merely

Table 23.1 The SAMR model for technology in learning. (Modified from Puentedura 2013)

Substitution	Technology acts as a direct substitute, with no functional change	Enhancement
Augmentation	Technology acts as a direct substitute, with functional improvement	
Modification	Technology allows for significant task redesign	Transformation
Redefinition	Technology allows for the creation of new tasks, previously inconceivable	

absorbed in existing planning and policy-making processes, the DSS will only substitute existing information and technologies utilized in these processes.

A DSS that *augments* decision-making also provides functional improvement to the decision process. For planning and policy making, this could be exemplified by a DSS that offers the ability to combine information in new ways and present them in a visual-intuitive form to create a better understanding of the (system) problems at hand and its potential solutions. An interactive digital twin-based planning support tool using e.g. augmented reality technology for land-use and transportation planning an example of such a tool. The functional change in this type of DSS is brought about by permitting new ways to interact with and interpret data.

To achieve task *modification* in planning and policy decision-making, the DSS must also enable significant redesign of these decision-making processes. Although this could be done in numerous ways, an example could be an open solution where citizens may enter data and access and interact with the system to offer their feedback, questions, and comments to ongoing processes. A good example of a planning support tool utilized in this manner is the CityPlanner map service piloted in Ulstein municipality in Møre & Romsdal county in Norway. During the public consultation process of the area zoning plan in the municipality in 2018, the 3D mapping tool CityPlanner was deployed to permit citizens to comment on plans for new trekking paths in the local mountains (Ulstein Municipality 2020). The planners also used social media to promote citizen engagement through the tool.

Lastly, a DSS that *redefines* public planning and policy-making helps create new processes previously inconceivable. It could potentially offer new ways for decision-makers and other stakeholders to generate, exchange and negotiate information. Considering contemporary planning and policy-making processes, there is great improvement potential with respect to the transparency and engagement achieved in these processes across the wide range of stakeholders involved. The same could be said for exploring how the DSSs are deployed throughout the problem-solving processes they are designed to support. While DSSs often are designed to predefined (recurring) problems, few tools are designed for more open-ended problem exploration and structuring as part of early planning and policy-making activities.

23.5 Conclusion

Designing and implementing decision support systems for sustainable transformation at the system level is a complex task which requires enabling approaches and tools. In this chapter, three such approaches have been proposed within the framework of Post-Normal Science. First, the *who* of the system needs to be carefully curated. This pertains not only to system users once it is designed, but also who is involved during the design and development of the DSS and what roles they are assigned. Co-creative and participatory forms of research and engagement are critical for establishing systems that tackle the task complexity for system stakeholders, ensures meaningful problem-solving functionality and impactful use. Next, the *how* of system development with system stakeholders needs to be addressed. Soft systems engineering methodologies have been used in multiple domains to engage stakeholders in system development. The domain offers language, procedures and tools to translate between a messy problem context and the structured environment of DSSs. Lastly, the *what* of system development needs to be further explored in the context of transformative change. This concerns the role of the DSS in the decision-making processes they are used and the form and functionality it contains to achieve its role. The SAMR model offers a useful taxonomy to address this question as it distinguishes levels of learning and task performance enabled by ICT tools in problem solving processes. The model was initially developed for instructors to curate and design tasks for learners using ICT tools. In the context of planning support, a DSS is an ICT tool used to aid decision makers in addressing sustainable transformation in a pedagogical manner. The remaining challenge is to understand how to move from enhancement to transformation, which implications this has for the wider decision-making processes the DSS is utilized within, and how this dynamically influences further DSS development and application.

References

Arnott D, Pervan G (2005) A critical analysis of decision support systems research. J Inf Technol 20:67–87

Arnott D, Pervan G (2008) Eight key issues for the decision support systems discipline. Decis Support Syst 44:657–672

Belton V, Stewart TJ (2002) Multiple criteria decision analysis: an integrated approach. Kluwer Academic, Boston

Checkland P (1985) From optimizing to learning: a development of systems thinking for the 1990s. J Oper Res Soc 36:757–767

Checkland P (1999) Systems thinking, systems practice. Wiley, Chichester

Funtowicz SO, Ravetz JR (1993) Science for the post-normal age. Futures 25(7):739–755

Geertman S (2017) PSS: beyond the implementation gap. Transp Res A Policy Pract 104:70–76

Geertman S, Stillwell J (2004) Planning support systems: an inventory of current practice. Comput Environ Urban Syst 28:291–310

Geertman S, Stillwell J (2020) Planning support science: developments and challenges. Environ Plan B Urban Anal City Sci 47:1326–1342

Pidd M (2003) Tools for thinking: modelling in management science. Wiley, Chichester

Puentedura RR (2006) Transformation, technology, and education in the state of Maine. http://www.hippasus.com/rrpweblog/archives/2006_11.html.

Puentedura RR (2013) SAMR: Moving from enhancement to transformation. http://www.hippasus.com/rrpweblog/archives/000095.html.

Ravetz JR (1999) What is post-normal science. Futures 31(7):647–653

Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4:155–169

Simon HA (1960) The new science of management decision. Harper & Row, New York

Sprague RH Jr (1980) A framework for the development of decision support systems. MIS Q 4:1–26

Te Brommelstroet M (2010) Equip the warrior instead of manning the equipment: land use and transport planning support in the Netherlands. J Transp Land Use 3:25–41

Ulstein Municipality (2020) Rapport frå prosjektet Styrka innbyggardialog og lokaldemokrati (Report from the project enhanced citizen dialogue and local democracy)

Vonk G et al (2005) Bottlenecks blocking widespread usage of planning support systems. Environ Plan A Econ Space 37:909–924

Witte E (1972) Field research on complex decision-making processes – the phase theorem. Int Stud Manag Organ 2:156–182