Complexity in Design Management: Layered System Dynamics Graphs

Dr. Terence Love
Edith Cowan University

Citation:
Love, T. (2002). *Complexity in Design Management: Layered System Dynamics Graphs.* ANZSYS'02 'Management Approaches to Complex Systems', Mooloolaba, Qld.

Abstract

This paper describes the application of System Dynamics (SD) in developing strategies to improve design management. The problem has a significant disciplinary breadth, from internal individual functioning to national political agendas. An unusual feature of this use of SD is its focus on meta-theoretically structuring existing theories, which contrasts with traditional SD methods that model the physical phenomena directly. This approach resulted in the development of a modified SD method using layered, interconnected SD graphs.

Keywords: system dynamics, layered graphs, design, management, theory, epistemology

INTRODUCTION

This paper reports Systems Dynamics research undertaken at Edith Cowan University across three research projects aimed at improving design management processes and, through them, designed outcomes. Design management is a complex issue because it encompasses a very wide range of phenomena and processes. These include: individual human creative cognition; communication between stakeholders; designing enterprises, social and economic systems; interactions with business processes; decision making in situations of limited knowledge; cultural considerations; technical issues; and national policymaking (Forrester 1998; DMI 2000; Jevnaker 2000). Systems approaches, and especially System Dynamics, are well suited to addressing situations of this level of complexity (Forrester 1968; Wolstenholme 1990; Forrester 1998). A system dynamics approach was chosen, in part because it offers a combination of qualitative and quantitative modes of analysis, and, in part, because its logical basis aligns with many theories relating to phenomena that impact on design management (Wolstenholme 1990; Hutchinson 1997; Forrester 1998; Senge 2001).

Applying system dynamics to design management proved to be more difficult than expected. The usual approach would be to model the phenomena directly (see, for example, Wolstenholme 1990; Forrester 1998; Belyazid 2002). In the case of design management, however, there are several considerable bodies of existing theory and well-established research findings that relate to different aspects of design activities. The challenge is to bring this knowledge together into a coherent contiguous holistic system model. The approach that was developed in this case was to modify the System Dynamics method to facilitate the integration of these large numbers of theories. This required a refocusing of the SD model to become a means of representing interactions between theories. That is, the new SD focus was on the *theories as phenomena*. This contrasts with the traditional SD approach that focuses *directly on the phenomena* (see, for example, Belyazid 2002) and in which the elements of the SD model are themselves symbols or tokens representing elements of reality. Using System Dynamics in this new role also required moving away from traditional 2D representation, and led to the use of interlinked layers of SD graphs separated using epistemological criteria. This new layered form was discovered to have additional unforeseen benefits. It was also found to align with an approach recently advanced by Barros, Werner and Travassos (2002) that structures SD graphs through discipline domains.

There are five sections to the paper. The next section outlines the problem situation vis a vis design management, and System Dynamics. The third section describes the layered SD model. The fourth section reviews the situation with respect to improving design management. The final section summarises the paper and points to future developments.

PROBLEM SITUATION

Managing design activity and design infrastructure involves managing systems with high levels of complexity (DMI 2000). This complexity is reflected in the high levels of theoretical confusion in the design literature (see, for example, O'Doherty 1964; French 1985; Ullman 1992; Hollins 1994; Reich 1995; Hubka and Eder 1996). To date, individual strategies and heuristics for improving design management have been based on partial information that does not include many of the factors likely to impact strongly on outcomes (Elliott 1999; DMI 2000), and results in efficiency and effectiveness of design management being seriously compromised. This is an important issue because design activity underpins almost all areas of endeavour that directly impact on national and local economic and social development. The four main aspects of the problem that must be addressed are:

- Designing occurs as a result of a complex, highly interdependent and often non-routine creative systemic processes that span from individual activities to national governance. The interconnectedness means effective design management strategies and initiatives must take into account the whole system of influences rather than addressing them piecemeal.
- Existing theories of designing and design management are derived from a variety of different disciplines and methods in ways that are substantially incommensurate.
- Design research has been marked by a lack of epistemological coherency and consistency
- New insights from neuro-physiological research provide significant challenges to many theories that inform design managers about how designing is undertaken in specific circumstances.

Addressing these design management issues is well aligned with systems approaches because, conceptually, the design phenomena divide into discrete, though highly interlinked, sub-system nodes around entities, constituents and processes such as individuals, teams, organisations, stakeholders, information flows, value chains, cultural identities. Major sub-system areas include:

- Individuals' internal routinised cognitions
- Individuals' internal creative cognitions
- The ways individuals interact with designed and natural contexts and artefacts
- The external aspects of the ways individuals interact with other individuals
- The internal processes involved in the ways individuals interact with other individuals
- The ways individuals interact with historical data or 'memories
- The dynamic behaviour of groups

- The dynamic behaviour so organisations as institutions (differentiated by, e.g. scale, structure, aims, objectives, and disciplinary foci)
- The ways individuals interact with national processes such as systems of government and law.
- The ways groups and organisations interact with national-scale processes
- Systemic functioning and makeup of national governance systems
- How individuals, groups, organisations, institutions and government bodies generate and use abstract representations.

Each of the above items represents extensive bodies of existing theory and research. These theories shape design management strategies and decision-making and thus are epistemologically similar to SD *policies* (see, for example, Forrester 1998).

LAYERED SYSTEM DYNAMICS GRAPHS

The problem is to create a system that brings together all this existing knowledge rather than creating a new systemic model of all these phenomena and their relationships from scratch. The systemic approach, therefore, focused on building a *system of theories* that apply to the phenomena rather than on the *phenomena themselves*. This makes sense because epistemologically, there is topological congruity between an integrated system model of theories that individually describe phenomena, and a system representation of the phenomena: in the limit, as theories and systems are decomposed into elemental abstractions.

Some design management theories are intrinsically incommensurate, e.g. those in different subjective, external and theory 'worlds' (Popper 1976) but many do not fit together simply because of the inconsistent ways they have been defined and conceptualised. These theories can be brought into a single coherent theory frame by breaking them into primitive, elemental abstractions and relationships, and then reconstituting the decomposed theories into a single coherent theoretical whole using a holistic systemic framework. This process is similar to computerised voice transcription in which sounds are turned into phoneme elements and remapped into an alternative conceptual modality (words, sentences and punctuation). A meta-theoretical hierarchy for decomposing design theories into basic theoretical elements and relationships has been developed that provides an axiomatically-based technique for decomposing design theories and their relationships (Love 2000; Love 2001; Love 2002). System Dynamics provides the other half of the method by providing the basis for bringing together the decomposed theory elements into an epistemologically coherent whole. Fig 1 shows this process.

Figure 1: Decomposition and systemic recomposition

Incommensurate, inconsistent and incoherent design theories used in Design Management

↓

Apply meta-theoretical decomposition process

↓

Theories decomposed into elementary abstractions and relationships

↓

Apply SD method using elementary abstractions and relationships

↓

SD model of interactions between theories expressed in terms of above elementary abstractions and relationships

A System Dynamic model of a coherent holistic theory structure is a system model of the phenomena themselves because it includes all the theory representations and relationships in a similar topological relationship as would be found in a theory model of the phenomena. Incommensurability between theories, however, is a stumbling block, especially in relation to designing where the subjective, external and theory worlds are often highly intermingled. The problem is to find an appropriate representational graph. The usual 2-dimensional SD representation proved to be problematic for several reasons (similar to those found by Barros et al (2002)):

- A single picture (graph) is simply too big and complicated
- The problems with the lack of epistemological coherence become more significant
- It is not possible to use many of the classical validation checks that can be used on epistemologically consistent 'groups'

These problems led to separating the decomposed theories onto different SD 'layers' either on the basis of epistemological similarities or because they were incommensurate. That is, a layered collection of System Dynamics graphs was used. This echoes the systemic thinking underlying Newell's levels-based designs of architectures for software, intelligence and cognition (Newell 1990). It offers the opportunity of placing incommensurate theory elements on separate layers, but with links between the layers representing correspondences between incommensurate representations. There are also additional benefits in adding a measure of epistemological consistency and coherence to System Dynamics. (In SD there is no requirement that all system elements and their relationships be dimensionally consistent in the same way that, e.g. all terms in an equation representing a physical phenomenon must be consistent. This is a strength offering simplicity, for example, it enables a hand, a tap and water to be put on the same SD graph without abstracting the functions and properties into epistemologically consistent groupings. It is also, however, a handicap because it precludes using all the benefits of validation and abstract manipulation that accrue from epistemological consistency.) Using epistemologically consistent interconnected layers in system dynamics models offers the benefits of epistemological consistency alongside the flexibility and simplicity of use. Using layers also offers benefits in the following areas:

- Object count in individual SD graphs is reduced making the graphs easier to read and interpret in human terms
- Separation of information processes from physical processes. Most physical systems consist of at least two incommensurate subsystems: one comprising the physical resources and flows that result in the physical actualisation of the end behaviour of the system, and the other comprising the information states, flows and transformations that guide the modification of states and flows in the physical system. These, in many systems, are highly interactive but are actualised differently.
- In models of cognition that take into account human affective experiencing, then, systemically, this can be more easily represented through the use of multiple 'layers' because it helps conceptually separate the number of similar phenomena that are part of physically different subsystems. These include for example: emotion processes that are different from the feeling processes giving rise to emotions; the 'perception and feeling' processes that precede emotions; multiple parallel processes by which all of these latter processes interact with imagogenic 'thinking' processes; homeostatic processes underpinning sense of self and consciousness; embedded memories in the individual's bodily viscera, musculo-skeletal and fine touch systems, automated

reactions at imagogenic and conceptual levels embedded in brain systems such as the basal ganglia, and the valuing and closure processes making use of other brain regions such as the amygdala and anterior cingulate cortices (see, for example, Damasio 1994; Sloman 1998; Damasio 1999; Love 2002).

SYSTEMS DYNAMICS MODELS OF PHENOMENA

The above has focused on using System Dynamics to build a layered system of *theory* representations. The development of this approach was based on the topological congruity between an integrated system model of theories that individually describe phenomena, and a system representation of the phenomena. With the theory elements recomposed into a coherent layered structure, the reverse applies. That is, the new System Dynamic graphs notionally *also represent the phenomena*. This is an important point because it implies that these new systems representations of theory structure also map structurally as graphs of the real phenomena (designing and associated activities). The whole process is outlined in Fig .2.

Figure 2: Transformation to a System Dynamic graph of phenomena

Incommensurate, inconsistent and incoherent design theories used in Design Management

↓

Apply meta-theoretical decomposition process

↓

Theories decomposed into elementary abstractions and relationships

↓

Apply SD method using elementary abstractions and relationships

↓

Layered SD model of interactions between theories expressed in terms of above elementary abstractions and relationships

↓

Transform layered SD model of theory into layered SD model of phenomena

↓

Layered SD model of physical phenomena

This process essentially depends on transformation of representations and is crucially dependent on the types of representations and the phenomena being represented: care is needed here to avoid assuming a mechanistic model. In theory (!) there is no loss of information as theories are decomposed and recomposed. In fact, the increased ordering as a result of bringing the decomposed theory elements into a coherent whole would be expected to reduce informatic entropy. The theories that are brought together are not, however, bound to be deterministic or contiguous.

The emergence of a 'system representation of phenomena' from a 'system of theories' points to other core advantages of System Dynamics as the basis for a representation of design management issues. First, the representation of semi-complete elements of the larger design management system model can be developed relatively independently from each other. Second, additional details of these practical SD models can initially be based on qualitative data, i.e. it is possible to map out a structure of relationships and the connections of actions and influences on the basis of empirical data where an accurate knowledge about causal mechanism remains elusive. These qualitative system representations can be later modified to include new quantifiable causal and predictive mechanisms as quantified knolwedge in specific areas becomes available.

Of special systems interest in this sequence of mappings (real system -> theories -> decomposed theory elements and relationships -> layered system dynamic model of decomposed theory elements and relationships -> layered system dynamic model (using decomposed theory elements and relationships) of real system) is whether sub-systems emerge that are similar to existing System Dynamics tools. For example, it would be interesting to see whether in areas of the layered model (e.g those relating to individual creative cognition, or management decision making) there emerged structures that reflect the concept of cognitive map analysis as used to analyse mental models by, for example, Ajami (2002).

DESIGN MANAGEMENT

The focus of this paper has been on application and development of a system method. However, the importance of the underlying practical design management problem should not be ignored because management of design and innovation processes has direct impact on social and economic outcomes at local, enterprise and national levels (see, for example, Freeman 1995, p. 24; Technopolis Innovation Policy Research Associates CENTRIM & SPRU 2002). These occur via:

- The designing of products, systems and services
- The designing of improved business processes
- The designing of government policy initiatives
- The creation of innovation programs
- The designing of knowledge creation initiatives and research programs

The combined complex of business and design activities found in design management situations is notoriously difficult to manage (Leech 1972; Elliott 1999; DMI 2000) because it involves radically different domains such as:

- Processes of individual creative cognition
- Multidisciplinary team and stakeholder interactions
- The parallel development of design and business activities
- The technical, ethical, environmental and social issues relating to the designs themselves
- The provision and management of national, local and business design infrastructures
- Constituent market orientation management
- The interactions between new creative design opportunities and business' vision, corporate image, mission, strategy and value building processes.

Each of the domains impacting on design management and designed outcomes presents its own system problems, and all domains are highly interlinked in ways that influence outcomes. The systems approach presented in this paper offers four improvements to design management. The decomposition of theories offers opportunities for reducing conceptual conflation and confusion, and for building coherent new high-level concepts. Qualitative layered systems dynamics models provide a means for identifying new design management strategies and heuristics based on a 'whole system' perspective. This is something that has not been possible to this time. Finally, the new layered System Dynamic model provides the basis for quantitative analysis of specific design management initiatives.

SUMMARY AND FUTURE DEVELOPMENTS

This paper has outlined a modified application of Systems Dynamics, for improving design management and design infrastructure. Previous sections have outlined the need for such an approach in addressing situations of high theoretical complexity that span a large number of disciplinary realms, theoretical perspectives, and levels of social and technical organisation. The modified layered System Dynamic method addresses the complexity in a way that has four benefits:

1. Theories from different domains and addressing different topoi are located in an epistemologically coherent system theory frame
2. The method draws on and intgrates existing theory and research findings
3. The method helps identify inconsistencies and conceptual weaknesses in existing theories and research findings
4. The method helps identify valuable but previously unnoticed relationships between theories and findings that were either incommensurate or located in disparate and poorly connected disciplines

Unusually, the proposed research approach applies Systems Dynamics to *theories about phenomena* rather than the phenomena themselves. It does this through the use of 'layered' Systems Dynamics graphs. The layers are used to separate epistemologically incommensurate or theoretically distinct, networks of theory and research findings whilst maintaining, through mapping and linking in the overall system dynamic graph, appropriate connections between concepts, theory patterns in the different layers. This goes some way to addressing epistemological issues in System Dynamics relating to conceptual or epistemological inconsistency within a single SD graph or between graphs. The approach presented in this paper leads to a theoretically and conceptually coherent model that brings together for the first time all the core issues relevant to managing design processes at a business level, and managing design activity and design infrastructure at a national level including strategy and policy-making. In addition, the nature of the modelling process helps identify areas of weakness in which further research effort in Design Management is indicated.

To this point, the proposed combination of systems tools have been lightly tested across a small range of relatively idealised scenarios. The ways forward are to apply each of the elements of the proposed methodic to more complex situations and to populate the larger systems model with epistemologically coherent decomposed System Dynamics models of subsystems. These activities will be undertaken as a part of the three research projects being undertaken later in the year at Edith Cowan University. The effectiveness of the approach will be assessed as the research progresses, and will be reported in the Systems literature and through conferences such as ANZSYS'03.

REFERENCES

Ajami, M. (2002). A Comparative Study among Policy and Decision Makers through their Mental Models. The 20th International Conference of The System Dynamics Society July 28 - August 1, 2002 - Grand Hotel Villa Igiea, Palermo, Italy, Palermo, The System Dynamics Society.

Barros, M. d. O., C. M. L. Werner, et al. (2002). Enhancing Meta-models with Scenarios: Plug-&-Simulate Extensions for Model Developers. The 20th International

Conference of The System Dynamics Society July 28 - August 1, 2002 - Grand Hotel Villa Igiea, Palermo, Italy, Palermo, The System Dynamics Society.

Belyazid, S. (2002). Studying a Multi-dimensional Problem using System Dynamics The Case of Sustainability in the Semi-aridArgane Forest in Morocco. The 20th International Conference of The System Dynamics Society July 28 - August 1, 2002 - Grand Hotel Villa Igiea, Palermo, Italy, Palermo, The System Dynamics Society.

Damasio, A. (1994). Descartes' Error: Emotion, Reason and the Human Brain. New York, Grosset.

Damasio, A. (1999). The Feeling of What Happens. London, Random House.

DMI (2000). "Papers on the Nature and Practice of Design Management." DMI Academic Review **1**(1): electronic.

Elliott, L. (1999). Design Management. Australia, Australian Graphic Design Association with Fuji Xerox Australia.

Forrester, J. W. (1968). "Market Growth as Influenced by Capital Investment." Industrial Management Review **9**(2).

Forrester, J. W. (1998). Designing the Future. Seville, Universidad de Sevilla.

Freeman, D. (1995). Competing by Design, National Design Review Steering Committee.

French, M. J. (1985). Conceptual Design for Engineers. London, Design Council.

Hollins, B. (1994). "Conference report: International conference on engineering design (ICED 1993)." Design Studies **15**(2): 227-229.

Hubka, V. and W. E. Eder (1996). Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge. London, Springer-Verlag.

Hutchinson, W. (1997). Systems Thinking and Associated Methodologies. Perth, WA, Praxis Education.

Jevnaker, B. H. (2000). "Championing Design: Perspectives on Design Capabilities." DMI Academic Review **1**(1).

Leech, D. J. (1972). Management of Engineering Design. London, John Wiley & Sons.

Love, T. (2000). "Philosophy of Design: a Meta-theoretical Structure for Design Theory." Design Studies **21**(3): 293-313.

Love, T. (2001). Concepts and Affects in Computational and Cognitive Models of Designing. *Computational and Cognitive Models of Creative Design*. J. S. Gero and M. L. Maher. Sydney, University of Sydney**:** 3-23.

Love, T. (2002). "Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues." International Journal of Design Studies **23**(3): 345-361.

Newell, A. (1990). Unified Theories of Cognition. Cambridge, Mass., Harvard University Press.

O'Doherty, E. F. (1964). Psychological Aspects of the Creative Act. *Conference on design methods*. J. C. Jones and D. G. Thornley. New York, Macmillan**:** 197–204.

Popper, K. (1976). Unended Quest. Illinois, Open Court.

Reich, Y. (1995). "A Critical Review of General Design Theory." Research in Engineering Design **7**: 1-18.

Senge, P. M. (2001). *Illuminating the Blind Spot: Leadership in the Context of Emerging Worlds Comments by Peter M. Senge Feb 15, 2001*, [html document]. Dialog on Leaders. Available: www.dialogonleadership.org/SengeComment.html

Sloman, A. (1998). Damasio, Descartes, Alarms and Meta-management. *Proceedings Symposium on Cognitive Agents: Modeling Human Cognition, IEEE International Conference on Systems, Man, and Cybernetics*. San Diego, Cybernetics.

Technopolis Innovation Policy Research Associates CENTRIM & SPRU. (2002). *Overall Policy Framework and the Development of the Industrial Innovation System* (Vol1), [html document]. Technopolis. Available: www.technopolis.co.uk/reports/201VOL1

Ullman, D. G. (1992). "A Taxonomy for Mechanical Design." Research in Engineering Design **3**: 179-189.

Wolstenholme, E. F. (1990). System Enquiry: A System Dynamics Approach. Chichester, John Wiley & Sons.