Systems Research and Behavioral Science
Syst. Res. **23**, 583–594 (2006)
Published online in Wiley InterScience
(www.interscience.wiley.com) **DOI**: 10.1002/sres.800

■ *Research Paper*

System Dynamics and the Evolution of the Systems Movement

Markus Schwaninger*

University of St. Gallen, Institute of Management, St. Gallen, Switzerland

The purpose of this contribution is to give an overview of the role of System Dynamics (SD) in the context of the evolution of the systems movement. This is necessary because SD is often erroneously taken as the systems approach as such, not as part of it. It is also requisite to show that the processes of the evolution of both SD in particular and the Systems Movement as a whole are intimately linked and intertwined. Finally, in view of the purpose of the paper the actual and potential relationships between SD and the other strands of the systems movement are worked out. This way, complementarities and synergies are identified. Copyright © 2006 John Wiley & Sons, Ltd.

Keywords system dynamics; systems movement; systems approach

INTRODUCTION

The purpose of this contribution is to give an overview of the role of System Dynamics (SD) in the context of the evolution of the systems movement. 'Systems movement'—often referred to briefly as 'systemics'—is a broad term, which takes account of the fact that there is no single systems approach, but a range of different ones. The common denominator of the different systems approaches in our day is that they share a worldview focused on complex dynamic systems, and an interest in describing, explaining and designing or at least influencing them. Therefore most of the systems approaches offer not only a theory but also a way of thinking ('Systems Thinking' or 'Systemic Thinking') and a methodology for dealing with systemic issues or problems.

System Dynamics is a discipline and a methodology for the modelling, simulation and control of complex, dynamic systems.[1] The particular approach of SD lies in representing the issues or systems-in-focus as meshes of closed feedback loops made up of stocks and flows, in continuous time and subject to delays. For this purpose powerful software is available.

The development of the SD methodology, and the worldwide community that applies SD to modelling and simulation in radically different contexts, suggest that it is a 'systems approach' on its own. Nevertheless, taking 'System

* Correspondence to: Markus Schwaninger, University of St. Gallen, Institut für Betriebswirtschaft, Dufourstr. 40a, CH-9000 St. Gallen, Switzerland.
E-mail: markus.schwaninger@unisg.ch

[1] SD was developed by MIT professor Jay W. Forrester [e.g. 1961, 1968] and propagated by his students and associates. SD has grown to a school of numerous members in academia and practical life all over the world.

Dynamics' as the (one and only) synonym for 'systemic thinking' would be going too far, given the other approaches to systemic thinking as well as a variety of systems theories and methodologies, many of which are complementary to SD. In any case, however, the SD community has become the strongest 'school' of the Systems Approach, if one takes the numbers of members in organizations representing the different schools as a measure.[2]

The rationale and structure of this paper is as follows. Starting with the emergence of the Systems Approach, the multiple roots and theoretical streams of systemics are outlined. Then the common grounds and differences among different systems approaches are highlighted. From there, the variety of systems methodologies is explored. Finally, the paper presents an analysis of the distinctive features of SD and an ensuing reflection on the relationships of SD with the rest of the systems movement as well as potential complementarities and synergies.

In the Appendix, a timeline overview of some milestones in the evolution of the Systems Approach in general and SD in particular is given. Elaborating on each of the sources and dates quoted therein would reach beyond the possibilities of this paper.

THE EMERGENCE OF THE SYSTEMS APPROACH

The systems movement has many roots and facets, with some of its concepts going back as far as ancient Greece. What we name as 'the systems approach' today materialized in the first half of the twentieth century. At least two important components should be mentioned, those proposed by von Bertalanffy and by Wiener.

Ludwig von Bertalanffy, an American biologist of Austrian origin, developed the idea that organized wholes of any kind should be describable, and to a certain extent explainable, by means of the same categories, and ultimately by one and the same formal apparatus. His *General Systems Theory* triggered a whole movement, which has tried to identify invariant structures and mechanisms across different kinds of organized wholes (e.g. hierarchy, teleology, purposefulness, differentiation, morphogenesis, stability, ultrastability, emergence and evolution).

Norbert Wiener, an American mathematician at Massachusetts Institute of Technology, building on interdisciplinary work, carried out in cooperation with Bigelow, an IBM engineer, and Rosenblueth, a physiologist, published his seminal book on *Cybernetics*. His work became the transdisciplinary foundation for a new science of capturing, as well as designing, control and communication mechanisms in all kinds of dynamic systems. Cyberneticians have been interested in concepts such as information, communication, complexity, autonomy, interdependence, cooperation and conflict, self-production ('autopoiesis'), self-organization, (self-) control, self-reference and (self-) transformation of complex dynamic systems.

Along the genetic line of the tradition which led to the evolution of General Systems Theory (von Bertalanffy, Boulding, Gerard, Miller, Rapoport) and Cybernetics (Wiener, McCulloch, Ashby, Powers, Pask, Beer), a number of roots can be identified, in particular:

- Mathematics (e.g. Newton, Poincaré, Lyapunov, Lotka, Volterra, Rashevsky);
- Logic (e.g. Epimenides, Leibniz, Boole, Russell and Whitehead, Goedel, Spencer-Brown);
- Biology, including general physiology and neurophysiology (e.g. Hippocrates, Cannon, Rosenblueth, McCulloch, Rosen);
- Engineering, including its physical and mathematical foundations (e.g. Heron, Kepler, Watt, Euler, Fourier, Maxwell, Hertz, Turing, Shannon and Weaver, von Neumann, Walsh) and
- Social and human sciences, including economics (e.g. Hume, Adam Smith, Adam Ferguson, John Stuart Mill, Dewey, Bateson, Merton, Simon, Piaget).

In this last-mentioned strand of the systems movement, one focus of inquiry is on the role of feedback in communication and control in (and

[2]At this stage, the System Dynamics Society has more than 1000 members (1052 by 2005; communication from the System Dynamics Society).

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

between) organizations and society, as well as in technical systems. The other focus of interest is on the multidimensional nature and the multilevel structures of complex systems. Specific theory building, methodological developments and pertinent applications have occurred at the following levels:

- Individual and family levels (e.g. systemic psychotherapy, family therapy, holistic medicine, cognitive therapy, reality therapy);
- Organizational and societal levels (e.g. managerial cybernetics, organizational cybernetics, sociocybernetics, social systems design, social ecology, learning organizations) and
- The level of complex technical systems (systems engineering).

Furthermore, the notion of 'socio-technical systems' has become widely used in the context of the design of organized wholes involving interactions of people and technology (for instance, Linstone's multi-perspectives-framework, known by way of the mnemonic TOP (Technical, Organizational, Personal/individual)).

As can be noted from these preliminaries, different kinds of system theory and methodology have evolved over time. One of these is a theory of dynamic systems by Jay W. Forrester, which serves as a basis for the methodology of SD. In SD, the main emphasis falls on the role of structure and its relationship with the dynamic behaviour of systems, modelled as networks of informationally closed feedback loops between stock and flow variables. Several other mathematical systems theories have been elaborated, for example mathematical general systems theory (Klir, Pestel, Mesarovic and Takahara), as well as a whole stream of theoretical developments which can be subsumed under the terms 'dynamic systems theory' or 'theories of non-linear dynamics' (e.g. catastrophe theory, chaos theory and complexity theory). Under the latter, branches such as the theory of fractals (Mandelbrot), geometry of behaviour (Abraham) and self-organized criticality (Bak) are subsumed. In this context, the term 'sciences of complexity' has also been used. In addition, a number of mathematical theories, which can be called 'system theories', have emerged in different application contexts, examples of which are discernible in such fields as:

- Engineering, namely information and communication theory and technology (e.g. Kalman filters, Walsh functions, hypercube architectures, automata, cellular automata, artificial intelligence, cybernetic machines, neural nets);
- Operations research (e.g. modelling theory and simulation methodologies, Markov chains, genetic algorithms, fuzzy control, orthogonal sets, rough sets);
- Social sciences, economics in particular (e.g. game theory, decision theory) and
- Ecology (e.g. E. and H. Odum's systems ecology).

Examples of essentially non-mathematical system theories can be found in many different areas of study, for example:

- Economics, namely its institutional/evolutionist strand (Veblen, Myrdal, Boulding);
- Sociology (e.g. Parsons' and Luhmann's social system theories, Hall's cultural systems theory);
- Political sciences (e.g. Easton, Deutsch, Wallerstein);
- Anthropology (e.g. Levi Strauss's structuralist-functionalist anthropology, Margaret Mead);
- Semiotics (e.g. general semantics (Korzybski, Hayakawa, Rapoport));
- Psychology and psychotherapy (e.g. systemic intervention (Bateson, Watzlawick, F. Simon), and fractal affect logic (Ciompi));
- Ethics and epistemology (e.g. Vickers, Churchman, von Foerster, van Gigch).

Several system-theoretic contributions have merged the quantitative and the qualitative in new ways. This is the case for example in Rapoport's works in game theory as well as General Systems Theory, Pask's Conversation Theory, von Foerster's Cybernetics of Cybernetics (second-order cybernetics), and Stafford Beer's opus in Managerial Cybernetics. In all four cases, mathematical expression is virtuously connected to ethical, philosophical and epistemological reflection. Further examples are Prigogine's theory of dissipative structures,

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

Mandelbrot's theory of fractals, CAS-Complex Adaptive Systems (Holland *et al*.), Kauffman's complexity theory, and Haken's Synergetics, all of which combine mathematical analysis and a strong component of qualitative interpretation.

A large number of systems methodologies, with the pertinent threads of systems practice, have emanated from these theoretical developments. Many of them are expounded in detail in specialized encyclopedias (e.g. François, 2004 and, under a specific theme, named *Systems Science and Cybernetics*, of the Encyclopedia of Life Support Systems, 2002). In this paper, only some of these will be addressed explicitly, in order to shed light on the role of SD as part of the systems movement.

COMMON GROUNDS AND DIFFERENCES

Even though the spectrum of system theories and methodologies outlined in the preceding section may seem multifarious, all of them have a strong common denominator: They build on the idea of systems as organized wholes. An objectivist working definition of a system is that of a whole, the organization of which is made up by interrelationships. A subjectivist definition is that of a set of interdependent variables in the mind of an observer, or, a mental construct of a whole, an aspect that has been emphasized by the position of constructivism. From the standpoint of operational philosophy, a system is, as Rapoport (1953) says, 'a part of the world, which is sufficiently well defined to be the object of an inquiry or also something, which is characterized by a structure, for example, a production system'.

In recent theory building, the aspect of relationships has been emphasized as the main building block of a system, as is discernible from a recent definition published by ISSS (the International Society for the Systems Sciences): 'A system is a family of relationships between its members acting as a whole' (Shapiro *et al*., 1996). Also, purpose and interaction have played an important part in reflections on systems: Systems are conceived, in the words of Forrester (1968), as 'wholes of elements, which cooperate towards a common goal'. Purposeful behaviour is driven by internal goals, while purposive behaviour rests on a function assigned from the outside. Finally, the aspects of open and closed functioning have been emphasized. Open systems are characterized by the import and export of matter, energy and information. A variant of particular relevance in the case of social systems is the operationally closed system, that is, a system which is self-referential in the sense that its self-production (autopoiesis) is a function of production rules and processes by which order and identity are maintained, and which cannot be modified directly from outside.

At this point, it is worth elaborating on the specific differences between two major threads of the systems movement: The cybernetic thread, from which Managerial Cybernetics has emanated, and the servomechanic thread in which SD is grounded (Richardson, 1991/1999). As Richardson's detailed study shows, the strongest influence on cybernetics came from biologists and physiologists, while the thinking of economists and engineers essentially shaped the servomechanic thread. Consequently, the concepts of the former are more focused on the adaptation and control of complex systems for the purpose of maintaining stability under exogenous disturbances. Servomechanics, on the other hand, and SD in particular, take an endogenous view, being mainly interested in understanding circular causality as the principal source of a system's behaviour. Cybernetics is more connected with communication theory, the general concern of which can be summarized as how to deal with randomly varying input. SD, on the other hand, shows a stronger link with engineering control theory, which is primarily concerned with behaviour generated by the control system itself, and by the role of nonlinearities. Managerial cybernetics and SD both share the concern of contributing to management science, but with different emphases and with instruments that are different but in principle complementary. Finally, the mathematical foundations are generally more evident in the basic literature on SD than in the writings on Managerial Cybernetics, in which the formal apparatus underlying model formulation is confined to a small number of publications

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

(e.g. Beer, 1962/1994, 1981), which are less known than the qualitative treatises.

THE VARIETY OF SYSTEMS METHODOLOGIES

The methodologies that have evolved as part of the systems movement cannot be expounded in detail here. The two methodologies in which they are grounded, however, can be identified—the positivist tradition and the interpretivist tradition.

Positivist tradition denotes those methodological approaches that focus on the generation of 'positive knowledge', that is, a knowledge based on 'positively' ascertained facts.

Interpretivist tradition denotes those methodological approaches that emphasize the importance of subjective interpretations of phenomena. This stream goes back to the Greek art and science of the interpretation and understanding of texts.

Some systems methodologies have been rooted in the positivist tradition, and others in the interpretivist tradition. The differences between the two can be described along a set of polarities, namely:

- an objectivist versus a subjectivist position;
- a conceptual–instrumental versus a communicational/cultural/political rationality;
- an inclination to quantitative versus qualitative modelling and
- a structuralist versus a discursive orientation.

A positivistic methodological position tends toward the objectivistic, conceptual–instrumental, quantitative and structuralist–functionalist in its approach. An interpretive position, on the other hand, tends to emphasize the subjectivist, communicational, cultural, political, ethical and esthetic—that is, the qualitative and discursive aspects. It would be too simplistic to classify a specific methodology in itself as being 'positivistic' or 'interpretative'. Despite the traditions they have grown out of, several methodologies have evolved and been reinterpreted or opened to new aspects (see below).

In the following, a sample of systems methodologies will be characterized and positioned in relation to these two traditions:

- *'Hard' OR methods*: Operations research (OR) uses a wide variety of mathematical and statistical methods and techniques—for example of optimization, queuing, dynamic programming, graph theory, time series analysis—to provide solutions for organizational problems, mainly in the operational domains of production and logistics, and in finance.
- *Living Systems Theory*: In his LST, James Grier Miller (1978), identifies a set of 20 necessary components that can be discerned in living systems of any kind. These structural features are specified on the basis of a huge empirical study and proposed as the 'critical subsystems' that 'make up a living system'. LST has been used as a device for diagnosis and design in the domains of engineering and the social sciences.
- *Viable System Model*: Stafford Beer's VSM specifies a set of management functions and their interrelationships as the sufficient conditions for the viability of any human or social system (cf. Beer, 1981). These are applicable in a recursive mode, for example, to the different levels of an organization. The VSM has been widely applied in the diagnostic mode, but also to support the design of all kinds of social systems. Specific methodologies for these purposes have been developed, for instance for use in consultancy. The term viable system diagnosis (VSD) is also widely used.

The methodologies and models addressed up to this point have by and large been created in the positivistic tradition of science. However, they have not altogether been excluded from fertile contacts with the interpretivist strand of inquiry. In principle, all of them can be considered as instruments for supporting discourses about different interpretations of an organizational reality or alternative futures studied in concrete cases. In our time, most applications of the VSM, for example, are constructivist in nature. To put it in a nutshell, these applications are (usually collective) constructions of a (new) reality, in which interpretation plays a crucial part. In this process, the actors involved make sense of the

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

system under study, that is, the organization at hand, by mapping it on the VSM. At the same time they bring forth 'multiple realities rather than striving for a fit with One Reality' (Harnden, 1989: 299).

- *Interactive Planning*: IP is a methodology, designed by Russell Ackoff (1981), and developed further by Jamshid Gharajedaghi (1999), for the purpose of dealing with 'messes' and enabling actors to design their desired futures, as well as to bring them about. It is grounded in theoretical work on purposeful systems, reverts to the principles of continuous, participative and holistic planning, and centres on the idea of an 'idealized design'.
- *Soft Systems Methodology*: SSM is a heuristic designed by Peter Checkland (1981) for dealing with complex situations. Checkland suggests a process of inquiry constituted by two aspects: A conceptual one, which is logic based, and a sociopolitical one, which is concerned with the cultural feasibility, desirability and implementation of change.
- *Critical Systems Heuristics*: CSH is a methodology, which Werner Ulrich (1996) proposed for the purpose of scientifically informing planning and design in order to lead to an improvement in the human condition. The process aims at uncovering the interests that the system under study serves. The legitimacy and expertise of actors, and particularly the impacts of decisions and behaviours of the system on others—the 'affected'—are elicited by means of a set of boundary questions.

All three of these methodologies (IP, SSM and CSH) are positioned in the interpretive tradition. They were designed to deal with qualitative aspects in the analysis and design of complex systems, emphasizing the communicational, social, political and ethical dimensions of problem solving. Several of them mention explicitly that they do not preclude the use of quantitative techniques.

In an advanced understanding of SD both of these traditions—positivist and interpretivist—are synthesized. The adherents of SD conceive of model building and validation as a semi-formal, relativistic, holistic social process. Validity is understood as usefulness or fitness in relation to the purpose of the model, and validation as an elaborate set of procedures—including logico-structural, heuristic, algorithmic, statistical, and also discursive components—by which the quality of and the confidence in a model are gradually improved (cf. Barlas and Carpenter, 1990; Barlas, 1996).

DISTINCTIVE FEATURES OF SD

Among the distinctive features of SD, in the context of the multiple theories and methodologies of the systems movement, are:

- *Focus on feedback-driven, mainly internally generated dynamics*: The model systems are networks of closed loops of information. However, they are not limited to the representation of 'closed systems', in that (a) flows can originate from outside the system's boundaries, (b) exogenous factors or systems can be incorporated into any model as parameters or special modules and (c) new information can be accommodated via changes to a model. Neither are they deterministic; stochastic variables and relationships have been a standard modelling feature since Forrester's *Industrial Dynamics* (1961) was published.
- *High degree of operationality*: SD relies on formal modelling. This fosters disciplined thinking; assumptions underlying equations and quantifications must be clarified. Feedback loops and delays are visualized and formalized; therewith the causal logic inherent in a model is made more transparent and better discussable than in most other methodologies. Also, the achievable level of realism is higher than, for example, in econometric models.
- *Far-reaching possibilities for the combination of qualitative and quantitative aspects of modelling and simulation*: The focus is not on point-precise prediction, but on the generation of insights into the patterns of behaviour generated by the systems under study.
- *High level of generality and scale robustness*: The representation of dynamical systems in terms of stocks and flows is a generic form, which is

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

adequate for an enormous spectrum of potential applications. This spectrum is both broad as to the potential subjects under study, and deep as to the possible degrees of resolution and detail.

- *Availability of powerful application software*: The packages (Stella/Ithink, Powersim, VENSIM and MyStrategy) are easy to handle and give access to a high variety of mathematical functions. Part of this applications array offers optimization procedures and validation tools. Also, some support for collaborative modelling and the communication with databases is provided.
- *Potential synergies*: Combination with many other tools and methodologies is possible, both conceptually and technically.

Given these strengths, the community of users has recently grown significantly. It has transcended disciplinary boundaries, ranging from the formal and natural sciences to the humanities, and covers multiple uses from theory building to education and to the tackling of real-world problems at any conceivable level. Applications to organizational, societal and ecological issues have seen a particularly strong growth.

System Dynamics also has an outstanding record in classroom applications. Its specific features make it an extraordinarily effective tool for conveying systemic thinking to anybody. The pertinent audiences range from school children at the levels of secondary and primary schools to managers and scientists (cf. Forrester, 1993). In any one of these contexts, closed-loop modelling has been found useful for conveying insights into the functioning of complex systems.

Other methodologies exhibit certain features that traditionally were not incorporated, or at least not explicit, in SD methodology. One aspect concerns the features that explicitly address the subjectivity of purposes and meanings ascribed to systems. In this context, support for problem formulation, model construction and strategy design by individuals on the one hand and groups on the other are relevant issues. Also, techniques for an enhancement of creativity (e.g. the generation and the reframing of options) in both individuals and groups are a matter of concern. Two further aspects relate to methodological arrangements for coping with the specific problematics of negotiation and alignment in pluralist and coercive settings.

One clarification as to the positioning of SD is necessary. SD, much like the VSM, has been positioned by outsiders as inherently positivist and adequate only for unitary contexts (i.e. agreement among decision-makers, cf. Jackson, 1987). However, at least part of SD practice and conceptual work on collaborative modelling—especially Vennix (1996)—has refuted this attribution. Features of the discourse in pluralistic settings, such as dialectical inquiry, as well as methods which address the aspect of subjectivity in individual interpretations (e.g. Nominal Group Technique), are increasingly being incorporated into the model-building process repertoires of seasoned system dynamicists.

ACTUAL AND POTENTIAL RELATIONSHIPS

It should be clear by now that the systems movement has bred a number of theories and methodologies, none of which can be considered all-embracing or complete. All of them have their strengths and weaknesses, and their specific potentials and limitations.

Since Burrell and Morgan (1979) adverted to incommensurability between different paradigms of social theory, several authors have acknowledged or even advocated methodological complementarism. They argue that there is a potential complementarity between different methods, and, one may add, models, even if they come from distinct paradigms. Among these authors are, for example, Jackson (1991); Brocklesby (1993); Mingers (1997); Schwaninger (1997); Yolles (1998); Midgley (2000). These authors have opened up a new perspective in comparison with the non-complementaristic state-of-the-art.

In the past, the different methodologies have led to the formation of their own traditions and 'schools', with boundaries across which not much dialogue has evolved. The methodologies have kept their protagonists busy testing them and developing them further. Also, the differences

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

between language games and epistemological traditions have often suggested incommensurability, and therewith have impaired communication. Prejudices and a lack of knowledge of the respective other side have accentuated this problem: Typically, 'hard' systems scientists are suspicious of 'soft' systems scientists. For example, many members of the OR community, not unlike orthodox quantitatively oriented economists, adhere to the opinion that 'SD is too soft'. On the other hand the protagonists of 'soft' systems approaches, even though many of them have adopted feedback diagrams (causal loop diagrams) for the sake of visualization, are all too often convinced that 'SD is too hard'. Both of these judgments indicate a lack of knowledge, in particular of the SD validation and testing methods available on the one hand and the technical advancements achieved in modelling and simulation on the other (see Barlas and Carpenter, 1990; Sterman, 2000).

In principle, both approaches are complementary. The qualitative view can enrich quantitative models, and it is connected to their philosophical, ethical and esthetical foundations. However, qualitative reasoning tends to be misleading if applied to causal network structures without being complemented by formalization and quantification of relationships and variables. Furthermore, the quantitative simulation fosters insights into qualitative patterns and principles. It is thus a most valuable device for validating and honing the intuition of decision makers, via corroboration and falsification.

Proposals that advocate mutual learning between the different 'schools' have been formulated inside the SD community (e.g. Lane, 1994). The International System Dynamics Conference of 1994 in Stirling, held under the banner of 'Transcending the Boundaries', was dedicated to the dialogue between different streams of the systems movement.

Also, from the 1990s onwards, there were vigorous efforts to deal with methodological challenges, which traditionally had not been an important matter of scientific interest within the SD community. Some of the progress made in these areas is documented in a special edition of *Systems Research and Behavioral Science* (Vol. 21, No. 4, July–August 2004). The main point is that much of the available potential is based on the complementarity, not the mutual exclusiveness, of the different systems approaches.

In future, much can be gained from leveraging these complementarities. Here are two examples of methodological developments in this direction, which appear to be achievable and potentially fertile: The enhancement of qualitative components in 'soft' systems methodologies in the process of knowledge elicitation and model building (cf. Vennix, 1996), and the combination of cybernetics-based organizational design with SD-based modelling and simulation (cf. Schwaninger *et al*., 2004).

From a meta-methodological stance, generalist frameworks have been elaborated which contain blueprints for combining different methodologies where this is indicated. Two examples are:

- *Total Systems Intervention*: TSI is a framework proposed by Flood and Jackson (1991), which furnishes a number of heuristic schemes and principles for the purpose of selecting and combining systems methods/methodologies in a customized way, according to the issue to be tackled. SD is among the recommended 'tools'.
- *Integrative Systems Methodology*: ISM is a heuristic for providing actors in organizations with requisite variety, developed by Schwaninger (1997, 2004). It advocates (a) dealing with both content- and context-related issues during the process and (b) placing a stronger emphasis on the validation of qualitative and quantitative models, as well as strategies, in both dimensions of content and context. For this purpose, the tools of SD (to model content) and Organizational Cybernetics—the VSM (to model context)—are cogently integrated.

These are only two examples. In principle, SD could make an important contribution in the context of most of the methodological frameworks, far beyond the extent to which this has been the case. Systems methodologists and practitioners can potentially benefit enormously from including SD methodology in their repertoires.

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

OUTLOOK

There have recently been calls for an eclectic 'mixing and matching' of methodologies. In the light of the epistemological tendencies of our time towards radical relativism, it is necessary to warn against taking a course in which 'anything goes'. It is most important to emphasize that the desirable methodological progress can only be achieved on the grounds of scientific rigor. This postulate of 'rigor' is not to be confused with an encouragement of 'rigidity'. The necessary methodological principles advocated here are disciplined thinking, a permanent quest for better models (i.e. thorough validation), and the highest achievable levels of transparency in the formalizations as well as of the underlying assumptions and sources used. Scientific rigor, in this context, also implies that combinations of methodologies reach beyond merely eclectic add-ons from different methodologies, so that genuine integration towards better adequacy to the issues at hand is achieved.

The contribution of SD can come in the realms of

- fostering disciplined thinking;
- understanding systemic behaviours and the structures that generate them;
- exploring paths into the future and the concrete implications of decisions and
- assessing strategies as to their robustness and vulnerabilities, in ways precluded by other, more philosophical, and generally 'soft' systems approaches.

These latter streams can contribute to reflecting and tackling the meaning- and value-laden dimensions of complex human, social and ecological systems. Some of their features should and can be combined synergistically with SD, particularly by being incorporated into the repertoires of system dynamicists. From the reverse perspective, incorporating SD as a standard tool will be of great benefit for the broad methodological frameworks. Model formalization and dynamic simulation may even be considered necessary components for the study of the concrete dynamics of complex systems.

Finally, there are also many developments in the 'hard', that is, mathematics-, statistics-, logic- and informatics-based methods and technologies, which are apt to enrich the SD methodology, namely in terms of modelling and decision support. For example, the constantly evolving techniques of time-series analysis, filtering, neural networks and control theory can improve the design of system-dynamics-based systems of (self-)control. Also, a bridge across the divide between the top-down modelling approach of SD and the bottom-up approach of agent-based modelling appears to be feasible. Furthermore, a promising perspective for the design of genuinely 'intelligent organizations' emerges if one combines SD with advanced database-management, cooperative model building software and the qualitative features of the 'soft' systems methodologies.

The approaches of integrating complementary methodologies outlined in this contribution definitely mark a new phase in the history of the Systems Movement.

ACKNOWLEDGEMENTS

The author wishes to thank Prof. Dr. Franz Pichler, Mr. Camilo Olaya, Dr. John Peck and Prof. Dr. Maurice Yolles for their valuable comments on earlier versions of this paper.

REFERENCES

Ackoff RL. 1981. *Creating the Corporate Future*. Wiley: New York.

Ashby WR. 1956. *An Introduction to Cybernetics*. Chapman & Hall: London.

Barlas Y. 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* **12 Fall**(3): 183–210.

Barlas Y, Carpenter S. 1990. Philosophical roots of model validity: two paradigms. *System Dynamics Review* **6 Summer**(2): 148–166.

Beer S. 1959. *Cybernetics and Management*. English Universities Press: London.

Beer S. 1962/ 1994. Towards the cybernetic factory. In *How Many Grapes Went into the Wine. Stafford Beer on the Art and Science of Holistic Management*, Harnden

DOI: 10.1002/sres

R, Leonard A (eds). Wiley: Chichester; 163–225 [reprint, originally published in 1962].
Beer S. 1966. *Decision and Control*. Wiley: Chichester.
Beer S. 1981. *Brain of the Firm* (2nd edn). Wiley: Chichester.
Brocklesby J. 1993. Methodological complementarism or separate paradigm development—examining the options for enhanced operational research. *Australian Journal of Management* **18**(2): 133–157.
Burrell G, Morgan G. 1979. *Sociological Paradigms and Organisational Analysis*. Hants: Gower.
Checkland PB. 1981. *Systems Thinking, Systems Practice*. Wiley: Chichester.
Churchman CW. 1968. *Challenge to Reason*. McGraw-Hill: New York.
Churchman CW. 1968b. *The Systems Approach*. Delacorte Press: New York.
Encyclopedia of Life Support Systems. 2002. (Published under: http://www.eolss.net/).
Flood RL, Jackson MC. 1991. *Creative Problem Solving. Total Systems Intervention*. Wiley: Chichester.
Forrester JW. 1961. *Industrial Dynamics*. MIT Press: Cambridge, MA.
Forrester JW. 1968. *Principles of Systems*. MIT Press: Cambridge, MA.
Forrester JW. 1969. *Urban Dynamics*. MIT Press: Cambridge, MA.
Forrester JW. 1971. *World Dynamics*. Pegasus Communications: Waltham, MA.
Forrester JW. 1993. System dynamics and the lessons of 35 years. In *Systems-Based Approach to Policy Making*, DeGreene KB (ed.). Kluwer Academic Publications: Boston.
François C. 2004. *International Encyclopedia of Systems and Cybernetics* (2nd edn). Saur: München, Germany.
Gharajedaghi J. 1999. *Systems Thinking. Managing Chaos and Complexity*. Butterworth-Heinemann: Boston.
Harnden RJ. 1989. *Technology for Enabling: The Implications for Management Science of a Hermeneutics of Distinction*. The University of Aston: Birmingham.
Jackson MC. 1987. New directions in management science. In *New Directions in Management Science*, Jackson MC, Keys P (eds). Gower: Hants; 133–164.
Jackson MC. 1991. *Systems Methodology for the Management Sciences*. Plenum Press: New York and London.
Klir GJ. 1969. *An Approach to General Systems Theory*. Nostrand: New York.
Lane DC. 1994. With a little help from our friends: how system dynamics and soft OR can learn from each other. *System Dynamics Review* **10 Summer–Fall**(2–3): 101–134.
Lane DC, Oliva R. 1998. The Greater Whole: towards a synthesis of system dynamics and soft system methodology. *European Journal of Operations Research* **107**(1): 214–235.
McCulloch WS. 1965. *Embodiments of Mind*. MIT Press: Cambridge, MA and London.
Meadows DH, Meadows DL, Randers J, Behrens WWIII. 1972. *Limits to Growth*. Universe Books: New York.
Mesarovic MD, Takahara Y. 1985. *Abstract Systems Theory*. Springer: Berlin.
Midgley G. 2000. *Systemic Intervention. Philosophy, Methodology, and Practice*. Kluwer: New York.
Miller JG. 1978. *Living Systems*. McGraw-Hill: New York.
Mingers J. 1997. Multi-paradigm multimethodology. In *Multimethodology*, Mingers J, Gill A (eds). Wiley: Chichester.
Pask G. 1961. *An Approach to Cybernetics*. Hutchinson: London.
Pichler F. 1975. *Mathematische Systemtheorie*. de Gruyter: Berlin and New York.
Rapoport A. 1953. *Operational Philosophy: Integrating Knowledge and Action*. Harper: New York.
Rapoport A. 1986. *General System Theory. Essential Concepts and Applications*. Abacus Press: Turnbridge Wells, Kent and Cambridge, MA.
Richardson GP. 1991/ 1999. *Feedback Thought in Social Science and Systems Theory*. Pegasus Communications: Waltham, MA (originally published in 1991).
Schwaninger M. 1997. Integrative systems methodology: heuristic for requisite variety. *International Transactions in Operational Research* **4**(4): 109–123.
Schwaninger M. 2004. Methodologies in conflict: achieving synergies between system dynamics and organizational cybernetics. *Systems Research and Behavioral Science* **21**(4): 1–21.
Schwaninger M, Pérez Ríos J, Ambroz J. 2004. System Dynamics and Cybernetics: A Necessary Synergy. *Proceedings, International System Dynamics Conference*, Oxford.
Senge PM. 1990. *The Fifth Discipline. The Art and Practice of the Learning Organization*. Doubleday: New York.
Shapiro M, Mandel T, Schwaninger M. 1996. *The Primer Toolbox*, International Society for the Systems Sciences, 1996. http://www.isss.org/primer/toolbox.htm
Simon HA. 1969. *The Sciences of the Artificial*. MIT Press: Cambridge, Massachusetts.
Sterman JD. 2000. *Business Dynamics. Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill: Boston, MA.
Ulrich W. 1983. *Critical Heuristics of Social Planning*. Haupt: Bern and Stuttgart.
Ulrich W. 1996. *A Primer to Critical Systems Heuristics for Action Researchers*. The Centre of Systems Studies, University of Hull: Hull.
Vennix JAM. 1996. *Group Model Building. Facilitating Team Learning Using System Dynamics*. Wiley: Chichester.
Vester F, von Hesler A. 1980. *Sensitivitätsmodell*. Regionale Planungsgemeinschaft Untermain: Frankfurt am Main, Germany.
von Bertalanffy L. 1945. Zu einer allgemeinen Systemlehre. *Blätter für Deutsche Philosophie*, **18**(3/4)

DOI: 10.1002/sres

(Excerpts: in Biologia Generalis **19**(1): 114–129 and in General System Theory, 1968, Chapter III).
von Bertalanffy L. 1950. An outline of general system theory. *The British Journal for the Philosophy of Science* **1**: 139–164.
von Bertalanffy L. 1968. *General System Theory*. Braziller: New York.
Warren K. 2002. *Competitive Strategy Dynamics*. Wiley: Chichester.
Wiener N. 1948. *Cybernetics: Control and Communication in the Animal and in the Machine*. MIT Press: Cambridge, MA.
Wolstenholme E. 2003. Towards the definition and use of a core set of archetypal structures in system dynamics. *System Dynamics Review* **19**(1): 7–26.
Yolles MA. 1998. Cybernetic exploration of methodological complementarism. *Kybernetes* **27**(5): 527–542.

APPENDIX

*Table 1. Milestones in the Evolution of the Systems Approach in General and System Dynamics in Particular**

Foundations of General System Theory		
Von Bertalanffy	Zu einer allgemeinen Systemlehre	1945
	An Outline of General System Theory	1950
	General System Theory	1968
Von Bertalanffy, Boulding, Gerard, Rapoport	Foundation of the Society for General Systems Research	1953
Klir	An Approach to General System Theory	1969
Simon	The Sciences of the Artificial	1969
Pichler	Mathematische Systemtheorie	1975
Miller	Living Systems	1978
Mesarovic and Takahara	Abstract Systems Theory	1985
Rapoport	General System Theory	1986
Foundations of Cybernetics		
Macy Conferences (Josiah Macy, Jr. Foundation)	Cybernetics. Circular Casual, and Feedback Mechanisms in Biological and Social Systems	1946–1951
Wiener	Cybernetics or Control and Communication in the Animal and in the Machine	1948
Ashby	An Introduction to Cybernetics	1956
Pask	An Approach to Cybernetics	1961
Von Foerster, Zopf	Principles of Self-Organization	1962
McCulloch	Embodiments of Mind	1965
Foundations of Organizational Cybernetics		
Beer	Cybernetics and Management	1959
	Towards the Cybernetic Factory	1962
	Decision and Control	1966
	Brain of the Firm	1972
Von Foerster	Cybernetics of Cybernetics	1974
Foundations of System Dynamics		
Forrester	Industrial Dynamics	1961
	Principles of Systems	1968
	Urban Dynamics	1969
	World Dynamics	1971
Meadows *et al.*	Limits to Growth	1972

(Continues)

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres

APPENDIX

(Continued).

Richardson	Feedback Thought in Social Science and Systems Theory	1991
Systems Methodology		
Churchman	Challenge to Reason	1968
	The Systems Approach	1968
Vester and von Hesler	Sensitivitätsmodell	1980
Checkland	Systems Thinking, Systems Practice	1981
Ackoff	Creating the Corporate Future	1981
Ulrich	Critical Heuristics of Social Planning	1983
Flood and Jackson	Total Systems Intervention	1991
Schwaninger	Integrative Systems Methodology	1997
Gharajedaghi	Systems Thinking	1999
Selected Recent Works in System Dynamics		
Senge	The Fifth Discipline	1990
Barlas and Carpenter	Model Validity	1990
Vennix	Group Model Building	1996
Lane and Oliva	Synthesis of System Dynamics and Soft Systems Methodology	1998
Sterman	Business Dynamics	2000
Warren	Competitive Strategy Dynamics	2002
Wolstenholme	Archetypal Structures	2003

*To achieve greater detail, System Dynamics methodology is treated separately.

Syst. Res. **23**, 583–594 (2006)
DOI: 10.1002/sres