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■ *Research Article*

Revisited: The Future of General Systems Research: Update on Obstacles, Potentials, Case Studies

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This paper updates observations made 25 years ago on more than 33 impediments, possibilities, and developments relative to the development of systems awareness. It briefly describes three new 'generations' of systems awareness that were only partly anticipated at that time, but spontaneously appeared since the original article. These three new 'movements' include ''complex systems'' research and tools from the hard sciences, systems science approaches in the descriptive sciences of geology and biology, and the computer simulation or systems engineering approaches of the new 'system of systems' (SOS) movement. Some trends in developments in systems education are cited. The article emphasizes the continuing need for stronger coupling of systems theories and systems applications as well as faster transfer from science to application. It ends with one sentence updates on each of the original 33 needs including information on how 4 have been substantially answered while 14 have shown only very limited progress, and 15 no progress at all. The paper also cites appearance of a significant new obstacle, namely incompatibility of systems modeling tools for hybrid system of systems problems. Overall, the conclusion is that this field devoted to synthesis and integration is actually becoming more fragmented and unintegrated while the information and tools for its eventual synthesis multiply in a healthy manner. Copyright © 2009 John Wiley & Sons, Ltd.

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A quarter of a century has passed. How have the many observations and predictions about the field of systems science expressed in the following paper fared during that time? If 'revisiting' the two cultures of C.P, Snow or MIT's Systems Dynamics-based Limits of Growth models was valuable, then perhaps it is equally valuable to take stock of how prospects in systems studies have changed. Age enables perspective.

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The limits and caveats stated at the beginning of the paper (i.e. special difficulties in predicting transdisciplinary developments, stating needs explicitly, describing obstacles in sufficient detail, identifying key questions, distinguishing leaders and investigators, identifying cross-impacts among obstacles and identifying participating domains & boundaries) are still valid because the overall field of systems science is still in formation. Although the phrase 'systems science' is much more acceptable than before, you are more likely to find 'system' used as an adjective or modifier of a conventional field of study (e.g. systems biology) than 'systems science' recognized as a field of study of its own. There is still a long way to go before we achieve wide acceptance that systems science has its own independent set of questions, hypotheses, methods and results. This may be due to the continuing tendency of humans to focus on the manifestations of real systems rather than the general mechanics common across real systems. Similarly, it is also more likely to see 'systems' used to define a crisis social problem area than to define a particular set of tools used to approach such problems. Phrases that have appeared more recently such as 'complex systems' are actually more acceptable than systems science. By comparison, the phrase 'general theory of systems' (GTS) has declined or nearly disappeared in usage relative to these new phrases even though there are aspects of the old approach and findings in the new, and the new continually provide evidence of the need, perhaps even unconscious yearning for the old, for the still-elusive promise of the unifying theory.

WHAT HAS CHANGED

Unexpected Appearance of Three!!! New 'Generations' of Systems Awareness

Although it is an oversimplification, it is useful in teaching students of systems science to recognize that there are distinguishable 'generations' in awareness of systems. In this formulation, the topic of the paper, general systems, constitutes the 2nd generation, and systems science is a 'generation' not yet born. Given this historical ontology, it is very interesting to note that a 3rd, 4th, and 5th 'generation' of systems awareness have appeared in the last 25 years. Actually, 'generation' may be a poor term to use to characterize these developments. 'Generation' implies descendence and relation whereas these movements sadly remain independent and unitegrated.

Complex Systems Approaches

The development of the field called 'complex systems' constitutes the 3rd generation. At about the time of the initial decline of general systems approaches, the usually reductionist fields of conventional hard sciences such as astronomy, physics, mathematics and the computer sciences discovered the relevance of system-wide approaches. Generally these studies in 'origins', 'chaos', 'scalar and scale-free regularities' and new tools such as agent-based modelling are called studies in 'complex systems'. This very active field continues to thrive and has been more successful at attracting younger workers and serious funding than GTS. A cursory search on the Internet for centres and institutes for complex systems yields from 21 000 to 59 000 hits while one for general systems theory 'institutes and centres' yields none. These institutional innovations are very interdisciplinary and spread across many of the major US, European and Asian universities. Examples include the ARC-COSNet program in Australia (www.complexsystems.net.au) directly funded by the national government, or that Japan has declared what is approximately 'social systems theory' as one of the fields, like biotechnology, set aside for major funding for expected major breakthroughs in the near future. Will other countries not identifying the importance of complex systems theory fall behind? The well-organized, well-funded and 'connected' Sante Fe Institute (founded 1984) has sponsored both established and young investigators in this area of complex systems. SFI has both a comprehensive library of systems works and has issued its own impressive series of working papers. New journals like *Complexity* (Wiley) and *Complex Systems* (founded 1987) have emerged to publish products of the widely dispersed investigators. Workshops and education

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programs in complex systems have appeared nationally. International conferences sponsored by government agencies or new organizations like NECSI (New England Complex Systems Institute, founded 1996) have sponsored serial conferences of initially high rigor involving workers from all of the conventional sciences and many technology fields. It appears that both the research and education programs of complex systems will enjoy a longer lineage than GTS did. It may be interesting to some that the founders of this complex systems generation explicitly and consciously rejected or ignored the earlier attempts of GTS when founding their movement.

Changes in the Relationship of the Natural Sciences to the Systems Sciences

This is the area which may be construed as the 4th generation of systems awareness. The original paper stated, '...while physical and natural scientists who once ignored or vilified the systems movement will begin to actually work with it to improve its utility for them'. This prediction proved to be correct as shown above and here. New specialties have appeared within the most rigorously reductionist fields with names like systems biology, earth systems science (geology), systems neurosciences, systems immunology, synthetic biology and others. Perusal of the most read multidisciplinary science publications (*Science*, *Nature*) reveals regular job announcements in these categories. These fields now have their own journals, numerous sessions in conferences or conferences solely on the new approach, as well as research programs that are well-funded by both private and government agencies. More remarkable still is the willingness of major traditional universities (Berkeley, Caltech, Johns Hopkins, Princeton, Harvard, Claremont Colleges) to invest their own endowments (to the tune of $34M to $100M each and half a billion taken together) to organize new Institutes and Centres in the area of systems biology in just the last 10 years. Lee Hood's independent, interdisciplinary, Institute for Systems Biology, for example, has attracted grants totaling $140M. This is just the beginning of the 4th generation natural systems science movement.

Systems of Systems (SoS) Movement

Ironically, in my schemata, engineering and the military were the domains of the 1st generation of systems awareness between 1890 and 1950 as they built the first man-made networks for communication, propulsion, power and defense. Now, the latest major development of systems awareness, the 5th generation, is a rebirth in these same domains as they recognize that many of the major crisis social problems (in health care, global warming, cancer, pandemics, international economies, education, security, transportation, education, etc.) are fundamentally system of systems (SoS) problems. Solving these problems requires going far beyond the need to understand one system to that of understanding many levels of nested systems, or hybrid systems and their interactions; not just the interaction of parts, but the systems-level interactions of the systems. Recently, I was part of a commission organized by the US National Science Foundation to determine whether or not SoS projects were ready for funding (2007). In 2006 the IEEE Systems, Man and Cybernetics Society launched the first of an annual series of international conferences on system of Systems Engineering. The third was hosted by NIST and sponsored by the Under Secretary of Defense. Some of the US National Laboratories (e.g. Sandia, Los Alamos) have very large-scale SoS-related projects. Given the importance and critical nature of the system of systems problems facing societies across the world, we can expect considerable growth in this movement in the next 25 years.

Changes in Systems Education

With few exceptions, all of the general systems education programs from the 70s and 80s have disappeared. Many new programs have appeared, but with different emphases from the earlier programs. All of the new movements described above have their own systems education

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components and there are additional new foci also. There are new national and international systems-based education programs in 'Regenerative Studies' (7590 google hits) and 'Sustainability Studies' (27 900 hits). Many of these have systems education components. There is great public and student interest in these challenges at present. At my university the Kellogg Foundation funded the construction and maintenance of several buildings for an entire satellite campus on regenerative studies. There are also many business-based programs that emphasize the systems nature of any large enterprise under the title Systems Management. There are now many diverse communities involved in the integration of knowledge typical of systems approaches that are not solely focussed on systems investigation. For example, E.O. Wilson started a related new emphasis in education with his book on *Consilience: The Unity of Knowledge* (1999). Consilience literally means finding, disseminating, and teaching what is common to all fields of study from the natural sciences to the arts (Wilson, 1998). There are a sufficient number of enthusiasts for unifying knowledge in this way that the NY. Academy of Science arranged a national conference and published a volume on this topic alone. Professional societies like the Association for Integrative Studies (AIS) are not focussed solely on systems studies, but do enable communications between multitudes of interdisciplinary programs at a wide range of American colleges. At our Institute for Advanced Systems Studies we were awarded over a million dollars from the California State University, the National Science Foundation, the Keck Foundation and others to develop an Integrated Science General Education (ISGE) program (Troncale, 2002). ISGE is 1-year of undergraduate study using computer-augmented modules via the internet that would satisfy *all* of the science general education requirements for non-science majors at most universities. It synthesizes very detailed coverage of the main facts and theories of astronomy, physics, chemistry, geology and biology as well as a detailed appreciation of mathematics and computer science organized NOT by the usual conventional disciplines, but by systems processes. We think systems processes are the most fundamental way to achieve integration of disciplinary information. In a sense, ISGE is simultaneously a 'stealth' systems science curriculum for every university.

Changes in Systems Applications

The major difference in this domain is captured by one word; Urgency. No longer are systems awareness and study primarily a matter of intellectual curiosity and satisfaction. Understanding how systems work in very practical, detailed and rigorous terms is now a matter of survival of our civilization. Another change in systems application is the slow, steady, but still far too weak use of more detailed systems theories and understanding of systems dynamics and mechanics in their attempts to solve systems-level problems. To workers in systems theory, the systems information contained in very popular business consultants like Peter Senge are actually embarrassingly oversimplified (Senge, 2006). I remember asking Peter Checkland, founder of the soft systems methodology movement for solving societal problems, what was in a particular central box in his diagram of the SSM. It was the underlying theory behind the soft systems interventions. He quipped, 'very little'. It seems that social applications was then, and now still is, too loosely coupled with advances in understanding how systems really work (systems theories). In my opinion it is very dangerous to intervene in major social systems without really knowing what the impact of the intervention will be—remember unintended consequences. We face the same problem as medicine—the need to speed theory to application like they need to speed basic research to the clinic. We need 'translational' systems theory like they need the new field of 'translational medicine'. One potential source of 'translation' from systems theory to practice is the new knowledge appearing of frequently used 'motif's' or 'circuits' of feedback and regulation found in the developmental stages of biosystems and/or in network theory. The millions of years of selection in the natural systems where they are found recommend these motifs and circuits for use in human systems.

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What is needed as we move more strongly to applying systems interventions for the systems of systems problems facing us is our version of the ancient Hippocratic Oath of medicine. 'Above all, do no harm'. I call for a systems version of this oath as we are forced into more and more extensive systems interventions. Already we have witnessed more harm caused by some systems applications than good. It appears that some of the financial market innovations that led to worldwide recession came from complex systems models in economics. This is the reverse of good exemplars.

The five aforementioned developments were unexpected, and unguided. They emerged of themselves and indicate the fecundity of the systems approach and its future.

WHAT HAS NOT CHANGED

Meaning of 'Movements'

While I characterized each of the above as 'movements' in the sense that they are a self-conscious aggregation of investigators intensely interested in similar questions and methods, together they do not constitute a single 'systems movement'. They are not so much a coherent movement as a series of independent discoveries of the need for and relevance of systems understanding in different domains, at different scales, and for different purposes. It is ironic that these self-organizing associations, whose ultimate expressed purpose is one of a unified understanding of systems are themselves relatively separated in terms of their literature, cross-referencing and products. Those who would integrate are themselves not integrated. It is also important for those in each of the movements to recognize that while they are surrounded with critical mass numbers of workers of similar interest and focus, these new specialties are still minorities in their larger, conventional communities. Systems biology, for example, is still regarded with some suspicion and considerable disapproval within the wider, more traditional field of biology as is earth systems science in geology.

Systems Domains

The discriminations between the different domains of systems studies as presented in the original paper (systems analysis & methodology, general theory, systems science, systems applications and systems thinking or philosophy) and the differences between their products (tools/methods, isomorphies, applications) are still viable and important to recognize and disseminate. Many internal critiques derive from workers in these different domains confusing their own priorities and products with the unique priorities and products of other domains. Progress in each domain remains critical to the healthy development of the others. They are interdependent.

REVISITING THE NETWORK OF 33 INTERACTING OBSTACLES

The Appendix in the original paper listed 33 obstacles to further development of systems science and their cross-impacts and these were discussed in detail in the text of the paper. In my opinion, of these, ~4 have been substantially overcome, ~14 have made some limited progress and ~15 have exhibited virtually no change over the past 25 years. In this necessarily concise update on each obstacle, 'Ob#' stands for the number for that obstacle in the original text and Appendix. I have also combined some obstacles, limited the obstacle title to a few words, and, in most cases, the update to one sentence.

Obstacles Overcome

(Ob7) *Transdisciplinary Teams*—both the conventional sciences and the systems sciences are now more often than not characterized by very large teams populated by members from many different disciplines and specialties and funded as such by their sponsors. (Ob 11) *Increase Networking*—the arrival of the Internet, phone conferencing, Skype, email, computer-based conferencing and many other new tools has vastly increased our ability to network and accomplish work

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across space as well as disciplines. (Ob25) *Less Promises and Rhetoric* —this complaint was mostly levelled at general theory population who acted on and often spoke on faith that reductionism was dead and holism ascendant. With the rise of systems approaches in disciplines with strong histories of reluctance to reach consensus, much of this problem has taken care of itself. (Ob 32) *Rework Internal Criticism as Attractive Challenges*—with the appearance of complexity theory, new tools for simulations, the natural systems science specialties and system of systems problem awareness, there is an explosion of exciting new hypotheses to attract both students and experienced professionals of all kinds to the field.

Obstacles Showing Some Progress

(Ob1) *Needed Consensus Glossary*—now there are both published and online attempts to assemble collections of systems vocabulary. Francois published a two-volume encyclopedia of systems-related terms (François, 2004). The *Principia Cybernetica* (http://pespmc1.vub.ac.be/) project includes many definitions and certain groups have their own computerized listing of complexity vocabulary. Professional societies like the American Society for Cybernetics, ISSS and even Wikipedia have systems glossaries. New introductory texts by such experienced practitioners as Klir (Klir, 2001) and Warfield (the founding Editor of the original *Systems Research Journal* (Warfield, 2006) help introduce new workers to the field and its terminology. And there are introductory texts for complexity theory [e.g. Auyung, 1999]. However, none are complete across all its domains and consensus remains a problem. (Ob3) *More Extended Lineages of Work*—The three new generations of systems approach have traditions of not only continuing effort on a project, but lifelong effort in many cases. While the lifework of Prigogine, Odum, Miller, Klir, Forrester, Rosen, Banathy and Ackoff (1971) in general systems may be accurately characterized as extensive and continuous contributions, we may expect a growing list of such exemplars of systems research in the future. (Ob5&27) *Transcend Disciplinary Terms and Recognize Discinyms*—there is still little understanding of the impact of 'discinyms' on miscommunication between systems workers in different domains, but there is a growing recognition across those formerly completely separate domains that they are examining the same basic process, just with different manifestations. Our Institute defines a 'discinym' as a technical word peculiar to a particular discipline that designates the same dynamic or process as a different word peculiar to another discipline. Permit me one personal anecdote illustrating this dilemma. I spoke with a Nobel Laureate who had just delivered a keynote address to a biotechnology conference. He had described several examples in biochemical physiological networks of several different pathways resulting in the same result. He called it a new concept of 'degeneracy', a term borrowed from molecular genetics, recognized only when we experimentally became more aware of network effects in cells. But I pointed out to him that this was the three decade old concept of 'equifinality' first popularized in general systems theory. (Ob6&9) *Evidence for Isomorphy & Need to Increase Rigor*—since the natural sciences are now examining multiple processes at the systems level, extensive, appropriate evidence is accumulating for the isomorphic nature of systems processes. But who is collecting and organizing it for use of the field? The meaning of the evidence is lost for the systems theory aspect if it remains only at the specialty level. (Ob13) *New Institutional Structures Needed*—the many new organizations cited for the three new generations of systems studies indicate an explosion of remedies for this obstacle. (Ob 17) *Recognize Full Set of Isomorphies*—besides providing evidence for the already recognized systems processes, the new generations of systems research have added new isomorphies (such as self-criticality, solitons, fractals, allometry) to the growing list of 100 + included in the System of Systems Processes (SoSP) Model (Troncale, 1978, 2006). Just one example suffices. There has been a literal explosion in knowledge about networks as a key systems structure and process (Barabasi, 2002; Buchanan, 2002; Watts, 2003). Even usually reductionist fields such as molecular genetics

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have invited sessions on Network Theory. Several systems biology conferences have regular sessions on new network results. (Ob18&19) *Better Empirical Refinement and Coupling to Databases*—here again the new interest shown by the natural sciences automatically joins study of isomorphies to databases and the possibility of empirical study. What is missing is a new understanding of what it would mean to use data to prove an isomorphy relative to its conventional use. (Ob21) *Need Better Methods of Integration*—while reductionist experimentation is widely taught, no one teaches how to do synthesis and integration. It happens, but it is not yet systematic. (Ob26) *Better Coupling of Basic and Applied Domains of Systems Science*—as teams get larger, more comprehensive, and are funded by units expecting practical societal results, there is greater coordination between basic and applied, but much more is needed. (Ob31) *Need Exemplars of New Hypotheses & Solutions Provided by Systems Theory*. This obstacle will not be overcome until the systems movement domains are recognized as suggesting their own unique questions, ones that could not even be asked in the conventional disciplines, and then providing methods to answer those questions. (Ob33) *Attract Young Workers and Leaders*—The above-cited new movements are accomplishing this, but again more is needed.

Obstacles Virtually Unchanged

(Ob2&8) *Transcend Internal Conflicts & Counter Fragmentation*—Specialization has both positive and negative consequences. It can increase rigor but it often results in cutting the scope of inquiry into many fragments. In this sense, the above cited new systems approaches have led to more internal competition, miscommunication and fragmentation. (Ob10&12) *Need Performance Criteria for Systems Education & Better Consensus-Building Mechanisms*—It is difficult to set performance criteria for educational programs when a consensus still does not exist in the field being taught. There are considerable amounts of material that are known to be useful and are transmitted in the above cited workshops and conferences but only in the context of their limited domains. (Ob15) *Lack of a Systems' Taxonomy*—the absence of a consensus across all of the fragmented systems movements has inhibited emergence of a consensus taxonomy that puts all the isomorphies, tools and applications in hierarchical relations based on their internal systems logic. (Ob4&14&16) *Need to Formalize Interactions Between Systems Processes, Better Literature Synthesis Methods and Reconfiguring the Isomorphies as Self-Generating*—our institute has concentrated on formulating and testing Linkage Propositions between systems processes suggested by results from the natural science literature to overcome these obstacles. These Linkage Propositions tie the systems processes together in an interacting, but self-generating set that is the basis for the System of Systems Processes (SoSP) Model (Troncole 1978, 2006). But outside of our effort we have not found similar efforts or reaction to our effort. (Ob20) *ID a General Systems Methodology*—All verifiable fields have an algorithm for determining reliable knowledge from false. But efforts at GTS and proving isomorphy still does not have a comparable method. (Ob22&23) *Need for More Tools Based on Isomorphies and Overreliance on Tools*—The famous saying that 'to a man with a hammer, every problem looks like a nail' applies very appropriately to systems studies. The advent of agent-based modelling allows workers to approach certain aspects of systems problems to the exclusion of others. We still need a tool that captures all of the aspects of, especially, hybrid systems. (Ob24) *Making GTS More User-Friendly*—we have suggested several ways to make literature synthesis, the very detailed and complex System of Systems Processes Model, more widely available and usable by practitioners but have not had the manpower to convert the ideas into reality. Similar effort is needed in other systems approaches. An exemplar of success in this arena is Forrester's success in training teachers in many school districts to help their students construct sophisticated Systems Dynamics models, Lee Hood's attempt to bring systems biology to K-12 classrooms, and Odum's computerized tools for systems ecology and economic models using energy (Odum, 1983;

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Odum, 1994; Odum *et al*., 1998; Odum and Odum, 2000). (Ob28) Need for *Rules for Abstraction and Deabstraction*—to demonstrate isomorphy one must move several levels of abstraction from the real systems compared. Beyond the use of pure mathematics, there is still no algorithm for moving in either direction, that is, abstracting from real systems or moving back to the real systems from the isomorphic abstraction in a predictably reliable prescriptive manner. (Ob29) *Couple Systems Professionals and Decision Makers*—this continues to be a critical problem for those hoping to address societal problems. (Ob30) *Performance Criteria for A GTS*—The new emphasis on natural science and engineering systems' generations has both reduced and increased focus on research leading towards a general theory. The more I attend conferences from Systems Biology to Networking to SoS, I sense that the workers in these field eventually begin asking what is common to all of the fields. We may expect to come full circle back to a rediscovered emphasis on the elements of a unified theory.

APPEARANCE OF NEW OBSTACLES AND POTENTIALS

New Obstacle: Incompatibility of Systems Modelling Tools

It was the consensus of the commission convened on behalf of the NSF to assess the state of SoS problem solving (2007) that the central obstacle to solving the many SoS crises from the vantage point of systems modelling reduced to the incompatibility of the several sophisticated simulation tools available. How can you advise what to do when the problems (like pandemics or global warming) have both natural and human components? One tool (e.g. agent based modelling) might give you a better understanding of human decision making while another (interlocking differential equations) the dynamics of the natural system, but how can you get the two simulation tools to work together seamlessly and in a robust manner? As our models become increasingly sophisticated and incorporate more and more variables and components, this obstacle will increase in severity just when we need solutions more than ever.

New Systems Specialties to Watch

Just as the focus on SoS approaches and complex systems invigorated the field, our Institute is dedicating time and effort to developing new specialties we think will do the same. Unborn specialties such as systems pathology, systems allometry, artificial systems research and systems law and legislation have been proposed. By formalizing hundreds of explicit linkage propositions between nearly 100 isomorphic systems processes, we are hoping to test an integrated System of Systems Processes Theory (SoSP) that will serve as an examplar for general systems approaches. We also hope to organize institutional frameworks such as an American Association for Systems Pathology (ASP), a Foundation of Pacific Rim Complex Systems Institutes (fPARCSI) and a 23-campus Institute for Systems-Integrated Sciences (ISIS) to further encourage advances as well as synthesize a more comprehensive general theory of systems. Due to the recent advances it is possible that the next 25 years will actually see the birth of a rigorous science of systems.

Temporary Conclusion

All of the above approaches and domains indicate a dramatically increased recognition of the non-linear aspects of nature and society, and therefore of systems. But there is still insufficient integration of the many different strains of systems theory and systems tools. While the absence of consensus and synthesis is lamentable after 25 years of effort, the absence creates a strong stimulus for young workers entering the field. The unification that would be achieved by their effort would have great practical impact on solving the crisis system of systems problems facing society as well as constitute a major advance in human knowledge.

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