Information systems research with system dynamics

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Abstract

Catering to the growing community of scholars and practitioners who research information systems (IS) with system dynamics (SD), this article sketches IS research with SD as a genuinely transdisciplinary area that studies the design, implementation, management and effects of IS on people, organizations and markets. A preamble to a fascinating collection of five applied-research contributions to this *System Dynamics Review* (*SDR*) special issue, the article charts IS research and places these contributions in their proper context of IS research with SD. The article outlines criteria and themes for future high-quality IS research with SD, emphasizing the value of the SD modeling process for IS research. By integrating IS research with SD, this special issue might serve well as a prototype for future *SDR* special issues, which will further integrate SD with research and practice in other social sciences, and thereby help identify new, exciting opportunities for future research. Copyright © 2008 John Wiley & Sons, Ltd.

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Introduction

Vying to adapt to their fast-changing and most challenging business landscape, organizations increasingly invest in information systems (IS), creating business value in the process (Brynjolfsson and Hitt, 2000). In the face of fast-changing system requirements, organizations strive to design high-quality, agile IS architectures. They implement IS enterprise applications, such as customer relationship management (CRM) or knowledge management (KM) systems, with varying degrees of success and user satisfaction. Some organizations outsource IS development and other IS functions. They integrate their systems with those of customers and partners or the systems of the firms they merge with to create synergies. They develop e-commerce strategies and they introduce new IS-enabled products and services; they struggle initially to comprehend and then respond to the transformational effects of the Internet and IS on their own structures and on markets. To give but one example, look at the recent transformation of the music industry due to e-commerce (Laudon and Laudon, 2007). All these challenges and many more require rigorous IS research.

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IS research studies the development, management and effects of IS on people, organizations and markets, unveiling an exciting vista of themes that focus on the dynamic 'interactions' among IS and individuals, groups, organizations and markets. IS are socio-technical systems involving the interplay of technology components (hardware and software), people (with cognitive capabilities and associated shortcomings), data (to capture real-life situations) and organizational issues (processes and management). Dynamically complex,[1] these *interactions* render SD modeling most suitable for tackling interesting IS situations coherently as they evolve through time.

Applying the system dynamics (SD) modeling method (Forrester, 1958, 1961, 1987, 1992) to vexing IS research questions promises to help IS managers capture system requirements, design and develop high-quality IS, improve the success of IS development projects, increase user satisfaction and add business value (Abdel-Hamid and Madnick, 1989a; Madachy, 2008). It might also explain the dynamic effects of IS in managing complex business systems (Amaral and Uzzi, 2007; Sterman *et al.*, 2007), where the structure of feedback loop relations in a system gives rise to its dynamics (Meadows, 1989; Sterman, 2000, p. 16).

Providing ample evidence of the value of applying SD modeling to IS research questions, this article's introduction to IS research with SD and the fascinating collection of five contributions to this *System Dynamics Review* (*SDR*) special issue show how the dynamics of IS decision situations evolve through time, improving the IS development process and rendering IS-related organizational learning a prime source of sustainable competitive advantage (de Geus, 1992; Georgantzas and Acar, 1995; Morecroft, 1988, 1992, 2007; Senge and Sterman, 1992; Senge *et al.*, 1994; Sterman, 1989).

The cautious integration of IS research with SD might help to further groom a potent, high-quality research community of scholars and practitioners who research IS with SD. Catering to them, this article makes multiple contributions. First, it sketches the IS with SD integration through the dynamic interaction between IS and SD, with SD as the underlying research method. Using SD to model interesting IS situations, IS research with SD becomes a transdisciplinary area that helps design and manage the dynamic performance of complex IS (Sterman, 1994).

Second, the article charts IS research with SD. Hopefully, its crude charting will help the IS research with SD community identify new opportunities for future research. Third, it introduces five exciting contributions to this *SDR* special issue, which let the IS and SD academic and practitioner audiences gain insight into the scope, richness and policy implications of IS research with SD. Fourth, the article outlines criteria and themes for future high-quality IS research with SD, emphasizing the value of the SD modeling process for IS research.

Following the IS research background below, the article shows a high-level map of IS core research areas, subsequently used to formally define IS research

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with SD and group pertinent themes. Next, the IS research with SD map brings the five *SDR* special-issue articles into perspective and creates insight from their valuable contributions. Last but not least, the article offers criteria for high-quality research practices that can help the IS research with SD community grow and prosper.

IS research background

IS research aims at helping decision makers develop high-quality IS that create business value (Abdel-Hamid and Madnick, 1989a) and manage opportunities and risks linked to new technology (Agarwal and Lucas, 2005; Zeleny, 1986). Dhar and Sundararajan (2007) deem teaching and researching IS in business essential, because the capability to analyze and to leverage data as well as decisions about IS technology investment, governance and strategy are crucial to business success.

Charting IS research is challenging because of its great methodological and subject matter diversity. IS are socio-technical systems. Those who study them use a combination of technical, cognitive, organizational, economic and strategic approaches. The researcher's toolkit for IS research includes data and process modeling methods, experimental methods, survey-based research, field studies, statistical analysis, simulation and analytical modeling. The subject matter diversity is even greater than the methodological diversity. For instance, Banker and Kauffman (2004) review the IS research published in *Management Science*, which has had an IS department since 1969. The research streams identified are decision support, value of information and information sharing, human–computer interaction, IS organization and strategy, and IS economics.

Navigating through and making sense of this diversity require a high-level map. Like all maps, it too might be imperfect (Sterman, 2002) but useful. Again, IS research studies the design, implementation, management and effects of IS on people and organizations. Namely, it studies the interactions among IS and individuals, groups, organizations and markets through IS lifecycles. Individuals, groups, organizations and markets *shape* IS through development processes, planning and investment. IS adoption and implementation create the need for subsequent IS management, which affects individuals, groups, organizations and markets. Dynamically complex, these interactions distinguish IS research from other research fields. Figure 1 shows the dynamic interdependencies among these interactions, and thereby helps define IS research as a dynamically complex system.

Drawing primarily from Sidorova *et al.* (2008), Figure 2 shows a high-level map of IS research to put IS research with SD into perspective. Rather than delving into IS theories and methods, the map focuses on the IS research "object" of study and the dominant themes as they evolve through time. While

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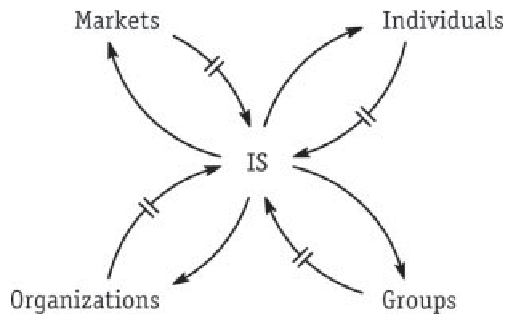

Fig. 1. Dynamically complex interactions in IS research

themes evolve, five IS core research areas persist through time: IS development and, after IS development, the dynamically complex interactions among IS and individuals, groups, organizations and markets (Figure 1).

Table 1 shows these IS core research areas and gives pertinent descriptions, along with select research themes. Sidorova *et al.* (2008) only review articles published in *Information Systems Research*, *MIS Quarterly* and the *Journal of MIS*. Table 1 builds on their themes by sampling from more than 30 major IS journals, which include IS journals of the Association of Computing Machinery (ACM), Association of Information Systems (AIS), IEEE, Elsevier, Wiley and others.

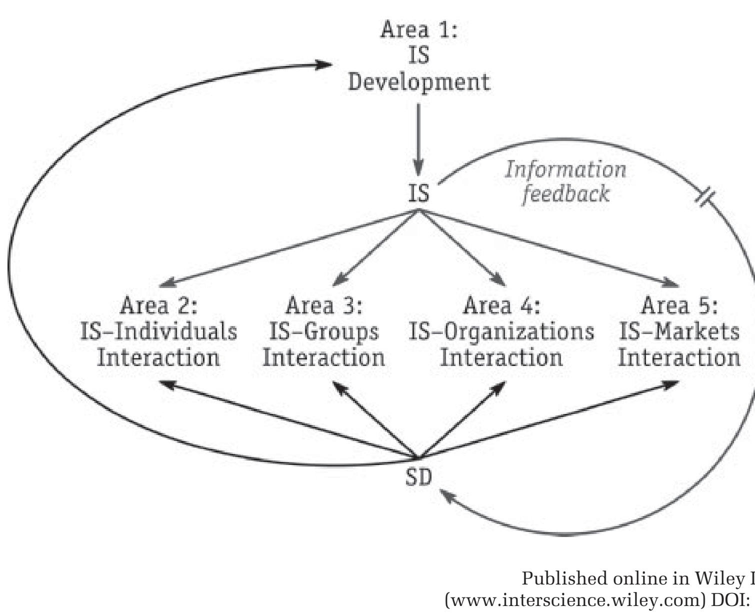

Fig. 2. IS research with SD

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Table 1. IS core research areas and select themes (adapted from Sidorova *et al.*, 2008, and sampling of more than 30 major IS journals)

Core area	Description/questions	Select themes (1991–today)
1: IS development	How IS are developed; systems development methodologies; system requirements engineering; design process and output; modeling techniques and technologies for IS development; management of the development process and project success; developing applications for various domains, e.g., business, education, government, healthcare, bioinformatics	Data management; database design; data mining; requirements elicitation, modeling and validation; data warehouses; data and service integration; information retrieval; knowledge representation; decision support systems (DSS); object-oriented systems; development methodologies; intelligent systems; open source software development; distributed development; agile development; prototyping; software cost and risk estimation; software quality; user involvement in development; IS project management; IS performance analysis and modeling
2: IS–individuals interaction	How individuals adopt and use IT; how computer interfaces affect use by people; how managers make decisions and interact with decision support systems	User technology acceptance, use and satisfaction; individual information technology (IT) adoption; human–computer interaction, interface design, task–IT fit; value of information; trust; web design, online consumer behavior
3: IS–groups interaction	How systems support groups; how systems affect group dynamics, trust, collaboration	Group support systems (GSS), virtual teams, collaboration, trust, online communities, social networks
4: IS–organizations interaction	How organizations invest in, implement, use and manage IS; how IS affects organizational strategy, structure, performance and business processes; what is the best way to organize and structure the IS function; how to model business processes and enterprises	Organizational adoption and diffusion of IT innovation; IS planning and IS strategy; process redesign, IS and organizational change; centralized/decentralized IS structure; IT governance; role of top management; value of IT, productivity paradox, IT investments; IT for competitive advantage; IS human capital, enterprise systems (ERP, CRM, SCM) implementation, knowledge management; business process modeling, enterprise modeling, workflow technology, service-oriented computing
5: IS–markets interaction	How systems affect inter-organizational relationships, supply chain performance and markets; how IT affects industry structure and competition; how electronic markets work and affect consumers and firms; what are the properties of digital goods and technology markets	Electronic data interchange (EDI); information sharing in supply chain; electronic markets and intermediaries; integration technologies; web services; electronic commerce, electronic auctions; real options, pricing, digital goods, technology markets; IT outsourcing relationships; IT effects on competition and industry structure, network externalities and network technologies; IT and firm boundaries, IT impact on financial markets

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Mapping IS research with SD

The identification of the IS core research areas in Table 1 allows defining the IS with SD integration through the dynamic interaction between IS and SD (Sterman, 2000, p. 88), with SD as the underlying research method (Figure 2). Even if information or "outcome feedback is patchy and tricky to interpret" (Morecroft, 2007, p. 379), as it seeks to apply SD to dynamically interesting IS situations, IS research with SD becomes a sub-area of both IS and SD. Also, as a research community, IS with SD becomes a sub-community of both the IS and the SD research communities. Thus IS research with SD becomes a genuinely transdisciplinary program that integrates IS and SD.

While SD research tackles the *patchy and tricky to interpret* information feedback link from IS to SD via algorithms for model partition and automatic parameter calibration (Oliva, 2004; Oliva and Mojtahedzadeh, 2004), the juxtaposition of Table 1 and Figure 2 shows that IS research with SD neither adds any new core area to IS research nor does it add any new IS research theme. But as the arrow links in Figure 2 show, IS research with SD creates the opportunity to use the SD modeling method to add unique dynamic insight to *all* five IS research areas. In Figure 2, each link that emanates from SD shows a challenging opportunity for IS research with SD.

Based on multiple research databases, Table 2 samples articles on IS research with SD, along with their major themes. Showing ample evidence that the application of SD to IS problems has already been fruitful, the sample research articles and themes in Table 2 emphasize IS research with SD published in more than 30 major IS journals, *SDR* and other IS-related journals. Only a few conference proceedings articles show on this list, but Table 2 does include articles presented in the annual International Conference of the System Dynamics Society.

Contributions to the *SDR* special issue

Using the SD modeling method, the five research articles of this *SDR* special issue provide a special collection of excellent contributions (Table 3). The *SDR* special issue sets the foundations for the growth of IS research with SD community, through cross-fertilization between the IS and SD research communities. Many of the contributing authors work in IS departments, while others are SD researchers. Their contributions span all five IS core research areas in Figure 2 and Table 3, and thereby provide rich insights across the whole spectrum of IS research, exemplifying the value of IS research with SD.

Luna-Reyes, Black, Creswell and Pardo develop a model of collaborative requirements analysis in IS development. Requirements analysis, an early phase of the systems development lifecycle (SDLC), is one of the most crucial phases for the success of a systems development project. Drawing on empirical

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Table 2. Charting IS research with SD sample articles and themes

Core area	Sample articles and themes
1. IS development	Focus on IS development *process* • Seminal work on systems development process modeling (Abdel-Hamid, 1988, 1989a, 1989b, 1990; Abdel-Hamid and Madnick, 1989a, 1989b) • Software development process (Lin and Levary, 1989; Barros *et al*., 2002; Chatters *et al*., 2000; Choi *et al*., 2006; Häberlein, 2004; Lee and Miller, 2004; Lehman and Ramil, 1999; Madachy and Tarbet, 2000; Martin and Raffo, 2000; Roehling *et al*., 2000; Ruiz *et al*., 2004; Wernick and Hall, 2002; Luna-Reyes *et al*., 2005; Madachy, 2008; Otto and Belardo, 2002) • Software project management (Rodrigues and Williams, 1997) • Software development cost estimation (Boehm *et al*., 2000) • Open source software development modeling (Katsamakas and Georgantzas, 2007) Focus on IS development *output* • Enterprise data modeling (Wang and Yi-Ming, 1998) • Requirements engineering (Williams, 2001; Loucopoulos and Prekas, 2003) • UML (Unified Modeling Language) and SD (Tignor, 2003) • Unifying SD and business objects in DSS development (Gregoriades and Karakostas, 2004) • Developing IT standards for the system dynamics community (Diker and Allen, 2005)
2. IS–individuals interaction	• DSS evaluation (Marquez and Blanchar, 2006) • IS use and productivity (Kanungo, 2003) • Internet growth and telecommunications (Dutta, 2001b; Dutta and Roy, 2003, 2004b) • Management support systems (Clark *et al*., 2007; Clark and Jones, 2008) • Strategic decision making, mental models and ERP (Ritchie-Dunham, 2001)
3. IS–groups interaction	• Groupware-facilitated learning in consulting (Rich, 1998) • Groupware use (Bordetsky and Mark, 2000) • Maintaining mutual knowledge in geographically dispersed virtual teams (Cramton, 2001) • Open online collaboration (Diker, 2003)
4. IS–organizations interaction	• ERP implementation critical success factors (Akkermans and van Helden, 2002) • IS investment appraisal (Kennedy, 2001, 2002) • Business planning for network services (Dutta, 2001a) • Diffusion of data warehouse (Quaddus and Intrapairot, 2001) • Healthcare delivery and services (Tan *et al*., 2005) • Information security (Xu and Lee, 2003; Torres and Sarriegui, 2004; Sveen *et al*., 2007; Melara *et al*., 2003) • IS and knowledge processes in networks (Katsamakas, 2007) • IS outsourcing decision process (McCray and Clark, 1999) • IT project justification in e-business environments (Dutta and Roy, 2004a) • Knowledge management (Garud and Kumaraswamy, 2005) • Value of information in a business firm (Clark and Augustine, 1992) • Business performance impact of poor IS integration (Georgantzas and Katsamakas, 2008)
5. IS–markets interaction	• Application service provisioning (Currie *et al*., 2007) • Commercialization process in IT industries (Pardue *et al*., 1999) • Disruptive innovation in IT markets (Georgantzas and Katsamakas, 2007) • E-commerce strategies in small–medium firms (Bianchi and Bivona, 2002) • Information privacy policies in health insurance markets (Thatcher and Clemons, 2000) • IS, information sharing and value chain (Croson and Donohue, 2005; Agarwal *et al*., 2006; Janamanchi and Burns, 2007) • Limits to growth in electronic commerce (Oliva *et al*., 2003) • Offshore outsourcing growth (Dutta and Roy, 2005) • Peer-to-peer networks and e-commerce (Pavlov and Saeed, 2004)

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Table 3. The *SDR* special issue contributions to IS research with SD and select themes

Core area	SDR special issue contributors	Themes
1. IS development	Luna-Reyes, Black, Creswell and Pardo	Collaborative requirements analysis, trust, knowledge sharing, development process, project success
2. IS–individuals interaction	Kanungo and Jain	IS use, effect on user productivity, transition to new IS, Technology Acceptance Model (TAM)
3. IS–groups interaction	Otto and Simon	Online community networks, growth and sustainability
4. IS–organizations interaction	Dutta and Roy	Security, investment in IT, IT value, technical vs. organizational issues
5. IS–markets interaction	Pavlov, Plice and Melville	Commercial email, spam, information overload, impact of email filtering on commercial email, electronic marketing

work at the Center of Technology in Government (University at Albany), they show the roles that trust, knowledge sharing and facilitative artifacts play in the requirements analysis process as different organizations collaborate in a development project.

Kanungo and Jain's article is motivated by a university's transition to a new email system. This case illustrates a challenge that many organizations often face: transition to a new and improved IS does not always lead to higher individual user productivity. To understand this problem, Kanungo and Jain propose a dynamic process-oriented approach to IS use. Modeling the relations among variables that affect email use and productivity metrics, they show which individual email use practices and organization policies can significantly affect user email productivity.

Motivated by the emergence of Internet-based online communities, Otto and Simon study the case of *Wikipedia*, an online user-created encyclopedia. They develop a model of online community growth and sustainability. Grounded on the social theory behind a grid/group typology, they provide insight into policies that can help online communities succeed.

Information security is a major challenge for most organizations. Hackers, viruses and other types of malicious code and digital attacks continuously threaten valuable digital assets. Dutta and Roy show how technical and behavioral factors interact dynamically to determine the state of information security in organizations. Their model helps managers look at information security from a business value perspective, and it provides a framework for information security investments.

The Internet has enabled several new information markets for digital goods and information services. One of these markets is commercial email, which

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intends to market products or services to Internet users, but also leads to unwanted email (spam), thereby causing an information overload. Pavlov, Plice and Melville model a message-based commercial communication system with bounded attention by users. They evaluate technical and economic-based policies to improve the social value of these systems, showing that poorly designed policies can have detrimental counterintuitive effects.

Future IS research with SD

Integrating SD with other social sciences is challenging, and it might be even more challenging with IS, which studies dynamically complex socio-technical systems. Yet, to Lane and Husemann (2008, p. 56), SD's "formal approach to feedback analysis seems well suited for engaging with empirical data and rigorously testing hypotheses [to] contribute to all of the social sciences". Indeed, SD can help appreciate and model the *real* complexity of IS, involving the interplay through time of technological components, people with bounded cognitive capacity, and organizational components. To appreciate the methodological value one need only contrast SD with other mainstream business modeling methods, which often overlook much of that real complexity, either by ignoring disequilibrium dynamics or by assuming hyper-rational people (Sterman *et al.*, 2007).

One quality criterion for IS research with SD, which might make the research widely accepted within both the IS and the SD communities, entails publishing IS research with SD in a large number of major IS journals. In order to meet this most challenging criterion, Repenning (2003) offers useful lessons to IS with SD researchers as he reflects on having his SD-based research on new product development (NPD) accepted by the greater NPD research community. IS research with SD must:

(a) be grounded in the terminology and literature of the IS community;
(b) avoid unnecessarily complicated models; and
(c) present the work in a way that emphasizes the contribution and intuition on the link between a model's causal structure and its dynamic behavior.

Hopefully, the IS research sampled in this article (Tables 1 and 2), along with the five *SDR* special issue articles (Table 3), will enable the SD community to become more familiar with IS research, per Repenning's first important lesson.

Depending on the use of solid IS research with SD criteria, Repenning's advice can help manifest the two reinforcing feedback loops in Figure 3, so that wide academic and practitioner audiences accept published high-quality research. The appeal of published high-quality IS research with SD to both academics and practitioners might in turn help the IS research with SD community grow, thereby leading to more published high-quality research.

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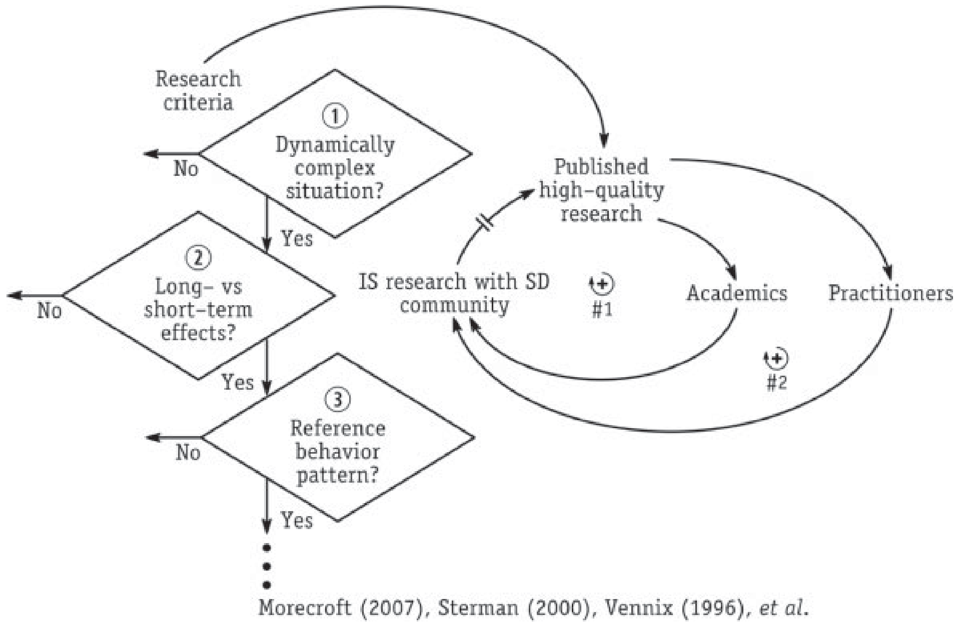

Fig. 3. Criteria and growth potential of high-quality IS research with SD

Regarding the use of solid IS research with SD criteria in Figure 3, following Morecroft (2007), IS with SD researchers might strive to replace the notion of modeling an objectively singular IS world *out there* with the much softer approach of building formal IS with SD models to improve IS managers' and users' mental models about the past, the present and the future (Ingvar, 1985). Similarly, immediately preceding his chapter on the SD modeling process (Sterman, 2000, Ch. 3), Sterman (2000, pp. 79–81) outlines 12 modeling principles that might feed the reinforcing IS research with SD feedback loops in Figure 3. Also, Vennix (1996, Ch. 4) insists on explicit SD group model-building criteria that might help design successful IS with SD research projects.

To facilitate the choices that must be made in the design of SD research projects, Vennix prefers to translate these criteria into pertinent questions. The decision diamonds in Figure 3 show a small but critical sample of three such questions. If the answer to all three questions in Figure 3 is "yes", then a potentially useful IS research with SD model might be in the making. But if just one of the answers is a "no", then you might as well abandon all hope for fame and glory in IS research with SD. Years of SD modeling practice shows that, unless a client or research team can produce a dynamic reference behavior pattern, there might not be any IS research with SD model worth writing about.

A multitude of research opportunities emerge when one takes a dynamic view across the whole range of IS research areas and applications. First, the special issue articles articulate future research directions pertaining to

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collaborative requirements analysis, IS acceptance and use, online communities, information security and Internet marketing. Second, the map of IS research consisting of five areas and numerous themes drawn from major IS journals provides a rich resource for the industrious SD researcher who would like to find research topics. Managing dynamic complexity in the development, management and impact of IS on people, organizations and markets is the underlying motivation.

Although space and time limitations as well as the introductory nature of this article preclude providing an exhaustive list of future research topics, a few interesting and important directions follow.

1. Among IS challenges that organizations face, many entail designing flexible information infrastructures, adopting agile IS development methods and developing flexible IS integration capabilities. It is imperative in all these challenges to attain flexibility and responsiveness to fast-paced business needs (Sambamurthy *et al.*, 2003). IS flexibility is a dynamically complex issue, and therefore ideal for SD modeling.
2. Modeling the dynamics of strategic resources can add to IS research on IS strategy and IS value (Ritchie-Dunham, 2000). Here, SD can help design effective IS planning systems and strategies. The dynamically complex constructs behind the strategic effects of IS on markets transformed by technological change might include disruptive innovation initiatives (Georgantzas and Katsamakas, 2007) and technology platforms (Economides and Katsamakas, 2006; Bakos and Katsamakas, 2008). This stream of research can complement and build on the strategy dynamics stream of research in the SD community (Warren, 2005).
3. Expand the use of SD into requirements engineering, enterprise and business process modeling and associated IS design issues (Kavakli and Loucopoulos, 1999; Loucopoulos, 2001; Bleistein *et al.*, 2006). Understanding the methodological affinities between SD modeling and traditional IS design methods, both involving abstract models of reality, might improve the IS design process (Williams, 2001; Madachy, 2008) and output (Loucopoulos and Prekas, 2003; Tignor, 2003).
4. Understand the implementation process and effects of large-scale enterprise applications such as CRM, value chain management (VCM), business intelligence (BI) and enterprise resource planning (ERP) systems (Akkermans and van Helden, 2002).

Concluding remarks

Charting the scope and core research areas of IS with SD, this article, along with the five contributions to this *SDR* special issue, build a foundation for a fruitful research agenda that might help the IS research with SD community

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grow and prosper. Developing successful IS and understanding the dynamic complexity of IS-enabled business systems are crucial challenges of our times. With accelerating change becoming the greatest constant (Kurzweil, 2005; Sterman, 1994), IS research with SD has a lot to offer in identifying and addressing dynamically complex issues and challenges in IS. The potential benefits that the SD modeling method might bring to IS research may include new insights into system development and implementation, flexible infrastructures and IS integration. SD promises to become a *new technology* for IS management and strategy.

Indeed, complexity theory and the exponential increase in computational power and its accessibility make simulation an indispensable managerial tool and a powerful theory development method: "fresh theoretical insights are possible from the precision that simulation enforces and the experimentation that simulation enables" (Davis *et al.*, 2007, p. 483). Simulation modeling with system dynamics permits IS researchers and practitioners to examine the aggregate, dynamic and emergent implications of the multiple, nonlinear, generative mechanisms embedded in the processes, capabilities and resources of every modern organization (Oliva and Sterman, 2001; Repenning and Sterman, 2002).

We sincerely hope that, by integrating SD with IS research, this *SDR* special issue might serve as a prototype for future *SDR* special issues. Assuredly, such focused issues will further integrate SD with research and practice in other social sciences.

Note

1. People often confuse the term "complex" with "complicated". But *complexity* must not be confused with the *simple-complicated* dimension (Lissack and Roos, 1999). Etymology shows that *complicated* uses the Latin ending *-plic*: *to fold*, but *complex* contains the Greek root *πλέξ-* "*plēx-*": *to weave*. A complicated structure is thereby folded, with hidden facets stuffed into a small space. But a complex structure has interwoven parts with interdependencies that cause dynamic complexity. Remember: complex is the opposite of simplex (or untwined) and complicated is the opposite of simple.

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