Table of Contents
Go Back

Exploring rationality with system dynamics based simulators: A literature review

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Extended Abstract

Simulators, interactive learning environments and microworlds have attracted attention for various reasons, both within and outside the field of system dynamics.[2] For more than 15 years many studies have either used simulators as research tools to explore human and organizational characteristics, or have presented simulators as instruments for teaching. For both purposes, simulators promise to be valid means to achieve the goals intended as exemplified by the following two quotes considering the potential value of simulators:

> "… simulation-based learning is usually expected to motivate, to invite active and deep processing of subject matter, to allow for systematic exploration, for fruitful failure, and for unlimited practice, all of which should contribute to better learning outcomes, reduced learning time, or both." (Goodyear et al. 1991, 274)

> "[With simulators we will] be able to do fieldwork in the laboratory, albeit under conditions where the characteristics of the field are known in detail. Thus, we will have escaped the narrow straits of the laboratory, as well as the deep blue sea of the field study, without losing too much of the advantages of either approach." (Brehmer/Dörner 1993, 183)

Simulators are computer-based simulation games of real-world scenarios. Regularly, simulators of social systems like, for instance, organizations are operating with a reduced level of detail compared to reality. Users of simulators take on the role of decision-makers within the systems. In many cases

they posses practically unlimited power to decide on available decision variables, similar to a manager-owner of a firm.

Together, (1) a pre-configured formal simulation model, (2) a human-computer interaction component and (3) gaming functionality build the three basic aspects of a simulator (Maier and Größler 2000). The formal model, which underlies the simulator, determines how user decisions are processed and what outcome they produce. The human-computer interaction component is responsible for presenting the current state of the model and allowing the user to input decisions. The gaming functionality lays down, for example, for what time interval decisions have to be made, whether and how different agents compete in the simulation, or the contextual story in which the simulation game is embedded. Simulators can be used for a variety of different purposes: research, teaching and training, entertainment, personnel selection, motivation, etc. In the context of this paper we concentrate on the first area of application. It is investigated, to which extent simulator based studies allow the examination of the kind and the degree of human rationality.

From the further discussion in this paper we exclude the following tools as not being a simulator:

1. modeling environments (e.g. Vensim, Powersim or Stella/iThink) because they focus on the users building models on their own, experimenting with them and changing them, not on pre-configured models;
2. board games (e.g. the "beer game", Senge 1990) because they are not computerized and, therefore, miss a lot of the features and peculiarities of simulators;
3. stand-alone simulation models (e.g. the "market growth model", Forrester 1968) because they usually do not comprise an elaborated user-computer interaction component or gaming functionality;

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1. We will use the term „simulator" throughout this paper. Our arguments apply to simulators of

4. role playing games because they do not use a formal model to calculate outcomes of decisions;
5. group model building interventions (Richardson and Andersen, 1995; Vennix 1996) because they concentrate on the creation of a model (not using an existing one) and draw their power mainly from the interaction between humans.

The objectives of this paper are twofold. First, we want to demonstrate the state of simulators as well-accepted instruments in the system dynamics area. Despite of some open questions concerning their validity they are used in a variety of ways to explore human and organizational decision-making. Second, we aim at summarizing empirical findings derived from a literature analysis. This endeavor is connected to providing starting-points for identifying a number of remaining issues of simulator usage in research.

Our review was deliberately constrained to literature from within the system dynamics literature. With this restriction we do not deny the extensive and elaborated work that has been done in other fields, for example, in psychology or in the teaching sciences. However, constraints on breadth and focus of the papers to be included seemed unavoidable in order to achieve interpretable results from the review. Literature reviews stemming from other branches of science can, for example, be found in Wolfe (1985), Kleinmuntz (1987), Funke (1991), Brehmer (1992), Funke (1995), Buchner (1995).

Besides that, the concentration on system dynamics based literature has two reasons:

1. We want to contribute to the ongoing discussion between system dynamicists whether simulation experiments without modeling can yield substantial gains for the user (Forrester 1961, Machuca 1992, Davidsen 1996).

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social, not merely technical systems.

2. System dynamics appears to be an appropriate and effective tool to create the underlying formal model of simulators (Größler 2001).

Thus, we used two major sources of references: the proceedings of the annual international system dynamics conferences from 1985 to 2002 and the back issues of the *System Dynamics Review* (Volumes 1 to 18). In addition, we included relevant papers from Morecroft and Sterman (1994) and two special issues of *Simulation and Gaming* (Symposium Issue: System Dynamics and Interactive Learning Environments, Vol. 31, Nos. 2 and 3, 2000). We did not include "isolated" other papers published in this or another journal or in another book. In total, our database contains more than 200 entries from these sources. The complete database will be accessible at the World Wide Web at the time of the workshop.

In the system dynamics field two literature reviews on simulators exist. Both, the work of Sterman (1994) and Hsiao and Richardson (1999) provided valuable sources of inspiration. Our work, however, differs from their studies regarding scope of the review (as measured by number of literature sources taken into account) and focus of investigation: on the one hand, this paper has a narrower perspective because it only considers literature from a system dynamics context; on the other hand, it is broader because it not only examines papers where simulators were used as instruments to conduct research in decision-making but also evaluation studies, general discussions on simulator design and mere presentations of simulators. Thus, we split the total sample of papers into four main categories according to their primary focus:

(A) Presentation of simulator only;

(B) Evaluation studies that explore the effectiveness of a simulator (effects beyond the simulator context on e.g. transfer of learning to daily work);

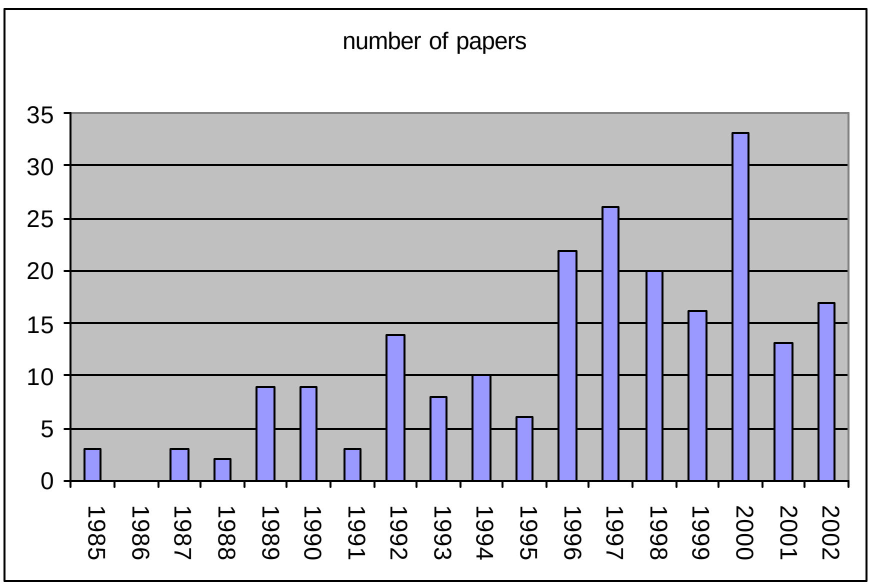
(C) Investigations into dynamic decision-making with the help of simulators (effects within a simulator on e.g. performance);

(D) General discussions of simulator usage, design and utility without intensive reference to one or more specific simulators;

After some remarks on the definition and the expected value of simulators, the paper presents a broad sample of studies from the system dynamics literature; descriptive statistics from this sample are shown. In the section after that a summary of empirical findings from the literature sample is given. The paper closes with the discussion of issues connected to the usage of simulators in research about rationality.

General description of the database

The results presented here very much represent work in progress and preliminary outcomes are based on 214 collected papers. The following figure orders the papers by their year of publication.



As can be seen from the figure, there has been an interest in simulators from the middle of the 1980s on. Although the number of publications generally increased over the years, the last two years have seen a decline from 33 papers in 2000, to 13 in 2001 and 17 in 2002. Of the total number of 214 papers, at present 30 papers have not been placed in one of the categories A to D described above. In most cases the uncategorised studies are presentation handouts only and do not include a full paper. Of the 184 papers which are categorised, the majority (80) concerns presentations of a simulator without further reference to evaluations. These are the papers categorised as A. Categories B and C are of main interest here and include 12 and 49 papers respectively. Category D includes 43 papers.

General description of research into dynamic decision making (category C)

Independent variables	**Effect on performance**		
	Positive effect	**Negative effect**	**Mixed/ no effect**
Model characteristics delay	high frequency (Bakken, 1992)	misperception time delay (Sterman, 1989)	- no effect (Diehl, 1989) - physical easier than reporting delays (Brehmer, 1989) - continuous easier than discrete delays (Barlas and Öcevin, 2001)
strength feedback		- misperception feedback decision to environment (Sterman, 1989) - increased negative or positive feedback (Diehl, 1989) - Langley, Paich and Sterman (1998) - Young, Chen, Wang and Chen (1997)	
structural complexity		- change in competitor behavior (Langley, Paich and Sterman, 1998) - turbulence decreases performance (Schultz, Dutta and Johnson, 2000)	- step increase exogenous input no effect (Barlas and Öcevin, 2001)
Simulator characteristics length of decision interval			- no effect (Barlas and Öcevin, 2001)
transparency	- Größler (1998) - Größler, Maier and Milling (2000)	- CLDs confusing (O'Neill, 1992)	- graphical more useful than numerical (O'Neill, 1992)
interface design	- Howie, Sy, Ford and Vicente (2000, reduction misperception) - screen design impacts performance (Young, Yang and Wang, 1992)		

cognitive feedback	- decision rules and structure – behavior relationships (Langley, 1995) - threshold warnings effective (O'Neill, 1992)		- outcome feedback is not sufficient (Diehl, 1988) - teaching how to make decision rules explicit has no effect (Langley and Morecroft, 1996)
Player characteristics decision strategy			- feedforward better than feedback strategy (Park, Kim, Yi and Jun (1996) - idem (Schultz, Dutta and Johnson, 2000)
mental model/ cognitive style	- higher similarity mental model to simulator increases performance (Ritchie-Dunham, 2001) - financial models better than health care models (Schultz, Dutta and Johnson, 2000)	- short term goals negatively affect performance (Yang, 1996, 1997)	- neither GCSI, nor MBI explain variation in scores; The two abstract components of the GSD (AS and AR) seem to explain simulator scores (Scott-Trees, Doyle and Radzicki, 1996)
group composition			- pairs better than individuals (Park, Kim, Yi and Jun, 1996)

The literature also suggests a number of control variables that can influence dependent variables in addition to the variables manipulated in the research: number of hours played, simulator (complexity simulator), instructions, presence of a facilitator, practice (Diehl, 1989) presence of monetary rewards (Sterman, 1989: 310).

Other dependent variables, apart from performance in the table above, are the following:

- performance, transfer of learning (between simulators),
- insight: dynamic understanding or mental models (Doyle, Radzicki and Scott-Trees, 1996), knowledge (Vennix 1990), knowledge (Größler, 1998), causal understanding (McCormack and Ford, 1998), number of information terms, inspecting time, mental model correctness (Young, Yang and Wang, 1992), mental model development (Shields 2001, 2002).
- thinking skills: systemic thinking (Cavalari and Thompson, 1995), presence seven system thinking skills (Maani and Maharaj, 2001)
- others: perceived usefulness elements (Cavaleri and Thompson, 1996), number of trials before equilibrium achieved (Jensen, 2002), satisfaction (e.g. Kim, 1989), collective versus 'egotistic' decisions (o'Neill, 1992)

Finally, the literature also suggests combinations of independent variables or intermediate variables:

- combinations of independent variables and decision rules Sterman (1989), Langley, Paich and Sterman (1998, in the form of simple CLD), Barlas and Öcevin (2001)

- transparancy to knowledge to performance (cf. Größler, Maier and Milling, 2000)

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