An approach for understanding learning and decision making in complex dynamic systems

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People often fail in controlling complex dynamic situations. Research on dynamic decision making serves the purpose of learning about how people come to think, learn and act in complex dynamic and opaque situations, where the general objective is to draw general conclusions about the nature of tasks and differences between people in learning and decision making. Dynamic decision making research differ from traditional decision making research by explicitly addressing issues of feedback in the task. For a definition of dynamic decision making see Brehmer (1992). Introducing concepts from system dynamics offer new possibilities for research on dynamic decision making by presenting a framework for understanding real life systems. System dynamics also offers a possibility to provide transparency to complex microworlds, provides ideas on how to improve learning in and about complex dynamic systems and, finally, system dynamics methodology can be used to ease microworld construction and improve aspects of ecological validity. The full version of this paper deal in more detail with research on dynamic decision making and issues on the development of methods for understanding learning and decision making in and about complex dynamic systems.

Dynamic decision making and system dynamics combined

"The importance of gaining an awareness of the enemy before the enemy gains a similar awareness" (quoted in Gilson 1995) was expressed by Oswald Boelke during WW I and represents a dynamic decision problem where failure can cause disaster. The concept of dynamic decision making was originally described by Edwards (1962) and extended by Rapoport (1975), where typical research in dynamic decision making concern problems of learning about the correct assessment of complex dynamic and opaque task situations and the implementation of measures to achieve some desired state of affairs (Brehmer 1992). Control of any system can be understood within a control theory framework and can be described in terms of the constraints of the system (Vicente and Rasmussen 1992 for a framework). System dynamics and dynamic decision making have these underlying assumptions in common. In accordance with Ashby's (1956) demand for *requisite variety*, a decision maker needs to realise that controlling complex systems needs complex control and a correct representation of the system.

The human mind is limited in its capacity and is characterized by essentially sequential processing, limited memory, selective perception and reliance on cognitive simplification mechanisms (Hogarth 1981). As a consequence of cognitive stress a decision maker adopts a strategy to make it possible to exert some control over a task. The level of cognitive load is adapted to fit to the cognitive resources at hand (Bainbridge 1979). In identifying problems people conceptualize the current environment and draw conclusions according to the perceived state of the situation. System dynamics provide a means of improving our understanding of the systems we wish to control, and in a well understood control problem

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there is no cognitive stress and interaction is based on real-time, multi-variable, synchronous co-ordination (Rasmussen and Pejtersen, 1992). The presence of a correct model of the decision situation is the single most important component in being able to make a correct decision (Brehmer, 1992). When the mental model of a situation and the actual situation differ, errors come as an inevitable consequence. However, research about control of systems face great problems in that the complexity and nature of most dynamic systems outside laboratory conditions makes it impossible to obtain useful and valid information (Hoc 1989), not to say expensive. By using a computer simulated microworlds, simulating essential features of the real world (Brehmer and Dörner, 1993) it is possible to facilitate the testing of scenarios and to control learning in the interaction with these microworlds in an experimental way. In fact the microworld paradigm is the main source of theory and research on decision making in dynamic systems (Brehmer 1992). Some research in dynamic decision making has been performed within the system dynamics research tradition, where subjects have been presented to specific decision contexts such as oil tanker shipping, real-estate (Bakken 1993), and experimental markets (Kampmann 1992) etc. See Brehmer (1992), and Frensch & Funke (1995), for overviews of previous research. Typical for most studies however is that the microworld tasks are novel to the subjects and not based on problems in real life.

By combining disciplines, paradigms can be created, developed and explored (Kuhn 1970). System dynamics have two general goals, the first is to understand complex dynamic systems through analysis of these systems through modelling. This first objective is approached by doing empirical and theoretical studies on real life problems and implementing the results of these studies in a simulation model for analysis. The second goal is to improve peoples systems reasoning skills and develop skill in understanding, conceptualizing and building models of systems. System dynamics can provide specific and well built representations of real life problems that easily can be turned into microworlds by adding an interface to the system simulations, for instance by building management flight simulators (Sterman 1992). Simulations can represent the structure and complexity of aggregate dynamic systems with great fidelity and permit controlled manipulations of the decision contexts in the system (Sterman 1989a and others). Using the skills developed in system dynamics it is thus possible to represent specific rather than general characteristics of real life systems. By being able to integrate and model the micro behavior of decision makers in aggregate structures it is possible to model aggregate dynamic systems (Sterman 1989b). This however assumes that we know and can simulate the behavior of decision makers.

> "It appears that the experimental exploration of dynamic decision making strategies in aggregate systems is feasible. The fidelity and flexibility of simulation models enables the investigator to construct rich, complex decision making environments... the marriage of experimental research of judgement with realistic simulation models thus offers a reproducible procedure to explore the endogenous generation of macro behavior from the micro structure of complex systems" (Sterman, 1989a, p 330)

Computational cognitive modelling is a growing field in psychology with research attempting to make more or less dynamic models of the human decision making process (see Cacciabue et al. 1992 and Dörner and Wearing, 1995 for examples). A greater understanding of decision makers cognitive structure and processes can contribute to improved learning methodologies and the development of psychologically relevant decision support systems and modes of control. One route to the development of more accurate measures of peoples learning and decision making is by moving closer to real world decision making. A way of reaching this goal is through the microworld paradigm. This is however not an easy path to walk and there are serious problems with adopting microworlds that simulate naturalistic decision situations (Brehmer and Dörner 1993). By combining system dynamics and dynamic decision making two general objectives can be achieved. First, microworlds are easier to make using the tools and methods used in system dynamics and can thus flexibly be made to fit different structures of tasks, different subjects and system demands. Second, what is learnt from dynamic decision making and the experimental paradigm can be integrated in the system dynamics modelling program, to provide simulated aggregate behavior of decision makers and test the intended rationality of decision rules in the simulation models.

The integration of research traditions can be achieved through the development of the microworld paradigm. An obvious first step in the combination of the two methodologies is to fit the management flight simulators of the system dynamics tradition with "flight recorders". By providing measures of decision maker's performance and mental models this can provide important information about how decision makers assess their situation, learn and make decisions. In view of this and the great potential gains from the respective disciplines, the marriage between system dynamics and dynamic decision making may provide new means to understand the formulation and revision of decision makers mental representations and decisions. However, understanding peoples mental models will still remain a difficult methodological problem because of the aggregate nature of peoples mental models, and especially concerning naturalistic decision problems.

Directions for future research

By providing microworlds with proximity to every day decisions "gut level"-responses may be facilitated and validity may be improved in a range of experimental settings. Combined with measures of the decision process and subjects mental models, system dynamics modelling procedures may enable us to create flexible microworlds to explore learning and decision making where critical ecological issues may be addressed and the validity of experiments can be improved and explored. It may be possible to establish measures of learning based on psychologically relevant frameworks (See Vicente and Rasmussen 1992 for an example). Based on the learning history of decision makers, measures of mental processes can be improved, providing opportunity to move closer to real life learning and decision making in decision research. Typical problems to address may concern subjects mental representations of systems in terms of situation assessment, and to model the consequences of subjects mental representations. To what extent is this knowledge automated into schemas, for example in the skill-rule-knowledge framework (Rasmussen and Pejtersen 1992). Other issues to deal with are the importance of situation characteristics (surface characteristics) for situation awareness, and how we can move toward system understanding and more autonomous decision making, following the ideas of Piaget (1932). Another problem area concern the representation of solutions to problems, see for example Reason 1990 and Klein 1993. Measures of general performance will remain a problem as these are limited by our own understanding of the problems under study. Eventually we will be better able to answer how systems are learned and represented in our minds and how this knowledge is transformed into decisions, where new insights can help us design systems that are better able to facilitate the formation of correct mental representations and efficiently communicate the developments of a system. If not, at least we will be able to model the consequences of our failure.

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