A Preliminary Experiment on Examining Thinking in a Meta-Dynamic Decision Making Environment

Sy-Feng Wang
Showing H. Young

Department of Business Management
National Sun Yat-Sen University
Kaohsiung, Taiwan

ABSTRACT

For system dynamicists, it is important to understand how humanbeing solving problems and making decision in the real world. However, how humanbeing solving problems and making decision in the dynamic causal feedback environment are still not well understood both in psychology and in system dynamics. This paper is a preliminary study which attempts to deal with issues of problem solving, thinking strategy and pilot knowledge in a so called meta-dynamic decision making environment. The task was a computerized beer game modified from the board type beer game. Experiment results showed that there existed a goal-strategy dynamics in human problem solving. The thinking strategy contained both "structure-understanding" and "non-structure-understanding". The pattern's pilot knowledge from previous trials had influence on some subjects' decision making. It's possible influences in real world are discussed. Finally, from experiment results, two general problem solving processes (the servomechanism process and the cybernetic process) are proposed. Implications for system dynamics management flight simulator and systems thinking are also discussed.

INTRODUCTION

For system dynamicists, it is important to understand how humanbeing solving problems and making decision in the real world. It is important not only for modelling the policy and decision function in the simulation model, but also for teaching and learning Systems Thinking. Because, if we want to teach or learn the new thinking paradigm effectively, to understand human's natural thinking pattern is very important.

However, the understanding of how humanbeing solving problems and making decision in the dynamic causal feedback environment are still insufficient both in the cognition psychology and in system dynamics. Psychologists had paid little attention in dynamic decision making (Brehmer, 1990). Judgement and decision making in dynamic tasks had hardly been touched, almost all the researches focused on static tasks (Hammond, 1988). Human problem solving is a complex cognition process for which no established classification or taxonomy exists (Enkawa and Salvedy, 1989). The task used in problem solving, such as chess, logic problem, and cryptarithmetic task (Nellen and Simon, 1972), are not generalized enough to be transferred to other situations (Best, 1989).

Furthermore, in methods of system dynamics modelling, the understanding of human problem solving process is relatively weak to decision making process. If we define problem solving as the process of achieving the current condition to the desired condition (Best, 1989), it is much difficult to be simulated when the achieving process is a discontinuous "rull-setting" (strategies) process with the continuous feedback loop of system dynamics (Merten, 1988).

This paper is a preliminary study which attempts to deal with issues of problem solving, thinking strategy, and pilot knowledge in a so called meta-dynamic decision making environment. In a "dynamic decision making environment," the situation requires a series of decisions, these decisions are interdependent, and the environment changes, especially as a consequence of the actions taken by the decision maker; while in a "meta-dynamic decision making environment," the decision maker can experience the similar "dynamic decision making environments" many times but with some slightly different scenarios.

In such meta-dynamic decision making environment, subjects can not only use adaptive policies to control behaviors (e.g., feedback control), but also can change their strategies to enhance their performance. How people changing their strategies, and by what process? This question is the first concern of this study. Our second concern is the thinking strategies used (consciously or unconsciously) before playing a new trial as suggested by Brehmer (1990). Berndt Brehmer suggested that the dynamic decision experiment needs to consider the overall strategy before evaluating decision maker's mental model. Finally, owning to the used task was a stock management problem with cyclical structure, the patterns faced by subjects in difference trials were similar. Are those patterns recognized by subjects? If it is, what are the possible influences? This is the third issue concerned by this research.

METHOD

Task and Subject

The task used in this research was a computerized beer game, which are modified from the beer game development by MIT's System Dynamics Group (Forrester, 1969; Lyneis, 1980; Sterman, 1989; Senge, 1990). Subjects played one role in the game while the computer played the others. The parameters and the infrastructure of the computerized beer game are all the same with the board type beer game. The decision rules of the roles played by the computer were formulated by the experimental results of Sterman (1989). The interface was constructed by STELLA-STACK (Peterson, 1988). The information received by subjects were the same as the board game, except the display of inventory condition (backlog would be shown as zero) of other three roles. The information used in every period would be automatically recorded when subjects click mouse to show that information.

Subjects were 24 undergraduate students from a class of the Department of Finance , National Sun Yat-Sen University. Subjects would be paid $4 to $ 8 depend on their performance.

Procedure

The experiment was a three hours session. Subjects were required to play five trials if time was enough (20 subjects played five trials, 4 subjects played four trials). Each trial had 50 periods, and their scenarios were all the STEP pattern with slight difference in step time, step height, and random disturb. Subjects played the role of the wholesaler in the first three trials, while played the role of the factory in the others. After finished each trial, subjects were asked to report their decision rule and strategy used in this trial, and to complete a questionnaire to evaluate the degree of feedback perception at the end of the experiment.

Design

The experiment was designed as an exploration study. Some reference goals were set in accordance with the role subjects played. One trial's performance was measured by the ratio of the accumulated cost of 50 periods to the reference goal. The relations between goal setting and strategy change were observed and tested. Here strategy change means whether or not subjects had changed the strategy used in the previous trial. The index of strategy change was coded from some transformation of the information search type (four types) and the prior activity (three kinds). Either the information search type changed or the prior activity changed, the strategic change will be coded as "changed", else coded as "unchanged".

Decision making can be described as an information integration process. If the information search type was changed, it usually reflects some strategy changes. In the task, the information search type was measured firstly by the percentage of use times of inventory/backlog, received order, and the inventory of other three roles, and then was clustered (by two-stage clustering approach) to four types as: reactive type, up/down-stream type, down-stream type, and up-stream type, as shown in Table 1. The reactive type reflected subjects' system's boundary concentrated on the role they played, that is, eliminated the information of up-stream's inventory (mean=8%) and down-stream's inventory (mean=8%), and focus on the information of stock/backlog and received order (mean=84%). The up/down-stream type had an equivalent attention to up-stream, down-stream and its own information (means =33%, 33% and 34% respectively). Finally, the down-stream type heavily relied on down-stream's information (mean=44%) and slightly on up-stream's information (mean=17%), while the up-stream type heavily relied on up-stream's information (mean=38%) and slightly on down-stream's information (mean=6%).

Table 1: Cluster of Information Search Type

Cluster	Average Percentage of used times		
	Stock/Backlog & Received Order	Up-stream's Inventory	Down-stream's Inventory
Reactive type	84%(18%)	8%(9%)	8%(9%)
Up/down-stream type	34%(5%)	33%(5%)	33%(6%)
Down-stream type	38%(10%)	17%(6%)	44%(8%)
Up-stream type	56%(10%)	38%(6%)	6%(7%)
	F=74.64 P<0.0001	F=62,63 P<0.0001	F=74.87 P<0.0001

Note 1: The numbers in parentheses represent standard deviation.
Note 2: Only the first three trials (played the role of the wholesaler) were included, the fourth and fifth trials' case (factory's role) only contained the Reactive type and the Down-stream type.

The prior activity(named here as "Proaction") was the degree of subject's order decision prior to his received order; it was a sensitivity decision rule in the task. The use of the "Proaction" rule will improve performance significantly. Proaction was measured firstly by the ratio of accumulated order decision to accumulated received order from period 1 to the period of received order larger than the step value of this trial's scenario, then was coded as three levels: "too little" (Proaction<=0.4), "non-proaction" (0.4<Proaction<=1.3), and "proaction" (Proaction>1.3). If other conditions remain the same, the simulation results indicate that the performance of the "proaction" is better than that of the "non-proaction", and the the performance of non-proaction is also better than that of the "too little".

In addition to the relations between goal setting and strategy change, the thinking strategies used in the meta-dynamic decision making environment was another concerned issue in the study. In most researches with dynamic tasks, cybernetics (or control theory) is often proposed as a theoretical framework (Lord and Maher, 1990; Brehmer, 1990). From control theory, Brehmer (1990) proposed two thinking strategies: the feedback control and the feedforward control in a dynamic task of fighting forest fires. Kleinmuntz and Thomas (1987) compared action-oriented (cybernetic) to judgment-oriented (rational) decision strategies in a dynamic medical decision-making task.

However, the feedback thoughts existed in social science and systems theory were not only the "cybernetics thread", but also the "servomechanisms thread" (Richardson, 1991). One of the key features distinguishes between the cybernetics thread and the servomechanisms thread lies in the problem solving strategies and the attitudes toward complexity. The cybernetics thread thought complex systems were not understandable in causal terms, but could be controlled by the black box controller. The servomechanisms thread focused on the understanding of the feedback structure of concerned phenomena, and improved system's behavior by regulation.

In the computerized beer game, subjects could enhance their performances trial by trial with thinking strategy of structure-understanding (the servomechanisms thread), or strategy of black box control (non-structure-understanding or the cybernetics thread). For example, subjects may use the "proaction" rule by "feedback perception" defined as follow.

Feedback perception means the degree of decision maker perceiving the feedbacks resulted from his own actions. In the task, the feedback perception was measured with the conditions subjects can or can't report the causal structure like this: "my inventory / backlog will influence the level of down-stream's inventory/backlog after some periods of delivery time, then will influence the level of over-ordering(due to the higher backlog) of down-stream sector, and consequently increasing the received order by me", then he was coded as YES, else coded as NO.

However, subjects may also use the "proaction" rule without structure-understanding of the feedback perception, for example, from the pilot knowledge of the historical pattern of received order. In the task, the patterns faced by subjects in different trials were similar. If subjects had recognized the boom-and-bust patterns, they might act prior to the growth of received order. Whether the pattern's pilot knowledge was used or not was coded with protocol records in the questionnaires.

Finally, the thinking strategies were observed from reasons of the use of "proaction" rule with protocol records in the questionnaires and also from the information search type.

RESULTS

Goal-Strategy Dynamics in Human Problem Solving

As shown in Table 2, the total accumulated cost of four roles was improving significantly ($F(4,119)=3.86$, prob.< 0.006) when subjects played more trials (from trial 1's 33566 to trial 5's 10660).

Table 2: One factor ANOVA for Total Cost and Trial

Trial	Total Cost Mean(SD)
Trial 1	33566 (41991)
Trial 2	27154 (29728)
Trial 3	16483 (16735)
Trial 4	12746 (5823)
Trial 5	10660 (6956)

Note: Missing values of four trial 5 are replaced by its previous trial's values

Using the term of "the laundry lists"(Richmond, et al.,1990), there are many causes for the improvements, such as considering the pipeline effect, correcting inventory smoothly, and increasing the inventory goal (in the board type beer game, analyzed by Sterman (1989)), and other decision rules or strategies in this task (e.g., act prior to received order, pattern recognition, shortening the information delay, etc...).

However, this research concerns more about the dynamic forces which improve the performance. In dynamic view, there seems to have a goal-strategy dynamic loop dominantes the improving behavior, as shown in Figure 1. When the performance was far from the reference goal, subjects were then faced goal pressure. The pressure would be released while performance had achieved the goal. The achieving process was not an adaptive decision, but was a discontinuous "rull-setting" process with strategy changes. In such process, subjects were searching strategies from the strategic set consciously or unconsciously. The strategic set is the collection of all the possible strategies existed in the task[1], it is something like the concept of "problem space" proposed by Newell and Simon (1972).

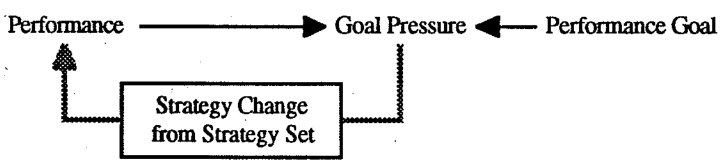

Figure1: Goal-Strategy Dynamics in Human Problem Solving

The hypothesis of the goal-strategy dynamics in human problem solving was supported by some statistical evidences. In using the ratio of accumulated cost to goal as an index of goal pressure (low pressure(0-1.4), middle pressure(1.4-3), and high pressure(>3)), Table 2 shows that more pressure leads to higher probability of strategy change (Chi-Square =10.77, p<.005). When the goal pressure is high, there are 78% subjects changed their strategies used in previous trials. When the pressure is low, there are 61% subjects did not change their strategies.

Table2: Chi-Square Test of Goal Pressure and Strategic Change

Strategic Change	Goal Pressure		
	Low	Middle	High
Unchanged	11(61%)	20(53%)	8(22%)
Changed	7(39%)	18(47%)	29(78%)

When subjects changed their strategies, if the new strategies were ineffective (performance had not improved or even worse), then subjects will search another strategy from the strategic set until subjects had changed to an effective strategy. That is, if subjects' strategies had reached steady, the goal pressure was becoming lower, as predicted by the hypothesis. Using the the strategy change (changed or unchanged) of five trials, twenty four subjects were classified to steady group (n=10) and unsteady group (n=14). The T-test (two-tail) showed that the steady group achieved smaller pressure (average of trial 4 and 5) and lower variance than the unsteady group (t-

[1] The strategy set contained, at least, considering the pipeline effect, correcting inventory smoothly, and increasing the inventory goal (in the board type beer game, analyzed by Sterman (1989)), and other decision rules or strategies in this task (e.g., act prior to received order, pattern recognition, shortening the information delay, etc...).

value=1.80, prob.<.09). The mean pressure of steady group had achieved 1.88 (SD=0.79), while the mean pressure of unsteady group remained in 3.46 (SD=2.67).

Thinking Strategy and Pattern's Pilot Knowledge

As mentioned previously, cybernetics is often proposed as a theoretical framework in researches using dynamic tasks. However, the feedback thoughts existed in social science and systems theory were not only the "cybernetics thread", but also the "servomechanisms thread". In the task of the computerized beer game, subjects could enhance their performances trial by trial with thinking strategy of structure-understanding (servo-mechanisms thread), or strategy of black box control (cybernetics thread). For example, subjects may use the "proaction" rule by feedback perception or by pattern's pilot knowledge. The key difference lied in whether or not subjects used the thinking strategy of structure-understanding. That is, in such meta-dynamic decision making environment, we found that there existed two major types of thinking strategies: structure-understanding and non-structure-understanding.

Those two types of thinking strategy might not be different in the use of decision rules, but were different in reasons or processes of finding or using those decision rules. The thinking strategy of structure-understanding tended to use reasoning method to find decision rules, while the non-structure-understanding's strategy tended to use trial and error, memory control, or analogy to find rules. That is, the thinking strategy would guide the searching methods or processes to change decision rule or strategies from the strategy set. Using the same decision rules did not mean using the same thinking strategy. The rule of "proaction" was a good example. If the use of proaction rule was due to structure-understanding, subjects should understand the structure of feedback perception defined in this paper. However, only one subject had identified this structure. But, based on the "proaction" data of the five trials, there were fifteen subjects (62.5% of all subjects) classified as "proaction group" (that is, had used "proaction" rule steadily and used it more than three times). There were fourteen subjects used the "proaction" rule without structure-understanding.

From protocol records in the questionnaires, there were four reasons of the first time's use of "proaction" rule in those fourteen subjects (the second or third used time were due to rule's effectiveness, as explained in goal-strategy dynamics hypothesis). Firstly, due to the inventory cost ($0.5/unit) was cheaper than the backlog cost ($1/unit), one subject was motivated to order more in the beginning. This reason was obviously classified as thinking strategy of non-structure-understanding. Secondly, the use of "proaction" rule was due to worrying about the shipment delay(n=3), so they order in advance. It is interesting to notice that the only one "feedback perception" subject's first proaction activity was also due to the same reason (shipment delay). However, may be due to the difference of thinking strategy, or may be due to individual difference, those three subjects didn't achieve the understanding of feedback perception's structure. Thirdly, the use was due to the pilot knowledge of boom-and-bust pattern of received order/custom demand (n=6), so subjects proact to the growth stage. The use of the "pattern's pilot knowledge" was obviously belonged to the analogy's thinking strategy, that is, the thinking strategy of non-structure-understanding. Finally, there are four subjects reported that they used the informations of down-stream inventories to shorten the information delay time and then to get much more complete information about consumer demand so that they could order in advance. The use of "shorten information delay" was indeed just a successful rule in the task, it was also obviously belonged to the thinking strategy of non-structure-understanding.

Those protocol records about the reasons of proaction rule's usage had shown some evidences to support the existences of "structure-understanding" and "non-structure-understanding" thinking strategies. They also showed that less subjects used the thinking strategy of structure-understanding than the thinking strategy of non-structure-understanding.

In addition to the reasons of "proaction" rule's use, the information search types also could provide some evidences about the existence of thinking strategy. One of the necessary conditions about understanding the structure of the task was whether or not subjects could extend their thinking of the system's boundary (Senge, 1990). The extension of system's boundary may be reflected by whether or not subjects had extended information search areas to up-stream and/or down-stream. As a consequence, the reactive information search type (see details in Table 1) reflected smaller boundary used, while the other types reflected larger boundary. Based on the clustered information types, twenty four subjects were classified to smaller boundary group (n=13) and larger boundary group (n=11)[2]. Therefore, the thirteen subjects of smaller boundary group could then be classified as thinking strategy of non-structure-understanding. However, the larger boundary group could not be classified as thinking strategy of structure-understanding, because the extension of system's boundary was only the necessary condition of structure-understanding. In deed, from protocol records about reasons of search up-stream's information (all the eleven subjects of larger boundary group had heavily searched up-stream's information more than three trials), there were eight subjects (73% of those 11 subjects) used up-stream's information as methods of "shortening the information delay" to gain much more complete information about consumer demand[3]. The use of "shortening the information delay" was indeed just a successful rule in the task, it was obviously belonged to the thinking strategy of non-structure-understanding.

The analysis about "proaction" rule and information search type manifested some evidences to support that there exist thinking strategies of "structure-understanding" and "non-structure-understanding", and subjects tended to use the thinking strategy of non-structure-understanding than the thinking strategy of structure-understanding. One of the reasons of why subjects tended to use thinking strategy of non-structure-understanding might be due to its relatively fewer cognition efforts needed than the thinking strategy of structure-understanding in the task. Another reason might be due to the lack of dynamic language or dynamic thinking skill (Richmond,1990) to reason the structure of the task.

Furthermore, the thinking strategies of structure-understanding and non-structure-understanding were not absolutely exclusive in the task. Subjects could use both of them in the same trial, just as humanbeing would used reasoning and analogy strategies in the same time to solve problems (observed by Herbert A. Simon, sited from Best(1989)).

Finally, as stated previously, the pattern's pilot knowledge did influence some subjects' decision making. There were six subjects' (25% of 24 subjects) "proaction" rule was due to the pilot knowledge of boom-and-bust pattern of received order or custom demand. It is interesting to ask: what were the possible influences when the pattern's pilot knowledge interacted with the real world's causal structure? This will be discussed later in the paper.

2 Smaller boundary group was coded when (1) four trials are reactive type in five trials (n=8), (2) three trials are reactive type in five trials, and the other two trials' information search type were not used steadily in final three trials (n=4), and (3) three trials are reactive type when subjects only played four trials (n=1).

3 The other three subjects of the larger boundary group were the subject of "feedback perception" (structure-understanding) and two other subjects which had not reported their reasons.

DISCUSSION AND IMPLICATIONS

Cybernetic and Servomechanism Problem Solving Process

George P. Richardson (1990) had proposed two threads of feedback thought in social science and systems theory: the servomechanisms thread and the cybernetics thread. If we combined goal-strategy dynamics with thinking strategies of structure-understanding and non-structure-understanding, then there seems to have two general problem solving processes, the servomechanism process and the cybernetic process, to achieve desired goal in the meta-dynamic decision environment.

The servomechanism process means subject focuses his cognition efforts in reasoning and understanding the reasons and structure of concerned phenomena, and then improves his performance until satisfied. The cybernetic process means subject does not focus their cognition efforts on structure-understanding, and seems to treat the structure as a black box, may use methods of analogy, trial and error or memory control to search strategies (or rules) from strategy set, then tests them. If the output of the input strategy is effective, he keeps on that rule; if not, he changes until his performance is satisfied.

The difference between the servomechanism process and the cybernetic process lies in whether or not the thinking strategy is to understand the structure. In deed, they shared the same goal achieving feedback process (as shown in Figure 1) and may use the same decision rule. When the performance (current state) was far from the reference goal (desired state), the pressure would force people to search strategies from the strategy set, then used and tested new strategies until achieved the desired state. Thinking strategy would guided the searching process either consciously or unconsciously. The searching results (strategies or rules) might be the same (e.g., the "proaction rule").

In addition, as the use of the cybernetics thread was popular than the servomechanisms thread in social science and systems theory (Richardson, 1990), there seemed to have more subjects used the cybernetic problem solving process than the servomechanism process. The results might explain why humanbeings are poorly dealed with dynamic feedback problem, but they still work (at least, live) in such complex real world.

Possible Influences of Pattern's Pilot Knowledge in Real World

As shown in the experimental results, the pattern's pilot knowledge did have some influence on some subjects' decision making. There were six subjects' (25% of 24 subjects) "proaction" rule was due to the pilot knowledge of boom-and-bust pattern of received order or custom demand. Due to the importance of the pattern's pilot knowledge, it is interesting to discuss the possible influences of the pattern's pilot knowledge in the real world.

The real world has many cyclical systems, e.g., the economic cycles, the Taiwan's real estate cycle (Wang, et al., 1991; or Hu and Lo, 1992), and so on. Those cyclical systems are some what like the meta-dynamic environment, especially when there exist some steady time after boom-and-bust are passed (for example, the Taiwan's real estate cycle). When a part of people in those systems had the pattern's pilot knowledge caused by past experience, they may proact (around the time they believed) to their believed pattern. If the system exists some strong positive feedback loops (for example, the accelerator and multiplier mechanism, the speculative loop in Taiwan's real estate cycle), and the force of the proaction is strong enough to fuse the positive loop, then the next cycle will be self full-filling. Furthermore, in addition to the original positive loops, the positive loop of "self full-filling prophecy" will be created, as shown in Figure 2.

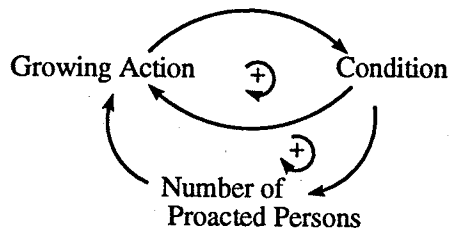

Figure 2: the self full-filling prophecy fused by pattern's pilot knowledge

Issues in Teaching and Learning System Dynamics

If we define the purpose of learning system dynamics is to enhance the problem solving ability about dynamic complexity problems, then there are two questions must be answered: can the learner understand the knowledge and the tools of system dynamics? and will the learner use system dynamics to solve problems, or just a pure knowledge? For researchers in system dynamics' education, those two questions can be changed as: can we develop some tools or processes to enhance or accelerate learners to learn knowledge and tools of system dynamics? and how to help learners to use the knowledge of system dynamics in real world problem solving?

The second question seems to be less emphasized than the first. However, to answer the question needs much more research efforts and is beyond the scope of this paper. But, from the experiment results, one of the difficulties is identified. That is, human being's natural problem solving process tends to use the "cybernetic process", while the training of system dynamics is to teach a different process, the "servomechanism process". Thinking pattern's shifts are usually difficult and time consuming.

Issues in the System Dynamics Management Flight Simulator

The relationship between performance and task's understanding is not consistent in various researches. Broadbent (Broadbent, et al., 1978; 1986) have documented that performance can be unrelated to understanding. On the other side, Bakken argued that there was a positive relationship between performance and understanding of the game, and he said "researchers who use games of complex, dynamic systems as tools to transfer systems insights can therefore safely use performance measures as first approximations of structural understanding" (Bakken, 1989).

However, this study shows that if subjects have the chance of using non-structure-understanding strategy (or the cybernetic problem solving process) to reach the desired goal, then they tend to use it. That is, thinking strategy is a contingent variable when we consider the relationship between performance and task's understanding, which is the same as the observation of other researches (Brehmer,1990; Young, et al., 1992). As a consequence, only when experimenter can make sure that the task can reach high performance by the structure-understanding strategy alone (or the servomechanism problem solving process), otherwise it is not safe to use performance measures as index of structural understanding. For the same reason, the design of the system dynamics management flight simulator and its learning program should pay more attention on the issue of thinking strategy. If the purpose of designing management flight simulator is to enhance structure-understanding or to enhance the ability of systems thinking, then the simulator should correspond the thinking strategy of structure-understanding, and the learning program must emphasize on the structure-understanding too.

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