Participatory Simulations as Training Tools - A Study Based on the Market Growth Model

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ABSTRACT

A participatory simulation based on the market growth model is developed. The performance of eight subjects is evaluated and compared against the results of a simulation analysis of the model. Compared to the benchmark derived from the simulation analysis, the subjects' performance is surprisingly low. It is argued that participatory simulations can be valuable teaching instruments but that they need to be combined with additional learning support tools.

INTRODUCTION

Laboratory learning has long occupied a prominent place in the curricula of the hard sciences. The rapid evolution of microcomputer technology has fueled attempts to utilize similar methods for the teaching of the social sciences. It is hoped that social system laboratories in the form of computerized microworlds can teach people how the structure of complex dynamic systems produces behavior and help them understand how their individual actions relate to overall system performance. While the idea of computerized laboratories is very exciting, considerable uncertainty exist as to how to design effective laboratories and how to achieve maximum learning efficiency. Research in this area can draw on studies in various academic fields. Two important research traditions have been established in control theory and behavioral decision theory.[1]

While the traditional focus of control theory lies on automatic control, there exists a small but important literature that focusses on human control. Early literature was motivated by the need to understand the human operator's characteristic in order to integrate the operator effectively into a man-machine system (Crossman and Cooke 1974, Sheridan and Ferrell 1974). More recent literature reflects the shift that humans have increasingly become supervisors of complex automated machinery instead of being operators (Rasmussen and Rouse 1981). Automatic control rules work only under normal sets of conditions. Human supervisors are still needed to regulate unusual cases and unexpected failures. To understand how humans learn to control complex dynamic systems is understandably of great interest not only in such applications as the supervision of nuclear power plants (Lees and Sayers 1976, McLeod 1976).

Topics that have received particular attention in the field include the effects of information display on performance (Sheridan and Johannsen 1976, West and Clark 1974, Attwood 1974) the effects of training on performance (Kragt and Landeweerd 1974, Shepherd et al. 1976, Morris and Rouse 1985, Mann and Hammer 1986, Moray et al. 1986) and the performance difference of novices and experts (Bainbridge et al. 1974, McLeod 1976, Mann and Hammer 1986). Results of experiments in process control and supervisory control are published in *Ergonomics*, *Human Factors* and *IEEE Transactions on Systems, Man and Cybernetics*. Many studies in the field are hardly accessible or unpublished, however. See Edwards and Lees (1972) and Lees (1974) for an overview and Edwards and Lees (1974) for a collection of some better known studies.

Compared to the decision problems examined by researchers in the engineering tradition, the problems examined by behavioral decision theorists are typically less applied. Stimulated by papers by Edwards(1962) and Toda(1962) a literature known as dynamic decision theory developed in the 60's and early 70's. See Rapoport and Wallsten(1972) and Rapoport(1975) for an overview. Of particular interest are the studies on multistage control problems. Rapoport(1966a,1966b) examines how people learn to control an unstable process of the kind x(k+1)=a*x(k) where a>1. Rapoport(1967) and Ebert (1972) report experiments on stock-adjustment problems.

Although interest in dynamic decision theory has continued through the 70's until today (Mackinnon and Wearing 1980, Hogarth 1981, Hogarth and Makridakis 1981, Kleinmuntz 1985, Kleinmuntz and Thomas 1987, Brehmer 1987), dynamic decision theory has not been a very active research area. Slovic et al (1977) suggest that the mathematical sophistication of dynamic decision problems and the need for time consuming computer programs might be some of the reasons behind the decline in interest among psychologists.

Given its ties to control theory and bounded rationality (Morecroft 1983, 1985), system dynamics provides well-suited concepts that can guide future research on learning and control of complex dynamic systems. In particular, system dynamics provides a readily available concept that links task characteristics to behavior. The need for a unifying concept that relates complexity of decision situations to the likelihood of dysfunction in human decision strategies is widely acknowledged (Hogarth 1981, Kleinmuntz 1985, Mackinnon and Wearing 1985).

I believe that the different generic structures that have been identified in system dynamics can provide guidance for future experimental research (Graham 1988). Practitioners in the field have already begun to conduct studies into how people learn to control stock-adjustment structures (Bakken 1988, Sterman 1988a, 1988b). In this paper I report on a study that is based on another well-known generic structure: promotion and sustaining of growth.

EXPERIMENTAL DESIGN

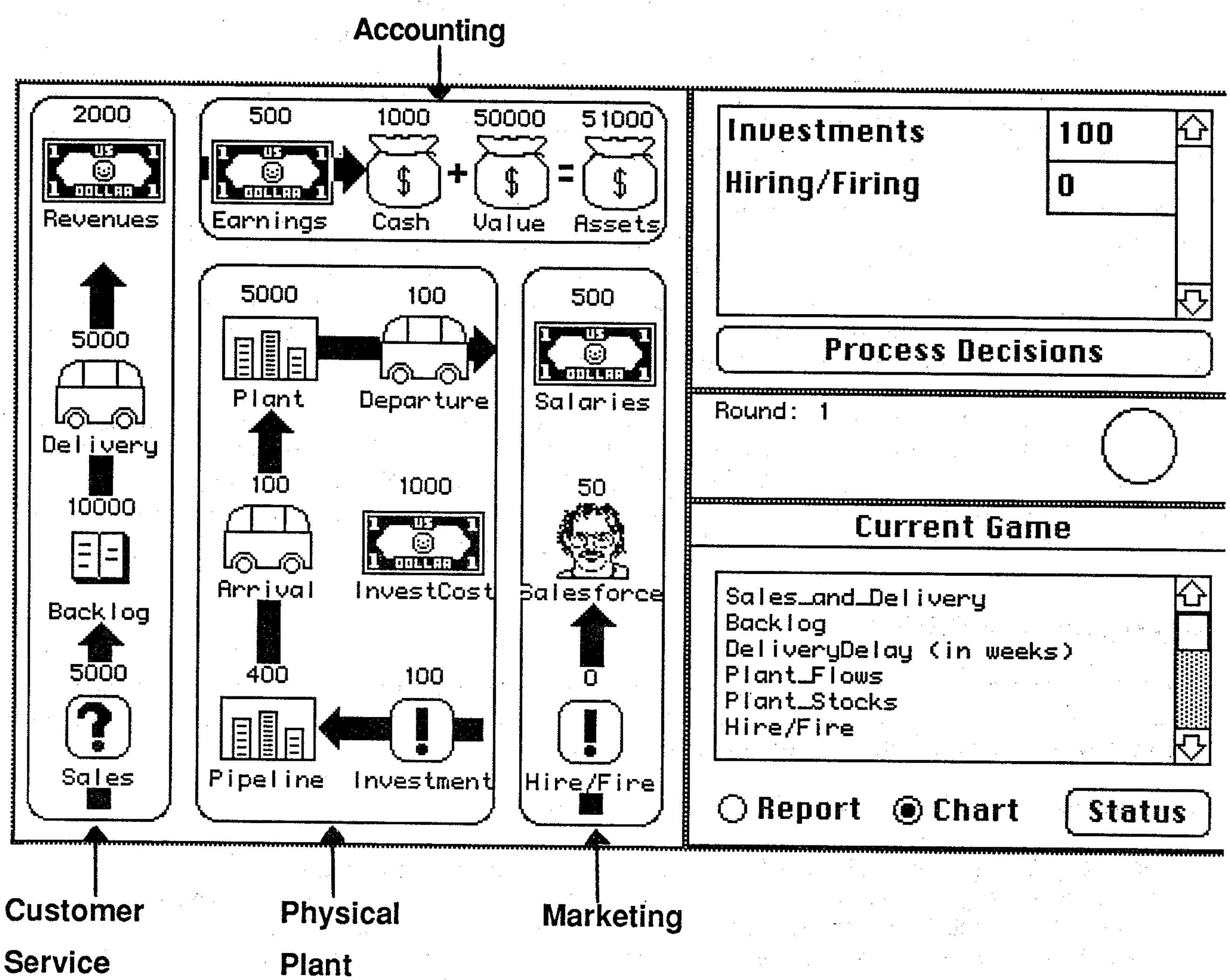
The social laboratory used in the experiment was designed after the market growth model (Forrester 1968) and implemented on a Macintosh computer using Microworlds Creator™ (MICROWORLDS 1988). The model equations are provided in the appendix.

The students are provided with the following guidelines:

> "You are the manager of a high technology company in a new emerging market. Your objective is to manage the growth of your company and to increase its worth. In particular, you have to coordinate the activities of the two major departments in your company: marketing and physical plant. Marketing generates sales, physical plant provides the capacity to produce and deliver the sold goods. Imbalances in the size of these two departments will lead either to overcapacity or to long delivery delays. Both are costly.
>
> The game lasts 50 rounds. Each round represents a quarter of a year. In each round you have to make two decisions, (1) how much capital to order and (2) how many salespeople to hire or fire. You enter your decision in the dialog box that appears in the upper right corner of your screen (Figure 1). Your decision is completed once you have clicked the mouse in the 'Process Decisions' button.
>
> To show you how your decisions influence the outcome of the game and to help you in your decision making, you have two support tools available, the status window and the graph/report facility. Both are described in detail in the following.
>
> **Status window**
>
> The status window facility gives you an up-to-date overview of the current status of your company. Figure 1 displays the status windows at round 1. The status window displays the four departments your company consists of: (1) marketing, (2) physical plant, (3) customer service and

(4) accounting. Each of these departments is described in detail below.

Figure 1: Screen with status window active



(1) Marketing department

At the center of your marketing department is the salesforce you employ. Your **sales are the product of NormalSalesPerSalesperson * Salespersons * Salesforce-Effectiveness**. NormalSalesPerSalesperson is a constant. The number of salespersons is decided by you through hiring or firing of people. SalesforceEffectiveness depends on your delivery delay and will vary throughout the game. The longer it takes for customers to receive goods, the less are they inclined to order from you. In times of high delivery delay the same salesforce will sell fewer goods than in times of low delivery delay. The computation of the delivery delay is explained below in the section on customer service.

While a large salesforce generates high sales, it comes at a cost. You have to pay a salary to each sales person you employ.

(2) Physical plant

At the center of your physical plant is the capital stock you own. You can only deliver goods to customers if you have the capacity to produce them in the first place. The average lifetime of the equipment in your plant is 12.5 years (50 quarters). Thus, you loose 2% of your plant each quarter. To replace this worn out equipment or to increase the size of your plant, you need to invest and to order equipment from your suppliers. You do not receive the equipment as soon as you order it. Rather it takes four quarters until your supplier delivers the equipment and you can use it. In the meantime your orders are in a 'pipeline' waiting to be delivered to you. You pay for your equipment when it arrives at your company.

(3) Customer service

Your customer service department keeps track of the sales you made. It keeps a backlog that is increased by new sales and decreased by deliveries. Each quarter you produce and deliver as much as your plant capacity allows you to. If you have fewer sales contracts in backlog than you have capacity, you suffer from overcapacity. In this case you a part of your plant will be idle. Once you deliver a good you get paid by your customers.

The ratio between delivery and backlog is very important in that it determines how long on average your customers have to wait until they get the products they ordered. For example, if the backlog/delivery ratio is 2, it will take 2 quarters (26 weeks) until a newly ordered good will be delivered. As described in the section on marketing, a high delivery delay makes it hard for your salesforce to generate sales. Marketing research tells you that customers do not react promptly to a change in delivery delay, but that it takes them about 2 quarters to perceive a change.

(4) Accounting

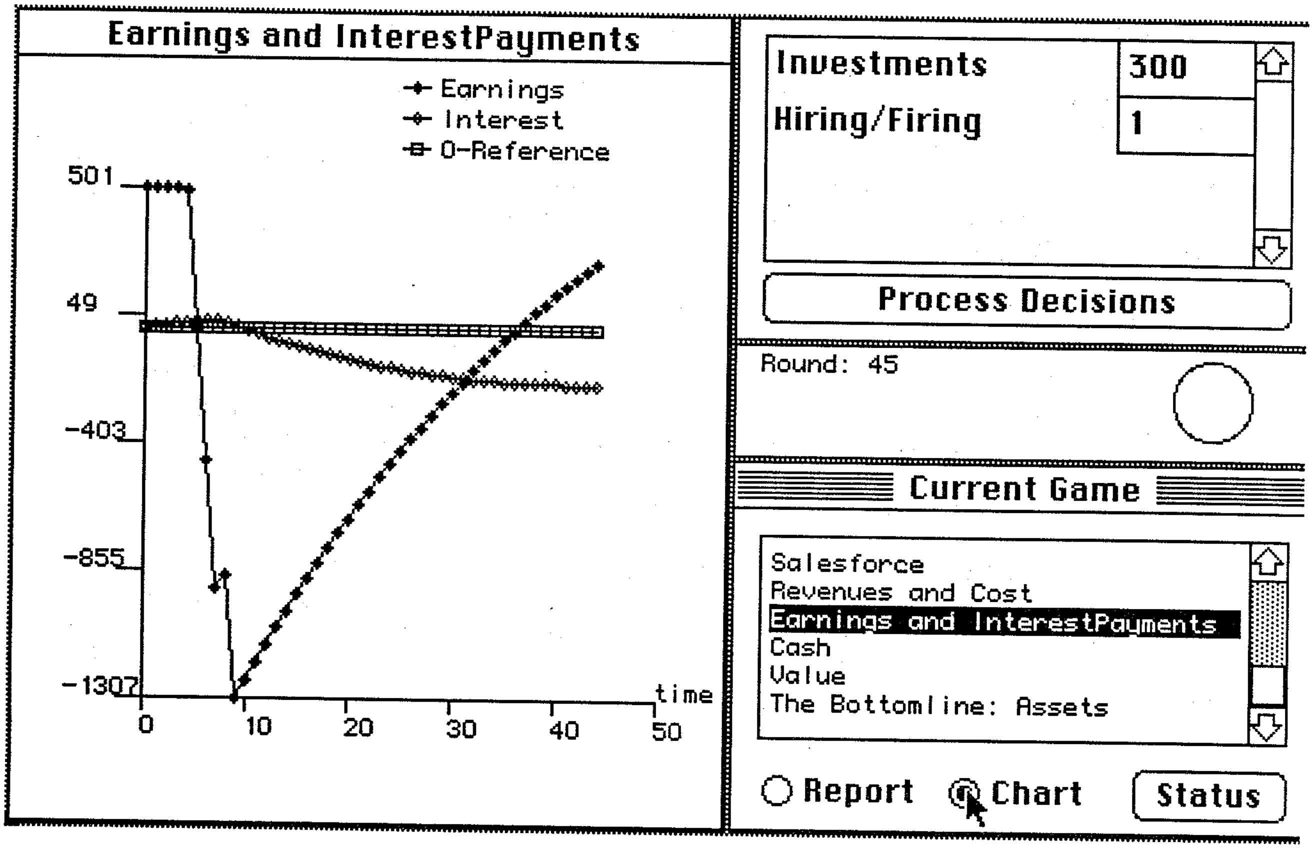
The total worth of your company consists of your cash balance and of the value that your physical plant represents. In your cash funds you accumulate the earnings you make each quarter (Revenues - InvestCost - Salaries). In addition you receive quarterly interest payments if your cash position is positive and you have to pay interest in case it is negative. The interest rate is 1% per quarter and is the same for both positive and negative balances. Your equipment is valued with the price you paid for it.

If you decided to do nothing for the course of the total game and to just replace depreciation, you would earn $32 million and the assets of your company would total $83 million at the end of the game. This is the reference value for assets that you will wish to exceed.

Chart and Report tools

In addition to the status window, you have access to a chart and report facility that allows you to review the development of all game variables. You select the report you want to look at, by clicking on it and then clicking on either 'Report' or 'Chart'. In the example shown below to, the manager selected a chart of 'Profit and Interest'. Clicking on 'Status' brings you back to the status window.

Figure 2: Screen with chart/report facility active



Feel free to ask questions about the rules of the game at any time. You may play the game as often as you wish."

The experiment was run during a one-week intensive training seminar in system dynamics for managers. Eight particpants of the seminar volunteered to take part in the study. The subject with the highest score in a game received a price of $50.

The subjects could play the game as often as they wished. Subjects could take as long to complete a game as they deemed necessary. The experimental conditions were thought to emulate the conditions in which an adult might use an educational computer program on his/her own.

SIMULATION RESULTS

A simulation analysis of the model reveals that performance is influenced by two main factors: delivery delay and capital growth. The effects of those two factors are quite different, however. While a lower delivery delay unambigously leads to higher performance, growth merely amplifies existing good or poor performance. A subject that acquires these two crucial insights of the model, should do well in the experiment.

To illustrate the *effects of delivery delay*, the model is run with a 'depreciation replacement only' policy for different initial settings for fifty quarters. In all these runs, backlog (10000 units) and initial assets ($51000) are the same. What differs is the composition of the intial value into cash balance and value of the physical plant. All the runs are equilibrium runs in the sense that the only variable that changes during the fifty rounds is cash balance as it accumulates net earnings and bears 1% interest per quarter.

An example: To simulate a delivery delay of four quarters (52 weeks), deliveries = MIN(Physical Plant, Backlog) has to be 2500 units given a backlog of 10000 units. 2500 units of physical plant valued at $10 each lead to a value of $25000. Given total initial assets of $51000, the initial cash balance is $26000. This run yields an accumulated profit of $21,573 as Table 1 shows.

Table 1: Results of equilibrium runs for different delivery delay conditions

Delivery Delay (weeks) (1)	Assets at t=50 (2)	Cash at t=50 (3)	Value of Plant (4)	Cash at t=0 (5)	Profit (3)-(5)
13	93,518	-6,482	100,000	-49,000	42,518
26	83,046	33,046	50,000	1,000	32,046
39	77,810	44,476	33,333	17,667	26,810
52	72,573	47,573	25,000	26,000	21,573
65	64,195	44,195	20,000	31,000	13,195
--	83,046	83,046	0	51,000	32,046

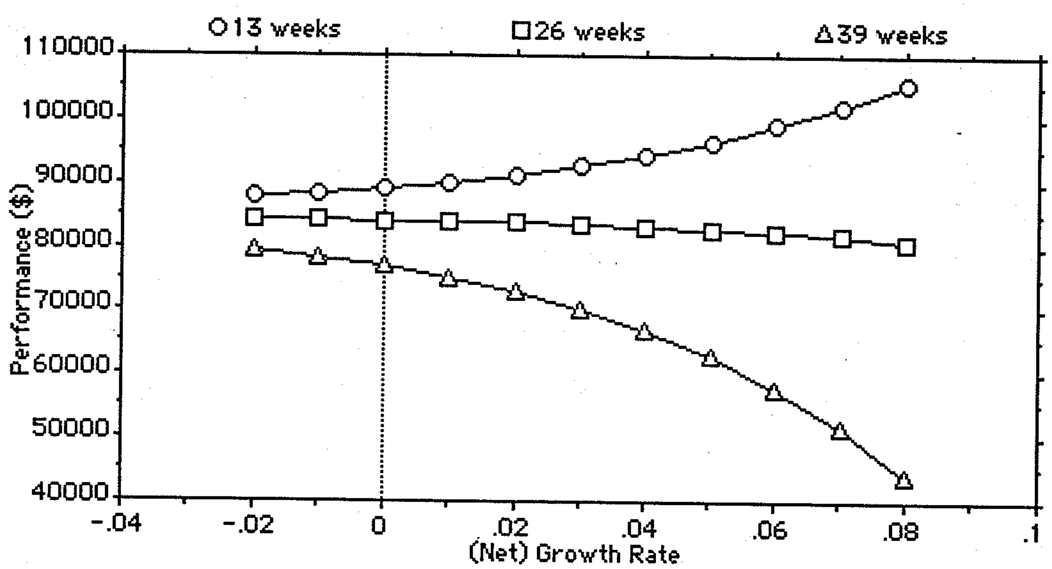
Table 1 illustrates that profit is the higher the lower delivery delay is. The last row in the table shows a situation where the company is merely a bank with no operating business. It is important to note that a company that maintains a delivery delay of 26 weeks does as well as a bank. If delivery delay is higher than that, the company would be better off to convert its physical plant into cash. A delivery delay lower than 26 weeks justifies investments into the operating business of the company, since the operations yield higher results than the opportunity to save the money and earn interest. This relation between operations and finance will prove to be important in understanding the effects of growth as discussed further below.

Although a low delivery delay unambigously improves performance, care has to be taken that physical plant does not exceed backlog. Such an overcapacity situation implies that part of the plant depreciates without having been used to its full production potential. The game is set up under the assumption that the minimum time it takes to produce an item is 13 weeks. An attempt to decrease delivery delay below thirteen weeks thus will fail and will lead to an overcapacity situation.

To show the *effects of growth on performance*, investment was stipulated as a fraction of current plant size. Since the quarterly depreciation is 2%, an investment fraction of 0.02 corresponds to the 'replace depreciation only' policy as conducted in experiment 1. To make the different growth scenarios comparable, the complete salesforce was laid off shortly before the end of the game to lead to a zero backlog situation at the end of the game.

Figure 2. shows the results of the game for three delivery delay conditions. Growth amplifies performance. If the company's operations yield better results than the company's saving would do, it makes sense to borrow money and to increase operations (see 13 weeks delay). Vice versa, if the company were better off to be a bank in the first place, it would be foolish to borrow money and to invest it into the unprofitable operations (see 39 weeks delay). If operations are as lucrative as savings, it does not matter if the company borrows money to invest into operations (see 26 weeks delay). In this situation, performance is insensitive to growth.

Figure 2: The effects of growth on performance under different delivery delay conditions



EXPERIMENTAL RESULTS

Figures 3a-h plots the outcome of the experiment for each subject on three dimensions: performance, delivery delay (incl. overcapacity), and maximum plant size. The number of games that a subject played ranges from 3 (subject F) to 16 (subject A).

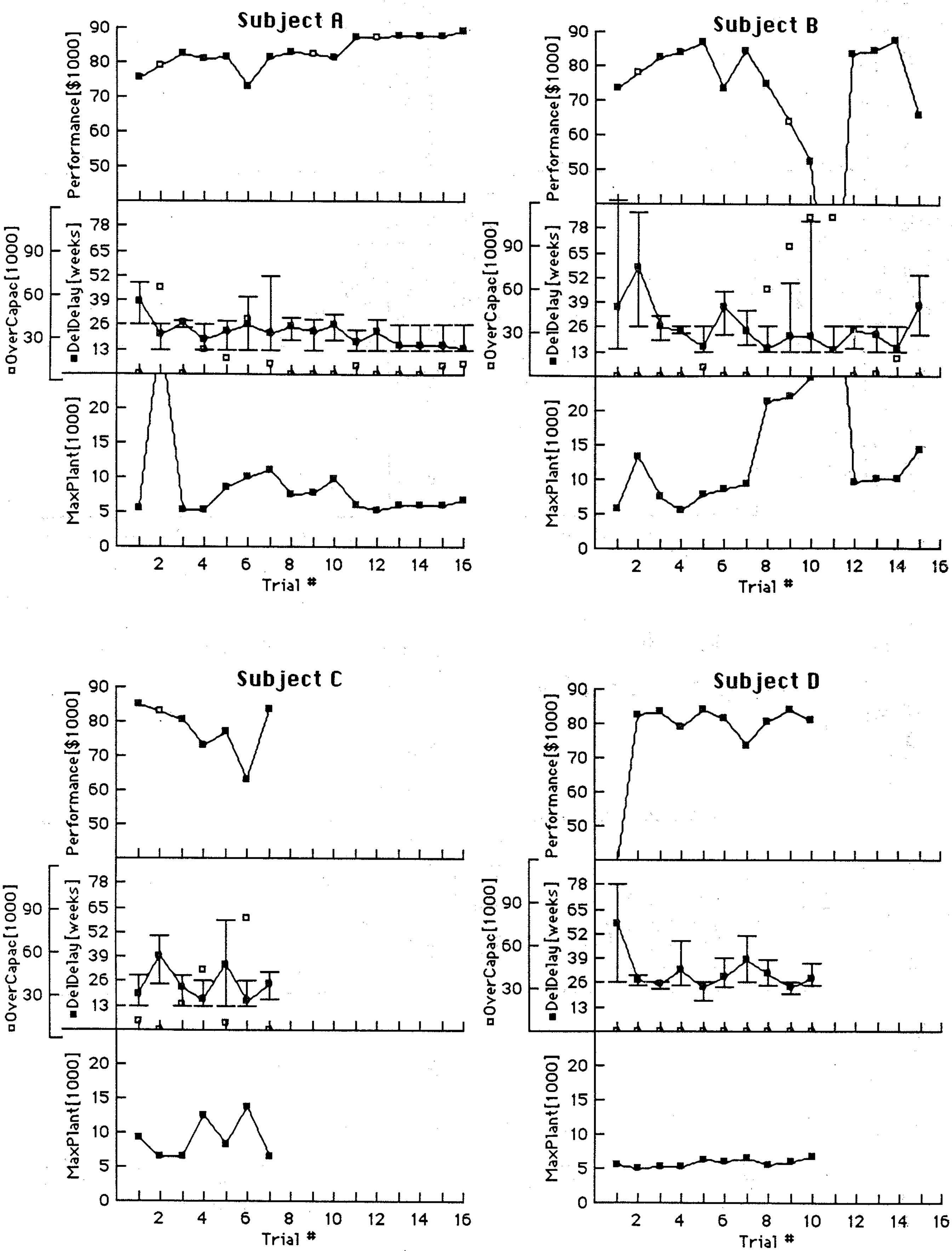
Most trials ended with total assets of $70000 - $85000 as the upper line charts illustrate.[2] This is quite an astonishing result. It means that in the majority of games, subjects performed worse than the 'replace depreciation only' policy that leads to assets of $83046. Subjects F,G, and H did not even achieve $83046 in their **best** try. An analysis of delivery delay and plant size provides a closer look at the causes for this surprisingly low performance.

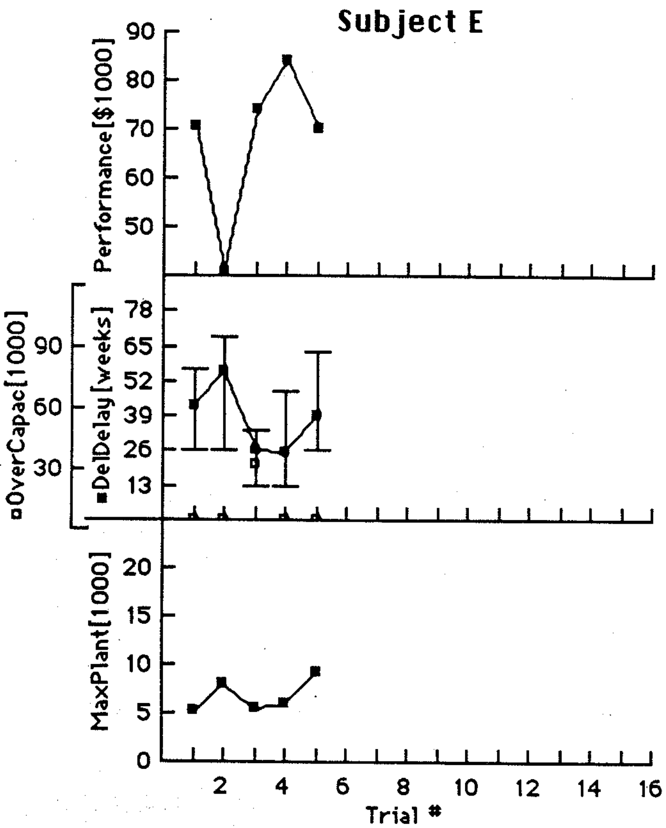
The middle charts show minimum, average and maximum value for delivery delay. In addition, accumulated overcapacity (unfilled rectangles) is shown.[3] All subjects (perhaps with exception of subject H) seem to employ some heuristics that prevent delivery delay from reaching extreme high values. The data do not allow to conclude if subjects deliberately controlled delivery delay or reacted to pressures in the system that are correlated with delivery delay. Only subject A, however, seems to have achieved a clear and concise understanding of the role of delivery delay and tightly controls it to a value of 13 weeks after trial 12, while at the same time avoiding overcapacity.

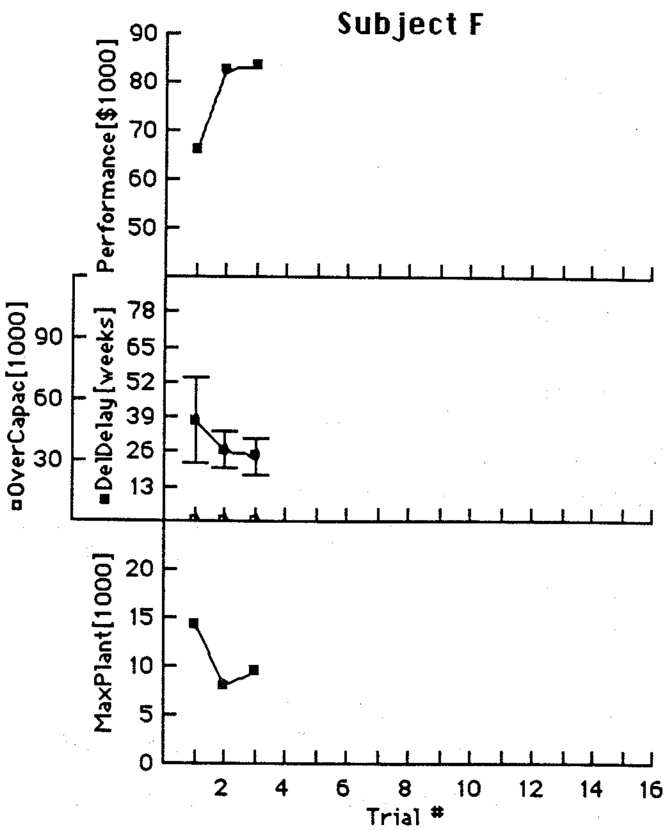
The lower charts show maximum plant size per trial. In most trials, the maximum plant size remained below 10000. That is, in the majority of games subjects have not even doubled the size of their plant after 12.5 years. With the exception of subject B, the chosen maximum plant size does not vary substantially between trials.

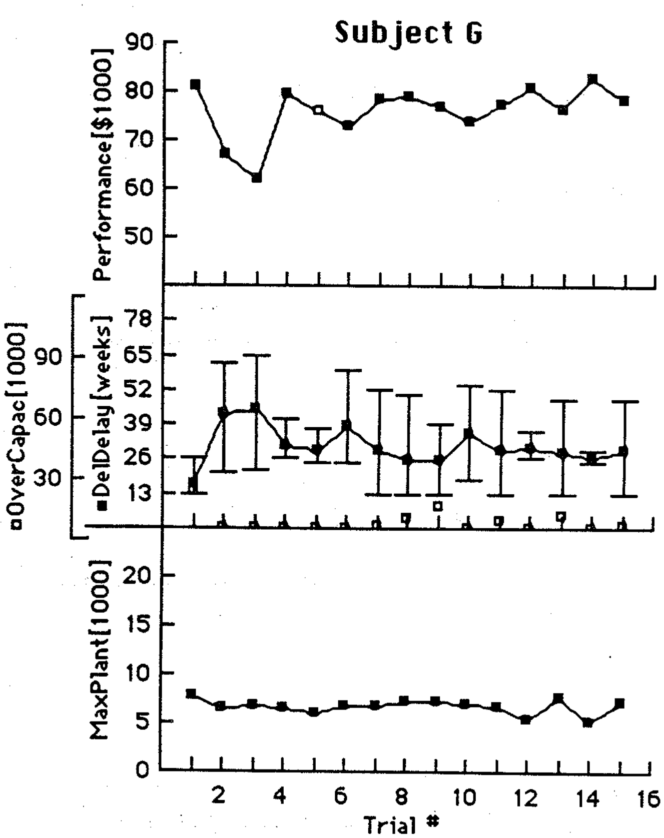
The results of this participatory simulation experiment confirm the experience that system dynamicists have gained in their traditional teaching practice using non-participatory simulations: If left completely to their own, students have difficulty to identify the high leverage points in a system and to implement succesful policies.

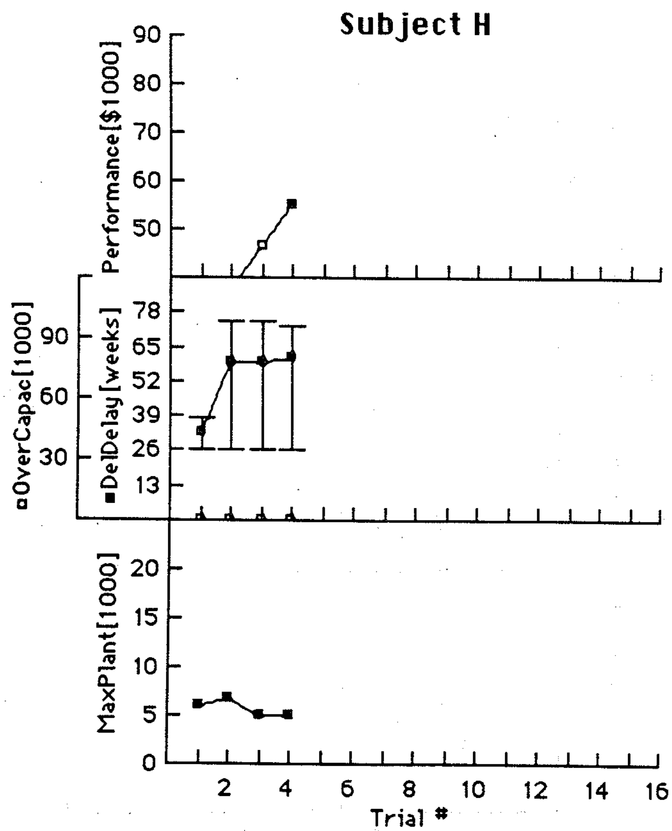
Figure 3a-h


Subject A
Subject B
Subject C
Subject D
Performance[$1000]
90
80
70
60
50
▫OverCapac[1000]
90
60
30
▪DelDelay[weeks]
78
65
52
39
26
13
MaxPlant[1000]
20
15
10
5
0
2
4
6
8
10
12
14
16
Trial #


Subject E
Performance[$1000]
▫OverCapac[1000]
▪DelDelay[weeks]
MaxPlant[1000]
Trial #


Subject F
Performance[$1000]
▫OverCapac[1000]
▪DelDelay[weeks]
MaxPlant[1000]
Trial #


Subject G
Performance[$1000]
▫OverCapac[1000]
▪DelDelay[weeks]
MaxPlant[1000]
Trial #


Subject H
Performance[$1000]
▫OverCapac[1000]
▪DelDelay[weeks]
MaxPlant[1000]
Trial #

CONCLUSIONS

In the experiment students were unaided in the sense that they did not receive any teacher-feedback about the effectiveness of their decision processes. The subjects had to rely on outcome feedback only. In static decison tasks, learning through outcome feedback has been shown to be rather ineffective (Todd 1965). The same seems to be true for dynamic decision tasks as this experiment and other studies have shown (Brehmer 1987).

Effective experiential learning thus needs to be facilitated through supplemental teaching aids. Rather than to confront the students with a complex dynamic system all at once, a succession of training exercises, each based on the lessons of the previous one, might be used. For example, rather than require the student to understand the consequences of delivery delay and growth in one step, a two- step experiment might be more effective. Providing process feedback might be another way to increase the effectiveness of experiential learning. Finding effective learning support tools is a major research challenge ahead.

NOTES

[1]Other fields of interest not reviewed in this paper include group dynamics, education and developmental psychology.

[2]An unfilled rectangle indicates that the subject chose not to finish the game.

[3]Overcapacity is the difference between plant and backlog for those instances where plant exceeds backlog; otherwise opercapacity is 0.

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APPENDIX

(1) Marketing department

Salesforce(t) = Salesforce(t-1) + HireFire(t)
HireFire(t) = DECISION(t)
Salaries(t) = Wage * Salesforce(t)

(2) Physical plant

Plant(t) = Plant(t-1) + Arrival(t) - Departure(t)
Arrival(t) = Investment(t-4)
Investment(t) = DECISION(t)
Departure(t) = Plant(t) / AverageLifetimeOfCapital
Pipeline(t) = Pipeline(t-1) + Investment(t) - Arrival(t)
InvestCost(t) = Arrival(t) * CostPerInvestment

(3) Customer service

Backlog(t) = Backlog(t-1) + Sales(t) - Delivery(t)
Sales(t) = NormalSalesPerSalesPerson * Salesforce(t) * SalesforceEffectiveness (t)
SalesforceEffectiveness(t) = MAX[0, 1.4 - PerceivedDeliveryDelay(t) / 65]
PerceivedDeliveryDelay(t) = DeliveryDelay(t-2)
DeliveryDelay(t) = 13 * Backlog(t) / Delivery(t)
Delivery(t) = MAX[Backlog(t), Plant(t)]
Revenues(t) = Price * Delivery(t)

(4) Accounting

Assets(t) = Value(t) + Cash(t)
Value(t) = Plant(t) * CostPerInvestment
Cash(t) = Cash(t-1) + Earnings(t) + InterestPayments(t)
Earnings(t) = Revenues(t) - InvestCost(t) - Salaries(t)
InterestPayments(t) = Cash(t) * InterestRate

(5) Initial Conditions and Constants

InitialSalesforce = 50
InitialCapital = 5000
InitialPipeline = 400
InitialBacklog = 10000
InitialCash = 1000

AverageLifetimeOfCapital = 50
CostPerInvestment = 10
InterestRate (per quarter) = 0.01
NormalSalesPerSalesPerson = 100
Price = 40
Wage = 10