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Decision Making Tests with Different Variations of the Stock Management Game

SERHAT AYBAT
Boğaziçi University

SİNEM DAYSAL
Boğaziçi University

BURCU TAN
Boğaziçi University

FULDEN TOPALOĞLU
Boğaziçi University

Abstract

The aim of this article is to find out the systematic errors underlying the decision making behavior of subjects by analyzing the results of controlled experiments via simulation models. The experiments were performed with a students' population on the generic linear stock management model, with inventory as level target variable and inflow and outflow as control variables with delay and secondary stock. Dynamic-complexity of Inventory Management Game is gradually increased by adding delay and secondary stock. In two sets of experiments, the effect of increasing dynamic complexity is analyzed with respect to three response variables. The 2-factor X 2-level parametric ANOVA was used to analyze the results of the experiment. The obtained results clarified authors' hypothesis that the performance of subjects tend to get worse as the clarity of feedback is reduced with increasing dynamic complexity. Majority of subjects had difficulties in controlling the inventory via a secondary stock even when the external conditions are at steady state. The presence of delay has a statistically significant effect on each response variable.

1. Stock Management Game

To analyze the systematic errors underlying the decision making behavior of subjects, the generic stock management problem, one of the most common dynamic decision problems, is chosen as the interactive gaming environment and it is extended in several directions. In a stock management problem one seeks to maintain a quantity at a particular target level or at least within an acceptable range. This quantity is the stock and it cannot be controlled directly but must be filled by its inflows and drained by its outflows. Another essential point of the stock-management problem is the decision rule used by the individual, which represents the decision-making process that takes place in the mind of the individual. In the generic case the only decision variable is “orders” as illustrated in Figure 1.

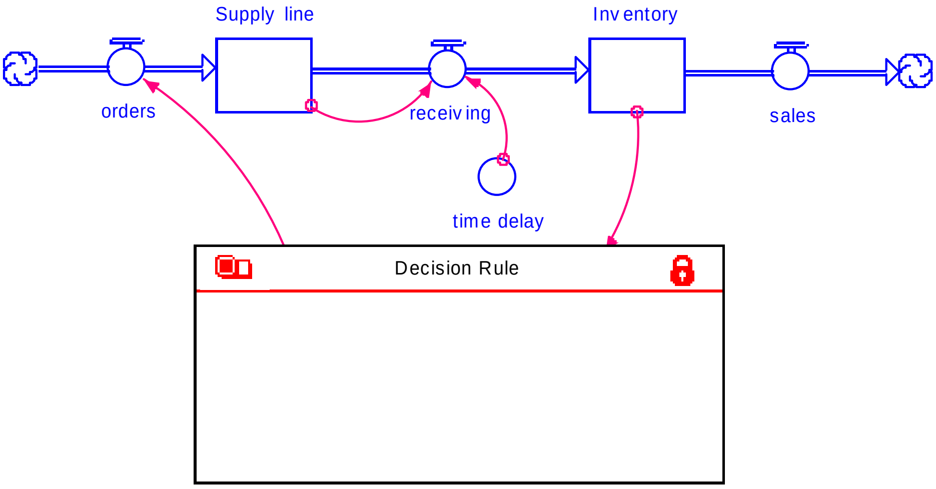


Figure 1: Generic Stock-Management Problem where the control variable is “orders”

This generic game is expanded in two major avenues, which are further divided into different levels of complexity. The first main model structure is “*single flow control of a stock” (SFC)*. For this set of models the commonality is the fact that only the inflow is to be controlled in managing the stock. The extensions for this class are designed to indicate the main effects as well as the interaction effects of a delay structure and a secondary stock structure integrated to the inflow.

The second main model structure is “*the control of a stock by two simultaneous decisions” (TSD)*. As the name implies in this set of models the control of the stock is accomplished by adjusting the inflow and the outflow levels of the stock simultaneously.

The objective of the games is defined as “holding the inventory at a level as stable as possible”. Fluctuations in the inventory level imply various costs, which is regarded as poor management and therefore subjects are asked for minimizing the fluctuations. The objective is kept as simple and as non-composite as possible. For this purpose, since driving the inventory to a target level is itself an issue, the target level concept is kept out of consideration. Backlogging is allowed and is not punished. Therefore subjects are left free to stabilize their inventory at any level.

Subjects are recruited from Boğaziçi University, mostly from undergraduate and graduate engineering students. (Refer to the demographic information at Table 1) Each experiment is carried out with a set of 10 subjects, who play the role of an inventory manager by making use of the interactive computer simulation game. In total, 100 runs of experiment are made; 9 of them are considered to be outliers, which are excluded. To obtain unbiased results, subjects did not play more than once.

Field of Study:	**Number of subjects**	**Percentage**
Engineering	66	0,73
Business/Management	9	0,10
Economics	9	0,10
Science	5	0,05
Social Sciences	2	0,02
Degree Status:	**Number of Subjects**	**Percentage**
Undergraduate	82	0,90
Graduate	8	0,09
Ph.D	1	0,01

Table 1: Subject Demographics

Monetary reward is used to motivate subjects. Economists generally argue that subjects should be paid in proportion to performance in experiments and find the results questionable when performance incentives are weak (Sterman, 2000b). It is questionable whether monetary reward is a sufficient incentive to guarantee that subjects put full effort into their tasks. Yet, there is some empirical evidence that the addition of rewards at least makes the results more reliable and reproducible (Friedler and Sunder, 1994).

In our experiments the score of subjects are determined in terms of their Fluctuation Measures. (Refer to Statistical Analysis and Experiments Section for the computation of the Fluctuation Measure) Lower costs imply better performance and higher reward.

Subjects are given a trial game of 10 decision periods whose results are not included to any analysis. The idea is to provide familiarization with the software and the mechanics of the game. The step-up in the demand is not observed in the trial game; therefore subjects do not take real actions against any disturbance.

Games are simulated for 75 periods. There is no time pressure upon subjects; they are allowed to play at their own pace. While playing the game, subjects can monitor the system from the information displays, which are designed to show their levels of inventory and decision variables. As the game progresses, they can also see the dynamics of these variables plotted on the graph. “Fluctuation Measure” figures are not displayed explicitly. However its definition is clearly stated in the instruction given to subjects at the beginning of each session. Each subject is also given a written instruction sheet presenting the problem and their task. Realistic stories are made up in order to form a parallelism between game structure and naturally occurring systems. Stories are told regarding the principle of keeping general contextual terms but avoiding terms with stronger flavor (Friedler and Sunder). Subjects are given a post-game questionnaire to obtain qualitative description of their decision-making processes.

2. Game Structures

Experiments are classified into two main classes according to their structures and further divisions within these classes are present.

1. Single Flow Control of a Stock (SFC)

The first main game structure is "*the single flow control of a stock" (SFC)*. For this set of games the commonality is the fact that only the inflow is to be controlled in managing the stock. The extensions for this class are designed to indicate the main effects as well as the interaction effects of a delay structure and the secondary stock structure inserted to the inflow of the stock.

SFC Game 1

The base model of the SFC game set is the one that lacks both of the above mentioned complexity factors. In this model the control of the stock is accomplished directly via its inflow and without any delay (Figure 2).

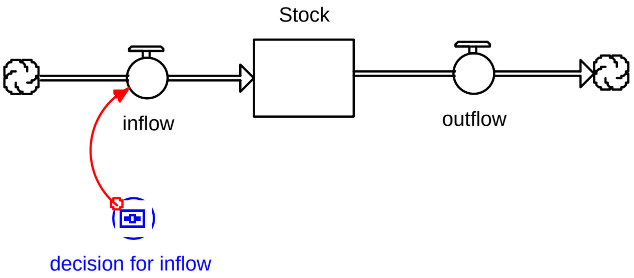


Figure 2: Base model for SFC

In SFC Game 1, the inventory has one inflow, which is the *"Order"* decision made by the decision maker and one outflow called *"Sales",* which corresponds to the customer demand.

SFC Game 2

The first extension of the base game is built by the inclusion of a first order material delay structure (Supply Line) to the inflow control of the stock (Figure 3).

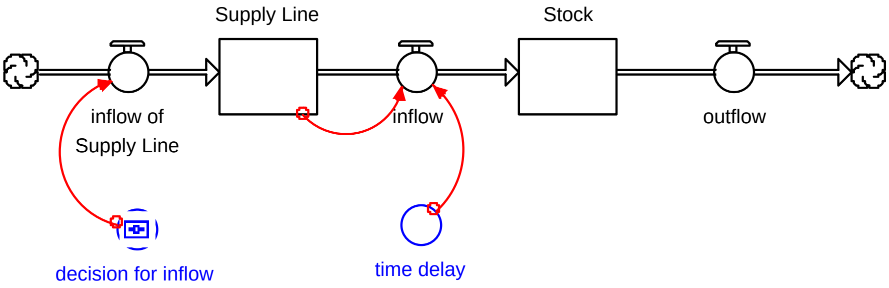


Figure 3: Delayed inflow control for SFC

In SFC Game 2, the only change with respect to SFC Game 1 is the fact that *"Order"*, which is placed by the decision maker, first enters the Supply line before altering the stock.

SFC Game 3

A second extension for SFC is the inclusion of the secondary stock to the inflow control structure. The challenge in this model is the control of the inflow indirectly by controlling the in/outflows of another stock known as the secondary stock (Figure 4).

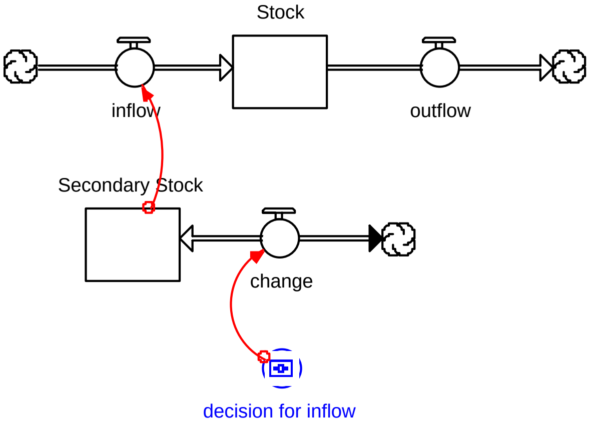


Figure 4: Indirect Control of the Inflow for SFC

This structure is converted to SFC Game 3, where the inflow of the "*Inventory*" (stock) is controlled by managing a secondary stock called "*Production Capacity*". The decision maker decides on the level of *"Capacity Change"* (decision for inflow) to alter the "*Production Capacity*" stock. The only outflow is *"Sales"*, which corresponds to the unknown customer demand.

SFC Game 4

Finally to test the interaction effect of the two complexity factors, the delay and the secondary stock, an information delay is imposed on the secondary stock structure in the inflow control. Therefore, in this model the control of the inflow is managed by influencing the in/outflow of another stock with an information delay, which in turn influences the inflow of the stock of consideration (Figure 5).

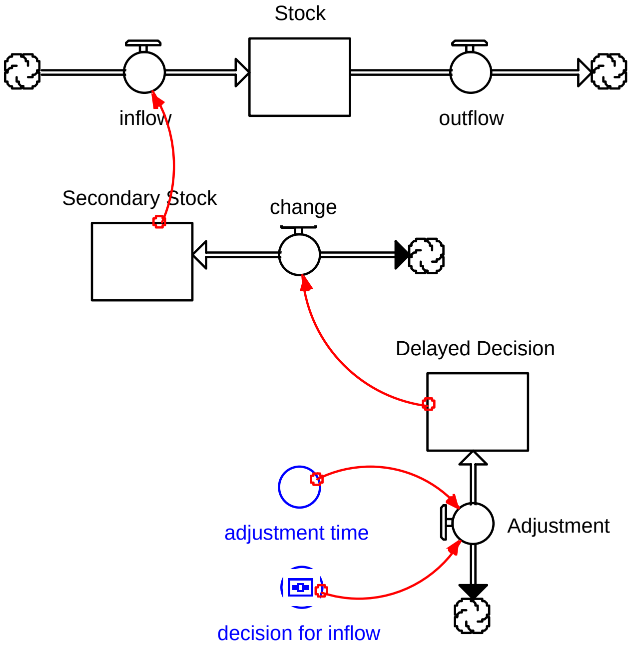


Figure 5: Indirect and Delayed control of the Inflow for SFC

In SFC Game 4, the only change with respect to SFC Game 3 is the fact that *"Capacity Change"* decision (decision for inflow) alters "*Capacity Adjustment"* (change) now with a first order exponential delay.

2. Control of a Stock by two Simultaneous Decisions (TSD)

The second main game structure is "*the control of a stock by two simultaneous decisions" (TSD)*. As the name implies in this set of games the control of the stock is accomplished by adjusting the inflow and the outflow levels simultaneously. For this set of games the commonality can be stated as the presence of the supply line, which induces a first order continuous delay to the effect of inflow on the stock level. The extensions for this class are designed to indicate the main effects as well as the interaction effects of an additional delay structure and a secondary stock structure integrated to the outflow control of the stock.

TSD Game 1

The base model for TSD game set is the one that lacks both of the above mentioned complexity factors. In this model the control of the stock is accomplished via its outflow and another stock's (Supply Line) inflow, which in turn influences the inflow of the stock of consideration with an explicit first order material delay (Figure 6).

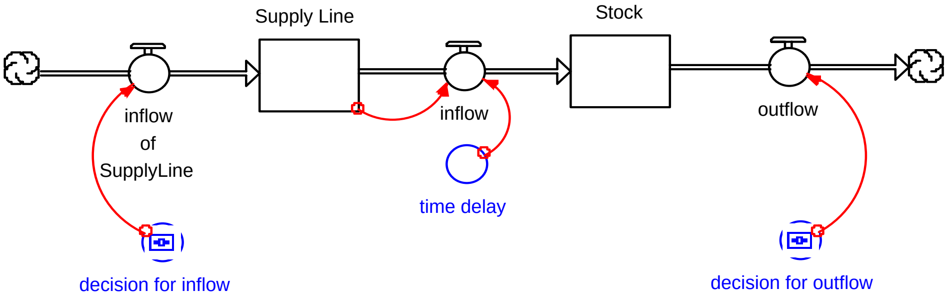


Figure 6: Base Model for TSD

Regarding this basic structure, TSD Game 1 is built, where the inflow of the *"Inventory"* (stock) is controlled via the *"Order"* decision (decision for inflow), with a first order exponential delay. Orders that are placed by the decision maker first enter the *"Supply line"* (Supply Line); they are said to be in transit. Inventory has two outflows: "*Sales"* and "*Extra Shipments",* which are combined under the name outflow in the figure above. "*Sales"* is equal to the customer demand over which the decision maker has no control. *"Extra Shipments"* is controlled via the *"Extra Shipments Decision*" (decision for outflow) directly.

TSD Game 2

The first extension of the base game is built by the inclusion of an information delay structure to the outflow control of the stock. (Figure 7).

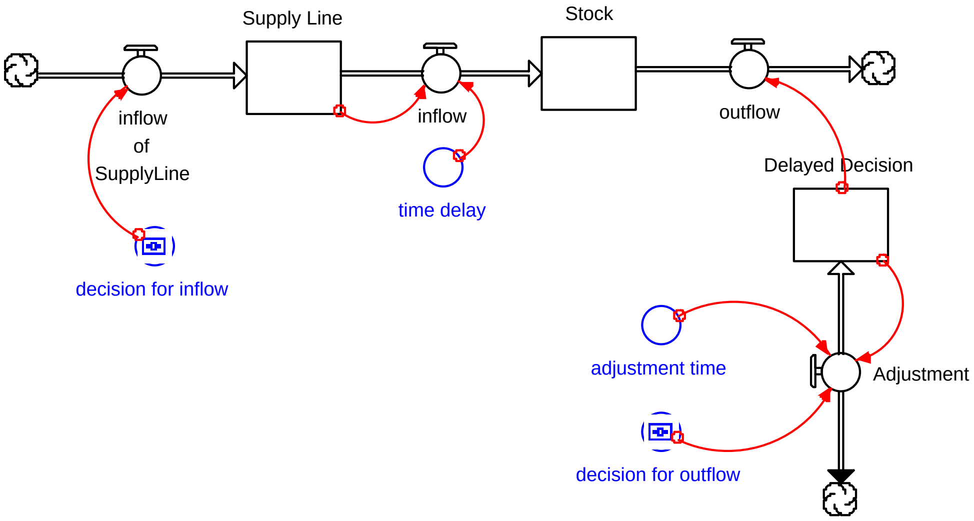


Figure 7: Delayed outflow control for TSD

In TSD Game 2, *"Extra Shipments Decision"* alters the *"Extra Shipments"* (Delayed Decision) with an information delay.

TSD Game 3

A second extension for TSD is the inclusion of the secondary stock at the outflow control structure. The challenge in this model is the indirect control of the outflow by controlling the in/outflows of another stock known as the secondary stock (Figure 8).

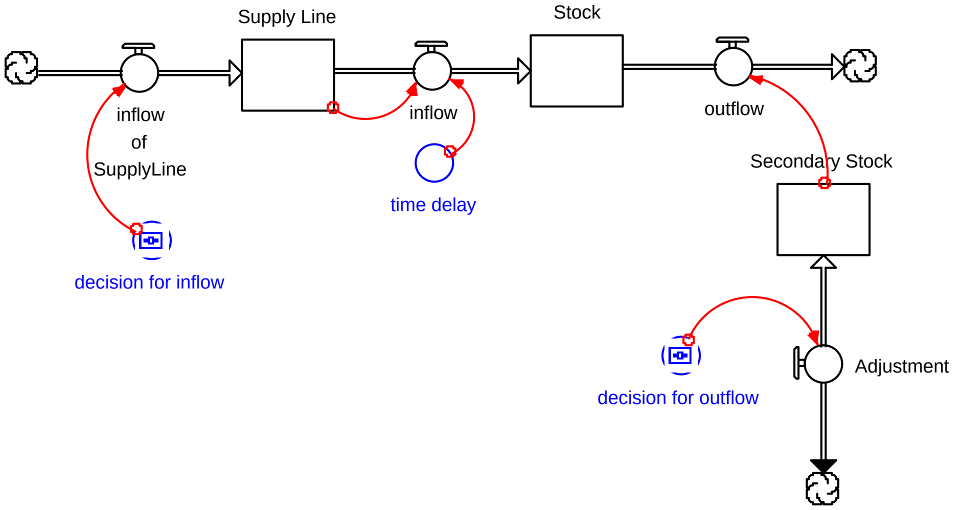


Figure 8: Indirect Control of the Outflow for TSD

This structure is converted into TSD Game 3, where *"Inventory"* (Stock) has two outflows being *"Wholesaler Sales"* and *"Retailer Sales"*, which are combined in a single outflow in the above figure. *"Wholesaler sales"* corresponds to the customer demand pattern, over which the decision maker has no control. *"Retailer sales"* is controlled via controlling a secondary stock called *"Marketing Budget per Month"*. Each dollar of "*Marketing Budget per*

Month" creates a specified demand for retailer sales per period. The decision maker decides on the amount of *"Budget Change"* (decision for outflow), which determines the level of retailer sales indirectly.

TSD Game 4

Finally to test the interaction effect of the two complexity factors, which are the additional information delay and the secondary stock, both structures are integrated to the system by imposing an information delay on the secondary stock structure of the outflow control. (Figure 9).

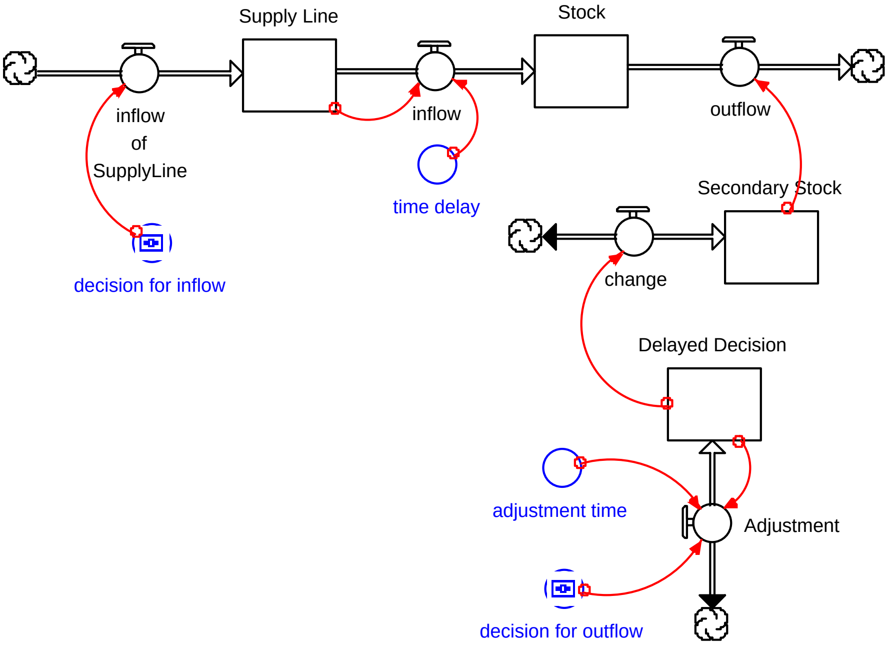


Figure 9: Indirect and Delayed control of the Outflow for TSD

In TSD Game 4, the only change with respect to TSD Game 3 is the fact that *"Budget Change"* decision (decision for outflow) alters *"Marketing Budget per Month"* (Secondary Stock) now with a first order exponential delay.

3. Statistical Analysis and Experiments

In this study, experiments are designed to capture the interaction as well as the main effects of two dynamic complexities: delay and the secondary stock.

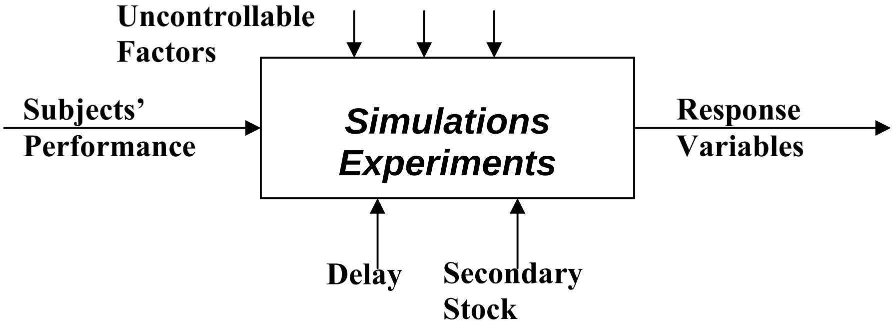
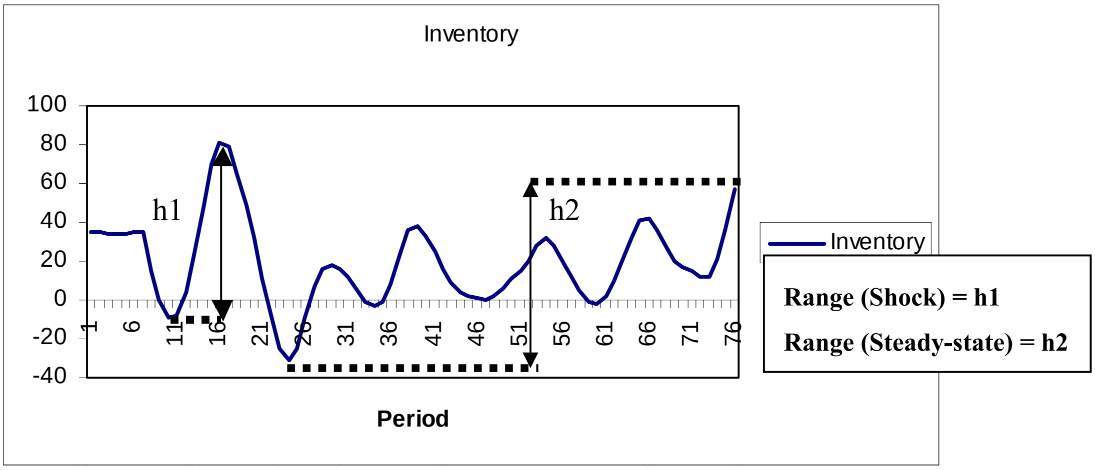


Figure 10: Design of Models

The response variables are:

- Range (Shock): The maximum change in the level of the stock under consideration in the transient period just after the disturbance.
- Range (Steady State): The range of the level of stock under consideration after the effect of disturbance is diminished.
- Fluctuation Measure: The total sum of successive ranges of stock under consideration.

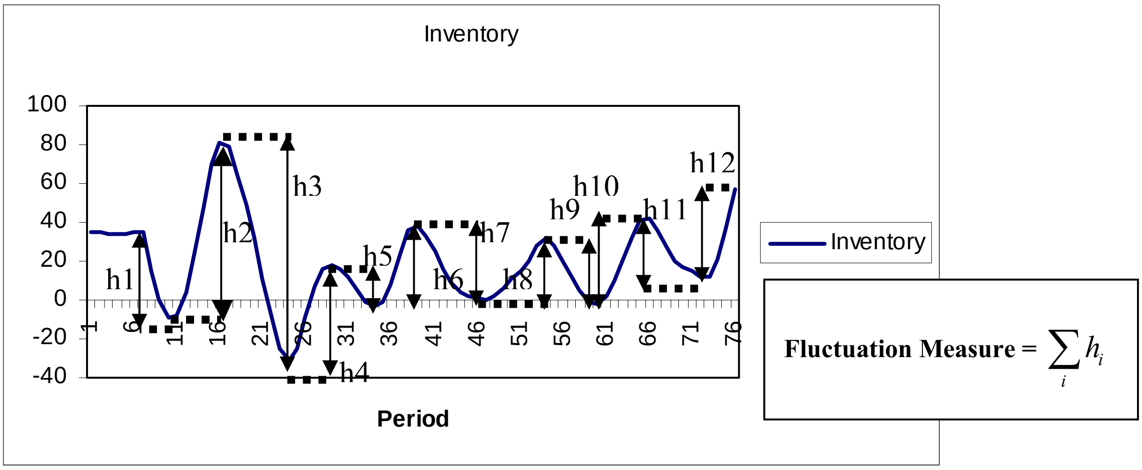
The above stated response variables explain the subjects' decision making behaviors in a direct and non-composite way. To be stated explicitly, the *shock range* measures the effect of disturbance in the demand pattern on the behavior of subjects. *Steady-state range* measures the capability of subjects to control the stock (inventory), under steady-state external conditions (demand). *Fluctuation Measure* indicates the total sum of fluctuations in the level of the stock throughout the game. Figure 11 and Figure 12 demonstrate the computation of the response variables.



Range (Shock) = h1

Range (Steady-state) = h2

Figure 11: Calculation of Range (Shock) and Range(Steady-State)



Fluctuation Measure = $\sum_i h_i$

Figure 12: Calculation of Fluctuation Measure, $\sum_t |I_t - I_{t-1}|$ **, I=inventory**

Representative summary measures of inventory levels computed from the experimental results are summarized in Table 2 and Table 3. The averages of the three output measures are also displayed for each of the experiments to give the reader an insight about the effects of the two factors on each of these measures. For instance, as one moves from run 1 to run 3 of the TSD games the only complexity factor added to the experimental design is the secondary stock. In this case the average of the two output measures, maximum change in the transient phase and the range of oscillations in the steady state period are affected significantly, whereas a minor change is observed in the total oscillations (a t-test between run 1 and run 2 would also yield the same conclusion).

	Experiment	R(Shock)	R(Steady)	Fluctuation Measure
SFC Game 1	**1**	40	13	148
	2	47	30	386
	3	24	43	158
	4	21	10	104
	5	40	24	152
	6	112	17	227
	7	58	4	208
	8	29	43	359
	9	169	73	590
	10	418	154	1313
	Avg. Of Run 1	95.8	41.1	364.5
SFC Game 2	**11**	184	10	306
	12	47	84	382
	13	23	56	190
	14	80	92	353
	15	171	61	353
	16	99	20	536
	17	301	22	1141
	18	71	44	281
	19	148	186	393
	20	61	54	498
	Avg. Of Run 2	118.5	62.9	443.3
SFC Game 3	**21**	62	576	939
	22	81	311	669
	23	36	115	471
	24	60	63	499
	25	241	141	609
	26	47	119	1305
	27	135	43	415
	28	61	16	217
	29	203	13	429
	30	118	56	698
	Avg. Of Run 3	104.4	145.3	625.1
SFC Game 4	**31**	721	111	1679
	32	84	203	993
	33	231	18	478
	34	862	2716	4976
	35	180	163	783
	36	383	83	731
	37	488	238	1748
	38	157	363	1801
	39	129	61	516
	40	340	384	1702
	Avg. Of Run 4	357.5	434	1540.7

Table 3: Experiment Data for SFC Game Set

	Experiment	R(Shock)	R(Steady State)	Fluctuation Measure
TSD Game 1	**1**	43	8	177
	2	75	19	152
	3	26	32	273
	4	28	45	257
	5	287	94	1412
	6	65	34	447
	7	33	22	279
	8	105	34	434
	9	128	43	352
	10	20	23	134
	Avg. Of Run 1*	81.00	35.40	391.70
TSD Game 2	**11**	39	464*	2450*
	12	92	88	592
	13	165	78	413
	14	83	51	572
	15	125	28	330
	15	53	1052*	2202*
	16	170	63	312
	17	205	106	903
	18	51	21	230
	Avg. Of Run 2*	109.22	62.14	478.86
TSD Game 3	**19**	83	57	461
	20	545	348*	1487*
	21	98	85	524
	22	417	1538*	6179*
	23	31	131	588
	24	106	51	350
	25	51	77	682
	26	339	465*	2895*
	27	97	46	220
	28	110	109	527
	Avg. Of Run 3*	187.70	79.43	478.86
TSD Game 4	**29**	136	68	270
	30	179	21	314
	31	145	242	867
	32	50	270	715
	33	159	564	1424
	34	93	61	397
	35	291	70	831
	36	116	124	516
	37	122	123	264
	38	53	38	270
	Avg. Of Run 4*	134.4	158.1	586.8

Table 2[*] Experiment Data for TSD Game Set

- Outliers are excluded from the analysis thus they are not considered in the averages.

For a definite conclusion about the significance of each of the factors on each of the output measures, an analysis of variance (ANOVA) has been carried out. The analysis is carried out for two game sets, first being the single flow control of a stock (SFC) and the other being the control of a stock via two simultaneous decisions (TSD). For each of the aforementioned analysis there are two factors of consideration; delay and secondary stock, which can take on only two values: existent and non-existent. To summarize, there are four combinations of the above two factors across the two levels of each. For this reason 2^2 factorial design is used for the statistical analysis of the experiments. Each condition is played ten times (random replications), yielding a total of forty experiments for one group of analysis. Outliers are removed from the sample set.

For each analysis normality assumption is checked. Whenever it is concluded that the data do not come from a normal distribution, necessary transformations are made in order to make t-test and f-test applicable. ANOVA is carried out for each game set using DESIGN EXPERT Software.

Analysis for SFC Game Set

The factors used in the factorial design of the SFC games are secondary stock and delay structure integrated to the inflow control of the stock.

	I	A	B	AB
SFC game 1	+	-	-	+
SFC game 2	+	+	-	-
SFC game 3	+	-	+	-
SFC game 4	+	+	+	+

Table 4: Factorial Design (A: Delay, B: Secondary Stock)

A summary table derived from ANOVA study of TSD games is shown in Table 7.

Factors		Range(Shock)	Range(Steady State)	Fluctuation Cost
Delay	Fo	10.84777	3.85685	8.47084
	P value (υ1=1,υ2=35)	0.0022	0.0573	0.0062
	Result	significant α=0.05	significant α=0.1	significant α=0.05
Secondary Stock	Fo	8.91101	12.10824	22.24498
	P value (υ1=1,υ2=35)	0.0051	0.0013	<0.0001
	Result	significant α=0.05	significant α=0.05	significant α=0.05
Interaction	Fo	2.01439	0.07714	0.00302
	P value (υ1=1,υ2=35)	0.1644	0.7828	0.9552
	Result	insignificant	insignificant	insignificant

Table 5: ANOVA Results for SFC Game Set

R (Shock)Response Variable

ANOVA results summarised in Table 7 show that delay and a secondary stock are significant model terms, which means controlling the inflow of the target stock with a secondary stock and controlling the inflow with delay have significant effects on the maximum change in the inventory level in the transient period just after the disturbance of the demand pattern. As illustrative game dynamics, see Figures 13,14,15,16.

R (Steady State) Response Variable

Statistical analysis shows that secondary stock is a significant model term, which means controlling the inflow of the target stock with a secondary stock has a significant effect on the range of inventory level in the steady state period after the effect of disturbance of the demand pattern on the inventory level has diminished. If we alter the confidence level to 90%, delay comes out to be a significant model term as well, meaning that delay has also a significant effect on the range of inventory level in the steady state period. As illustrative game dynamics, see Figures 13, 14, 15, 16.

Fluctuation Measure Response Variable

In the analysis of Fluctuation Measure output variable, delay and secondary stock are significant model terms, which means both delay structure and secondary stock have a significant effect on the Fluctuation Measure as illustrative game dynamics, see Figures 13, 14, 15, 16.

Figure 13: no delay, no secondary stock

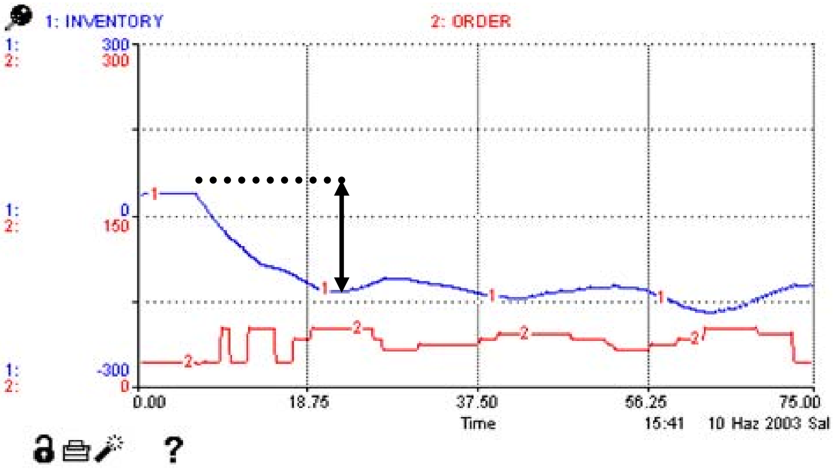


Figure 14: delay but no secondary stock

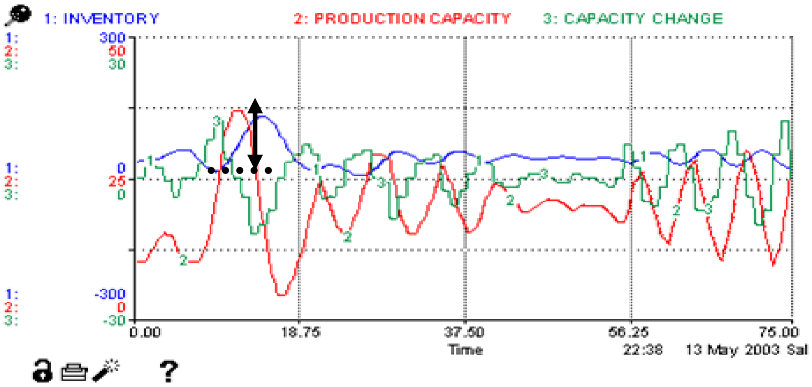


Figure 15: secondary stock but no delay

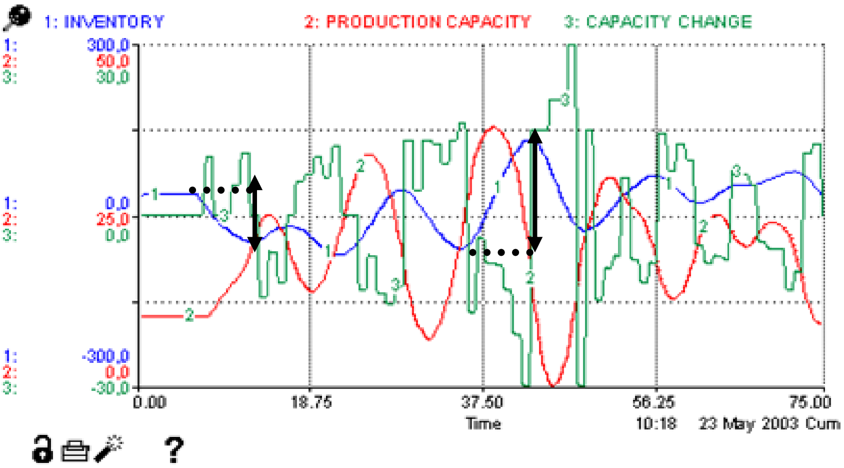


Figure 16: delay and secondary stock

Analysis for TSD Game Set

The analysis carried out for TSD focuses on the effects of complexity factors inserted to the outflow control of the stock of consideration, given that there exists first order material delay at the inflow.

	I	A	B	AB
TSD game 1	+	-	-	+
TSD game 2	+	+	-	-
TSD game 3	+	-	+	-
TSD game 4	+	+	+	+

Table 6: Factorial Design (A: Delay, B: Secondary Stock)

In Table 6, the first row shows names of the effects and the first column shows the experiments. ‘I’ refers to the basic effect that exists even all factors are absent, in other words it is a reference point. Due to the fact that it exists regardless of the type of experiment, its existence is denoted by ‘+’ in the design table. ‘A’ and ‘B’ denote the effects of delay structure and secondary stock, respectively. Finally, ‘AB’ denotes the interaction effect of delay structure and secondary stock when they coexist. To deduce the main effects and their interaction effect, four experiments were conducted. In *TSD game 1* both factors do not exist and it is denoted by ‘-‘ in the row of *TSD game 1*, under the names of factors, namely “A” and “B”. In *TSD game 2* only the delay structure and in *TSD game 3* only the secondary stock is added to the outflow control of the target stock. However, in *TSD game 4* both factors coexist that can cause an interaction effect beside the two factor’s main effects and the basic effect of the model.

A summary derived from ANOVA study of TSD games is shown in Table 7.

Factors		**Range(Shock)**	**Range(Steady State)**	**Fluctuation Measure**
Delay	Fo	1.85903	2.51677	0.90903
	P value ($\upsilon 1=1,\upsilon 2=35$)	0.1814	0.1216	0.3469
	Result	insignificant	insignificant	insignificant
Secondary Stock	Fo	5.13972	8.26160	2.77336
	P value ($\upsilon 1=1,\upsilon 2=35$)	0.0297	0.0068	0.1048
	Result	significant $\alpha=0.05$	significant $\alpha=0.05$	insignificant
Interaction	Fo	1.76837	5.90817	5.98450
	P value ($\upsilon 1=1,\upsilon 2=35$)	0.1922	0.0203	0.0196
	Result	insignificant	significant $\alpha=0.05$	significant $\alpha=0.05$

Table 7: ANOVA Results for TSD Game Set

R(Shock) Response Variable

ANOVA results summarised in Table 5 show that addition of a secondary stock is a significant model term, which means controlling the outflow of the target stock with a secondary stock has a significant effect on the maximum change in the inventory level in the transient period just after the disturbance of the demand pattern, given the model has a complexity factor of material delay at its inflow control structure. As illustrative game dynamics, see Figures 17, 18, 19.

R(Steady State) Response Variable

Statistical analysis shows that secondary stock and interaction are significant model terms, which means controlling the outflow of the target stock via controlling a secondary stock has a significant effect on the range of inventory level in the steady state period after the effect of disturbance of the demand pattern on the inventory level has diminished and coexistence of both delay structure and secondary stock creates a significant interaction effect on R(Steady State) As illsutrative game dynamics, see Figures 17, 18, 19.

Fluctuation Measure Variable

In the analysis of the response variable named Fluctuation Measure, the interaction effect of the delay and secondary stock is found to be the significant model term, which means coexistence of a delay structure and a secondary stock creates a significant interaction effect on Fluctuation Measure.

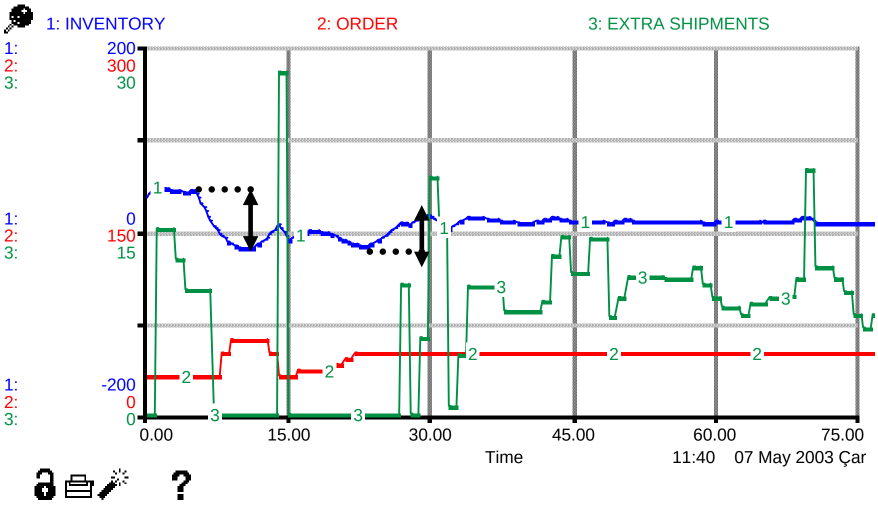


Figure 17: no delay no secondary stock

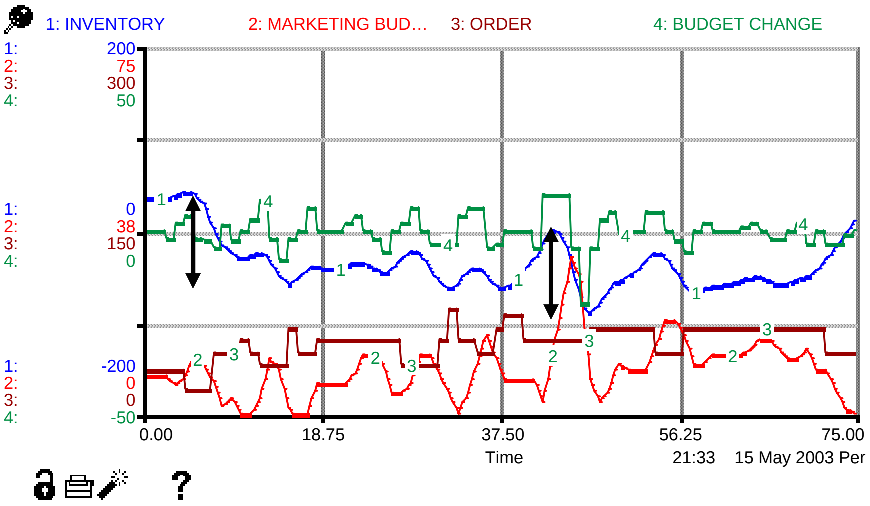


Figure 18: no delay, but secondary stock

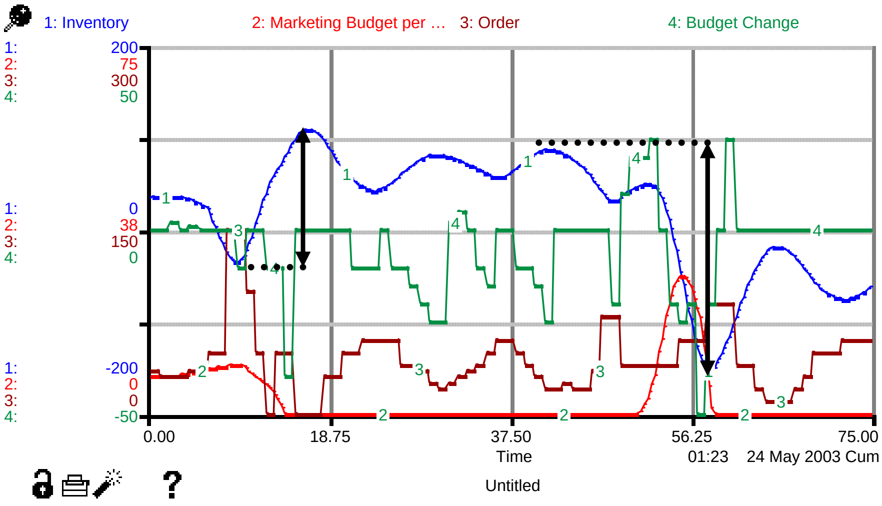


Figure 19: delay and secondary stock

4. Analysis of Post-Game Questionnaire

A post game questionnaire is used as a qualitative tool to understand the perception of the system by the subjects, to see if learning takes place and if it does to what extent. Below is a summary of the results of the post game questionnaire.

Estimation of Customer Demand

Throughout the game, subjects can monitor the levels of inventory and the decision variables using the graph and the information displays. Moreover, information on the delay structure and the delay time (when exists) are clearly stated in both verbal and written instructions. The only unknown is the independent customer demand, which can be figured out by monitoring the levels of inventory and decision variables and using the relation:

$$\mathbf{S_t = S_{t-1} + I_t - O_t}$$

where $\mathbf{S_t}$= Level of stock at t

$\mathbf{I_t}$= Net Inflow rate at t

$\mathbf{O_t}$=Net Outflow rate at t

However, in the questionnaire when subjects are asked to plot their best estimates of the customer demand, it is observed that only 24 % of the subjects are able to plot the demand pattern correctly. Majority of the subjects estimated a cyclic demand pattern, most probably due to their cyclic inventory patterns.

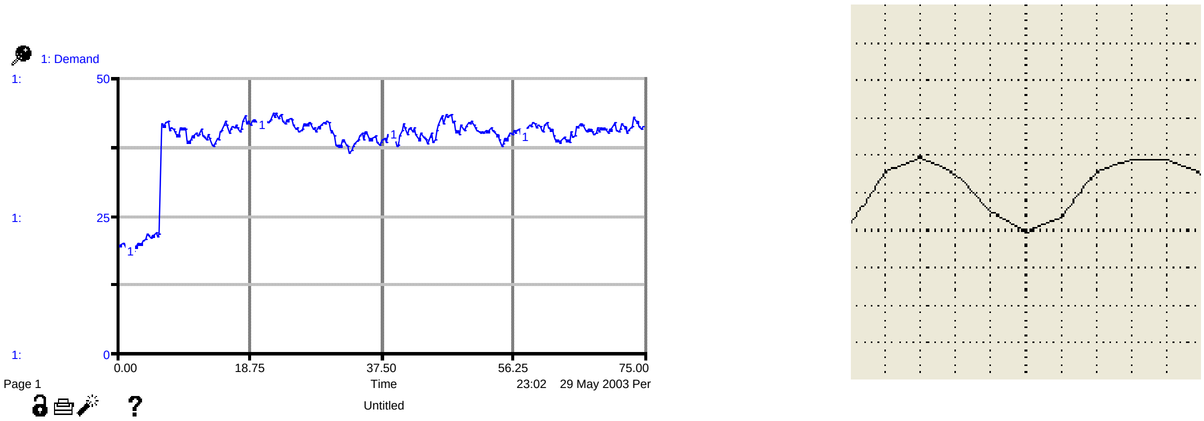


Figure 19: Actual Demand Data versus a typical estimation

Subjects' Explanation of Dynamics

The subjects are asked to state the cause(s) of the dynamics of their inventory(s). 14% of the subjects attributed the cause of the dynamics purely to external events stating that fluctuating customer demand is the cause of the fluctuations in the inventory. When they are asked to suggest ways to improve their performance, many requested better forecasts of customer demand and when they are asked to describe the pattern of customer demand, only a small fraction could suggest that it was essentially stable except for the shock at the 6th period. These explanations reflect an "open-loop" thinking of the origin of the dynamics, which is opposed to the thinking in which change occurs from the endogenous interactions of decision makers with their environment. (Sterman, 2000a) Although better forecasts can help to improve performance or noise in the demand can cause slight fluctuations, the key to the improved performance actually lies within the stock management policy. For example in Özevin (1999) availability of the demand data did not help at all to prevent over and undershooting of target inventory. After all, nothing can help a subject who cannot account for the supply line.

Answering the questions "What do you think is (are) the cause(s) of the behavior of your inventory?" and "How do you think you can improve your performance", many subjects displayed clues of learning effect. Specifically, to the second question, the most popular answer is "by trying once more". Some of the subjects explicitly stated that they began to play better towards the end of the game and that they wanted to replay. Figures 20 to 21 display the first and the second trials of two subjects. In both cases, the cycle amplitudes diminished and fluctuations decreased. However a diminishing cycle amplitude does not necessarily guarantee the presence of

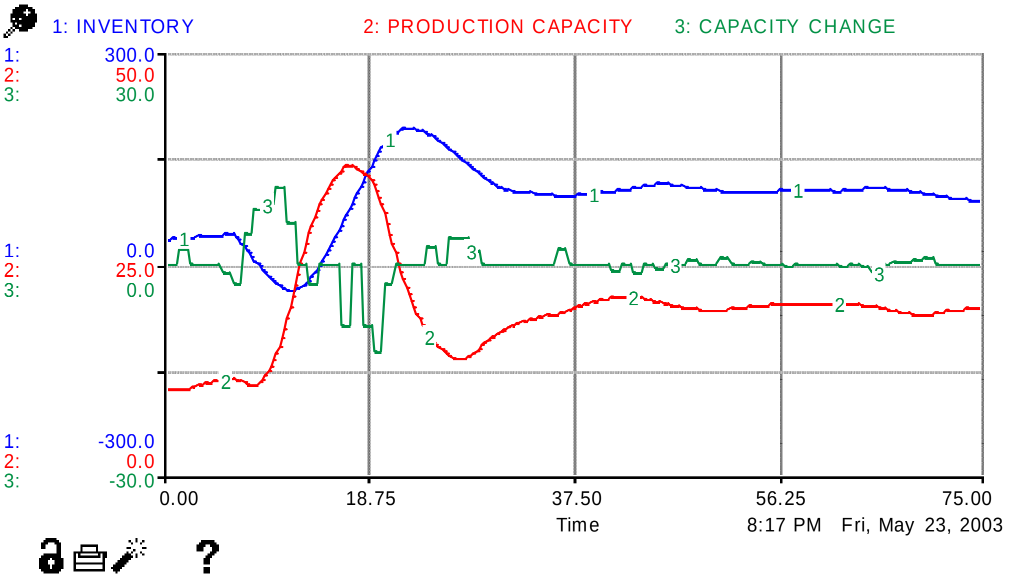


Figure 20: First trial of a subject in SFC Game 3.

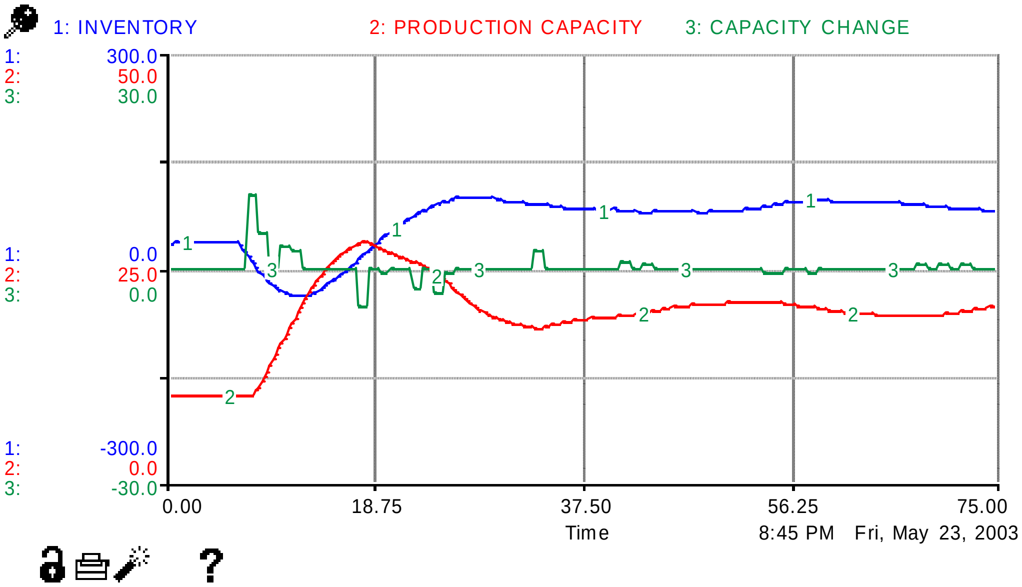


Figure 21: Second trial of a subject in SFC Game 3.

learning, or at least does not support any measure of how large the effect of learning is. Sterman (1987, p.1587) makes the differentiation as follows:

> "…Acquiring verbal reports from the subjects … may reveal the presence of learning within a single trial, but quantitative assessments of learning should probably be made by comparison of successive trials.
>
> Learning, however, does occur…. Subjects rapidly learn how to do better in the basic game, but an appreciation for the structure of the system and a robust ordering policy evolve more slowly."

Two Decision Variables versus One Decision Variable

In the first game set (TSD), subjects have two decision tools and are expected to make two simultaneous decisions, one regarding the inflow and one regarding the outflow control. However questionnaire data and screening of experiments revealed that almost 1/3 of subjects preferred to play by utilizing only one decision tool. Especially when the structure is asymmetric meaning that one decision affects directly while the other affects with a delay, naturally the former is preferred. What is not that obvious is on what grounds subjects prefer one tool to the other when the structure is perfectly symmetric. As a future work it would be interesting to test whether control of a stock is found "easier" with inflow control or vice versa.

Conclusions and Discussions

In this study, performances of subjects in an experimental stock management game are tested and analyzed to demonstrate and to recognize the systematic errors underlying the decision making behavior of subjects.

Controlling the target stock via a secondary stock induces an implicit delay and its effects have not been thoroughly investigated before in SD literature. The results of the analysis of the first set of experiments revealed that the majority of the subjects find it difficult to stabilize the inventory level via controlling a secondary stock, just after the dramatic increase in the demand pattern has occurred. The difficulty faced by the subjects is due to the fact that a simple stepwise increase in the value of the outflow control decision variable, results in a linear increase in the value of the secondary stock that gives rise to an exponential decrease in the value of the target stock over time. Nevertheless, another result demonstrated that performances are still poor even when the external conditions are at steady state. Effect of the additional delay structure at the outflow control is found to be statistically insignificant, which is surprising at the first glance. However, the delay structure on the inflow control may have screened the effect of the additional delay structure inserted to the outflow control. The results gathered from the analysis of the second set of experiments supported the authors' hypothesis.

The results of the analysis of the second set of experiments revealed that the presence of a delay structure has a statistically significant positive effect (CI=90%) on each of the response variables. This is again the case for controlling the inflow of the target stock over a secondary stock These results together with the ones explained above supported the hypothesis that the performance of subjects tend to get worse with the increasing dynamic complexity in the stock management system.

The subject set is composed of undergraduate and graduate students. Almost all of the subjects have taken courses in calculus and nearly 40% have taken courses in inventory management. Therefore, this naïve subject set can be expected to perform better than the average person in the given task. Furthermore there were monetary incentives motivating for high performance. Training in the task is provided through the trial game and no time pressure is applied. Feedback is instantaneous and clear. Yet, performances of subjects were not satisfactory with respect to the minimization of fluctuations objective. Subjects produced cycles even though the input to the system is non-oscillatory. Especially as the clarity of feedback reduced with increasing dynamic complexity, subjects' understanding of dynamic feedback environment decline resulting in poor performances. One could argue that the performances would be significantly better if the amount of the available information is extended to cover past sales data and supply line information. Though not statistically analyzed, a rough comparison made between the results of Özevin (1999) and the current study suggests that the poor performance in terms of inventory level fluctuations is unchanged, in spite of the fact that the information was available in Özevin's experiments. However a thorough analysis is left as future work.

To expand the study, there may be several directions. System Dynamics literature on dynamic decision-making does not provide many studies on the analysis of the effects of learning on the performance of subjects. Quantitative assessments of learning can be made by the comparison of successive trials, which is left as future work.

The objective of the games, which is "holding the inventory at a level as stable as possible", keeps the "target level" concept out of consideration. However the games may be tested with several other objectives such as "taking the inventory to a given target level as fast as possible and keeping it there in a stable manner" and "determining the 'best' level and stabilizing the inventory around that level". Studies on the former are being carried out.

Another research line, which is kept out of the scope of this study, is the analysis of decisions by fitting decision-making heuristics. For appropriate game structures, the performances of subjects can be compared to the simulated results that are obtained using various inventory control rules such as anchoring and adjustment rule, (s,S) policy, so as to test these decision rules.

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