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Title: THE DEVELOPMENT OF A METHODOLOGY TO STUDY THE EFFECTS OF PROCESS DYNAMICS AND COSTS ON OPERATOR BEHAVIOR

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Dr. Edward D. McDowell

A computer simulation was developed as a technique for studying the effects of the process dynamics on the operator's sampling and control behavior. This methodology was used to study the effects of the process input memory variation in the presence of different observation noise levels. It was concluded that the input memory and the observation noise level did not have any effect on the operator's sampling and control behavior.

The experimental design was then reformed, and another set of experiments was conducted to study the effects of the observation noise level on the operator's behavior in the absence of any input memory variation. It was concluded that the different noise levels had an adverse effect on the operator's behavior. That is, it was concluded that as the noise component increased, the operators tended to behave less economically.

In addition to the above, it was concluded that the operators had experienced a learning phenomenon in relation to the performed task.

The Development of a Methodology to Study the Effects of Process Dynamics and Costs on Operator Behavior

by

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Typed by Deanna L. Cramer for Mohammad Vahid Saedi

To my parents

and

my brother, Saeed

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CHAPTER I. INTRODUCTION

In almost any man-machine interaction the process can be assumed to be an environment consisting of an input, an output, and a control variable[(1)] which is specified by a human operator. The human operator can function as a supervisory controller by programming or adjusting the control variables, thereby optimizing a given performance function.

The main emphasis of this project is on processes consisting of a self-paced manual control task. These processes can be found in almost any type of an industry or managerial function such as chemical plants, aluminum factories, quality control, inventory control, and managerial auditing and accounting.

Considering the above processes, this study is beneficial in terms of

1. Training the new operators.
2. Retraining the operators so as to improve their skill in behaving more optimally.

[(1)] Control variable is that aspect of the system which is being controlled such as the altitude of a plane, flow of water, or speed of a vehicle.

3. Designing a work incentive through the use of the appropriate performance function.
4. Designing optimal control programs.

As was explained before, generally the process is assumed to be an environment. Granted, it certainly has some dynamic variables associated with it. Therefore, sampling can be defined as the identification of these variables, and its rate is dependent upon the rate of change of these variables.

Figure 1 is a pictorial representation of a typical process and its attributes where:

X(t) = input to the process

Y(x,z) = output of the process

Z(t) = control variables

V(x,y,z) = value function

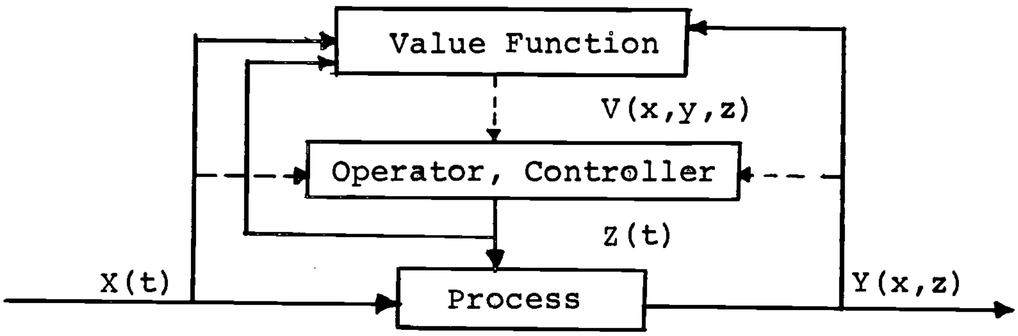

Figure 1. A typical process and its attributes.

The operator (i.e., controller) pictured above is defined by Sheridan and Rouse (1972) to be:

> ".... the person who decides when to sample the process input and what values of a control variable to specify in order to maximize (minimize) a given value function of input sampling period, control setting, and process state."

Up to now much has been said about the control function of a supervisor. Control function, as suggested by Crossman (1960), may be exercised through the following operations: (1) sense, (2) perceive, (3) predict, (4) familiarize oneself with the controls, and (5) decide. Through these operations and as suggested by Sheridan and Rouse (1972), three different control procedures become available to the operator as follows:

1. Operator can select and feed a desired objective to a computer. The computer then selects the parameters so as to match its system state to the specified objective. This is an example of an automated control system performing without operator's intervention.
2. Operator can specify a performance (value) function and preprogram the process as far as he thinks would maximize the performance function. This is a semi-automated control system in which the operator is only regulating the process.
3. Operator can select the parameters himself so as to optimize his performance. This is a manual control system in which the operator controls the

process himself. An example of this control system is the process of matching the input and the output of a system. In this system, the operator has three modes of control available to him as follows:

a. Continuous monitoring of the variables;

b. Sampling the variables;

c. Setting a control variable and ignoring the outcome of the process.

Considering the manual control procedure, the performance of the operator is evaluated through a value function which is expressed in terms of errors and their associated cost along with any appropriate sampling or control cost. An example of this performance function is the amount of CPU time consumed during a computer run.

The advantages of continuous monitoring of the performance function are twofold. It serves as a continuous feedback. Moreover, it serves as a reinforcement or reward in terms of optimizing the operator's performance. The disadvantages of this continuous monitoring is that although it serves as a feedback, at the same time it distorts the optimal sampling performance of the operators by providing a tool with which to set an erroneous upper limit on the level of their performance. As was explained before, the value function is expressed in terms of error and/or any appropriate sampling and/or control cost. Since not all performance functions incorporate a control cost, Sheridan (1970) suggests a "rule-of-thumb" for optimizing performance in the presence of a control cost:

> "If there is a significant cost of updating Y, the control setting or strategy, apart from the cost of sampling input X, then the supervisor may do better to sample X more often than he modifies Y, changing Y only if the new optimal Y nets a difference in return which is greater than the cost for modification."

The above rule-of-thumb might be applicable in theory but since Sheridan has not defined the significance level of the cost of control setting, this might not be applicable in practice. That is, there is no indication of an upper-limit on the control cost above which the cost would be significant in relation to the input sampling cost.

The foregoing discussions on control would be applicable to any type of process namely a single instrument process or a many-instrument process. A single instrument process is a process in which only one source of information is available to the operator. In this case if there is continuous visual attention, then the operator will receive adequate information by simply monitoring the variables very few times. But due to tremendous fatigue and cost, continuous visual attention and monitoring is not possible. In this respect, the operator needs a process control with little physical work and an optimal sampling strategy in order to make an optimal sequence of sampling, therefore, optimizing performance.

A many-instrument process is a process in which several sources of information compete for the operator's attention. By analyzing certain criteria such as importance of the information received from the source, cost of ignoring the source which is the same as the cost of error and sampling or control costs, the operator selects a specific source of information. Selection of this source, then forces the other sources to form a queue. So naturally the operators need a model to figure how optimally their attention should be distributed among various sources of information.

In designing an optimal sampling and control strategy the effects of some important variables should be evaluated on the operator's sampling and control behavior. The following is a list of the necessary variables along with their importance:

1. Nature of the process. This is significant because the operators tend to behave differently depending upon the response time of the process.
2. Operator's knowledge of the process. Studying this variable yields the understanding of how different operators with different backgrounds perform a given task. In other words, this is the effects of instructions.

3. Effective costs (e.g. sampling, error, and control). This is significant because theoretically as the error cost increases, the operators should take more samples to compensate for their errors. Also as the control cost increases, operators should sample very few times because there is no point in sampling if no control is desired.
4. Nature of the input. This relates to the memory of the input function of the given process and is significant because theoretically as the memory increases the operators should take less input samples, because the process would be more dependent on the historical values.
5. Uncertainty in the behavior of the system. This relates to the noise component of the process, and is important because the uncertainty tends to follow the general pattern as suggested by Crossman, Cooke and Beishon (1964) as depicted in Figure 2a and b).

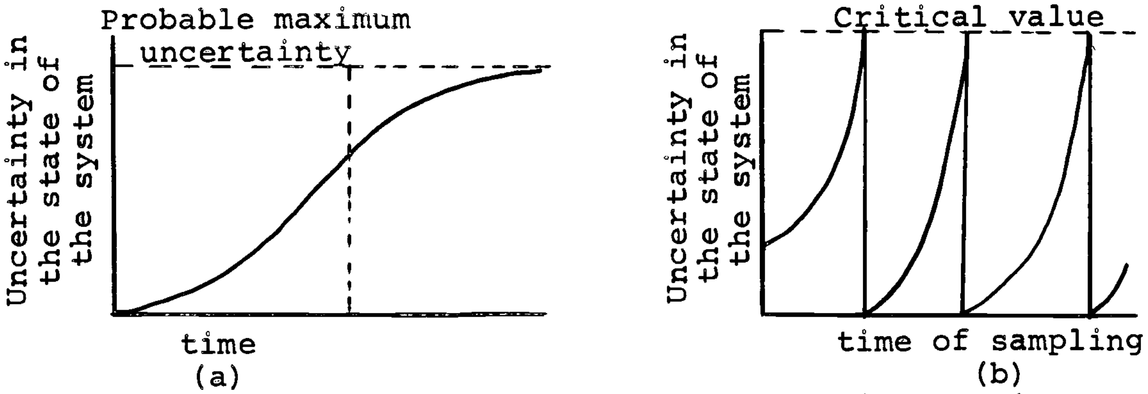

Figure 2. Level of uncertainty as a function of time.

This suggests that as the time progresses uncertainty may or may not reach a maximum limit (2a). Upon reaching the limit, the operator takes a sample to reduce the uncertainty from a critical value to zero, although at time zero the operator has a certain level of uncertainty which cannot be reduced to zero (2b).

Objective

As explained before, the variables listed on pages 7 and 8 should be analyzed individually in terms of their effects on the sampling and control behavior of an operator in order to develop models of sampling and control behavior.

The primary objective of this project is to develop a general research methodology based upon computer simulation to serve as a tool in studying the effects of the variables listed on page 8 on the sampling and control behavior of an operator. It should be noted that this methodology is applicable only to those processes which involve a self-paced task where time is not a constraint.

In order to test this methodology, it will be used to examine the effects of the nature of the input process memory and the observation noise.

In the first phase the effect of the nature of the process input will be studied in the absence of any control cost. The nature of the process input is the level of its memory or capacity (i.e., the level of its dependency on the historical values). The hypothesis being considered in this phase is that there is an inverse relationship between the memory of the input function and the sampling rate of the operator. That is, as the memory increases, the number of samples per observation decreases.

In the second phase, the effect of the observation noise will be studied in the absence of any process input memory variation (i.e., while keeping the process input memory constant). The hypothesis being considered in this phase is that there is a direct relationship between the observation noise level and the sampling rate of the operator.

Along with the two phases mentioned above, an Embedded Figures Test (EFT)[2] will be conducted in order to examine the hypothesis that there is a direct correlation between the achieved results and the perception capacity of the operators.

Organization and Scope

The literature survey and the theoretical background is presented in Chapter II.

Chapter III presents the designed methodology along with all the necessary documentations for further use. The two phases of the experiment, along with all the tests

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(2) For more information regarding the test, refer to Chapter IV and Witkin and *et al*. (1971).

and designs are presented in Chapters IV and V. Chapter VI presents the experimental results along with recommendations and suggestions for future studies.

CHAPTER II. LITERATURE SURVEY AND THEORETICAL BACKGROUND

The problem of designing an optimal control and sampling strategy has long been considered by researchers. In 1970, Sheridan (1970) developed an equation for the optimal sampling interval T and the optimal control Y as follows:

$$T_{opt} = \underset{T}{\text{Max}} \left\{ \frac{1}{T} \int_{t=0}^{t} \left[\int_{x_o} Y_{opt}[V(x,y), x_o t]\{x_o\} \right] - \frac{C}{T} \right\}$$

$$Y_{opt} = \underset{Y}{\text{Max}} \int_{x'} \langle V|x'y \rangle \{x'|x_o t\}$$

where: T = sampling interval

$V(x,y)$ = value function (reward or penalty)

$\langle\ \rangle$ = expected value

C = cost of sampling the input

{ } = probability density

x = input, y = control variable

x' = value of x at time t

x_o = value of x at time t = 0

$\{x'|x_o t\}$ = conditional probability density

The above theory is applicable for any input time series and its probability along with any value function and sampling cost. In some instances where computer solutions to Y_{opt} and T_{opt} are desired, the values for the conditional probability density can be generated using a Monte Carlo simulation instead of generating them analytically.

In an experiment Sheridan and Rouse (1972) tested the above theory through a prediction task. The experiment consisted of a self-paced task in which the subjects were asked to make predictions (in a least-squared error sense) of the future values of a time series. These values were the outputs of a second-order digital filter driven by a zero-mean white noise realized using a Gaussian random number generator. All the process constants, including the bandwidth and the sampling cost were specified by the experimenter.

Before the experiment, each subject was told that the input he was predicting was the output of a second-order filter, and that this output had a mean equal to 50 and a variance of σ_0^2. After inputting the appropriate predicted value (integers between 0 and 100), the subjects were given the following as feedback:

1. Actual input values
2. Sampling cost per unit time
3. Squared error per unit time
4. Value function (score) = sampling cost/time + squared error/time
5. Amount made during the run, given at the end of each run.

The experiment was conducted in two phases. In the first phase the subjects were allowed to select the prediction or sampling period themselves. In the second phase the sampling period was specified by the experimenter. So, actually the purpose of the two phases of the experiment was to study the operator's ability to pick optimal prediction intervals and to predict between intervals. The results of the experiment are summarized as follows:

1. The subjects consistently underestimated the optimal sampling periods except on the low sampling intervals.
2. The subjects were closest to optimal for sampling interval of five with a percentage of 0.864.
3. The subjects' scores were much different than optimal due mainly to higher sampling cost per unit time (because of selection of low intervals by the subjects).
4. Long intervals showed the effect of a suboptimal prediction strategy more than short intervals.

In an attempt to identify the effects of instructions and conditions of practice on the operator's behavior, Crossman and Cooke (1962) conducted an experiment using a slow-response system. The subject's task was to bring the temperature of water from 70°C to 85°C and maintain it for 30 minutes. The control was applied using a voltage transformer, and sampling was done via a thermometer. In addition, a lag of two minutes was introduced into the process.

Regarding the effects of instructions, it was concluded that those subjects who were technically informed about the nature of the process performed worse than those subjects who were simply told what voltages would produce what temperatures.

In relation to the effects of the conditions of practice, it was concluded that transferring from a difficult control task to an easy one was likely to be better than vice versa.

Two years later, Crossman, Cooke, and Beishon (1964) studied the effects of practice and the relationship between the sampling interval and the system state using the above experimental setup with a minor modification. In this experiment, the thermometer and the transformer were covered by a flap which the subjects had to remove for inspection.

The researchers' usage of the flap to cover the displays introduced the use of the operant conditioning studies of animal behavior presented by B. F. Skinner. This requires the subjects to make an "observing response" by pressing a key or flipping a lid when they wish to view the displays or a portion of them. In this respect, the signals act as the reinforcing agents. However, as the above researchers suggest, it might not be the signals but the detections that provide reinforcement and hence control the rate of the observing responses. This principle would be helpful in studying the sampling problem of how operators should distribute their attention when too much information is available.

Returning to the experiment, it was proved that:

1. There existed an inverse relationship between the sampling cost and the sampling rate.
2. No extra sampling was caused by forgetfulness.
3. Sampling rate increased as the variable got closer to its tolerance limits.

In a recent experiment, Rouse (1973) studied the effects of the input variability and the operator's knowledge of the system on the operator's performance using a prediction task. An output of a discrete linear dynamic system using Z transforms and rectangular integration was generated. The input to the system was a zero mean Gaussian process which was added directly to the output. The subject viewed the last ten points of the system output and was asked to predict the eleventh point.

The task was on a slow enough time scale in which physiological constraints were insignificant compared with cognitive limitations. So any suboptimality was due to mental limitations. It should be noted that the model used in the experiment was basically a linear regression system with a limited memory and noisy observation.

The observation-noise idea was applied to the model by assuming that the standard deviation of the subject's estimate (σ_x) of a quantity x was given by $F = \frac{\sigma_x}{|x|} =$ constant. Considering this fact, two values of F were selected namely, 0.07 and 0.12. Two sets of subjects were used, well acquainted with the system dynamics and optimal control and not acquainted with the system. Each subject performed ten trials. The last two trials served to show the effects of different input variances (and thus output variances) on similar dynamics.

The results of the experiment were as follows:

1. No statistical difference between the subjects was identified.
2. No statistical difference due to the two different values of F was identified.
3. Changing the input variances had no effect on the subject's performance.

In comparing the above experimental results with several actual models, Rouse concluded that a model with perfect memory did very much better than the data.

It should be clear by now that all of the above researchers have studied the effects of some aspect of the process dynamics. Although, none has attempted to design a general methodology with which to study the effects of the different variables involved, and at the same time isolate those environmental factors which are being introduced in the studies because of the use of the different experimental set ups.

Due to the above argument, the objective of this study is to develop a computer simulation to serve as the single experimental methodology in studying the process dynamics.

CHAPTER III. THE METHODOLOGY

The proposed methodology is based on a computer simulation which utilizes a CDC-3300 computer system and is written in BASIC language.

Model Attributes and Assumptions

The method developed here follows the same basic pattern of the typical process depicted in Figure 1. The output of a first order auto-regressive function driven by normally distributed random error terms with mean zero and variance one serves as the input to the process. The input could be characterized by the form:

$$(x_t - \mu) = \alpha(x_{t-1} - \mu) + k\ u_t \qquad (1a)$$

or more simply as

$$x_t = \alpha x_{t-1} + \mu(1 - \alpha) + k\ u_t \qquad (1b)$$

where: x_t = input to the process at time t

μ = constant specified by the experimenter

α = memory of the input function

u_t = random error distributed $\sim N(0,1)$

The output of the process is of the form

$$Y_t = \mu_1 Z_{t-1} \qquad (2)$$

where: Y_t = output at time t

Z_{t-1} = control variable at time t-1 specified by the operator

μ_1 = constant specified by the experimenter

This implies that the output of the process lags the control variable by one time unit.

The general form of the value function is as follows:

$$V_t = C_e[x_t - Y_t]^2 + C_x \sum_{i=0}^{N} \delta_{ti} + C_z\delta_t' + C_y\delta_t'' \qquad (3)$$

where: V_t = value at time t

C_e = error cost

C_x = input sampling cost

δ_t = 1 if input sample taken and 0 if sample not taken

N = total number of samples taken

C_z = control cost

δ_t' = 1 if control applied and 0 if control not applied

C_y = output sampling cost

δ_t'' = 1 if output sample taken and 0 if sample not taken

In the above, the principle of squared error is utilized to estimate the amount of error at each time unit. Assuming T to be the total time cycle of the process, the total value of the above function would be

$$V_T = \sum_{t=1}^{T} V_t \qquad (4)$$

Computer Simulation

The computer simulation is comprised of two computer programs: (1) auxiliary, and (2) main. The auxiliary program serves as an input data file to the main program. Upon calling and running the program, the experimenter can select and input the appropriate costs (e.g. error, sampling, and control costs), μ and the first term of the input function (i.e., x_o), the memory of the input function (α), coefficient of the output function (μ_1), experiment cycle (T), interval of statistics (i.e. the length of the interval which the results should be tabulated by) which could be either an interval of ten or twenty-five time units, and the noise factor (k) affecting the input observations. The use of the latter would be explained later.

Once all the above variables are entered, they would be stored in a file internally and subsequently used by the main program as the input data file. In essence, with the aid of the auxiliary program, the experimenter can select and build an input file without stepping into the main program. The listing and a sample run of the auxiliary program is presented in Appendix A.

The main program is comprised of the following segments:

I. Input

In this segment, initially the input file created by the auxiliary program is called and all the variables are read in. In addition, another internal file is created which serves as the output file for storing the tabulations and statistics performed on the experimental results. Moreover, two sets of random numbers are also read in. One contains 200 and the other contains 2000 normally distributed random numbers with mean zero and variance σ_e^2. The two sets of random numbers are generated and filed before hand using the Monte Carlo subsystem of the SIPS[(3)] program.

Following these, depending upon the value of the experiment cycle (duration) previously specified by the experimenter, an appropriate amount of input values are generated using equation (1b) to cover the experiment duration and five practice items.

II. Instructions

Depending upon the desire of the operator, the appropriate instructions would be printed out in this

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[(3)] Statistical Interactive Programming System (SIPS) is a statistical package on the CDC 3300, OS-3 computer system of Oregon State University. For more details refer to Guthrie <u>et</u> <u>al</u>. (1973).

segment. That is, with a positive reply by the operator, he would be able to see the set of instructions covering the nature of his task and the other pertinent information. A set of these instructions is presented in Appendix B.

III. Practice Cycle

No matter what action has been taken in the previous segment (whether the instructions segment has been bypassed with a negative reply or requested with a positive reply), the operator gets the option of going through a practice cycle of five time periods. Although the numbers generated in this segment will be different from the actual or main cycle, but the structure would be exactly the same as the main cycle (Part IV). In other words, the operator has the option of bypassing this segment with a negative reply or going through a practice cycle with the same structure as the main cycle and familiarize himself with the system.

IV. Main Cycle

The actual experiment starts in this segment. In other words, whether the two previous segments are bypassed or not, the operator has to go through this segment an appropriate amount of cycles as previously defined by the experimenter.

Before the main or the practice cycle starts, the value of the appropriate costs such as sampling, error, etc.

are printed out. Also at the beginning of each iteration a clock would be printed out which gives an indication of the point in time. This clock serves as a counter to inform the operator of his whereabouts in the given experiment cycle.

The main cycle is divided into three modes: input, output and control. In the input mode the operator has the opportunity of sampling the input values generated by equation (1b) in degree. That is, the operator could sample the process input any number of times (maximum of 20 per iteration). This is an extension to Sheridan's (1970) theory, in which he expresses the fact that "the theory is only valid for sampling in time, not in degree."

Usually while sampling the input, the operator is not able to see the exact value of the generated inputs. Consequently in this model, any time the operator asks for an input sample, the sample would be presented to him according to the following equation:

$$S_t = X_t + R \qquad (5)$$

where: S_t = input sample at time t

X_t = actual input at time t

R = random error (observation noise)

The variance of the input values, σ_x^2, is a function of the memory, α. In other words $\sigma_x^2 = \frac{1}{1 - \alpha^2}$. The assumption would be that the variance of the input samples, σ_s^2, should also be a function of σ_x^2. This assumption would not hold unless the variance of the observation noise, σ_R^2, in equation (5) becomes a function of σ_x^2 too. For this reason, R is calculated according to the following equation

$$R = R_1 \sqrt{\frac{k}{1 - \alpha^2}} \tag{6}$$

where: R_1 = random number N(0,1)

$K = \frac{\sigma^2 R}{\sigma^2 x}$ = constant specified by the experimenter

Based upon the total number of process input samples taken, the total input sampling cost would be:

$$C_E = N\ C_e \tag{7}$$

where: C_E = total input sampling cost

N = total number of input samples taken at each iteration

C_e = cost per input sample specified by the experimenter

If no input samples are desired, this mode could be by-passed in favor of a zero sampling cost.

The next step in the cycle is the output mode. In this mode, the operator has the option of taking an output sample (only one per iteration) or by-pass the mode in favor of a zero output sampling cost. If an output sample is requested, the sample would be presented using equation (2). In the first iteration, the output sample is automatically set equal to the actual input value at that point in time. That is, for iteration one (clock = 1), the output would be $y_1 = x_1$. It should be noted that μ_1 in equation (2) is usually set to have a value of one (i.e., μ_1=1).

The last step in the cycle is the control mode. In this mode the operator has the opportunity to update or keep the old control variable (by bypassing this mode). In the first iteration (clock = 1), the control variable is set equal to zero (i.e., $Z_1 = 0$). If the control variable is updated (changed), the new variable would be shown to the operator so as to make sure that the variable read by the computer is indeed the value that the operator meant to be. If the control variable is not changed, its previous value would be used for the next iteration.

Once the three modes are finished, the score for that iteration is calculated using equation (3). These steps would be performed for the total experimental cycle which is predefined by the experimenter. When the experiment cycle is finished, the total score for the total iterations is presented to the operator. A sample run covering all the above three modes is shown in Appendix C.

V. Statistics and Tabulations

This is the last segment of the main program. In this segment the experimental results are tabulated and statistics are performed on an interval basis. The interval is preassigned by the experimenter. In the tabulation, the actual input value, the specified control variable, the output value, the total number of input samples taken, an indication of whether an output sample has been taken or not, an indication of whether control has been applied or not, and the score for the round is tabulated against the time.

In the statistics segment, the total score, the average score, the total number of input samples taken, the number of rounds (iterations) sample taken, and the average number of rounds sample taken are calculated for a preassigned interval. The definition of these variables is given in Chapter IV. A sample statistics and tabulations is presented in Appendix D.

Figure 3 is a summarized flowchart of the structure of the main program for only one iteration. The complete listing of the main program is presented in Appendix E.

Design Verification

The statistical structure of the input function (equation (1b)) needed to be verified against its theoretical structure before the computer programs were implemented.

In theory, the mean and the variance of the input function are equal to $\frac{\mu \cdot \mu u}{1 - \alpha}$ and $\frac{\sigma^2 u}{1-\alpha^2}$, respectively. Consequently, for $\alpha = 0.99$, $\mu = 0$, and normally distributed

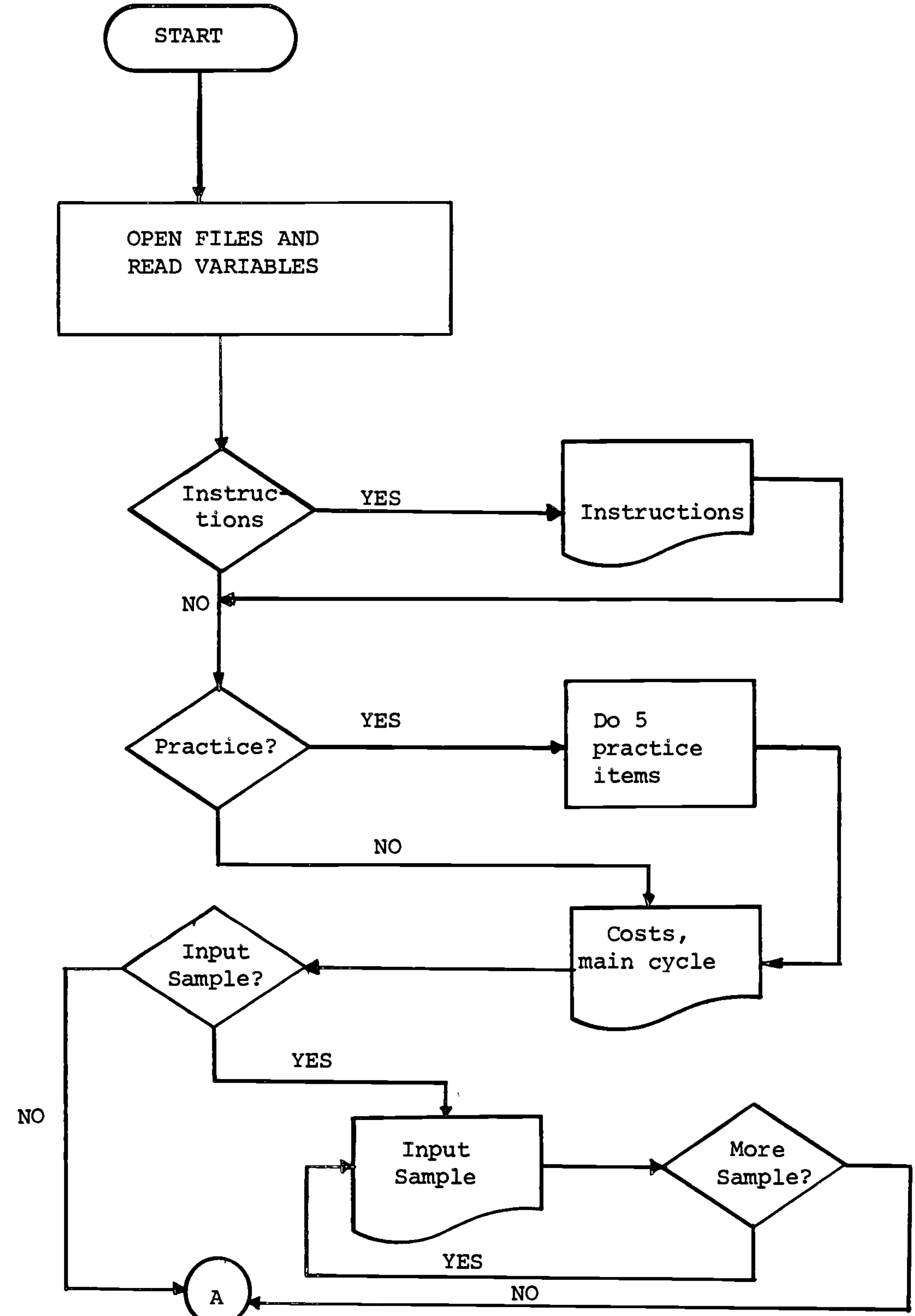

Figure 3. Summarized flow chart of the main program for only one iteration.

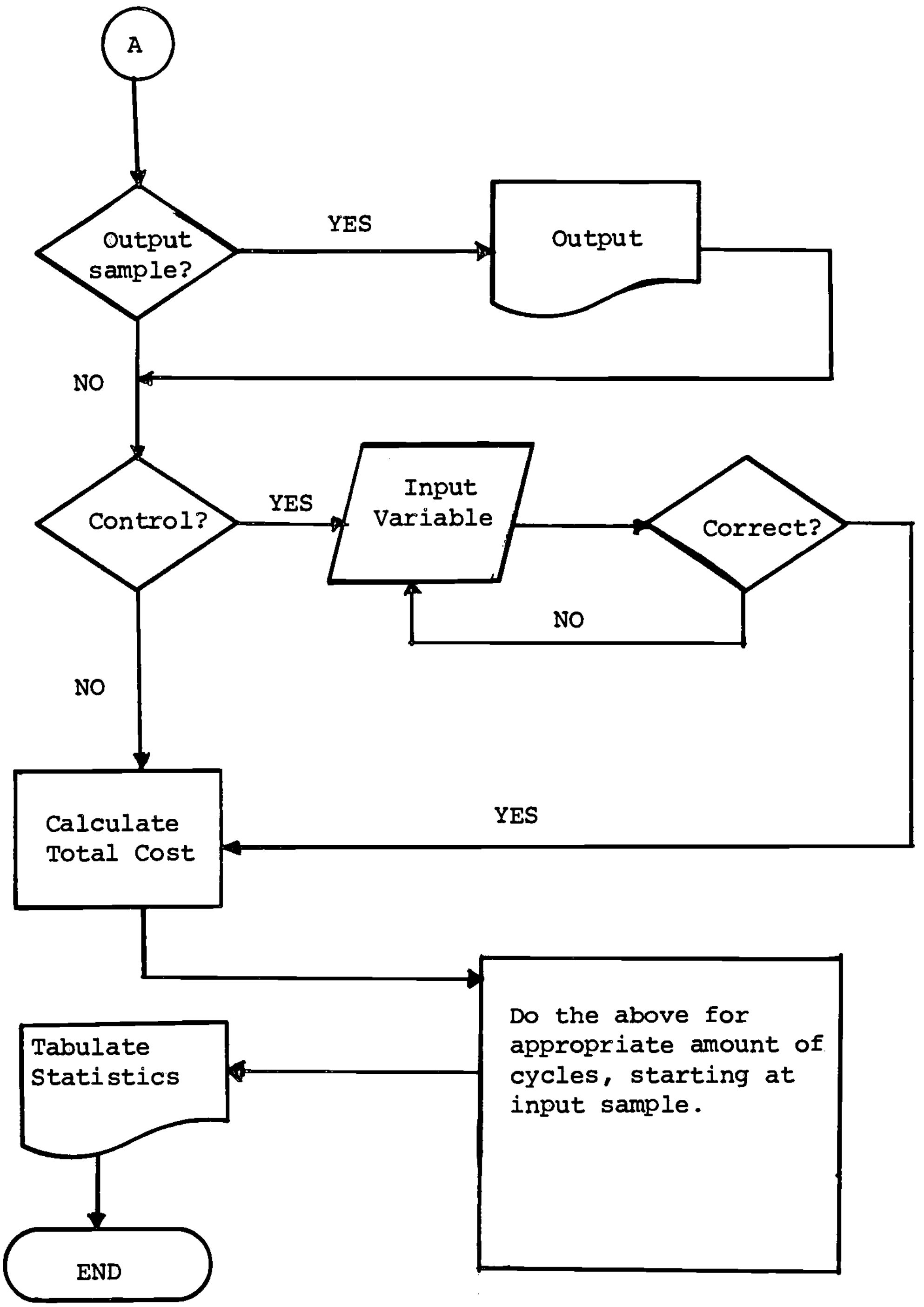

Figure 3 (continued)

u's with mean zero variance ten, the above values are $\mu_{x=0}$ and $\sigma_x^2 = 502.13$

Using the above α and μ values, 2000 input values were generated. The mean and the variance were found to be 11.253 and 577.113 respectively.

In addition to the above, the theoretical and the actual auto-correlations were also calculated. The following is a comparison between the theoretical and the actual auto-correlation of lags 1-10.

Table 1. Comparison between the theoretical and the actual auto-correlations of the input series.

Lag	Auto-correlation Theoretical	Actual
1	0.99	0.9917
2	0.9801	0.9836
3	0.9703	0.9758
4	0.9606	0.9676
5	0.9510	0.9591
6	0.9415	0.9507
7	0.9321	0.9421
8	0.9227	0.9334
9	0.9135	0.9251
10	0.9044	0.9158

It is apparent that the above values do not verify the theoretical values explained before. Two reasons are accounted for the difference:

1. The 2000 normally distributed random numbers did not have a true mean of zero and a true variance

of ten. The actual mean and variance were 0.1196 and 9.6203 respectively.

2. The sample size was not large enough to compensate for the differences.

Although the experiment cycle would always be considerably less than 2000 time units (e.g. 50-100 cycles), the long run was needed to verify the theoretical structure, since estimates calculated from short segments of data may be highly biased.

Since the estimates appeared reasonably close to the theoretical values, the assumption that the input series have the hypothesized statistical structure appears reasonable.

CHAPTER IV. AN APPLICATION OF THE METHODOLOGY

PHASE I

The purpose of this phase is to identify the effects of the variation of α (memory of the input function) and the observation noise (k) on the operator's sampling behavior.

A total of eight volunteer college students served as subjects. The subjects' task was to control the process such that the process output matched the input at any given time during a 100 cycle trial. This task was performed during four different sessions.

For the first session the experimental procedure was as follows:

A. Complete a questionnaire - Each subject had to complete a questionnaire which served as a screening device. A copy of this questionnaire can be found in Appendix F.

B. Embedded Figures Test - Each subject had to perform this psychological test which will be explained later.

C. Instructions - Each subject had to read and study the instructions explained in Chapter III and presented in Appendix B prior to the experiment. Also they had the option of trying a practice trial for five time periods.

D. Actual Experiment - Each subject had to perform the actual experiment for a total of 100 time periods.

The procedures A-C were not covered during the sessions 2-4. The subjects merely started at part D during those sessions.

The computer simulation discussed in Chapter III was used as the experimental setup in which the subjects were allowed to see their score at the end of each iteration.

The process constants (e.g. sampling and control costs) were pre-assigned and were kept unchanged throughout the entire experiment. The constants used in this phase are presented in Appendix G.

In addition to the above process constants, a combination of four different values of α (i.e. 0, .8, .9, and .99) and K (i.e. 0, 0.5, 1 and 1.5) was randomly presented to each subject on each run using a Graeco-Latin Square Design[4] as illustrated in Figure 4.

Subjects	Order of Presentation	T_1	T_2	T_3	T_4
	S1,S5	0 0	0.8 0.5	0.9 1.0	0.99 1.5
	S2,S6	0.9 0.5	.99 0	0 1.5	0.8 1.0
	S3,S7	.99 1.0	.9 1.5	.8 0	0 0.5
	S4,S8	0.88 1.5	0 1.0	0.99 0.5	0.9 0

Figure 4. The Phase I statistical design of Graeco-Latin squares.

[4] For more information regarding the Graeco-Latin design see Kirk (1968).

Statistical Analysis

The independent variables in this phase are the input memory and the observation noise. The dependent variables are:

1. Adjusted Total Score

   The raw total scores were adjusted for the variance of the input value (σ_x^2) by dividing the total scores by the variance at each α level ($\sigma_x^2 = \frac{1}{1-\alpha^2}$). Moreover, some of the scores were also corrected for typographical errors on the part of the subjects. This was done by calculating the total mistakes for a given interval, subtracting that from the total score for that interval, and averaging the result over the interval length.

2. Total Observations

   The total number of input samples for each iteration was summed up to yield the total observations for a given interval.

3. Number of Iterations Samples Taken

   The time periods (iterations) that a sample had been taken (regardless of the total number of samples) were summed up to yield this dependent variable. This measure excludes the time periods with no input samples taken. So actually it emphasizes those periods that an observation was made.

4. Samples per Observation

This measure is the average number of iterations sample taken, and is calculated by dividing the total number of observations by the number of iterations sample taken.

An analysis of variance using the Graeco-Latin design is performed on each of the above dependent variables using the last 50 of the 100 iterations (to isolate any learning effect). The objective of this analysis is to prove that the input memory and the sampling noise have an effect on the above four dependent variables. The results are as follows:

I. Total Adjusted Score

As can be seen in the analysis of variance presented in Table 2, none of the independent measures have a significant effect on the total adjusted score at significance level of 0.1. Although it seems that with a confidence level of 75 percent, it can be concluded that the independent variables, memory and noise have an effect on the total adjusted score.

The effect of the memory is that the total score decreases as the memory increases except at an α level of 0.9 where the total score increases again (Figure 5). The $\alpha = 0.9$ level is an experimental artifact.

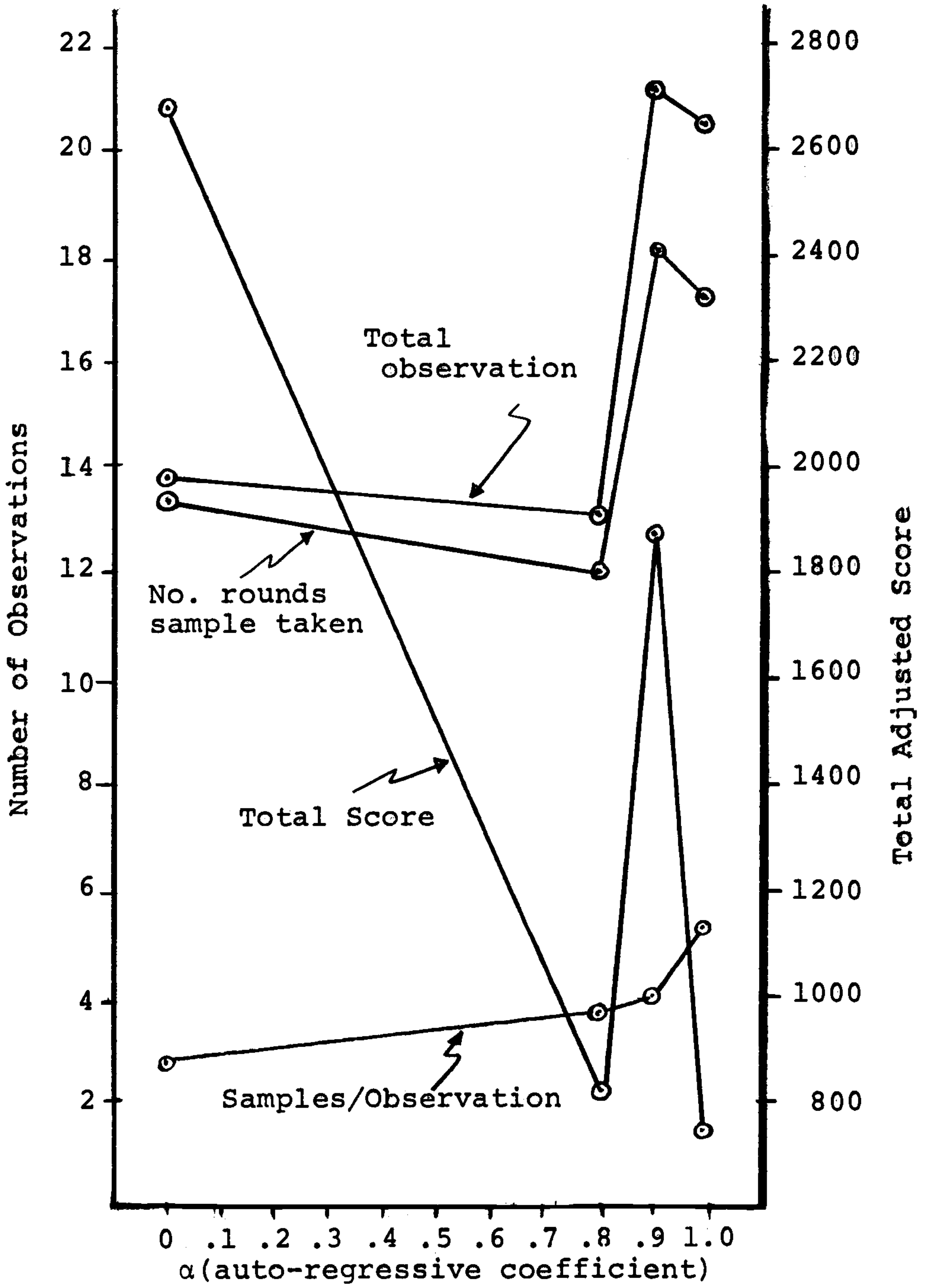

Figure 5. Total score and observations versus α.

Table 2. Analysis of variance table for the total adjusted score.

Source	Sum squares	D.F.	Mean squares	F value
Total	$2.65x10^8$	32	$8.28x10^6$	1.765
Mean	$8.99x10^7$	1	$8.99x10^7$	19.168
Adjusted Total	$1.75x10^8$	31	$5.65x10^6$	1.205
Subject	$2.14x10^7$	3	$7.13x10^6$	1.520
Trial	$1.95x10^7$	3	$6.5x10^6$	1.386
Memory	$2.29x10^7$	3	$7.63x10^6$	1.627
Noise	$2.91x10^7$	3	$9.7x10^6$	2.068
Residual	$3.67x10^8$	3	$1.22x10^8$	26.013
Within cell	$7.51x10^7$	16	$4.69x10^6$	

The total score also decreases as the noise increases. This effect continues up to a noise level of 1.0 where it starts to increase again (Figure 6).

II. Total Observations

The analysis of variance is given in Table 3 which suggests that none of the independent variables (e.g. memory and noise) have a significant effect at a significance level of 0.1.

As can be seen in Figure 5, the total observations almost follows a straight line up to α = .8 and then suddenly increases at the experimental artifact point α = .9. Moreover, the total observation decreases up to a noise level of 0.5, increasing thereafter (Figure 6).

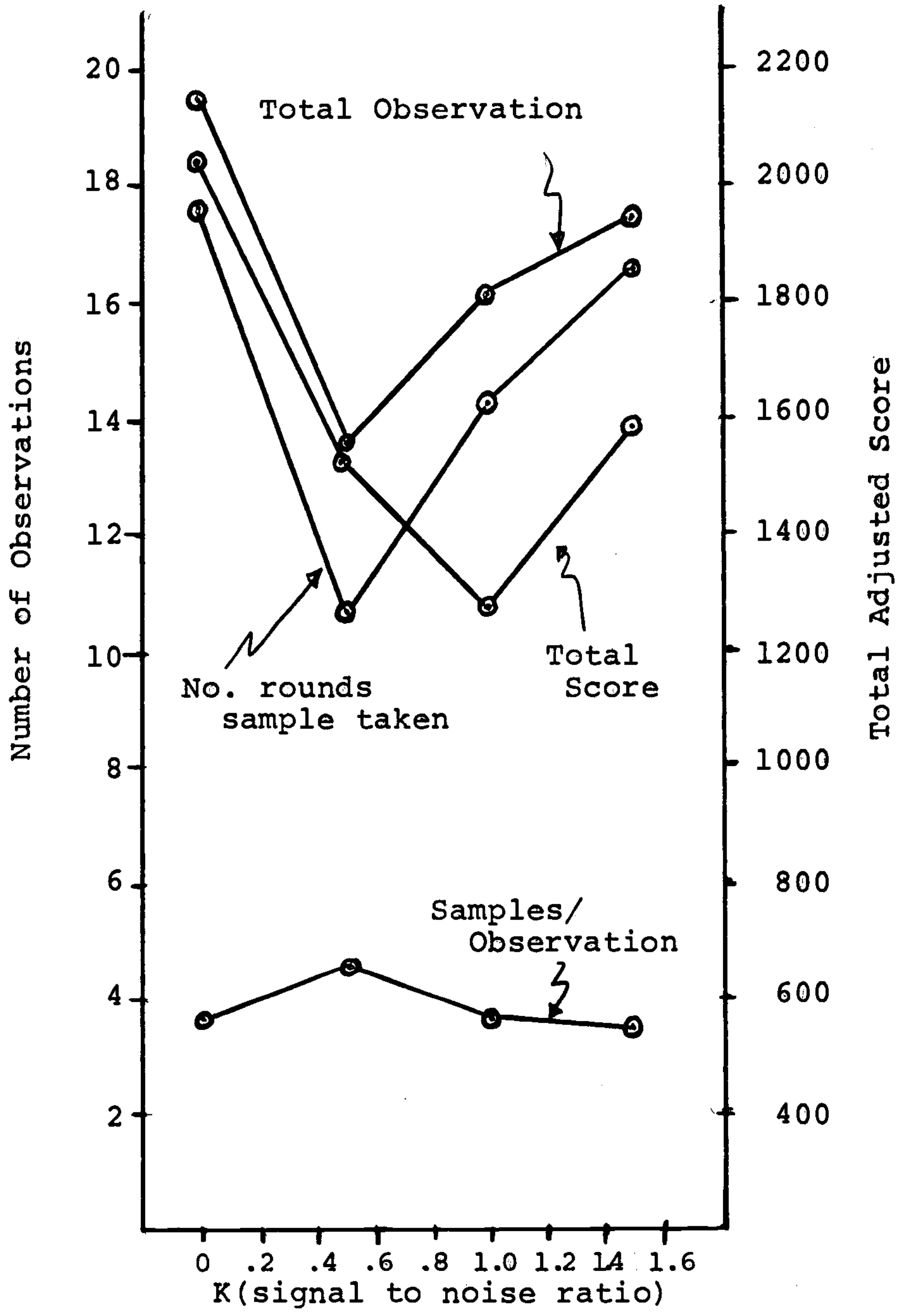

Figure 6. Total score and observations versus K.

Table 3. Analysis of variance table for the total observations.

Source	Sum squares	D.F.	Mean squares	F value
Total	9391	32	293.47	1.341
Mean	3220.03	1	3220.03	14.709
Adjusted Total	6170.97	31	199.06	0.909
Subject	233.34	3	77.78	0.355
Trial	1154.84	3	384.95	1.758
Memory	454.09	3	151.36	0.691
Noise	123.34	3	41.11	0.188
Residual	13583	3	4527.67	20.683
Within cell	3502.5	16	218.91	

III. Number of Iterations Samples Taken

The analysis of variance presented in Table 4 suggests that none of the independent variables have any effect on this dependent measure at a significance level of 0.1.

The memory and noise has the same effects on this dependent measure as they had on the total observations as can be seen in Figures 5 and 6.

IV. Sample per Observation

The analysis of variance for the last dependent measure is given in Table 5. The analysis suggests that none of the independent measures have an effect on the number of samples per observation at a significance level of 0.1, although there is a memory (α) effect at 0.25 level.

Table 4. Analysis of variance table for the number of iterations samples taken.

Source	Sum Squares	D.F.	Mean Squares	F value
Total	8573	32	267.91	1.289
Mean	2646.28	1	2646.28	12.728
Adjusted total	5926.72	31	191.18	0.919
Subject	346.59	3	115.53	0.556
Trial	1088.09	3	362.698	1.744
Memory	475.34	3	158.45	0.762
Noise	54.84	3	18.28	0.0879
Residual	11220.5	3	3740.17	17.989
Within cell	3326.5	16	207.91	

Table 5. Analysis of variance table for the number of samples per observation.

Source	Sum Squares	D.F.	Mean Squares	F value
Total	533.91	32	16.68	2.109
Mean	264.16	1	264.16	33.396
Adjusted total	269.75	31	8.70	1.099
Subject	32.93	3	10.98	1.388
Trial	20.26	3	6.75	0.853
Memory	39.52	3	13.17	1.665
Noise	26.08	3	8.69	1.099
Residual	1080.95	3	360.32	45.552
Within cell	126.62	16	7.91	

The effect would be that as the memory increases, the number of samples per observation increases (Figure 5).

In an attempt to identify any possible learning effect, a paired-t statistical analysis is performed for each of the four dependent variables using their total value of the first and last ten iterations. The t-values for each of the four dependent variables is presented in Table 6.

Table 6. T-values for the four dependent variables.

Source	T-value	D.F.
Total adjusted scores	1.625	31
Total observations	4.719	31
Number of iterations samples taken	4.177	31
Samples per observation	3.678	31

The above t-values suggest that the null hypothesis (H_o) is rejected for all of the variables at a 90 percent confidence level, except for the total adjusted scores. This proves that the mean value of the observations for the first ten iterations is different from that of the last ten. In fact, it suggests that the mean of the observations for the first ten iterations is much greater than that of the last ten iterations (Figure 7).

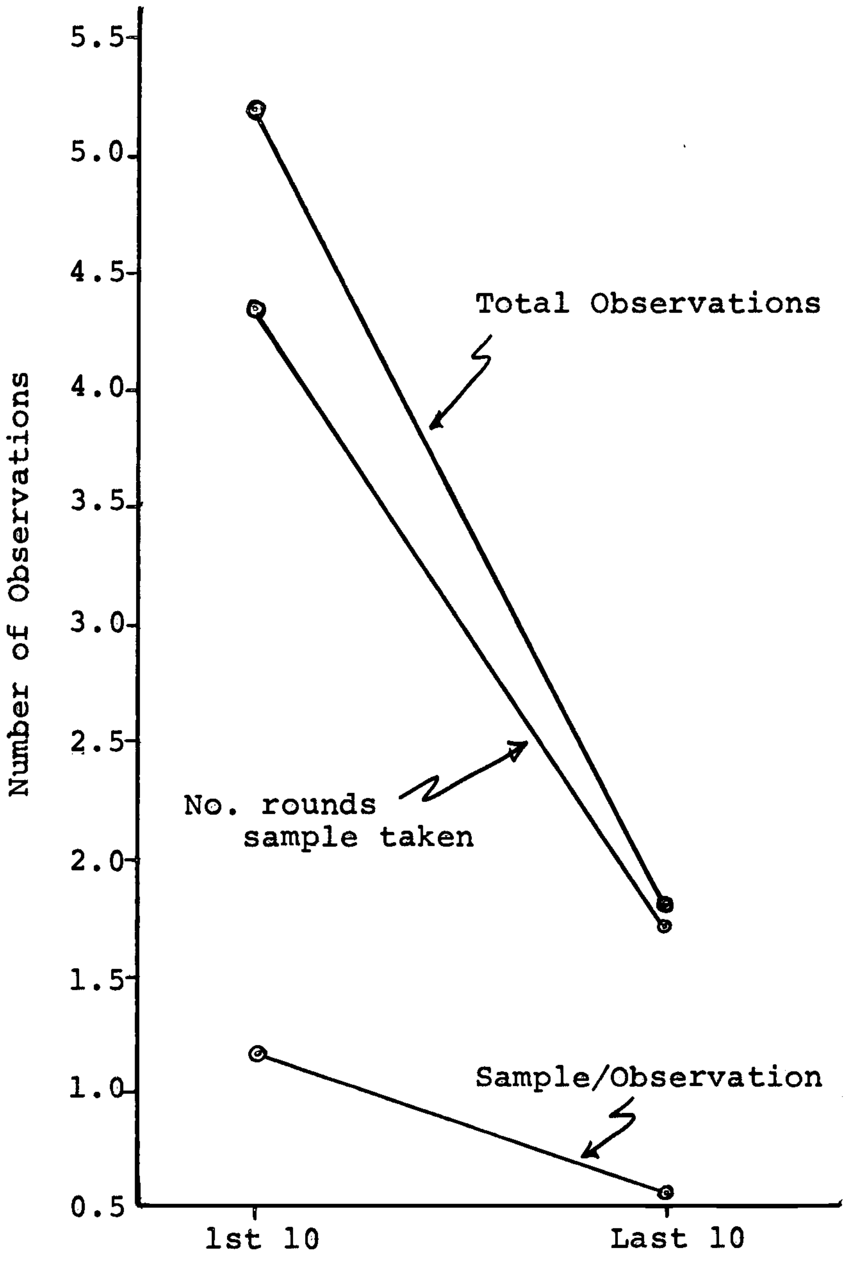

Figure 7. Mean observations for the first and last ten iterations.

Embedded Figures Test

The EFT is a perceptual test related to the cognitive-style theory in which the subject's task is to identify a previously seen simple figure embedded in a complex figure. The complex figure is so constructed as to obscure the desired simple figure.

A total of 12 figures are presented to the subject, and the subject has a maximum of three minutes to identify the simple figure in each. Then, the total time spent on identifying the 12 figures are averaged to come up with an EFT score for the particular subject.

Using the above procedures, an EFT was performed on each of the eight subjects used in this phase to identify any possible relationship between the perceptual capacity of the subjects and the achieved results. The EFT scores for the eight subjects are presented in Appendix F.

The achieved EFT scores were then paired with the values of the four dependent variables obtained from each subject during the 100 iterations to calculate a correlation coefficient (ρ) for each dependent measure.

Using the equation

$$t_{n-2} = \rho\sqrt{\frac{N-2}{1-\rho^2}}$$

where t is the value of the t-statistics, and N is the total observations, a significance level was calculated for each correlation coefficient to find out how significant the correlations are. Table 7 presents the correlation coefficients and their respective t values.

Table 7. The correlation coefficients and the t-values for the EFT

Source	Correlation coefficient	t-value D.F. = 6
Total adjusted score	0.5229	1.503
Total observations	-0.583	-1.757
Number of iterations sample taken	-0.5865	-1.77
Samples per observation	-0.402	-1.075

The t-values listed in Table 7 suggest that at a 0.1 significance level none of the correlation coefficients are significant enough to prove that there is any kind of correlation between the performance on the EFT and the achieved results.

CHAPTER V. AN APPLICATION OF THE METHODOLOGY

PHASE II

Since phase I of the experiment did not yield the expected results, and based on some post experimental interviews, the experiment design was reformed and another set of experiments was conducted to find the effects of the observation noise on the operator's behavior in the absence of memory variation.

A total of six volunteer college students served as subjects. Their task was basically the same as the phase I subjects except that in this phase the subjects were not allowed to see their score at the end of each iteration. Moreover, the random error terms used in this phase were normally distributed with mean zero and variance ten. Also, the input memory (α) was kept constant at 0.99 throughout the experiment, and only three different values of noise ($K = 0, 0.5, 1.0$) were randomly assigned to each subject. The instructions given to the subjects were the same as the ones given to the Phase I subjects.

Each subject had to do two different runs. The first run which was counted as a practice trial was 30 cycles long. The observation noise was held constant at zero ($K = 0$) for all the 30 cycle practice runs. The second run was the actual run which lasted 30 cycles, and each subject was assigned a different K value. The other pertinent process constants are presented in Appendix I.

Statistical Analysis

The independent variable in this phase is the observation noise level (K). The dependent variables are the same variables defined in Phase I except that the total scores are not adjusted in this phase.

Since there is only one independent variable, an one-way analysis of variance is used as the statistical tool to prove that the observation noise has an effect on the dependent variables discussed before. Tables 8 through 11 present the analysis of variance table for each of the four dependent measures.

Table 8. Analysis of variance table for the total score.

Source	Sum of squares	D.F.	Mean squares
Between groups	3.79×10^8	2	1.895×10^8
Within groups	3.72×10^8	3	1.24×10^8
Total	7.51×10^8	5	
F = 1.528			

The F values given in the analysis of variance table suggest that at a confidence level of 90 percent the different sampling noise levels have an effect on the number of iterations sample taken and the number of samples per observation.

Table 9. Analysis of variance table for the total observations.

Source	Sum of squares	D.F.	Mean squares
Between groups	265.33	2	132.665
Within groups	137.5	3	45.833
Total	402.83	5	
F = 2.895			

Table 10. Analysis of variance table for the number of iterations samples taken.

Source	Sum of squares	D.F.	Sum of squares
Between groups	121	2	60.5
Within groups	26.5	3	8.833
Total	147.5	5	
F = 6.849			

Table 11. Analysis of variance table for the number of samples per observation.

	Sum of squares	D.F.	Sum of squares
Between groups	13.034	2	6.517
Within groups	3.412	3	1.137
Total	16.446	5	
F = 5.732			

Translating the above analyses into a graphic form, Figure 8, it is clear that the number of samples per observation increases as the noise level increases, and although noise does not have a significant effect on the total score and the total observations, both of the above dependent variables increase as the noise increases.

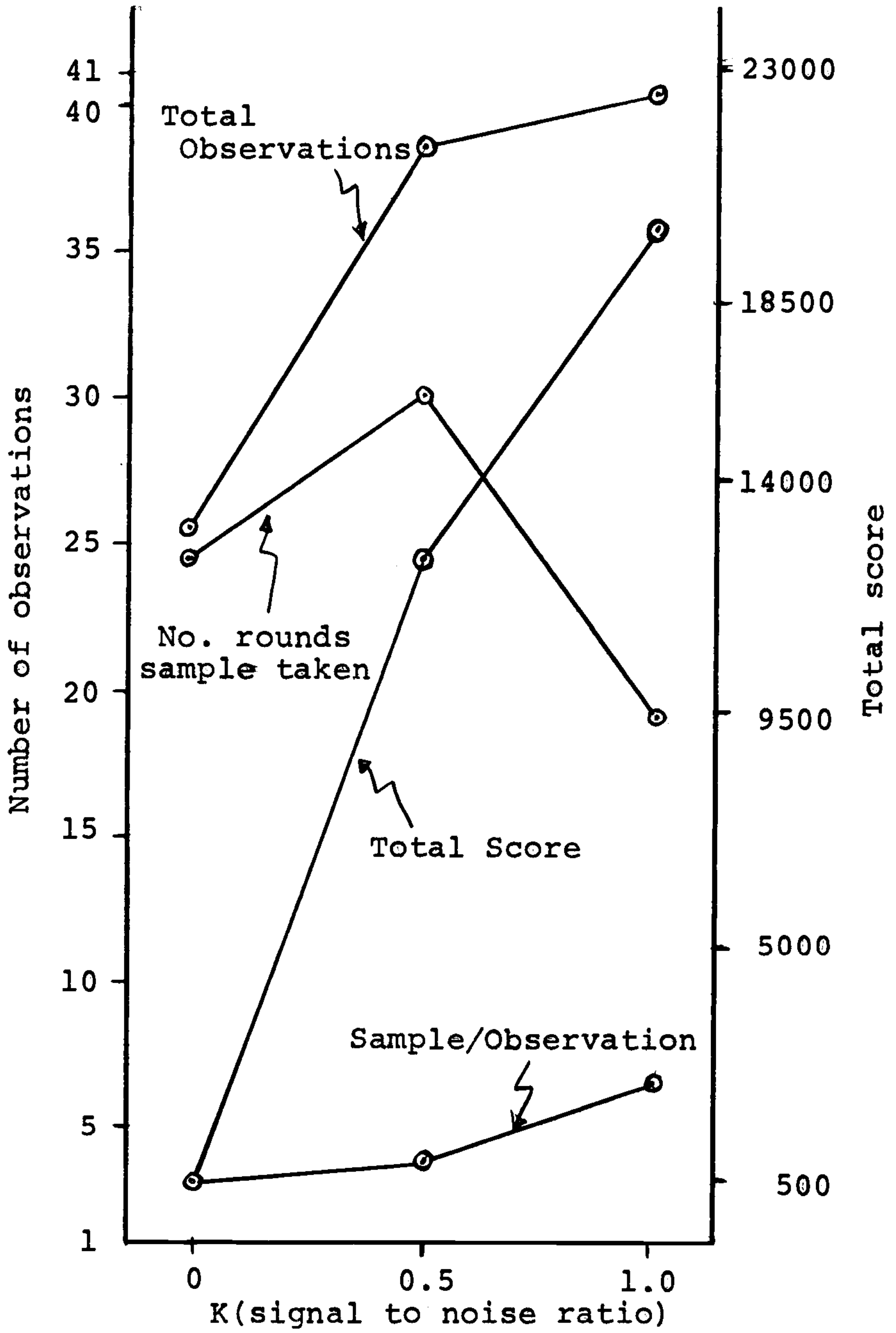

Figure 8. Total score and observations versus K.

CHAPTER VI. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to develop a methodology as a technique to study the effects of the process dynamics on the operator's sampling and control behavior. To accomplish this objective, a computer program was developed and discussed in Chapter III. It was then used to study the effects of the memory (of the input function) and the observation noise on the operator's behavior. The statistical results were discussed in Chapters IV and V. In this chapter the discussion of the results and the recommendations for future studies are presented.

Discussion of Results

In the experiments performed in this research project, the operator's sampling and control behavior was analyzed using the following dependent variables:

1. Total adjusted score
2. Total number of observations
3. Number of iterations (rounds) sample taken
4. Number of samples per observation.

Using the above variables, an experiment was conducted to study the effects of the input memory variation (in the presence of observation noise) on the operator's behavior.

Based on the statistical analysis presented in Chapter IV, it was concluded that at a 90 percent confidence level, the input memory and the observation noise did not have a statistically significant effect on any of the above dependent variables. This result contradicts the original hypothesis of an inverse relationship between the memory and the number of samples per observation, and the hypothesis of a direct relationship between the observation noise and the operator's sampling rate. Although the results seem to prove the original hypotheses at a 75 percent confidence level, they are not significant and should not be treated seriously because in reality the number of samples per observation increases as the input memory increases (Figure 5), which is exactly opposite to the original hypothesis.

In addition to the above, it was concluded that the subjects had undergone a learning phenomenon (90 percent confidence level) suggesting that they are able to gain a knowledge of the process as time increases. Therefore, the statistical result confirms the original hypothesized learning effect. Furthermore, in contrast to the hypothesis of a positive correlation between the EFT scores and the achieved results, no indication of any significant correlation was identified at a 90 percent confidence level. This suggests that regarding the type task involved, the subject's performance is not limited by their perceptual capacity.

Since the achieved results were not the expected results, the experimental design was reformed and another set of experiments was conducted to study the effects of the observation noise on the operator's behavior in the absence of any input memory variation.

Based on the statistical analysis presented in Chapter V, it seems that at a 90 percent confidence level the observation noise has an adverse effect on the operator's behavior (as measured by the number of iterations sample taken and the number of samples per observation). Although observation noise does not have a statistically significant effect on the total observations and the total score, nevertheless it is apparent from Figure 8 that all those dependent variables increase as the noise level increases. Clearly these results are in agreement with the original hypothesis of the direct relationship between the observation noise level and operator's sampling rate.

Recommendation for Future Studies

All of the above experiments were performed on a CRT (cathode ray tube) terminal using a time-sharing computer system. There are two disadvantages to this. First, while working with a CRT, because of the limited space on the screen, the subjects are not able to see their previous actions and the old input or output values. It should be noted that this problem cannot be solved by using a teletype terminal[6] because of its slow printing time.

Moreover, occasionally a computer system operating on a time-share basis has a slow response time (depending upon the load on the computer) which distracts the subjects.

Regarding the above problems, the possible course of action is to reconstruct the above computer program on a high speed non-time-share computer system (e.g. Wang 2200 programmable calculator or P.D.P.8 mini-computer), and allow the subjects to keep track of their prior actions. This can be done in two ways. First, the previous input, output, and control values can be presented to the subject in a table format. Moreover, the previous input values can be plotted and presented to the subjects in a graphical form. The latter course of action (i.e. presentation of the data points in a graphical form) was used by Rouse (1973) where ten points of a time-series were presented, and the subject's task was to predict the eleventh point. Nevertheless it should be noted that before using any of the above courses of action, an experiment should be conducted to find out what the optimal number of presentable data points should be.

Moreover, as was mentioned before, during the first phase of the experiment the subjects were allowed to see their score at the end of each iteration, and during the

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[6] A teletype terminal is not a high speed printer.

second phase of the experiment the subjects were prevented from seeing their score. However, the effect of this feedback was never tested. Therefore, it is recommended that the effect of presenting the total score as a feedback be studied on the outcome of the experiments.

In conclusion, regarding the significance of this study, different cost, input memory, and observation noise levels can be selected and tested on the behavior of the operators. Once the optimal combination is selected, the operators can be trained accordingly. Moreover, through the use of the costs, the best performance function can be selected. Then, this optimal performance function could be utilized as part of the management's work incentive program.

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APPENDICES

APPENDIX A

THE LISTING AND A SAMPLE RUN OF THE AUXILIARY PROGRAM

```
0001 REM   AUXILIARY PROGRAM
0002 REM   THIS PROGRAM SERVES AS AN INPUT DATA FILE FOR THE
0003 REM   MAIN PROGRAM.
0004 REM   ALL OF THE VARIABLES ARE STORED UNDER THE FILE NAME MVS.
0005 OPEN  %5,"MVS"
0006 REM   CE=THE ERROR COST
0007 REM   CX=THE INPUT SAMPLING COST
0008 REM   CZ=THE COST OF CONTROL
0009 REM   CY=THE OUTPUT SAMPLING COST
0010 PRINT " CE"," CX"," CZ","CY"
0015 INPUT C1,C2,C3,C4
0016 REM   ALPHA=MEMORY OF THE INPUT FUNCTION
0017 REM   MU=CONSTANT OF THE INPUT FUNCTION
0018 REM   X(0)=VALUE OF THE INPUT FUNCTION AT TIME ZERO
0019 REM   MU1=CONSTANT OF THE OUT PUT FUNCTION
0020 PRINT " ALPHA"," MU"," X(0)"," MU1"
0025 INPUT A,M,F,M1
0029 REM   VARIANCE OF R/X=K
0030 PRINT "VARIANCE OF R/X";"             EXPERIMENT CYCLE";
0045 INPUT S1,J
0050 PRINT " INTERVAL OF STATISTICS REQUIRED"
0055 INPUT K
0058 REM   NOW EVERY VARIABLE WILL BE STORED INTO THE MVS FILE
0060 WRITE %5,C1,C2,C3,C4
0061 WRITE %5,A,M,F,M1
0062 WRITE %5,S1,J,K
0063 PRINT " END OF PROGRAM"
0065 END
```

```
#BASIC
?FIN,*MOE
?RUN
 CE                CX                 CZ                CY
?1,5,0,0
 ALPHA             MU                 X(0)               MU1
?.99,3,3,1
VARIANCE OF R/X              EXPERIMENT CYCLE?
1,15
 INTERVAL OF STATISTICS REQUIRED
?10
 END OF PROGRAM

?
```

APPENDIX B

THE SUBJECTS' INSTRUCTIONS FOR PERFORMING THE EXPERIMENTS

IN THIS EXPERIMENT WE ARE TESTING YOUR ABILITY IN CONTROLLING A PROCESS. YOUR TASK IS TO CONTROL THE PROCESS SO THAT THE OUTPUT MATCHES THE INPUT.

THE PROCESS IS DEFINED IN TERMS OF 3 MODES; INPUT, CONTROL, AND OUTPUT. YOU WILL BE GIVEN A VALUE OF THE CLOCK REPRESENTING THE POINT IN TIME. FOLLOWING THAT YOU WILL BE IN THE INPUT MODE IN WHICH YOU CAN SAMPLE THE INPUT VALUE AS MANY TIMES AS YOU LIKE. EACH TIME YOU SAMPLE THE INPUT YOU WILL INCUR A COST WHICH WILL BE GIVEN TO YOU PRIOR TO THE START OF THE EXPERIMENT. WHEN YOU ARE FINISHED IN THE INPUT MODE YOU WILL GO INTO THE OUTPUT MODE IN WHICH YOU CAN SAMPLE THE OUTPUT JUST ONCE AND INCUR A GIVEN COST. FOLLOWING THIS YOU WILL GO INTO THE CONTROL MODE IN WHICH YOU CAN KEEP OR UPDATE YOUR PREVIOUS CONTROL VARIABLE AND INCUR A GIVEN COST.

WHEN THE EXPERIMENT IS FINISHED YOU CAN SEE YOUR TOTAL SCORE FOR THE EXPERIMENT. THE SCORE IS GIVEN BY CALCULATING SQUARED ERROR (ACTUAL INPUT-OUTPUT SQUARED) MULTIPLIED BY A GIVEN ERROR COST PLUS ANY SAMPLING OR CONTROL COST. YOUR OBJECTIVE IS TO MINIMIZE THIS SCORE BY OPTIMALLY CONTROLING THE PROCESS.

DURING EACH ROUND YOU WILL BE NOTIFIED OF THE MODE YOU ARE IN. DURING EACH MODE UPON RECEIVING A QUESTION MARK(?) YOU HAVE TO GIVE THE NECCESSARY INSTRUCTIONS. IN EACH CASE JUST TYPE IN THE REQUIRED NUMBER.

THE FOLLOWING IS A LIST OF THE APPROPRIATE INSTRUCTIONS ALONG WITH THEIR RESPECTIVE NUMBERS:

1	ONE OR MORE INPUT SAMPLES REQUIRED.
-1	NO MORE INPUT SAMPLES REQUIRED.
-2	NO INPUT SAMPLES AT ALL.
3	APPLY CONTROL (MAKE OR UPDATE PREDICTION).
-3	NO CONTROL DESIRED. LAST PREDICTION WILL BE COUNTED AS CURRENT.
4	OUTPUT SAMPLE REQUIRED.
-4	NO OUTPUT SAMPLE REQUIRED.

NOW WE WILL TRY THESE FOR 5 TIME UNITS TO SEE IF YOU UNDERSTAND THE PROCEDURE.

APPENDIX C

A SAMPLE RUN OF THE MAIN CYCLE OF THE MAIN PROGRAM

```
ERROR COST=  1

INPUT SAMPLING COST=  5

CONTROL COST=  0

OUTPUT SAMPLING COST=  0

              CLOCK= 1

 INPUT(1 OR -2):
?1

 INPUT=  6.71804
?1

 INPUT=  6.67215
?1

 INPUT= -8.28793
?-1

 OUTPUT(4 OR -4):
?4

 OUTPUT= -1.11597

 CONTROL(3 OR -3):
?3

 VARIABLE=?
-1
                 -1    CORRECT?
YES
```

```
              CLOCK=  2

 INPUT (1 OR -2):
?1

 INPUT= -28.0723
?1

 INPUT=  22.6809
?-1

 OUTPUT (4 OR -4):
?-4

 CONTROL (3 OR -3):
?3

 VARIABLE=?
-2.5
                    -2.50000    CORRECT?
YES
```

```
            CLOCK=  3

 INPUT (1 OR -2):
?-2

 OUTPUT (4 OR -4):
?4

 OUTPUT= -2.50000

 CONTROL (3 OR -3):
?3

 VARIABLE=?
-3.5
                     -3.50000   CORRECT?
YES

            CLOCK=  4

 INPUT (1 OR -2):
?-2

 OUTPUT (4 OR -4):
?-4

 CONTROL (3 OR -3):
?-3
```

```
              CLOCK=  5

 INPUT (1 OR -2):
?1

 INPUT=  64.7557
?1

 INPUT=  15.7752
?1

 INPUT=  5.03522
?-1

 OUTPUT (4 OR -4):
?4

 OUTPUT= -3.50000

 CONTROL (3 OR -3):
?3

 VARIABLE=?
3.8
                       3.80000   CORRECT?
YES
```

```
            CLOCK=  6

 INPUT (1 OR -2):
?1

 INPUT=  35.4943
?1

 INPUT=  14.7284
?-1

 OUTPUT (4 OR -4):
?4

 OUTPUT=  3.80000

 CONTROL (3 OR -3):
?3

 VARIABLE=?
-150
                  -150    CORRECT?
NO

 VARIABLE=?
3.5
                   3.50000    CORRECT?
YES
```

APPENDIX D

A SAMPLE OF THE STATISTICS AND THE TABULATIONS PERFORMED BY THE MAIN PROGRAM

```
ERROR COST=  1      INPUT SAMPLING COST=  5
COST OF CONTROL=  0      OUTPUT SAMPLING COST=  0
ALPHA=  0.99000            VARIANCE OF R/X=  1
MU=  3         MU1=  1         X(0)=  3
```

TIME	ACTUAL VALUE	CONTROL/OUT VALUE /PUT	INPUT SAMPLE	OUTPUT SAMPLE	CONTROL APPLIED	TOTAL SCORE
1	-1.12	-1.00 / -1.12	3	1	1	15.00
2	-4.00	-2.50 / -1.00	2	0	1	19.01
3	2.35	-3.50 / -2.50	0	1	1	23.56
4	7.11	-3.50 / -3.50	0	0	0	112.58
5	8.84	3.80 / -3.50	3	1	1	167.26
6	15.49	3.50 / 3.80	2	1	1	146.63
7	21.89	4.50 / 3.50	1	0	1	343.30
8	19.57	2.90 / 4.50	0	0	1	227.04
9	14.35	.90 / 2.90	1	1	1	136.12
10	9.34	.90 / .90	0	0	0	71.17
11	5.33	.90 / .90	0	0	0	19.58
12	4.55	1.20 / .90	1	0	1	18.29
13	-4.25	1.20 / 1.20	0	0	0	29.83
14	-5.40	2.90 / 1.20	0	0	1	43.50
15	-1.76	2.90 / 2.90	0	0	0	21.74

```
FOR TIME INTERVAL 1 TO 10
TOTAL SCORE                                  = 1261.67
AVERAGE SCORE                                = 126.167
TOTAL NO. OF OBSERVATIONS                    = 12
AVERAGE NO. OF OBSERVATIONS                  = 1.20000
NO. OF ROUNDS SAMPLE TAKEN                   = 6
AVG. NO. OF OBS. WHEN AN OBS. IS MADE        = 2

FOR TIME INTERVAL 11 TO  15
TOTAL SCORE                                  = 132.932
AVERAGE SCORE                                = 26.5865
TOTAL NO. OF OBSERVATIONS                    = 1
AVERAGE NO. OF OBSERVATIONS                  = 0.20000
NO. OF ROUNDS SAMPLE TAKEN                   = 1
AVG. NO. OF OBS. WHEN AN OBS. IS MADE        = 1
```

APPENDIX E

A COMPLETE LISTING OF THE MAIN PROGRAM

```
00090 REM THIS IS THE MAIN PROGRAM
00091 REM
00092 REM CALL AND OPEN THE FOLLOWING FILES:
00093 REM *RANDOM= FILE CONTAINS 200 RANDOM NUMBERS
00094 REM SUBJECT= OUTPUT FILE FOR THE COLLECTED INFORMATION
00095 REM *RAND= FILE CONTAINS 2000 RANDOM NUMBERS
00096 REM MVS= INPUT FILE CREATED THROUGH THE AUXILIARY PROGRAM
00097 REM
00100 OPEN %1,"*RANDOM"
00110 OPEN %2,"SUBJECT"
00120 OPEN %3,"*RAND"
00130 OPEN %4,"MVS"
00131 REM INITIALIZATION AND DIMENSIONING THE VARIABLES
00132 REM X= ACTUAL INPUT VALUE          A= TOTAL INPUT SAMPLES
00133 REM C= INDICATION OF CONTROL APPLIED        Z=CONTROL VARIABLE
00134 REM V= VALUE FUNCTION                    U= RANDOM NUMBER
00135 REM Y= OUTPUT VALUE             F=OUTPUT SAMPLES
00140 D=V1=V2=V3=0
00150 DIM X(105),A(105),C(105),Z(105),V(105),U(105),F(105),Y(105)
00155 REM
00156 REM READING THE PROCESS CONSTANTS FROM THE INPUT FILE
00160 READ %4,C1,C2,C3,C4
00170 READ %4,A,M,F,M1
00180 READ %4,S1,J,K
00185 REM
00186 REM READING 105 RANDOM NUMBERS
00190 FOR T=1 TO 105
00200 READ %1,U(T)
00210 NEXT T
00215 REM
00216 REM GENERATING THE NECCESSARY AMOUNTS OF INPUT VALUES
00217 REM
00220 X(1)=A*F+M*(1-A)+U(1)
00230 FOR T=2 TO 105
00240 X(T)=A*(X(T-1))+M*(1-A)+U(T)
00250 NEXT T
00260 PRINT "DO YOU WANT TO SEE THE INSTRUCTIONS":
00270 INPUT W$
00280 IF W$="NO" THEN 00670
00290 PRINT "    IN THIS EXPERIMENT WE ARE TESTING YOUR ABILITY IN"
00300 PRINT "CONTROLLING A PROCESS. YOUR TASK IS TO CONTROL THE"
00310 PRINT "PROCESS SO THAT THE OUTPUT MATCHES THE INPUT."
00320 PRINT "    THE PROCESS IS DEFINED IN TERMS OF 3 MODES: INPUT"
00330 PRINT "CONTROL, AND OUTPUT. YOU WILL BE GIVEN A VALUE OF THE"
00340 PRINT "CLOCK REPRESENTING THE POINT IN TIME. FOLLOWING THAT"
00350 PRINT "YOU WILL BE IN THE INPUT MODE IN WHICH YOU CAN"
00360 PRINT "SAMPLE THE INPUT VALUE AS MANY TIMES AS YOU LIKE. EACH"
00370 PRINT "TIME YOU SAMPLE THE INPUT YOU WILL INCUR A COST WHICH"
00380 PRINT "WILL BE GIVEN TO YOU PRIOR TO THE START OF THE EXPERI-"
00390 PRINT "MENT. WHEN YOU ARE FINISHED IN THE INPUT MODE YOU WILL"
00400 PRINT "GO INTO THE OUTPUT MODE IN WHICH YOU CAN SAMPLE THE "
00410 PRINT "OUTPUT JUST ONCE AND INCUR A GIVEN COST. FOLLOWING THIS"
00420 PRINT "YOU WILL GO INTO THE CONTROL MODE IN WHICH YOU CAN KEEP"
00430 PRINT "OR UPDATE YOUR PREVIOUS CONTROL VARIABLE AND INCUR A GIVEN"
00440 PRINT "COST."
00450 PRINT "   WHEN THE EXPERIMENT IS FINISHED YOU CAN SEE YOUR TOTAL"
00460 PRINT "SCORE FOR THE EXPERIMENT.  THE SCORE IS GIVEN BY CALCULATING"
00470 PRINT "SQUARED ERROR (ACTUAL INPUT-OUTPUT  SQUARED) MULTI-"
00480 PRINT "PLIED BY A GIVEN ERROR COST PLUS ANY SAMPLING OR"
00490 PRINT "CONTROL COST. YOUR OBJECTIVE IS TO MINIMIZE THIS SCORE"
00500 PRINT "BY OPTIMALLY CONTROLING THE PROCESS."
00510 PRINT "    DURING EACH ROUND YOU WILL BE NOTIFIED OF THE MODE"
00520 PRINT "YOU ARE IN. DURING EACH MODE UPON RECEIVING A QUESTION"
00530 PRINT "MARK(^) YOU HAVE TO GIVE THE NECCESSARY INSTRUCTIONS."
00540 PRINT "IN EACH CASE JUST TYPE IN THE REQUIRED NUMBER."
00550 PRINT "    THE FOLLOWING IS A LIST OF THE APPROPRIATE"
00560 PRINT "INSTRUCTIONS ALONG WITH THEIR RESPECTIVE NUMBERS:"
00570 PRINT "    1    ONE OR MORE INPUT SAMPLES REQUIRED."
00580 PRINT "   -1    NO MORE INPUT SAMPLES REQUIRED."
00590 PRINT "   -2    NO INPUT SAMPLES AT ALL."
00600 PRINT "    3    APPLY CONTROL (MAKE OR UPDATE PREDICTION)."
00610 PRINT "   -3    NO CONTROL DESIRED. LAST PREDICTION WILL BE"
00620 PRINT "         COUNTED AS CURRENT."
00630 PRINT "    4    OUTPUT SAMPLE REQUIRED."
00640 PRINT "   -4    NO OUTPUT SAMPLE REQUIRED."
00650 PRINT "NOW WE WILL TRY THESE FOR 5 TIME UNITS TO SEE IF YOU"
00660 PRINT "UNDERSTAND THE PROCEDURE."
00670 PRINT
00680 PRINT " DO YOU WANT TO TRY A TRIAL RUN":
00690 INPUT M$
00700 IF M$="NO" THEN 01690
00710 PRINT
00711 REM
```

```
00712 REM STARTING THE PRACTICE TRIAL RUN
00713 REM
00720 PRINT "ERROR COST= ";C1
00730 PRINT "INPUT SAMPLING COST= ";C2
00740 PRINT "OUTPUT SAMPLING COST= ";C4
00750 PRINT "CONTROL COST= ";C3
00760 PRINT
00770 PRINT
00780 PRINT "                                  CLOCK=101"
00790 PRINT
00800 T=101
00805 REM
00806 REM STARTING THE INPUT MODE
00810 PRINT " INPUT(1 OR -2);"
00820 INPUT A$
00830 IF A$="1" THEN 00870
00840 IF A$="-2" THEN 00960
00845 REM PRINTING AN ERROR MESSAGE
00850 GOSUB 06770
00860 GO TO 00820
00865 REM PRINT AN INPUT SAMPLE
00870 GOSUB 06790
00880 INPUT A$
00890 IF A$="1" THEN 00870
00900 IF A$="-1" THEN 00930
00910 GOSUB 06770
00920 GO TO 00880
00925 REM D= TOTAL INPUT SAMPLES
00930 V1=D*C2
00940 D=0
00950 GO TO 00980
00955 REM BY-PASSING THE INPUT MODE
00960 V1=0
00970 A(T)=0
00980 PRINT
00985 REM
00986 REM STARTING THE OUTPUT MODE
00990 PRINT " OUTPUT (4 OR -4);"
01000 INPUT B$
01010 IF B$="4" THEN 01050
01020 IF B$="-4" THEN 01080
01030 GOSUB 06770
01040 GO TO 01000
01050 Y(T)=M1*X(1)
01060 GOSUB 07000
01070 GO TO 01090
01075 REM BY-PASSING THE OUT PUT MODE
01080 V3=0
01090 Y(T)=M1*X(1)
01095 REM STARTING THE CONTROL MODE
01100 PRINT " CONTROL (3 OR -3 );"
01110 INPUT C$
01120 IF C$="3" THEN 01160
01130 IF C$="-3" THEN 01180
01140 GOSUB 06770
01150 GO TO 01110
01160 GOSUB 06870
01170 GO TO 01190
01175 REM BY-PASSING THE CONTROL MODE
01180 Z(T)=V2=0
01190 GOSUB 07050
01200 D=0
01205 REM GOING THROUGH THE PRACTICE TRIAL 4 TIMES
01210 FOR T=102 TO 105
01220 PRINT
01230 PRINT "                                   CLOCK= ";T
01240 PRINT
01245 REM STARTING THE INPUT MODE
01250 PRINT " INPUT(1 OR -2);"
01260 INPUT D$
01270 IF D$="1" THEN 01310
01280 IF D$="-2" THEN 01400
01290 GOSUB 06770
01300 GO TO 01260
01310 GOSUB 06790
01320 INPUT D$
01330 IF D$="1" THEN 01310
01340 IF D$="-1" THEN 01370
01350 GOSUB 06770
01360 GO TO 01320
01370 V1=D*C2
01380 D=0
01390 GO TO 01410
01395 REM BY-PASSING THE INPUT MODE
```

```
01400 V1=A(T)=0
01405 REM STARTING THE OUTPUT MODE
01410 PRINT " OUTPUT (4 OR -4 ):"
01420 INPUT E$
01430 IF E$="4" THEN 01470
01440 IF E$="-4" THEN 01490
01450 GOSUB 06770
01460 GO TO 01420
01470 GOSUB 06990
01480 GO TO 01500
01485 REM BY-PASSING THE OUTPUT MODE
01490 V3=0
01500 Y(T)=M1*Z(T-1)
01505 REM STARTING THE CONTROL MODE
01510 PRINT " CONTROL (3 OR -3 ):"
01520 INPUT F$
01530 IF F$="3" THEN 01570
01540 IF F$="-3" THEN 01590
01550 GOSUB 06770
01560 GO TO 01520
01570 GOSUB 06870
01580 GO TO 01610
01585 REM BY-PASSING THE CONTROL MODE
01590 Z(T)=Z(T-1)
01600 V2=0
01610 GOSUB 07050
01620 D=0
01630 NEXT T
01635 REM GO TO SUBROUTINE AND CALCULATE THE TOTAL SCOR FOR
01636 REM THE ROUND
01640 GOSUB 07070
01650 PRINT
01660 PRINT "THE TRIAL RUN IS FINISHED. IF YOU DO NOT HAVE ANY"
01670 PRINT "QUESTIONS TYPE GO AND START THE ACTUAL EXPERIMENT."
01680 INPUT I$
01690 FOR T=1 TO 5
01700 A(T)=Z(T)=F(T)=C(T)=V(T)=0
01710 NEXT T
01720 T=I=V1=D=I1=V2=I2=S=Y=V3=0
01730 PRINT
01740 PRINT
01741 REM
01742 REM START THE MAIN CYCLE
01743 REM
01750 PRINT "ERROR COST= ";C1
01760 PRINT
01770 PRINT "INPUT SAMPLING COST= ";C2
01780 PRINT
01790 PRINT "CONTROL COST= ";C3
01800 PRINT
01810 PRINT "OUTPUT SAMPLING COST= ";C4
01820 PRINT
01830 PRINT "                CLOCK= 1"
01840 PRINT
01850 T=1
01855 REM START THE INPUT MODE
01860 PRINT " INPUT(1 OR -2):"
01870 D=0
01880 INPUT G$
01890 IF G$="1" THEN 01930
01900 IF G$="-2" THEN 02020
01910 GOSUB 06770
01920 GO TO 01880
01930 GOSUB 06790
01940 INPUT G$
01950 IF G$="1" THEN 01930
01960 IF G$="-1" THEN 01990
01970 GOSUB 06770
01980 GO TO 01940
01990 V1=D*C2
02000 D=0
02010 GO TO 02040
02015 REM BY-PASSING THE INPUT MODE
02020 V1=0
02030 A(T)=0
02040 PRINT
02045 REM STARTING THE OUTPUT MODE
02050 PRINT " OUTPUT(4 OR -4):"
02060 INPUT J$
02070 IF J$="4" THEN 02110
02080 IF J$="-4" THEN 02140
02090 GOSUB 06770
02100 GO TO 02060
02110 Y(T)=M1*X(1)
```

```
02120 GOSUB 07000
02130 GO TO 02170
02135 REM BY-PASSING THE OUTPUT MODE
02140 V3=0
02150 F(T)=0
02160 Y(T)=M1*X(1)
02170 PRINT
02175 REM STARTING THE CONTROL MODE
02180 PRINT " CONTROL(3 OR -3):"
02190 INPUT K$
02200 IF K$="3" THEN 02240
02210 IF K$="-3" THEN 02260
02220 GOSUB 06770
02230 GO TO 02190
02240 GOSUB 06870
02250 GO TO 02290
02255 REM BY-PASSING THE CONTROL MODE
02260 Z(T)=0
02270 C(T)=0
02280 V2=0
02285 REM CALCULATE THE TOTAL SCORE FOR THE ROUND
02290 GOSUB 07050
02300 D=0
02305 REM DO THE MAIN CYCLE FOR THE APPROPRIATE AMOUNT OF TIME
02310 FOR T=2 TO J
02320 PRINT
02330 PRINT "            CLOCK= ";T
02340 PRINT
02345 REM START THE INPUT MODE
02350 PRINT " INPUT (1 OR -2):"
02360 INPUT L$
02370 IF L$="1" THEN 02410
02380 IF L$="-2" THEN 02500
02390 GOSUB 06770
02400 GO TO 02360
02410 GOSUB 06790
02420 INPUT L$
02430 IF L$="1" THEN 02410
02440 IF L$="-1" THEN 02470
02450 GOSUB 06770
02460 GO TO 02420
02470 V1=D*C2
02480 D=0
02490 GO TO 02520
02495 REM BY-PASS THE INPUT MODE
02500 V1=0
02510 A(T)=0
02520 PRINT
02525 REM START THE OUTPUT MODE
02530 PRINT " OUTPUT (4 OR -4):"
02540 INPUT N$
02550 IF N$="4" THEN 02590
02560 IF N$="-4" THEN 02610
02570 GOSUB 06770
02580 GO TO 02540
02590 GOSUB 06990
02600 GO TO 02640
02605 REM BY-PASSING THE OUTPUT MODE
02610 V3=0
02620 F(T)=0
02630 Y(T)=M1*Z(T-1)
02640 PRINT
02645 REM START THE CONTROL MODE
02650 PRINT " CONTROL (3 OR -3):"
02660 INPUT O$
02670 IF O$="3" THEN 02710
02680 IF O$="-3" THEN 02730
02690 GOSUB 06770
02700 GO TO 02660
02710 GOSUB 06870
02720 GO TO 02760
02725 REM BY-PASSING THE CONTROL MODE
02730 Z(T)=Z(T-1)
02740 C(T)=0
02750 V2=0
02755 REM CALCULATE THE TOTAL SCORE FOR THE EXPERIMENT
02760 GOSUB 07050
02770 D=0
02780 NEXT T
02785 REM PRINTING THE TOTAL SCORE FOR THE EXPERIMENT
02790 GOSUB 07070
02800 PRINT
02810 PRINT
02820 PRINT
```

```
02830 PRINT "THE EXPERIMENT IS FINISHED.      THANK YOU."
02833 REM
02834 REM STARTING THE TABULATION AND STATISTICS
02835 REM OUTPUT WOULD BE IN FILE SUBJECT
02836 REM
02840 PRINT %2,"ERROR COST= ":C1:"    INPUT SAMPLING COST= ":C2
02850 PRINT %2,"COST OF CONTROL= ":C3:"    OUTPUT SAMPLING COST= ":C4
02860 PRINT %2,"ALPHA= ":A:"                VARIANCE OF R/X= ":S1
02870 PRINT %2,"MU= ":M:"       MU1= ":M1:"       X(0)= ":F
02880 PRINT %2
02890 PRINT %2
02900 PRINT %2
02905 REM
02906 REM PRINTING THE TABLE
02910 PRINT %2," TIME":TAB(8):"ACTUAL":TAB(17):"CONTROL/OUT":TAB(32):
02920 PRINT %2,"INPUT":TAB(40):"OUTPUT":TAB(49):"CONTROL":TAB(60):"TOTAL"
02930 PRINT %2,TAB(8):"VALUE":TAB(17):"VALUE   /PUT":TAB(31):"SAMPLE":
02940 PRINT %2,TAB(40):"SAMPLE":TAB(49):"APPLIED":TAB(60):"SCORE"
02950 PRINT %2
02960 PRINT %2
02970 FOR T=1 TO J
02980 PRINT %2 USING 02990,T,X(T),Z(T),Y(T),A(T),F(T),C(T),V(T)
02990:  >>>    >>.>>    >>.>> / >>.>>     >>           >>          >>        >>>>>.>>
03000 NEXT T
03010 PRINT %2
03015 REM CHECKING THE INTERVAL OF STATISTICS
03020 IF K=10 THEN 03960
03025 REM CALCULATE THE STATISTICS FOR AN INTERVAL OF 25
03030 IF J>25 THEN 03160
03040 GOSUB 05700
03050 FOR I=1 TO J
03060 GOSUB 05590
03070 NEXT I
03071 REM O1=TOTAL SCORE               W1= AVERAGE SCORE
03072 REM O2= TOTAL OBSERVATIONS             W2 = AVG. OBSERVATIONS
03073 REM O3=NO. ROUNDS SAMPLE TAKEN          W3= SAMPLE PER OBS.
03080 W1=O1/J
03090 W2=O2/J
03100 W3=O2/O3
03110 PRINT %2
03120 PRINT %2
03130 PRINT %2," FOR TIME INTERVAL 1 TO ":J
03140 GOSUB 05740
03150 GO TO 07170
03160 IF J>50 THEN 03360
03170 GOSUB 05700
03180 FOR I=1 TO 25
03190 GOSUB 05590
03200 NEXT I
03210 GOSUB 05640
03220 PRINT %2," FOR TIME INTERVAL 1 TO 25"
03230 GOSUB 05740
03240 GOSUB 05700
03250 FOR I=26 TO J
03260 GOSUB 05590
03270 NEXT I
03280 W1=O1/(J-25)
03290 W2=O2/(J-25)
03300 W3=O2/O3
03310 PRINT %2
03320 PRINT %2
03330 PRINT %2," FOR TIME INTERVAL 26 TO ":J
03340 GOSUB 05740
03350 GO TO 07170
03360 IF J>75 THEN 03630
03370 GOSUB 05700
03380 FOR I=1 TO 25
03390 GOSUB 05590
03400 NEXT I
03410 GOSUB 05640
03420 PRINT %2," FOR TIME INTERVAL 1 TO 25"
03430 GOSUB 05740
03440 GOSUB 05700
03450 FOR I=26 TO 50
03460 GOSUB 05590
03470 NEXT I
03480 GOSUB 05640
03490 PRINT %2," FOR TIME INTERVAL 26 TO 50"
03500 GOSUB 05740
03510 GOSUB 05700
03520 FOR I=51 TO J
03530 GOSUB 05590
03540 NEXT I
03550 W1=O1/(J-50)
```

```
03560 W2=O2/(J-50)
03570 W3=O2/O3
03580 PRINT %2
03590 PRINT %2
03600 PRINT %2," FOR TIME INTERVAL 51 TO ";J
03610 GOSUB 05740
03620 GO TO 07170
03630 GOSUB 05700
03640 FOR I=1 TO 25
03650 GOSUB 05590
03660 NEXT I
03670 GOSUB 05640
03680 PRINT %2," FOR TIME INTERVAL 1 TO 25"
03690 GOSUB 05740
03700 GOSUB 05700
03710 FOR I=26 TO 50
03720 GOSUB 0559
03730 NEXT I
03740 GOSUB 05640
03750 PRINT %2," FOR TIME INTERVAL 26 TO 50"
03760 GOSUB 05740
03770 GOSUB 05700
03780 FOR I=51 TO 75
03790 GOSUB 05590
03800 NEXT I
03810 GOSUB 05640
03820 PRINT %2," FOR TIME INTERVAL 51 TO 75"
03830 GOSUB 05740
03840 GOSUB 05700
03850 FOR I=76 TO J
03860 GOSUB 05590
03870 NEXT I
03880 W1=O1/(J-75)
03890 W2=O2/(J-75)
03900 W3=O2/O3
03910 PRINT %2
03920 PRINT %2
03930 PRINT %2," FOR TIME INTERVAL 76 TO ";J
03940 GOSUB 05740
03950 GO TO 07170
03955 REM CALCULATE STATISTICS FOR AN INTERVAL OF 10
03960 IF J>10 THEN 03980
03970 GO TO 03040
03980 IF J>20 THEN 04120
03990 GOSUB 06050
04000 GOSUB 05700
04010 FOR I=11 TO J
04020 GOSUB 05590
04030 NEXT I
04040 W1=O1/(J-10)
04050 W2=O2/(J-10)
04060 W3=O2/O3
04070 PRINT %2
04080 PRINT %2
04090 PRINT %2," FOR TIME INTERVAL 11 TO ";J
04100 GOSUB 05740
04110 GO TO 07170
04120 IF J>30 THEN 04270
04130 GOSUB 06050
04140 GOSUB 06130
04150 GOSUB 05700
04160 FOR I=21 TO J
04170 GOSUB 05590
04180 NEXT I
04190 W1=O1/(J-20)
04200 W2=O2/(J-20)
04210 W3=O2/O3
04220 PRINT %2
04230 PRINT %2
04240 PRINT %2,"FOR TIME INTERVAL 21 TO ";J
04250 GOSUB 05740
04260 GO TO 07170
04270 IF J>40 THEN 04430
04280 GOSUB 06050
04290 GOSUB 06130
04300 GOSUB 06210
04310 GOSUB 05700
04320 FOR I=31 TO J
04330 GOSUB 05590
04340 NEXT I
04350 W1=O1/(J-30)
04360 W2=O2/(J-30)
04370 W3=O2/O3
04380 PRINT %2
```

```
04390 PRINT %2
04400 PRINT %2," FOR TIME INTERVAL 31 TO ";J
04410 GOSUB 05740
04420 GO TO 07170
04430 IF J>50 THEN 04600
04440 GOSUB 06050
04450 GOSUB 06130
04460 GOSUB 06210
04470 GOSUB 06290
04480 GOSUB 05700
04490 FOR I=41 TO J
04500 GOSUB 05590
04510 NEXT I
04520 W1=O1/(J-40)
04530 W2=O2/(J-40)
04540 W3=O2/O3
04550 PRINT %2
04560 PRINT %2
04570 PRINT %2," FOR TIME INTERVAL 41 TO ";J
04580 GOSUB 05740
04590 GO TO 07170
04600 IF J>60 THEN 04780
04610 GOSUB 06050
04620 GOSUB 06130
04630 GOSUB 06210
04640 GOSUB 06290
04650 GOSUB 06370
04660 GOSUB 05700
04670 FOR I=51 TO J
04680 GOSUB 05590
04690 NEXT I
04700 W1=O1/(J-50)
04710 W2=O2/(J-50)
04720 W3=O2/O3
04730 PRINT %2
04740 PRINT %2
04750 PRINT %2," FOR TIME INTERVAL 51 TO ";J
04760 GOSUB 05740
04770 GO TO 07170
04780 IF J>70 THEN 04970
04790 GOSUB 06050
04800 GOSUB 06130
04810 GOSUB 06210
04820 GOSUB 06290
04830 GOSUB 06370
04840 GOSUB 06450
04850 GOSUB 05700
04860 FOR I=61 TO J
04870 GOSUB 05590
04880 NEXT I
04890 W1=O1/(J-60)
04900 W2=O2/(J-60)
04910 W3=O2/O3
04920 PRINT %2
04930 PRINT %2
04940 PRINT %2," FOR TIME INTERVAL 61 TO ";J
04950 GOSUB 05740
04960 GO TO 07170
04970 IF J>80 THEN 05170
04980 GOSUB 06050
04990 GOSUB 06130
05000 GOSUB 06210
05010 GOSUB 06290
05020 GOSUB 06370
05030 GOSUB 06450
05040 GOSUB 06530
05050 GOSUB 05700
05060 FOR I=71 TO J
05070 GOSUB 05590
05080 NEXT I
05090 W1=O1/(J-70)
05100 W2=O2/(J-70)
05110 W3=O2/O3
05120 PRINT %2
05130 PRINT %2
05140 PRINT %2," FOR TIME INTERVAL 71 TO ";J
05150 GOSUB 05740
05160 GO TO 07170
05170 IF J>90 THEN 05380
05180 GOSUB 06050
05190 GOSUB 06130
05200 GOSUB 06210
05210 GOSUB 06290
05220 GOSUB 06370
```

```
05230 GOSUB 06450
05240 GOSUB 06530
05250 GOSUB 06610
05260 GOSUB 05700
05270 FOR I=81 TO J
05280 GOSUB 05590
05290 NEXT I
05300 W1=O1/(J-80)
05310 W2=O2/(J-80)
05320 W3=O2/O3
05330 PRINT %2
05340 PRINT %2
05350 PRINT %2," FOR TIME INTERVAL 81 TO ":J
05360 GOSUB 05740
05370 GO TO 07170
05380 GOSUB 06050
05390 GOSUB 06130
05400 GOSUB 06210
05410 GOSUB 06290
05420 GOSUB 06370
05430 GOSUB 06450
05440 GOSUB 06530
05450 GOSUB 06610
05460 GOSUB 06690
05470 GOSUB 05700
05480 FOR I=91 TO J
05490 GOSUB 05590
05500 NEXT I
05510 W1=O1/(J-90)
05520 W2=O2/(J-90)
05530 W3=O2/O3
05540 PRINT %2
05550 PRINT %2
05560 PRINT %2," FOR TIME INTERVAL 91 TO ":J
05570 GOSUB 05740
05580 GO TO 07170
05585 REM
05586 REM SUBROUTINE
05587 REM CALCULATE THE TOTAL SCORE AND TOTAL OBSERVATIONS
05590 O1=V(I)+O1
05600 O2=A(I)+O2
05610 IF A(I)=0 THEN 05630
05620 O3=O3+1
05630 RETURN
05635 REM
05636 REM SUBROUTINE
05637 REM CALCULATE THE AVERAGE SCORE , AVG. OBSE., AND SAMPLE/OBS.
05640 W1=O1/25
05650 W2=O2/25
05660 W3=O2/O3
05670 PRINT %2
05680 PRINT %2
05690 RETURN
05695 REM
05696 REM SUBROUTINE   INITIALIZATION
05700 O1=0
05710 O2=0
05720 O3=0
05730 RETURN
05735 REM
05736 REM SUBROUTINE
05737 REM PRINT THE STATISTICS
05740 PRINT %2," TOTAL SCORE                                 =":O1
05750 PRINT %2," AVERAGE SCORE                               =":W1
05760 PRINT %2," TOTAL NO. OF OBSERVATIONS                   =":O2
05770 PRINT %2," AVERAGE NO. OF OBSERVATIONS                 =":W2
05780 PRINT %2," NO. OF ROUNDS SAMPLE TAKEN                  =":O3
05790 PRINT %2," AVG. NO. OF OBS. WHEN AN OBS. IS MADE =":W3
05800 RETURN
05805 REM
05806 REM SUBROUTINE
05807 REM CALCULATE AVERAGES FOR INTERVAL OF 10
05810 W1=O1/10
05820 W2=O2/10
05830 W3=O2/O3
05840 PRINT %2
05850 PRINT %2
05860 RETURN
05865 REM
05866 REM SUBROUTINES
05867 REM PRINT HEADINGS FOR THE STATISTICS
05870 PRINT %2," FOR TIME INTERVAL 1 TO 10"
05880 RETURN
05890 PRINT %2," FOR TIME INTERVAL 11 TO 20"
```

```
05900 RETURN
05910 PRINT %2," FOR TIME INTERVAL 21 TO 30"
05920 RETURN
05930 PRINT %2," FOR TIME INTERVAL 31 TO 40 "
05940 RETURN
05950 PRINT %2," FOR TIME INTERVAL 41 TO 50 "
05960 RETURN
05970 PRINT %2," FOR TIME INTERVAL 51 TO 60 "
05980 RETURN
05990 PRINT %2," FOR TIME INTERVAL 61 TO 70 "
06000 RETURN
06010 PRINT %2," FOR TIME INTERVAL 71 TO 80 "
06020 RETURN
06030 PRINT %2," FOR TIME INTERVAL 81 TO 90 "
06040 RETURN
06045 REM
06046 REM SUBROUTINES
06047 REM CALCULATE AVERAGES FOR EACH INTERVAL
06050 GOSUB 05700
06060 FOR I=1 TO 10
06070 GOSUB 05590
06080 NEXT I
06090 GOSUB 05810
06100 GOSUB 05870
06110 GOSUB 05740
06120 RETURN
06130 GOSUB 05700
06140 FOR I=11 TO 20
06150 GOSUB 05590
06160 NEXT I
06170 GOSUB 05810
06180 GOSUB 05890
06190 GOSUB 05740
06200 RETURN
06210 GOSUB 05700
06220 FOR I=21 TO 30
06230 GOSUB 05590
06240 NEXT I
06250 GOSUB 05810
06260 GOSUB 05910
06270 GOSUB 05740
06280 RETURN
06290 GOSUB 05700
06300 FOR I=31 TO 40
06310 GOSUB 05590
06320 NEXT I
06330 GOSUB 05810
06340 GOSUB 05930
06350 GOSUB 05740
06360 RETURN
06370 GOSUB 05700
06380 FOR I=41 TO 50
06390 GOSUB 05590
06400 NEXT I
06410 GOSUB 05810
06420 GOSUB 05950
06430 GOSUB 05740
06440 RETURN
06450 GOSUB 05700
06460 FOR I=51 TO 60
06470 GOSUB 05590
06480 NEXT I
06490 GOSUB 05810
06500 GOSUB 05970
06510 GOSUB 05740
06520 RETURN
06530 GOSUB 05700
06540 FOR I=61 TO 70
06550 GOSUB 05590
06560 NEXT I
06570 GOSUB 05810
06580 GOSUB 05990
06590 GOSUB 05740
06600 RETURN
06610 GOSUB 05700
06620 FOR I=71 TO 80
06630 GOSUB 05590
06640 NEXT I
06650 GOSUB 05810
06660 GOSUB 06010
06670 GOSUB 05740
06680 RETURN
06690 GOSUB 05700
06700 FOR I=81 TO 90
```

```
06710 GOSUB 05590
06720 NEXT I
06730 GOSUB 05810
06740 GOSUB 06030
06750 GOSUB 05740
06760 RETURN
06765 REM
06766 REM SUBROUTINE
06767 REM PRINT THE ERROR MESSAGE
06770 PRINT "INPUT ERROR .     TRY AGAIN."
06780 RETURN
06785 REM
06786 REM SUBROUTINE
06787 REM READ A RANDOM NUMBER, CALCULATE AN INPUT SAMPLE,PRINT IT
06790 READ %3,R1
06800 R=R1*((1/(1-(A+2)))+(0.5))
06810 S=X(T)+R
06820 PRINT
06830 PRINT " INPUT= ":S
06840 D=D+1
06850 A(T)=D
06860 RETURN
06865 REM
06866 REM SUBROUTINE
06867 REM INPUT THE CONTROL VARIABLE AND CHECK TO SEE IF IT IS CORRECT
06870 PRINT
06880 PRINT " VARIABLE= ":
06890 INPUT Z(T)
06900 PRINT TAB(16):Z(T):" CORRECT":
06910 INPUT H$
06920 IF H$="NO" THEN 06870
06930 IF H$="YES" THEN 06960
06940 GOSUB 06770
06950 GO TO 06910
06960 C(T)=1
06970 V2=C3
06980 RETURN
06984 REM
06985 REM SUBROUTINE
06986 REM CALCULATE AND PRINT AN OUTPUT SAMPLE
06990 Y(T)=M1*Z(T-1)
07000 PRINT
07010 PRINT " OUTPUT= ":Y(T)
07020 F(T)=1
07030 V3=C4
07040 RETURN
07045 REM
07046 REM SUBROUTINE
07047 REM CALCULATE SCORE FOR EACH ROUND
07050 V(T)=((X(T)-Y(T))+2)*C1+V1+V2+V3
07060 RETURN
07065 REM
07066 REM SUBROUTINE
07067 REM CALCULATE TOTAL SCORE AND PRINT IT
07070 V8=0
07080 FOR I=1 TO J
07090 V8=V8+V(I)
07100 NEXT I
07110 PRINT
07120 PRINT
07130 PRINT "YOUR TOTAL SCORE IS=":V8
07140 PRINT
07150 PRINT
07160 RETURN
07170 PRINT " END OF PROGRAM"
07180 END
```

APPENDIX F

A SAMPLE OF THE QUESTIONNAIRE SERVED AS THE SCREENING DEVICE

QUESTIONNAIRE

NO.____________________

DATE:__________________

1. MAJOR:______________________________ 2. CLASS RANK:____________

3. DATE OF BIRTH:______________ 4. AGE:___________ 5. SEX:________

6. PLEASE LIST ALL YOUR MATHEMATICS COURSES BY SUBJECT AREA.

7. PLEASE LIST ALL YOUR STATISTICS COURSES BY SUBJECT AREA.

8. PLEASE LIST ALL THE COMPUTER LANGUAGES & SYSTEMS WHICH YOU FEEL MOST COMFORTABLE WRITING A PROGRAM IN.

9. HAVE YOU HAD NORMAL SLEEP PATTERNS RECENTLY?

10. ARE YOU TAKING ANY MEDICATION SUCH AS SOMINEX, NODOZ, COUGH SYRUPS, COLD TABLETS, AND ETC?

11. ARE YOU UNDER ANY EMOTIONAL, PSYCHOLOGICAL, PHYSIOLOGICAL STRESS SUCH AS A MIDTERM EXAMINATION WHICH WOULD AFFECT YOUR PERFORMANCE?

APPENDIX G

PROCESS CONSTANTS FOR PHASE I

Constant	Value
Error cost (C_e)	10
Input sampling cost (C_x)	5
Constant of the input function (μ)	3
Constant of the output function (μ_1)	1
Control cost (C_z)	0
Output sampling cost (C_Y)	0
Experiment cycle (T)	100
Input value at time t = 0 (x_o)	3

APPENDIX H

THE EFT SCORES FOR THE EIGHT SUBJECTS OF THE PHASE I OF THE EXPERIMENT

Appendix H

The EFT Scores for the Eight Subjects of the Phase I of the Experiment

Subject	EFT score (in seconds)
1	11.67
2	62.92
3	56.92
4	9.42
5	14.75
6	9
7	16.54
8	33.63

APPENDIX I

THE PROCESS CONSTANTS FOR PHASE II OF THE EXPERIMENT

Appendix I

The Process Constants for Experiment Phase II

Process Constant	Value
Error cost	1
Input sampling cost	5
Control cost	0
Output sampling cost	0
Constant of the input function (μ)	3
Constant of the output function (μ_1)	1
Input value at time t = 0 (x_o)	3