DEVELOPMENT OF A KNOWLEDGE BASED EXPERT SYSTEM FOR CONTROL CHART PATTERN RECOGNITION AND ANALYSIS

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RECOGNITION AND ANALYSIS

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Very special thanks go to my family. To my mother and grandmother for supporting me during this adventure. To my husband and best friend for encouraging me to pursue this degree and for helping me understand the "things of most importance".

Finally, I would like to dedicate this work to the fox and the little prince. Those who know them, will understand.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Background

In many companies, it is reasonably common to encounter control charts being used to solve individual or isolated problems. For example, this is done to determine the capability of a particular machine or to correct an engineering specification problem. Such isolated usages are termed quality control applications, which are useful but do not necessarily contribute to total system performance improvement. What is needed is a comprehensive quality control program. Such a program consists of a regular and systematic application of the charts to problems as they exist in a given area and as they arise. Therefore, there is a great need for specialists who are capable in control charting techniques and analysis.

One of the more popular control charts used in a quality control program is the $\overline{X}$ control chart. This chart is one of the more sensitive control charts for tracing and identifying causes since it analyzes some of the more sensitive process data available, the averages. Therefore, for ease of illustration, the $\overline{X}$ chart will be used throughout this research to represent the working of the expert system which will be developed. Since the "control chart has the ability to detect and identify causes" (AT&T ,1985), it has been the primary concern of process engineers for many years. The major drawback to the use of control charts is that the average user is untrained in control charting techniques, let alone control chart analysis. The problem sometimes is even more basic than that. Many times the process engineer assigns a line worker to collect the data needed without providing any insight on why the data is needed. Since the worker does not fully appreciate the need for reliable and accurate data, the worker may provide data that is not necessarily correct. However, with the advent of automatic testing equipment, the data collection problem has essentially been solved in many, but not all industrial areas. The problem now is to take this data and turn it into useful information that will help the engineer run the process. The major drawback here, is that there are relatively few qualified control chart analysts available to perform the necessary interpretation required for a proper quality control study.

Traditionally, the first thing done with the data is to plot it as an $\overline{X}$ and R chart. This in itself can become a tedious and time consuming task. If the plotter is not careful, inaccurate plotting can occur which causes inaccurate analysis. Next, the control limits are calculated and drawn onto the $\overline{X}$ and R charts. Now, the traditional AT&T run rules (AT&T, 1985, pp. 25-27) are applied and an analysis is done to check for unnatural patterns. All of this sounds easy, but in actual practice, many problems occur. Some of the more common problems which arise are as follows:

1. Inaccurate plotting of $\overline{X}$ and R charts.
2. Inaccurate calculation and plotting of control limits.
3. Inaccurate application of AT&T run rules.
4. Inaccurate pattern analysis.
5. Charts are considered "gospel".

Problems 1 and 2 arise because the average user does not have a full understanding of the mathematical or statistical techniques used. Problems 3 and 4 are the more difficult problems since they are ones of interpretation. And if the engineer performing tasks 3 and 4 does not fully understand how to interpret a chart, the conclusion arrived at and the subsequent corrections that are made may cause more damage. Finally, problem 5 is one where the "possible causes of unnaturalness" determined from the chart are declared as the "definite causes". This problem is inherent to those who use control charts but do not really understand the underlying theory. They do not understand that control charts are only tools used to identify for the engineer possible places to begin looking for the actual cause of the problem. If the plotting and analysis of the charts were to be accurately automated, problems 1 thru 5 could be eliminated.

Problems 1 and 2 have been addressed by a multitude of people. There are many software packages currently available on the market which will perform these tasks on most any type of computer (Industrial Engineering, July 1986, pp.33-49). Even the automatic testing equipment manufacturers are providing this capability in their equipment now (Production Engineering, Jan. 1984, pp. 54-59). It is problems 3 and 4 which have until recently been viewed as being too difficult to automate. But with the rapid advances in artificial intelligence, these problems are now being viewed as prime areas for automation. There is some research being done in this area, but the companies that are doing this have labeled it proprietary work (which has left a void in the available literature). Even so, literature on the tools needed for such a task is vast. Therefore, the purpose of this research is two-fold. The first is to automate the conversion of a set of inspection values to a plotted control chart and its corresponding control limits. The second is to develop an expert system to perform the pattern analysis on the charts. This package, if successfully developed, can be applied to many industrial processes. The major intention for developing this package is to aid rather than replace the industrial quality engineer.

1.2 Research Objectives

The major emphasis of this research is to develop a knowledge based expert system which will perform pattern analysis on control charts. In particular, algorithms will be developed which will take a given control chart and determine if an unnatural control chart pattern exists. If an unnatural pattern does exist, the expert system will identify it. Therefore, the overall goal of the research is to develop procedures for identifying and analyzing unnatural patterns in control charts which are demonstrably superior to currently available procedures. To achieve this goal, four research objectives were developed.

1.2.1 Control Chart Development

A pattern generator and graphics package will be developed. The pattern generator will be used to create data streams to emulate the various unnatural control chart patterns of interest. The pattern generator will interface with a graphics package which will plot the control charts and mark the "x's" according to the AT&T run rules.

1.2.2 Interactive Expert System

An expert system will be developed which will be capable of accepting the information provided by the pattern generator or real world data provided by an analyst and identify and analyze the particular unnatural patterns if they exist. The expert system will provide the user with an identification of the unnatural patterns and provide an approximate starting and stopping point for the identified pattern. It will also provide estimates of identifying parameters for the identified pattern.

1.2.3 System Validation

The interactive expert system developed will be used to analyze a series of unnatural patterns. The various patterns will be selected from the literature or generated by the author, as appropriate, to evaluate the effectiveness and efficiency of the model in analyzing control charts.

1.2.4 System Effectiveness Evaluation

The system will provide identification of the suspected pattern with estimates of start/stop points and identifying parameter. Since this information can be quite useful, an investigation into the system's ability to accurately identify the correct pattern, start/stop point and identifying parameter will be performed.

Figure 1 illustrates the layout and interconnectivity of these objectives.

1.3 Research Assumptions

In order to further define and delimit this research, certain general assumptions are made. They include:

1. The only unnatural patterns to be analyzed are trends, cycles, mixtures, sudden shifts in level, systematic variables and stratification.
2. The pattern flow to be studied is one that

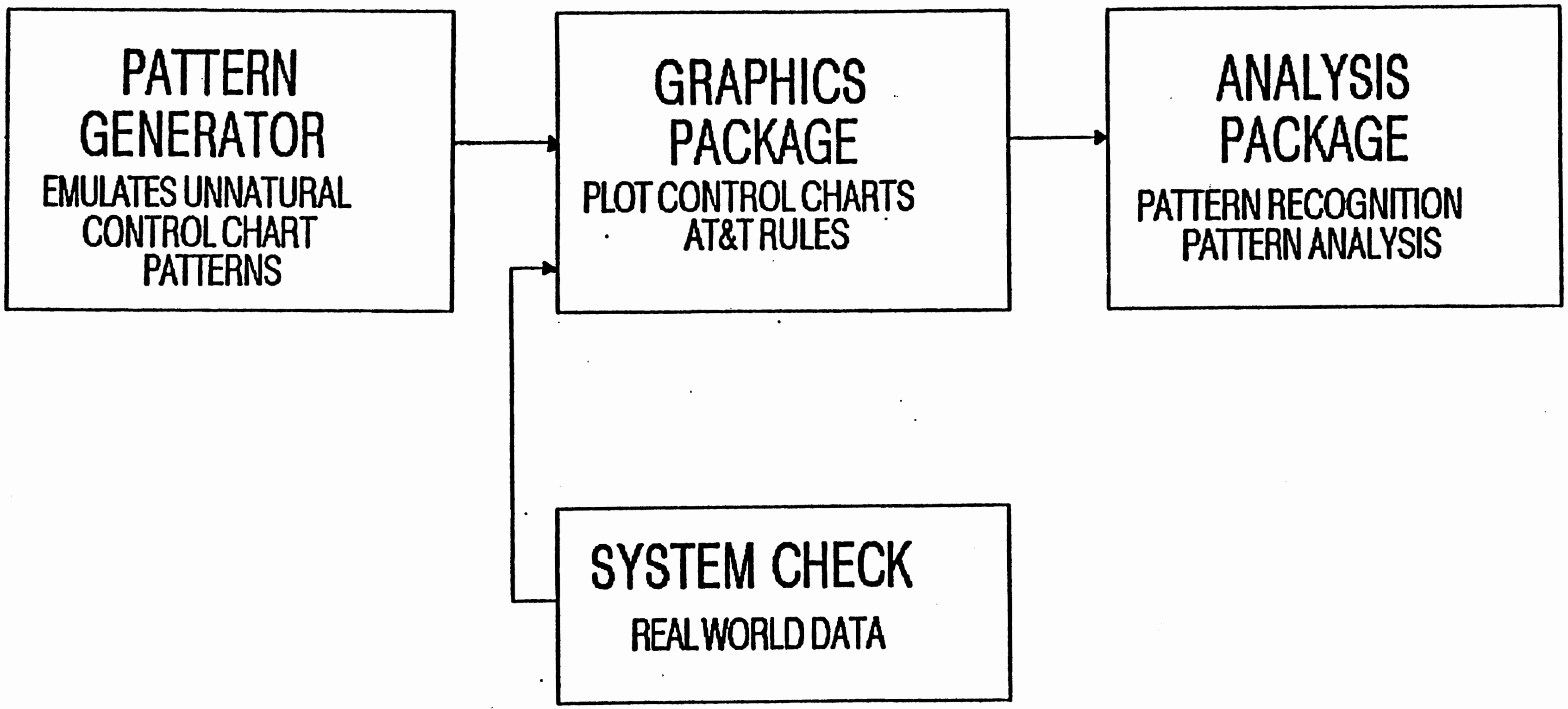


Figure 1. Objective Layout

proceeds from in-control to out-of-control back to in-control.

3. All data sets to be analyzed will contain only one unnatural pattern.
4. Correct identification of the unnatural patterns being analyzed are considered to be successful completion of the system.
5. The type of control chart under study will be monitoring in nature. This means that the control limits are already known and have been set by a process that is in-control.
6. The data generated for analysis represents the true behavioral nature of the process. Thus, the data generated will be assumed to represent data collected by a well designed and thorough sampling plan.

CHAPTER II

BACKGROUND OF THE STUDY

2.1 History of Quality Control

Quality control has had a long history. It is as old as industry itself. From the time man began to manufacture there has been interest in the quality of output (Duncan, 1974). For example, in 1791 Secretary of the Treasury Alexander Hamilton, prepared for the United States House of Representatives a report entitled "Report On Manufacturers" (Syrett, 1966). In this report was a section entitled "Judicious Regulations for the Inspections of Manufactured Commodities". In this report, Hamilton discussed the importance of providing a quality product to ensure sales and guard against foreign competitors. This is quite remarkable when manufacturers are just now beginning again to feel the full threat of foreign competition.

However, most of the early documented work in quality control was done within the Bell Telephone System. The company realized early the need for a means of generating confidence in the quality of their instruments. So they started an Inspection Department whose purpose was to inspect and assure the quality of their manufactured products, installed products and purchased materials. At this time, the only technique used was a form of sampling inspection since statistical techniques were still unknown to the quality process.

In 1925, the Inspection Department was transferred to the newly formed Bell Laboratories. Now, instead of inspecting products, the group's function was "to develop the theory of inspection: putting existing mathematical knowledge into available form for use in laboratory and factory and developing new principles where existing knowledge is inadequate" (Jones,1926). As the group began to work on this objective, the organization of the department evolved. George D. Edwards became Director of Quality Assurance, Walter A. Shewhart became responsible for theory and Harold F. Dodge was placed in charge of methods. These are all respected names in the quality control field. Two others who were involved with Bell Labs through Western Electric were Joseph M. Juran and Bonnie B. Small. Juran is also a well recognized name in the field whereas Bonnie Small is not. It should be noted that she was the original editor and primary author of the Western Electric (now AT&T) Statistical Quality Control Handbook. It is apparent from this list that much of what is known today in the field of quality control is directly attributed to the work done by the Bell Telephone System.

2.2 Control Charts

The concept of control charts was formally introduced by Shewhart (1931). The control chart is based on the principle that variations in measurements pertaining to the quality of the product from a process can be separated into two sources -- inherent (chance) variation and variation due to assignable causes. If the inherent process variation can be estimated, then using statistical procedures, it is possible to detect shifts in the mean and/or variability of the process. The objectives of control charts are to determine whether the process is in a state of statistical control, to assist in establishing a state of statistical control and to maintain current control of a process. (A state of statistical control exists if the process is operating without assignable causes of variation (Juran and Gryna, 1980).) This state of control results in a reduction in the cost of inspection, in the cost of rejection and the attainment of maximum benefit from quality production (Shewhart, 1931). Control charts are classified by the characteristics being tested (Grant and Leavenworth, 1980). If percent defective in the sample is being tested, a p chart is used. If the number of defects in a sample is being tested, a c chart is used. If the average and range of the measurements are being tested, an $\overline{X}$ and R chart, respectively, are used. There are other charts, but the two primary charts used are the $\overline{X}$ and R charts.

2.2.1 $\overline{X}$ and R Charts

The $\overline{X}$ chart is used to detect shifts in the mean level of a process. It shows trends and indicates whether there is stability in the center of the $\overline{X}$ distribution. The R chart is used to determine when a change has occurred in the variation in the output of a process. It shows the magnitude of spread in the output of the process. It also indicates whether the spread is stable and reveals information associated with mixtures, interactions and various forms of instability. R charts should always be interpreted before the corresponding $\overline{X}$ charts since $\overline{X}$ chart analysis is invalid if the R chart is out of control.

This leads to the actual setting up and analysis of the $\overline{X}$ and R charts. The development of the two charts has been well documented and can be found in any quality control book. Since there is no real concern with the development of the charts, it is felt that a formal description of the methodology is not needed in this dissertation. The area of primary concern however, is that of control chart analysis or pattern analysis.

2.2.2 Analysis of Control Charts

Once the control charts are developed, the control limits are drawn (usually as dotted lines). The control limits usually used are 3 sigma control limits, where sigma is a unit of measure which is used to describe the width or spread of a distribution or pattern (AT&T, 1985). (The fluctuations in a "natural" pattern tends to spread about $\pm$ 3 sigma.) The control limits are used to determine if the pattern is "natural" or "unnatural". The two primary characteristics of a natural pattern are that the points fluctuate at random and they obey the laws of chance. This implies that there are no extraneous causes working in the process. Unnatural patterns tend to fluctuate too widely (or not widely enough) or they fail to balance themselves around the centerline. This implies that there are outside disturbances affecting the process. When a pattern is found to be unnatural, an investigation is done to determine these outside causes.

2.2.3 Tests For Instability

The most common means of determining if a given pattern is unnatural is to check for instability. There are many methods for determining whether instability exists. They include methods developed by Western Electric (now AT&T), Lloyd Nelson, and Eugene Grant and Richard Leavenworth. When applying the AT&T rules, only one half of the control band (area between the centerline and one of the control limits) is considered at a time. This band is then divided into 3 equal segments labeled zone A, zone B and zone C, see Figure 2 (AT&T, 1985, p. 25). Each zone is 1 sigma wide since the control limit being used are $\pm$ 3 sigma.)

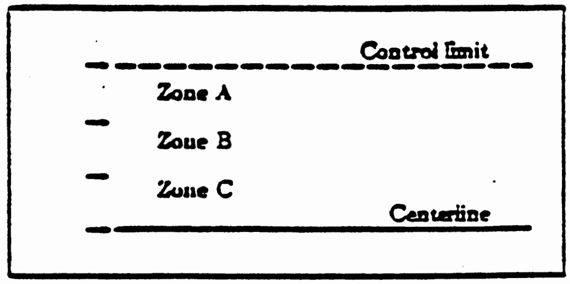


Figure 2. Test Zones

Next, x's are marked according to the following 4 rules (AT&T, 1985, p. 25-27).

Rule 1: A single point falls outside of the 3 sigma limit. This point is marked with an "x", see Figure 3 (AT&T, 1985, p. 25).

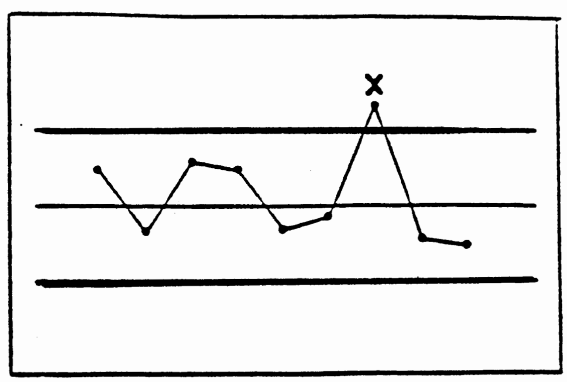


Figure 3. First Test for Unnaturalness

Rule 2: Two out of three successive points fall in zone A or beyond. The second of the two points in or beyond zone A is marked with an "x" . The other point may fall anywhere on the chart, see Figure 4 (AT&T, 1985, p. 26).

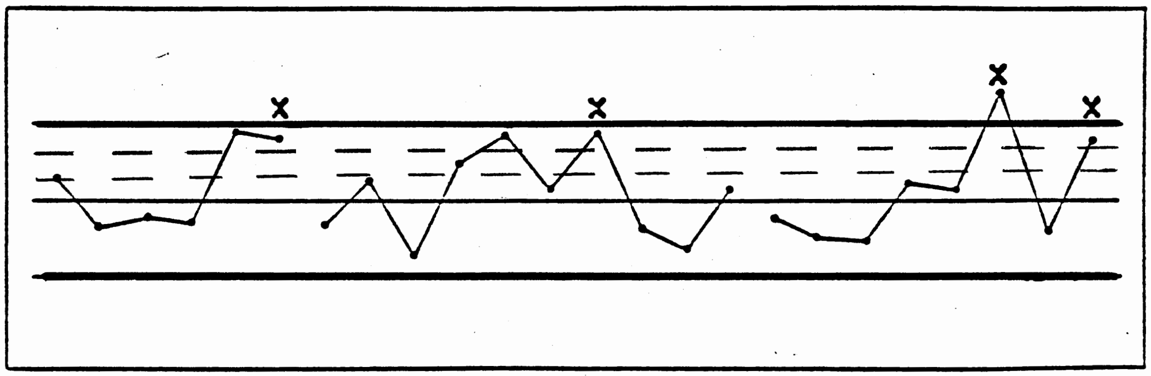


Figure 4. Second Test for Unnaturalness

Rule 3: Four out of five successive points fall in zone B or beyond. Only the fourth point in or beyond zone B is marked with an "x" . As in rule 2, the remaining point may fall anywhere, see Figure 5 (AT&T, 1985, p. 26).

Rule 4: Eight successive points fall in zone C or beyond. Only the eighth point is marked and all eight must be on the same side of the centerline see Figure 6 (AT&T, 1985, p. 27).

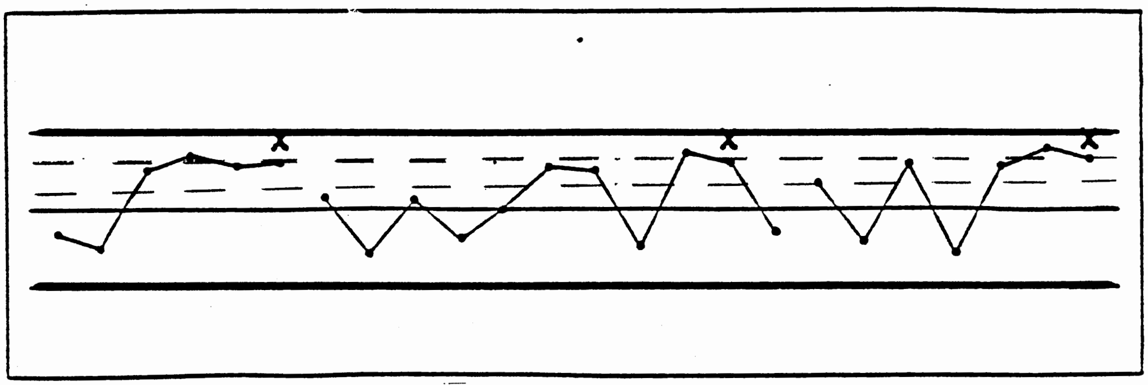


Figure 5. Third Test for Unnaturalness

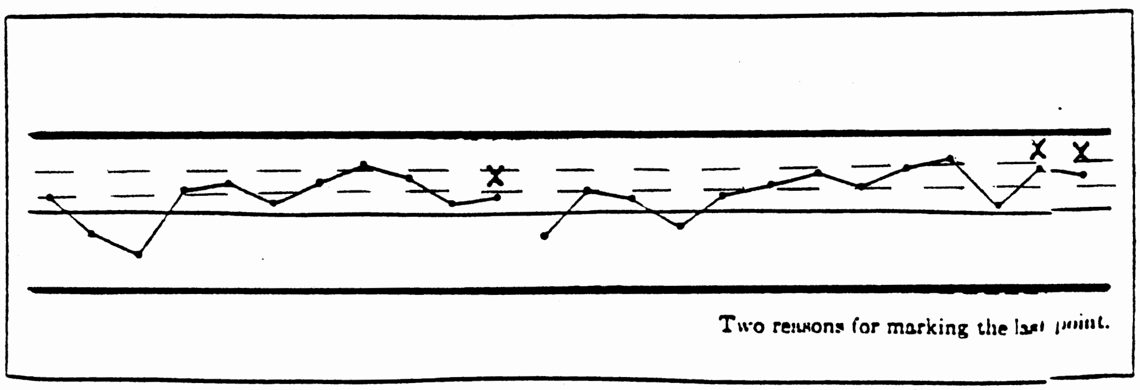


Figure 6. Fourth Test for Unnaturalness

These rules are applied to both sides of the centerline. The more x's that have been marked, the greater the instability in the system.

The method developed by Lloyd Nelson (Journal of

Quality Technology, October 1984, pp 237-239) consists of eight rules which are applied in the same manner as the AT&T rules.

Rule 1: One point falls beyond zone A.

Rule 2: Nine points in a row fall in zone C or beyond.

Rule 3: Six points in a row are steadily increasing or decreasing.

Rule 4: Fourteen points in a row are alternating up and down.

Rule 5: Two out of three points in a row fall in zone A or beyond.

Rule 6: Four out of five points in a row fall in zone B or beyond.

Rule 7: Fifteen points in a row fall in zone C. They can be either above or below the centerline.

Rule 8: Eight points in a row fall on both sides of the centerline with none of them falling in zone C.

To a large degree, Nelson's rules 1, 5 and 6 replicate AT&T's rules 1, 2 and 3. Nelson has just elaborated somewhat on the basic AT&T rules.

The method developed by Grant and Leavenworth in their book, <u>Statistical Quality Control</u> (1980), consists of seven rules.

Rule 1: A single point falls outside the control limits.

Rule 2: Eight points in a row fall between the center line and one control limit.

Rule 3: Seven successive points are all on the same side of the centerline.

Rule 4: Ten out of eleven successive points fall on the same side of the centerline.

Rule 5: Twelve out of fourteen successive points fall on the same side of the centerline.

Rule 6: Fourteen out of seventeen successive points fall on the same side of the centerline.

Rule 7: Sixteen out of twenty successive points fall on the same side of the centerline.

As with Nelson's method, Grant and Leavenworth have replicated two of the AT&T rules and elaborated on the rest.

All of these methods indicate two things; first, whether there is instability present in a process; and second, (if care was taken when plotting the control chart) the specific time of occurrence and operator present at the time of instability. (It must be remembered, however, that the cause of the instability has usually affected more points than the ones actually marked. It is for this reason that, when the data is being collected, any changes made to the process need to be recorded, as well as the time of occurrence and applicable operation.) Thus, as the AT&T rules appear to represent the core method for determining process instability, these rules will be used in this research.

2.2.4 Other Unnatural Patterns

In addition to patterns of instability, there are six other unnatural patterns to be watched for. They are trends, cycles, mixtures, sudden shifts in level, stratification and systematic variables. This research is primarily interested in the analysis and interpretation of these patterns.

2.2.4.1 Trends. A trend is defined as "continuous movement up or down; x's on one side of the chart followed by x's on the other; a long series of points without a change of direction" (AT&T, 1985). Figure 7 (AT&T, 1985, p. 30) illustrates two examples of trends.

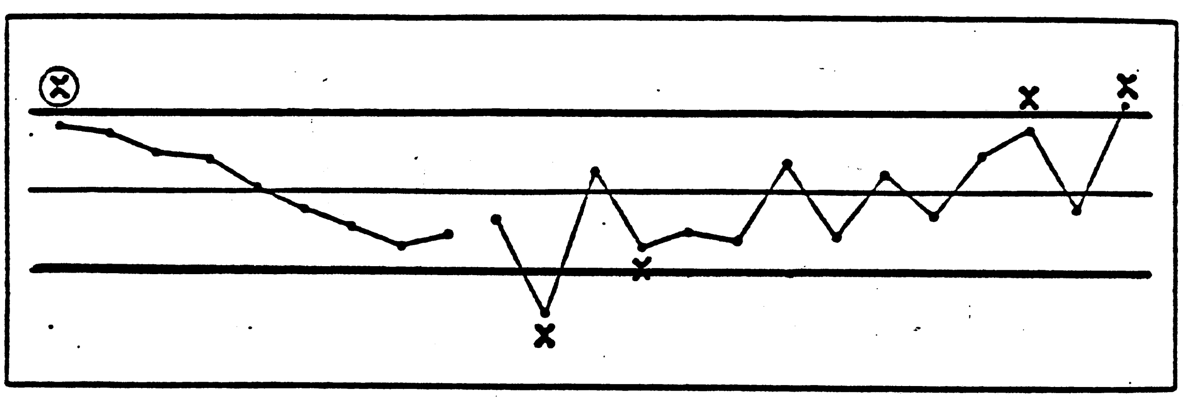


Figure 7. Trend Pattern

Trends usually result from any cause which gradually works on the process. Or in other words, the mean of the process shifts its location gradually in one direction over a period of time. Trends are relatively easy to identify and associate with the process. The nature of the cause can be determined by the type of chart it appears upon. If the trend appears on the $\overline{X}$ chart, the cause is one which moves the center of the distribution rather steadily from high to low or visa versa. If the trend appears on the R chart, the cause is one in which the spread is gradually increasing or decreasing. Some of the more common causes of trends are as follows:

<u>$\overline{X}$ Chart</u>

(R chart must be in control.)

1. Tool wear.
2. Seasonal effects, including temperature and humidity.
3. Operator fatigue.
4. Increases or decreases in production schedules.
5. Gradual change in standards.
6. Gradual change in the proportion defective in each lot.
7. Poor maintenance or housekeeping procedures.

<u>R Chart</u>

<u>Increasing trend</u>

1. Dulling of a tool.
2. Various types of mixture.

3. Something loosening or wearing gradually.

Decreasing trend

1. Gradual improvement in operator technique.

2. Effect of better maintenance program.

3. Effect of process controls in other areas.

4. Product more homogeneous (less affected by mixture).

It should be noted that care must be taken in the interpretation of trends. This is due to the fact that it is easy to imagine trends where none actually exist. To the untrained eye, the irregular up-and-down fluctuations that occur in a natural pattern are often mistaken for trends. This is one of the primary reasons that trend analysis so easily lends itself to automation.

2.2.4.2 Cycles. Cycles are "short trends in the data which occur in repeated patterns" (AT&T, 1985). An assignable cause is indicated when the pattern exhibits any tendency to repeat. This tendency is illustrated by a series of high portions or peaks interspersed with low portions or troughs. This is an indication of an assignable cause since the major characteristic of a random pattern is that it does not repeat. Figure 8 (AT&T, 1985, p. 162) illustrates a pattern with cycles present.

The phenomenon of cycles is caused by processing variables which come and go on a relatively regular basis such as in shift changes or seasonal conditions. Some of the more common causes of cycles are as follows:

$\overline{X}$ Chart

(R chart must be in control.)

1. Seasonal effects such as temperature and humidity.
2. Worn positions or threads on locking devices.
3. Operator fatigue.
4. Rotation of people on the job.
5. Difference between gages used by inspectors.
6. Difference between day and night shifts.

R Chart

1. Maintenance schedules.
2. Operator fatigue.
3. Wear of tool or die causing excessive play.
4. Tool in need of sharpening.
5. Difference between day and night shifts.

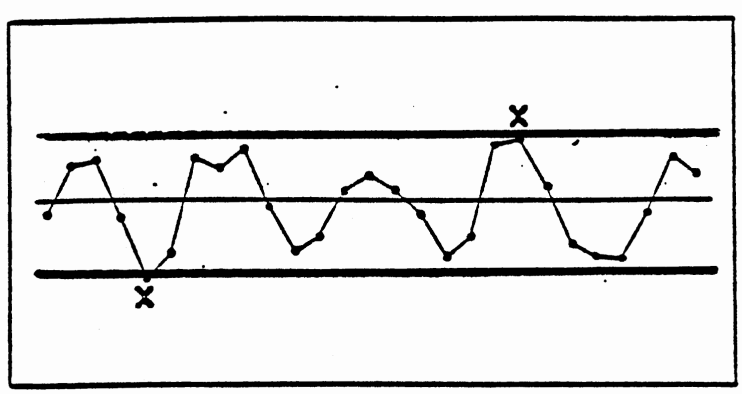


Figure 8. Cycle Pattern

Basically, cycles are identified by determining the time interval of the cycle peaks (or troughs) and relating them back to the process. Unless good documentation is done during the data collection phase (e.g. noting shift changes, tool changes, etc.) then identification of the cycle causes could become rather difficult.

2.2.4.3 Mixtures. A mixture pattern is identified by the points tending to fall near the upper and lower control limits with an absence of normal fluctuation near the middle. See Figure 9 (AT&T, 1985, p. 169).

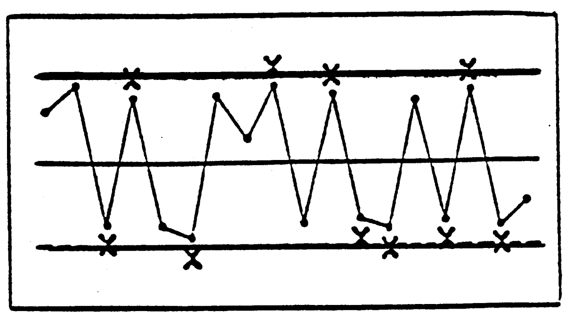


Figure 9. Mixture Pattern

A mixture pattern is actually a combination of two different patterns on the same chart (one centering around the upper control limit and one centering around the lower control limit). A mixture pattern can display two different tendencies. The first tendency is to be stable in nature. This occurs when the component distributions in the mixture maintain the same relative positions and proportions over a period of time. See Figure 10 (AT&T, 1985, p. 172). In stable mixtures, the causes producing

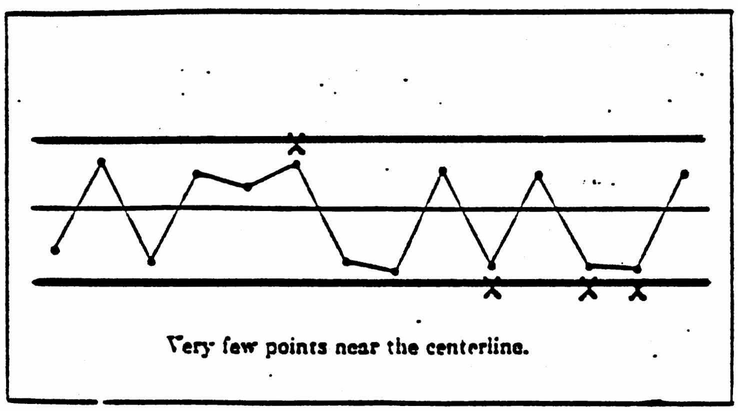


Figure 10. Stable Mixture Pattern

stable mixtures, the causes producing the distributions tend to be permanent in nature. Typical causes which may produce stable mixtures are as follows:

<u>$\overline{X}$ Chart</u>

1. Different lots of material in storeroom.
2. Large quantities of piece parts mixed on the line.
3. Differences in test sets or gages.
4. Consistent differences in material, operators, etc.

<u>R Chart</u>

1-3 Same as above.

4. Frequent drift or jumps in automatic controls.

Stable mixtures usually occur when the product is inspected at the end of the line instead of during manufacture.

The second tendency is to be unstable in nature. This occurs when the relative positions of the component distributions do not remain constant. See Figure 11 (AT&T, 1985, p. 179).

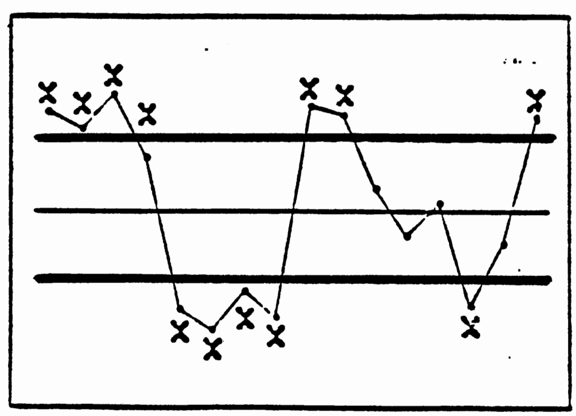


Figure 11. Unstable Mixture Pattern

Some of the more common causes of unstable mixtures are as follows:

<u>$\overline{X}$ Chart</u>

(R chart must be in control.)

1. Breakdown in facilities or automatic controls.

2. Overadjustment of the process.

3. Carelessness in setting controls.

4. Differences in material, operators, etc.

R Chart

1. Two or more materials, machines, operators, etc.

2. Mixture of material.

3. Too much play in a fixture.

4. Operator fatigue.

5. Machine or tools in need of repair.

Unstable mixtures are one of the most common and important types of patterns. This is because once the causes of unstable mixtures have been identified and eliminated, other patterns (which may exist) are much easier to interpret. Overall, unstable mixtures are more common than stable mixtures.

2.2.4.4 Sudden Shifts in Level. A sudden shift in level is shown by a positive change in one direction which causes a number of x's to appear on one side of the chart only. See Figure 12 (AT&T, 1985, p 174).

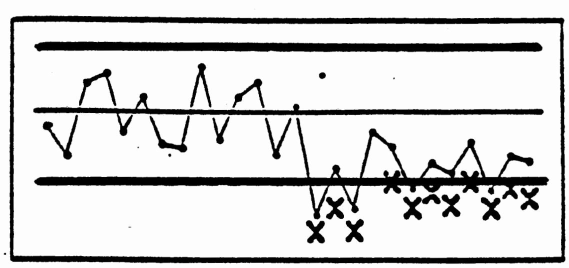


Figure 12. Shift Pattern

Some of the typical causes of a sudden shift in level include the following:

$\underline{\bar{X}}$ Chart

(R chart must be in control.)

1. Change due to a different kind of material.
2. New operator, inspector, machine, etc.
3. Change in set-up or method.
4. Chipped or broken cutting tool.
5. Damage to fixture.

R Chart

1. Change in motivation of operator.
2. New operators or equipment.
3. Change due to different material or supplier.

A sudden shift in level is one of the easiest patterns to interpret on any chart.

2.2.4.5 Stratification. Stratification is a form of stable mixture which has an unnatural constancy. A stratification pattern tends to hug the centerline with very few deviations. In other words, it does not fluctuate as one would naturally expect with occasional points approaching the upper and lower limits. See Figure 13 (AT&T, 1985, p. 173).

Stratification usually shows up more readily on the R chart than on the $\bar{X}$ chart. However, the most common causes for stratification on the $\bar{X}$ chart are anything that is capable of causing mixtures. Most frequently though, stratification on the $\bar{X}$ chart is due to an incorrect calculation of the control limits. As for causes associated with the R chart, they are the same causes that are listed under stable mixtures.

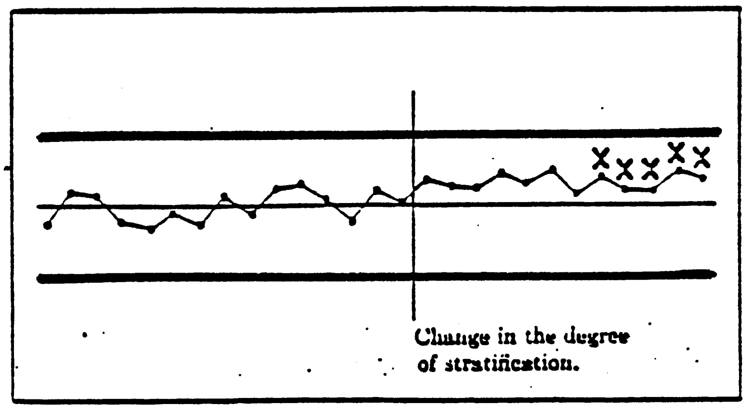


Figure 13. Stratification Pattern

2.2.4.6. Systematic Variables. A systematic pattern is one in which the pattern becomes predictable (for example, a low point is always followed by a high point or visa versa). The most common appearance of a systematic pattern can be seen in Figure 14 (AT&T, 1985, p. 176).

A systematic pattern indicates the presence of a systematic variable. Some of the more common causes of systematic variables are as follows:

$\overline{X}$ Chart

1. Difference between shifts.
2. Difference between test sets.

3. Difference between assembly lines where product is sampled in rotation.
4. Systematic manner of dividing the data.

R Chart

1. This effect is generally due to a systematic manner of dividing the data.

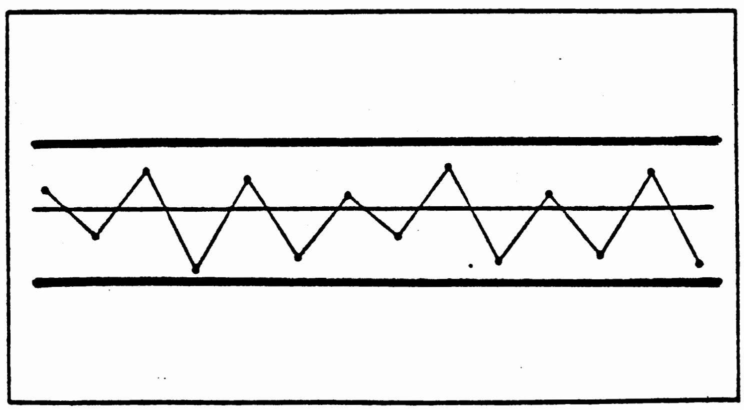


Figure 14. Systematic Pattern

2.2.4.7 Summary. These are just six of the more common unnatural control chart patterns. These six were chosen because they are the ones most likely to occur in a given situation. Since these six patterns illustrate the need for "expert analysis", an artificial intelligence system will be developed to interpret these six patterns.

2.3 Artificial Intelligence

Artificial intelligence (AI) is "the subfield of computer science concerned with the use of computers in tasks that are normally considered to require knowledge, perception, reasoning, learning, understanding and similar cognitive abilities" (Duda, 1981). Research in artificial intelligence began back in the 1950's, but was severely hindered by the limited processing capabilities of the available computers. With the tremendous advances in computer technology, artificial intelligence has become a major interest in present day research. AI research is currently being done in many areas, including machine vision, natural language processing, voice synthesis, voice recognition and pattern recognition. It is in the area of pattern recognition that AI will be most applicable in this research. But first, a brief overview of artificial intelligence is needed.

2.3.1 Components and Applications of Artificial Intelligence

There are four basic components of artificial intelligence. They are as follows:

1. Heuristic search.
2. Modeling and representation of knowledge.
3. Common sense reasoning and logic.
4. AI languages and tools.

From the very beginning, researchers in AI were interested in devising programs that would search for solutions to problems. As the problems increased in complexity, so did the search algorithms. Therefore, a means of narrowing down the number of alternatives to search through was needed. Thus, heuristics were applied. Heuristics, as applied to AI, are rules of thumb (empirical rules) which are used to direct the searching techniques in such a way that any unpromising paths are eliminated from the search. This results in speeding up the search process.

As AI research progressed, it was discovered that intelligent behavior was not so much due to the methods of reasoning used as it was dependent upon the available knowledge base. Therefore, when substantial knowledge was needed when addressing a particular problem, methods were needed to model this knowledge efficiently so that it was readily accessible. It is for this reason that this is one of the most active areas of research in AI.

Common sense reasoning is fundamental reasoning based on a wealth of experience. It is for this reason that it is one of the most difficult things to model in a computer. It is also a key research issue that as yet has not been completely solved. Likewise, logic is of relative interest. Logic is how something is deduced from a set of facts or how we prove that a conclusion follows from a given set of premises. It is also a topic with no final solution, but through the use of heuristics, solution convergence is now more readily accomplished.

Due to this increased research in AI, specific AI programming languages have been developed. The two main languages are LISP (List Processing Language) and PROLOG (Programming in Logic). It is through the utilization of these languages that other software tools have been developed for expressing knowledge, formulating expert systems and providing basic programming aids.

Based upon these basic elements, there are four principle AI application areas. They are natural language processing, computer vision, problem solving and planning and expert systems. Natural language processing is concerned with natural language front ends to computer programs, computer-based speech understanding and text understanding. Computer vision is concerned with enabling a computer to identify (or understand) what it sees and/or locate what it is looking for. Problem solving and planning is concerned with developing general-purpose problem solving techniques for situations in which there are no experts. Expert systems is concerned with making a computer act as if it were an expert in some given domain. It is the area of expert systems which can best be used to perform the pattern analyses on the control charts.

2.3.2 Knowledge-Based Expert Systems

Edward Feigenbaum (Feigenbaum, 1982) describes an expert system as follows:

> An "expert system" is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult

> enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses.

In short, it is desired to develop a computer program which will function like a human expert. Therefore, it must be able to do things that human experts commonly do.

A knowledge-based expert system is made up of (1) the knowledge base; (2) the inference engine; (3) the user interface, and; (4) the data base (see Figure 15). The knowledge base is made up of facts which describe the state of the "world" and rules which specify the relationships among the facts. The inference engine is the search control mechanisms used in solving the problem. The user interface connects the user to the inference engine for formulating a problem and supplying data as needed. The data base is the working memory of the system. In order to build this system, the following development scheme (Gevarter, 1985) should be followed.

1. Problem identification.
2. Location of knowledge.
3. Knowledge acquisition.

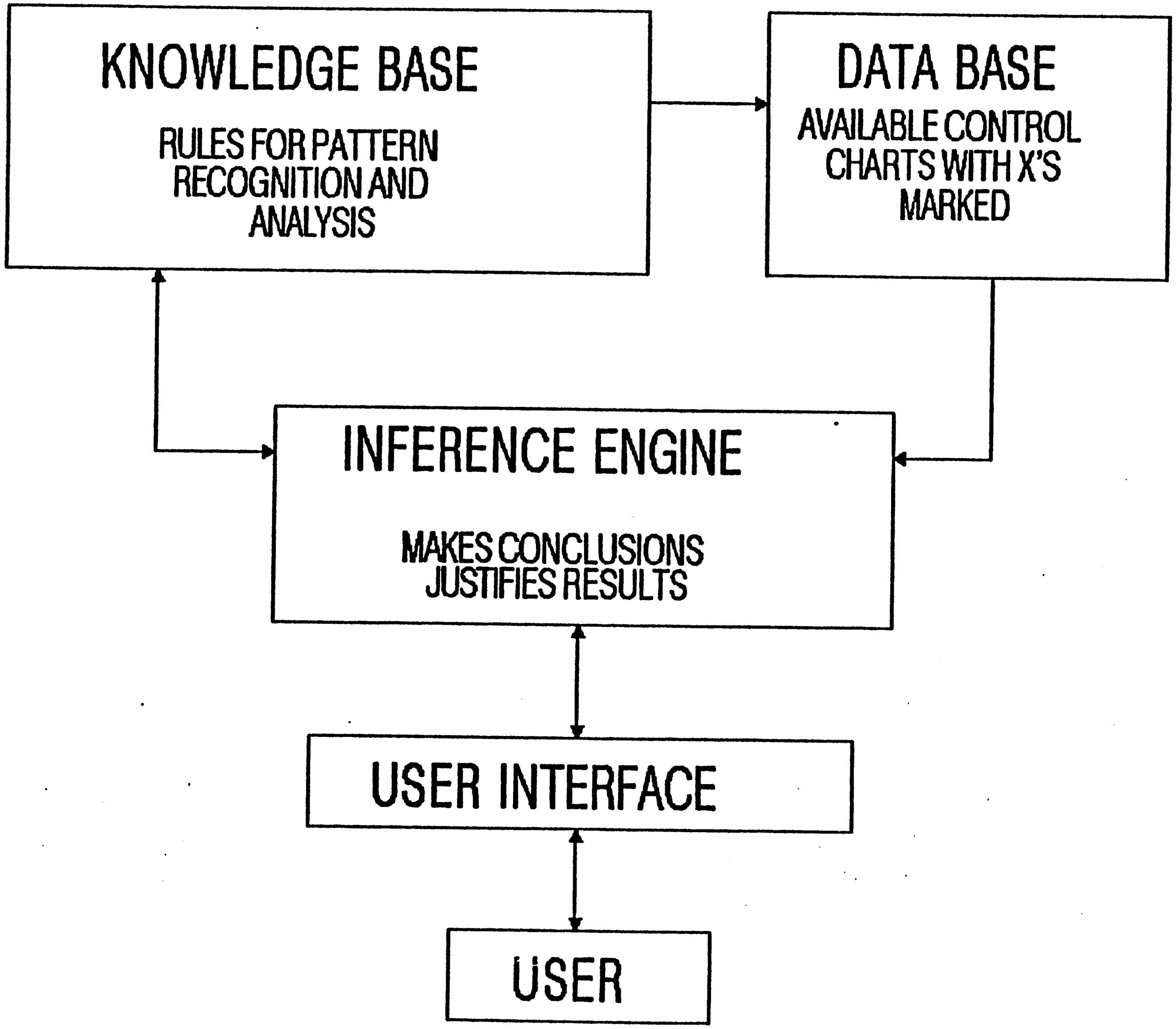


Figure 15. Expert System Framework

4. Knowledge base construction.

5. Design of the inference engine.

6. Construction of the system.

Steps 1-3 were developed in the first part of this chapter. Steps 4-6 are the main thrust of this research effort.

2.4 Pattern Recognition

We utilize pattern recognition every moment of our waking lives. We recognize objects around us and thus we can move or act in relation to them. We recognize friends and can understand what they say to us. We can also recognize the voice of a known individual. These are just a few of the abilities which illustrate the human being's superior pattern recognition capabilities. This capability led to the desire to develop devices which were capable of performing a given recognition task for a specific application. Therefore pattern recognition can be defined as "the categorization of input data into identifiable classes via the extraction of significant features or attributes of the data from a background of irrelevant details" (Gonzalez and Thomason, 1978). Thus the problem can be broken down into the following three steps.

1. Data acquisition.

2. Pattern analysis.

3. Pattern classification.

Data acquisition is concerned with converting the data into a form which is acceptable to the machine doing the analysis. Pattern analysis is concerned with organizing the data into a more efficient form (e.g. determining a pattern class). Pattern classification is concerned with characterizing and defining the pattern. All of this is kept in mind when designing a pattern recognition system.

2.4.1 Design Concepts

There are three basic design concepts which are routinely applied to the pattern recognition problem. They are the membership-roster concept, the common-property concept, and the clustering concept (Tou and Gonzalez, 1974). Membership-roster design concept characterizes a pattern class (a set of patterns that share some common properties) by template matching. This is done by storing a set of patterns belonging to the same pattern class in the pattern recognition system. Then when an unknown pattern is given to the system, it is compared with the stored patterns one by one. The pattern recognition system classifies this new pattern as a member of a pattern class if it matches one of the stored patterns belonging to that pattern class. This is a fairly simplistic approach and is really only useful when almost perfect pattern samples are available.

The common-property design concept characterizes a pattern class through detecting and processing on similar features. The primary assumption here is that all the patterns belonging to the same pattern class possess certain common properties or attributes. This is done by storing the common properties of a pattern class in the pattern recognition system. Then when an unknown pattern is given to the system, its major features are extracted and compared to the stored features. The recognition scheme will attempt to classify the new pattern as belonging to the pattern class with the most closely similar features. The only difficult thing in this approach is determining the common properties from a finite set of sample patterns known to belong to a certain pattern class.

The clustering design concept characterizes a pattern class by defining the pattern as vectors whose components are real numbers and then determining its clustering properties in the pattern space. This concept is based on the relative geometric arrangement of the various pattern clusters. If the clusters are far apart, the recognition process is fairly simple and can be based on a minimum distance classifier. If the clusters overlap, the recognition process is much more complicated and partitioning techniques are needed. Therefore, of all the design concepts, this one is the most difficult.

2.4.2 Existing Methodologies for Implementing the Design Concept

The above mentioned design concepts can be implemented using one of the three principal methodologies: heuristic, mathematical and syntactic, or some hybrid combination of the three.

The heuristic approach is based upon human experience and intuition. It is used primarily in the membership-roster and common-property design concepts. There are no general principles for this approach since a heuristic system consists of specialized procedures developed for specialized recognition tasks. In other words, the structure of a heuristic system is definitely unique to the problem and can be developed only by experienced system designers.

The mathematical approach is based on classification rules which are derived and formulated in a mathematical framework. It is used primarily in the common-property and clustering design concepts. The mathematical approach can be broken down into two categories: deterministic and statistical.

The deterministic approach was one of the first approaches developed for pattern recognition. It is based on a mathematical framework which does not make any assumptions concerning the statistical properties of the pattern classes. Two of the basic deterministic approaches are the Perceptron algorithm and the Least-Mean-Square-Error algorithm. The Perceptron algorithm was the first algorithm developed for pattern recognition. Its basic concept is one of reward and punishment. In simple terms, suppose there were two pattern classes W1 and W2 where each class had a unique set of attributes. An arbitrary weighting factor would be assigned to either W1 or W2. A test would be made on the first attribute of the unknown sample. If the attribute tested fit into the pattern class with the weight factor, the weight factor would remain unchanged and the next attribute would be tested. If the attribute tested did not fit into the pattern class with the weight factor, a punishment would be levied against the weight factor (it would be reduced). This algorithm converges when a weight vector classifies all patterns correctly. This algorithm is only applicable when the pattern classes have no common elements. If there is commonality, the Least-Mean-Square-Error algorithm could be used. This method also compares the unknown attributes of the pattern class with stored reference sets. But instead of re-weighting the weight vector, an estimate of the error difference is made. When all the tests are made, a selection is made based upon the "least mean square error". This permits convergence in a relatively short time.

The statistical approach naturally followed from the deterministic approach. This approach utilizes the statistical properties of the pattern classes. For the most part the design of statistical pattern classifiers is based on the Bayes classification rule. Simply put, the

Bayes decision function minimizes the average cost of misclassification in addition to finding the lowest probability of error. Therefore, the statistical approach is similar to the Perceptron approach in that it sets up as a test of hypothesis whether a given pattern "belongs" to some set pattern class. Its primary premise is that the competing hypotheses are mutually exclusive which is usually not the case. Therefore, the statistical approach is primarily useful in setting up abstract guidelines for designing pattern classifiers.

Due to the inability of the statistical approach to handle structural information, the syntactic approach was developed. The syntactic approach characterizes patterns by its primitive elements (subpatterns). This approach is used in the common-property design concept. Its basic premise is that "a pattern can be described by a hierarchical structure of subpatterns analogous to the syntactic structure of languages" (Tou and Gonzalez, 1974). In this approach, subpatterns are defined. The test pattern is fitted with a group of subpatterns to form a whole pattern which is then analyzed. This approach is most useful when a pattern cannot be easily described numerically or the pattern is so complex that specific features cannot be identified.

The hybrid approach is one which is currently gaining a lot of attention. All this approach does is use some combination of the above mentioned approaches (e.g. a syntactic-heuristic approach).

2.4.3 Approach in this Research

Pattern recognition techniques have been recently applied to a variety of systems such as vision systems for robotics. For the most part they have applied the membership-roster concept (template matching) and the common-property concept. The nature of this research precludes the template matching approach (e.g. the degree of trend will not be uniform from pattern to pattern). The best approach would be to use the common-property technique, but in a form that utilizes heuristics (representing the expert's decision process) rather that the more rigorous mathematical forms found in other fields. An expert system will be developed which will incorporate the heuristics in special algorithms.

2.5 Summary

Since there has not been any documented work done in the area of pattern analysis of control charts using artificial intelligence, this chapter has reviewed the nature and causes of unnatural patterns. It has also introduced the concept and components of artificial intelligence and knowledge-based expert systems. It has provided a look at the existing methodologies used in pattern recognition.

CHAPTER III

PATTERN GENERATOR AND GRAPHICS DEVELOPMENT

The initial phase consisted of developing (1) six pattern generators and (2) a graphics package. The pattern generators were needed to emulate the six unnatural control chart patterns of interest. They are shift, trend, cycle, systematic, mixture and stratification. The graphics package would take the data provided by the pattern generator and draw the corresponding control chart. In addition, the graphics package would analyze the data and identify out-of-control points with x's according to the AT&T run rules discussed in Chapter 2.

3.1 Development Of A Process Generator

For the purpose of demonstration, it was decided that the X control chart would be used. Throughout the remainder of this research, it will be assumed that the R chart is in-control thus permitting complete analysis of the X chart. With this in mind, it was necessary to develop a process generator for normally distributed data for the pattern generator since the underlying distribution of the X chart is normal. With most computer languages, the process generator is designed for uniformly distributed data. Therefore, a conversion must be made. It is known that a chi-square distribution with two degrees of freedom has the following probability density function.

$$f(y) = \begin{cases} 1/2 \ e^{-y/2} & y \geq 0 \\ 0 & \text{elsewhere} \end{cases}$$

The cumulative density function was found as follows.

$$F(y) = \int_0^y 1/2 \ e^{-y/2} \, dy$$

$$= - e^{-y/2} \Big|_0^y$$

$$= \begin{cases} 1 - e^{-y/2} & y \geq 0 \\ 0 & \text{elsewhere} \end{cases}$$

If R represents a uniform random number on the unit interval, then:

$$R = F(y) = 1 - e^{-y/2} \quad .$$

Solving this equation for y, results in the necessary formula for the chi-square random deviate.

$$e^{-y/2} = 1 - R$$

Since R is uniformly distributed between 1 and 0, then so is 1 - R. Thus, 1 - R can be replaced by R for convenience.

$$e^{-y/2} = R$$

$$-y/2 = \ln R$$

$$y = - 2 \ln R \tag{1}$$

Therefore, equation 1 represents a process generator for chi-square data with two degrees of freedom using a uniform random number.

It is known that a chi-square value with two degrees of freedom is equal to the sum of two independent chi-square values each with one degree of freedom. It is also known that a chi-square value with one degree of freedom is equal to the square of a standard normal variable. If Z1 and Z2 represent two standard normal variables, equation 1 can be written as:

$$y = Z1^2 + Z2^2 = -2 \ln R . \tag{2}$$

Equation 2 can now be solved to find the equations for the standard normal deviates. Using standard trignometric identities, equation 2 becomes:

$$Z1^2 + Z2^2 = -2 \ln R1 \, [\cos^2 (2 \pi R2) + \sin^2 (2 \pi R2)] \tag{3}$$

Note that R1 and R2 represent two different values of the uniform random deviate. Further manipulation results in:

$$Z1^2 + Z2^2 = [(-2 \ln R1)^{1/2} \cos(2 \pi R2)]^2 + [(-2 \ln R1)^{1/2} \sin(2 \pi R2)]^2$$

so that

$$Z1 = (-2 \ln R1)^{1/2} \cos (2 \pi R2) \tag{4}$$

$$Z2 = (-2 \ln R1)^{1/2} \sin (2 \pi R2) \tag{5}$$

Equations 4 and 5 represent process generators for standard normal data using a uniform random number. Since either or both equation 4 or 5 can be used successfully, equation 4 was chosen for use in the following pattern generators.

3.2 Pattern Generators

In order to acquire sufficient data for evaluating the pattern recognition capabilities of the expert system, reliable pattern generators were needed for each of the unnatural patterns under study. Development of each pattern generator required knowledge of the underlying causes for each particular pattern. Since the causes differ for each desired pattern, each one will be discussed separately.

3.2.1 Definition of Variables

For ease of reference, the following nomenclature was used to develop the required pattern generators.

$y(t)$ = plotted statistic of interest at time t.

μ = mean of y when the process is in a state of statistical control.

σ = standard deviation of y when the process is in a state of statistical control.

δ = a multiple of σ which corresponds to the shift in the process mean during the out-of-control condition. This variable is used in the shift, mixture, systematic and cycle generators.

θ = a multiple of σ which corresponds to the slope of the process during the out-of-control condition. This variable is used in the trend generator.

γ = a multiple of σ which corresponds to the new process standard deviation during the out-of-control condition. This variable is used in the stratification generator.

T = the period of the sinusoidal cycle. This variable is used in the cycle generator.

NRD(t) = standard normal random deviate at time t.

3.2.2 In-Control Generator

As discussed in Chapter 1, the data to be analyzed must first be in-control for a brief period of time, then out-of-control and finally back in-control. Therefore, a generator for in-control normal data was desired. Given that the mean and standard deviation of the in-control process was known, then an in-control pattern was generated from

$$y(t) = \mu + NRD(t)\sigma \tag{6}$$

Equation 6 was used in conjunction with the following unnatural pattern generators for development of the composite pattern required for analysis.

3.2.3 Shift Generator

A sudden shift in level is caused by an unexpected introduction of a new element or cause to the process. This new element causes the process center of the distribution to move to a new level (Figure 16). Once the shift has occurred, the new element no longer acts upon the process thus allowing the process to establish itself about the new level.

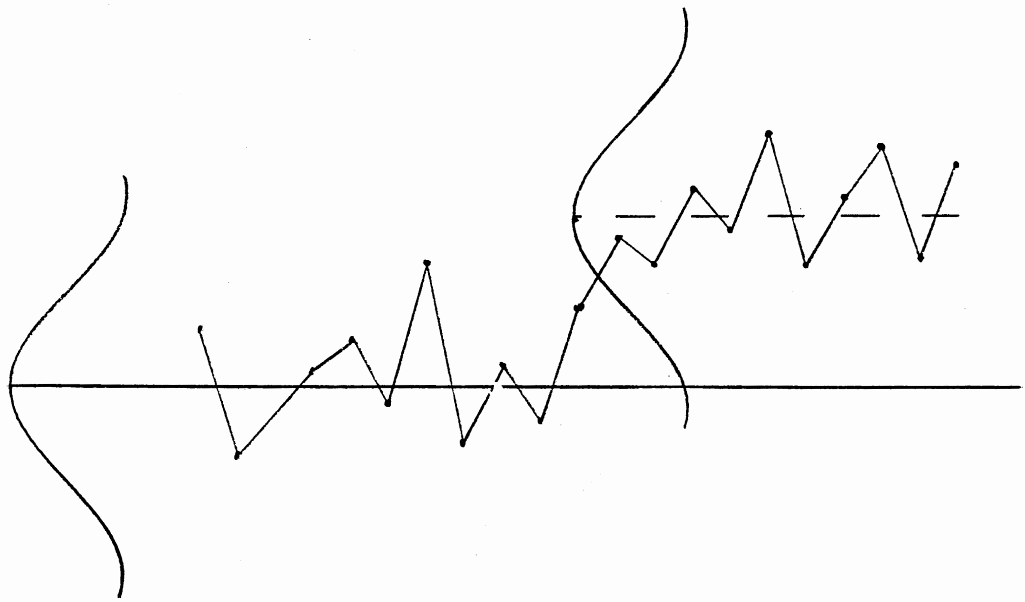


Figure 16. Sudden Shift in Level with Corresponding Distribution

Therefore, the generation of a shift in level was expressed by:

$$y(t) = (\mu + \delta \sigma) + NRD(t) \sigma \qquad (7)$$

Thus, equation 7 exhibited the same variation about the shifted mean as equation 6 exhibited about the in-control mean. For this study, δ was allowed to vary from 0.5 to 3.0 in increments of 0.5. It was felt that this range of values would provide a wide variety of data for the system to analyze.

3.2.4 Trend Generator

A trend is caused by something affecting the process gradually over a period of time. The total distribution when a trend is present is flat-topped and wider than would normally be expected (Figure 17).

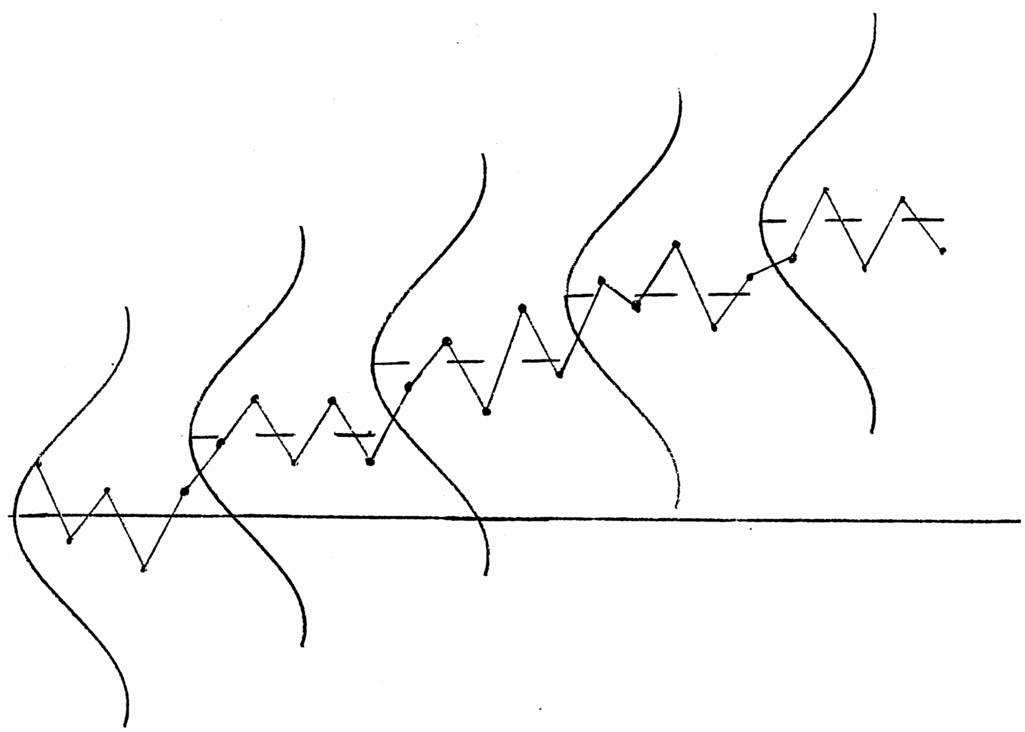


Figure 17. Trend With Actual Distributions

In the case of the trend, each successive data point is being shifted from the in-control process population mean, μ. If each successive shift beginning at time t_0 is defined as some multiple, θ, of the in-control process population standard deviation, σ, then the generation of a trend can be expressed by:

$$y(t) = (\mu + \theta(t-t_0)\sigma) + NRD(t)\sigma \qquad (8)$$

Equation 8 established the in-control population variation about the trend line. For this study, θ was allowed to vary from 0.05 to 0.25 in increments of 0.05.

3.2.5 Stratification Generator

Stratification is caused by some element of the process being consistently spread across the sample. It usually results when the samples are taken from widely different distributions (Figure 18) thus causing the

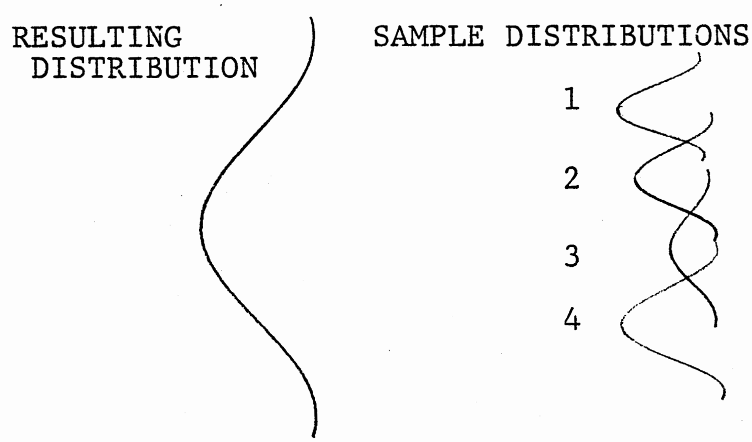


Figure 18. Distributions Associated with Process Samples Taken from 4 Different Processes

expected control limits to be wider than they actually should be (Figure 19).

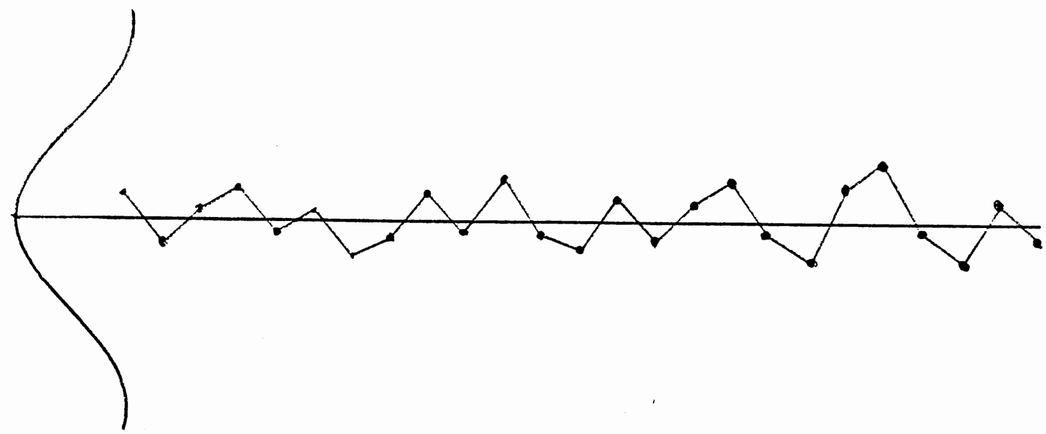


Figure 19. Stratification with Expected Distribution

This situation causes the data to appear to hug the mean of the process with very few large deviations. Let the deviation about the process mean during stratification be a fractional multiple of the regular in-control process population standard deviation. The stratification generator can then be expressed by:

$$y(t) = \mu + \delta \; [NRD(t)\, \sigma \;] \qquad (9)$$

Equation 9 established a reduced variation about the process mean. For this study, δ was allowed to range from 0.2 to 0.8 in increments of 0.2.

3.2.6 Mixture Generator

A mixture pattern is caused by combining two different patterns on the same chart where one pattern has a distribution mean located above the population mean and the other below. With this pattern, it appears that the process fluctuates at random uniformly from one distribution to the other (Figure 20). Let $\varepsilon = 0$ if the

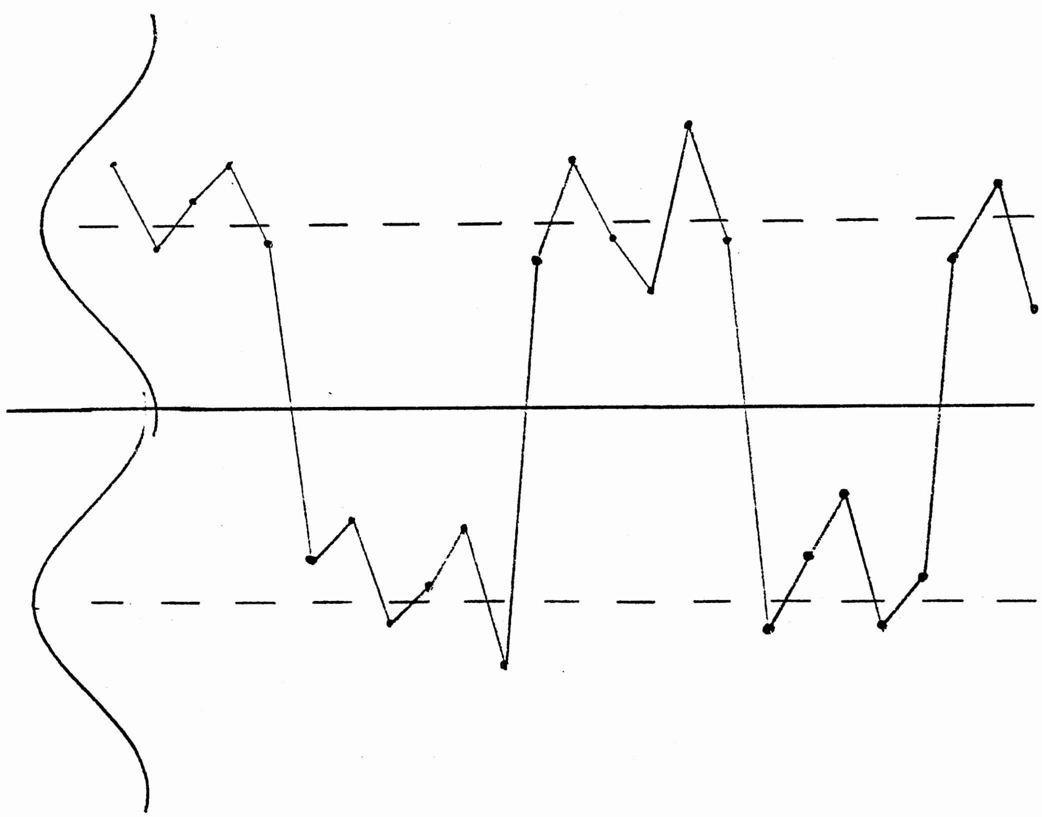


Figure 20. Mixture with Associated Distributions

uniform random variable is less than or equal to 0.5 and $\varepsilon = 1$ if it is greater than 0.5. With this definition, the mixture generator can be expressed as:

$$y(t) = (\mu + (-1)^{\varepsilon} \delta \sigma) + NRD(t)\sigma \qquad (10)$$

Equation 10 uniformly and randomly established the in-control process variation about the centerlines of the two mixture distributions. The locations of the mixture distributions were shifted symmetrically from the process as a multiple of the in-control process population standard deviation. For this study δ , was allowed to vary from 0.5 to 3.0 in increments of 0.5.

3.2.7 Systematic Generator

This pattern is caused by the presence of a systematic variable in either the process, data or data analysis. For all practical purposes, it behaves as if a sample is taken alternately from two separate distributions, where one distributions mean is located above the population mean and the other below (Figure 21). Let the location of the centerline of the two distributions be a multiple of the in-control process population standard deviation. The systematic generator can be expressed by:

$$y(t) = (\mu + (-1)^{t} \delta \sigma) + NRD(t)\sigma \qquad (11)$$

Equation 11 alternately establishes the in-control process variation about the centerlines of the two sample distributions. For this study, δ was allowed to vary from

0.5 to 3.0 in increments of 0.5.

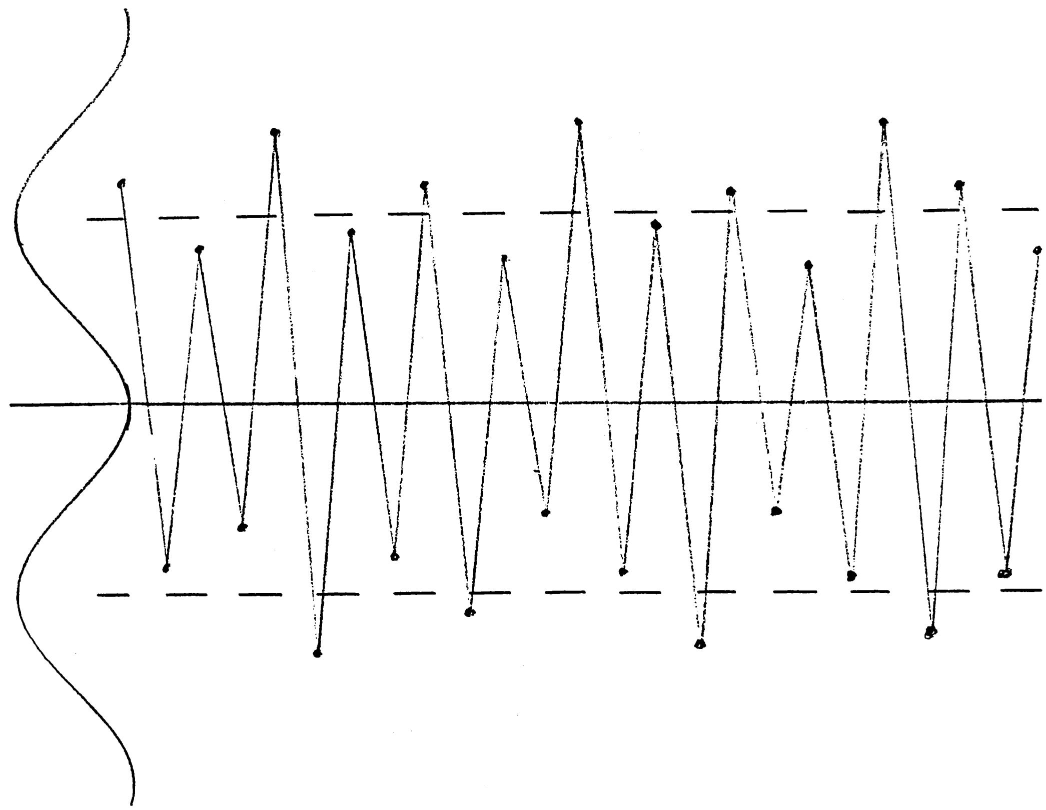


Figure 21. Systematic with Associated Distributions

3.2.8 Cycle Generator

Cycles are short trends that occur in repeated patterns. For all practical purposes, the pattern follows a sinusoidal shape (Figure 22). Let the amplitude of the cycle of period T beginning at time t_0 be a multiple of the in-control process population standard deviation. The cycle generator can be expressed by:

$$y(t) = (\mu + \delta \sigma \sin \left[\frac{2 \pi (t-t_0)}{T} \right] + NRD(t)\sigma \qquad (12)$$

Equation 12 established the in-control process variation about the sinusoidal cycle. For this study, δ was allowed to vary from 0.5 to 3.0 in increments of 0.5 for T values of 4, 8 and 12.

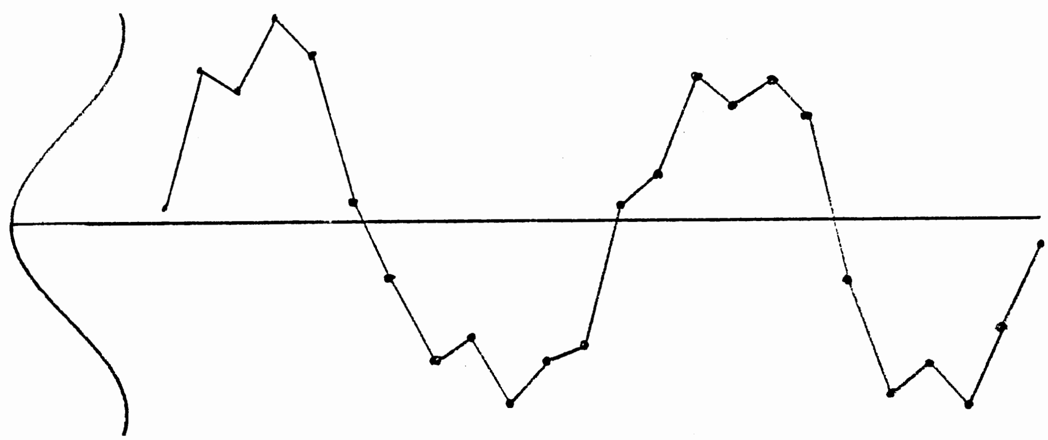


Figure 22. Cycle with Expected Distribution

3.3 Graphics Package

Once data was available either from the computer generators or from collected data, a plot was needed. The graphics package developed in this research plotted the points provided, just as one would do by hand with the upper and lower control limits hashed in. Once the plot had been completed, the AT&T run rules were applied with the x's being marked as discussed in Chapter 2. Figure 23 illustrates a systematic pattern with the x's marked.

3.4 Logic Chart

The gross logic chart for the pattern generator and graphics package is illustrated in Figure 24.

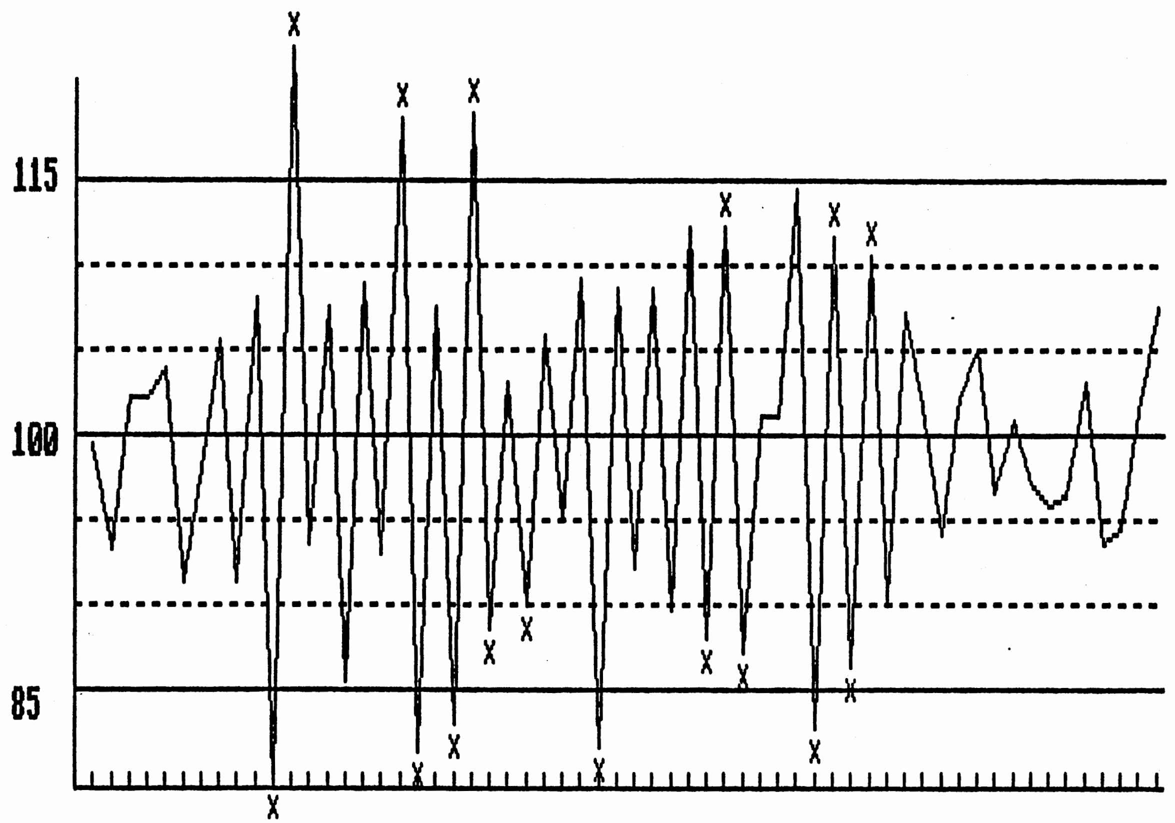


Figure 23. Sample Chart from Graphics Package

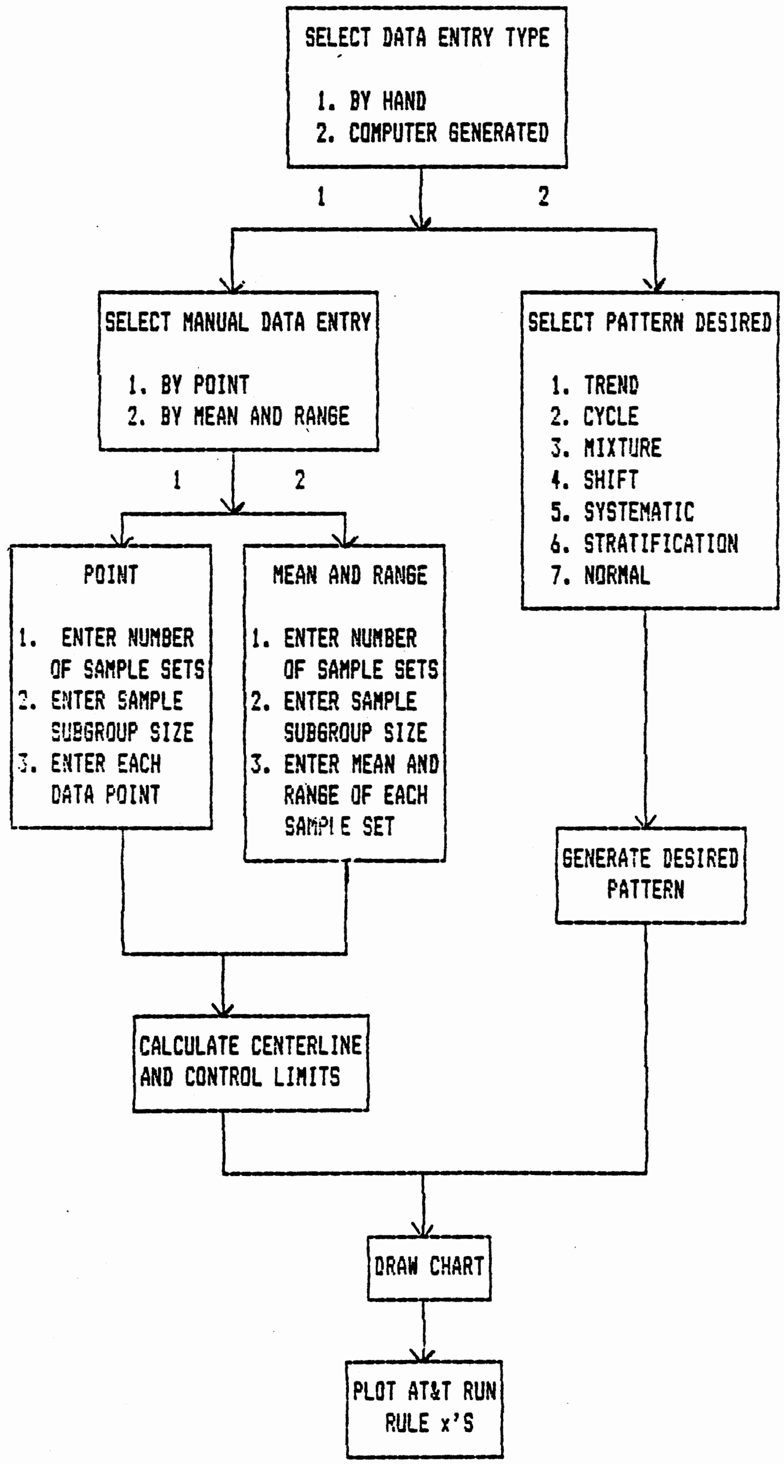


Figure 24. Gross Logic Chart for Pattern Generator and Graphics Package

CHAPTER IV

KNOWLEDGE BASED EXPERT SYSTEM

A knowledge based expert system "is a computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution" (Andriole, 1985). The knowledge and inference procedures used to accomplish this task are considered to be models of the practices and abilities practitioners in that field commonly use. A knowledge based expert system has three major components. They are (1) the knowledge base; (2) the inference engine; and (3) the data base. The development of the data base was presented in Chapter 3. The next steps consist of the construction of the knowledge base and the design of the inference engine.

4.1 Knowledge Base

The knowledge base contains the problem-specific knowledge acquired from the "experts". In this research, it consisted of knowledge of traits or behavioral patterns specific to each unnatural pattern of interest. This knowledge was attained through observation of patterns and preliminary testing of how basic variables such as the mean and the variance behave.

An initial test was designed to attempt to establish some of the more basic characteristics of the unnatural patterns under study. For this initial test, a few basic assumptions had to be made. First, since the research was focusing on monitoring charts, the mean and variance of the in-control (or desired) process were known. Second, only one unnatural pattern would ever be present in a particular data set. Third, the analysis package would have no knowledge of the actual location (beginning and ending points) of the unnatural pattern. Fourth, the entire data set would consist of an in-control process followed by an out-of-control process followed by another in-control process. The desired mean and desired variances used for testing would be the population mean and population variance of the in-control process. With these assumptions, a three part test was developed.

The first test set a 95 percent confidence limit on the population mean of the entire data set. It then calculated the sample mean of this data set and tested to see if this mean fell inside or outside of the expected limits.

The second test set an 80 percent confidence limit on the population variance of the entire data set. It then calculated the sample variance of this data set and tested to see if this variance fell within the expected limits or not. The confidence limit percentages for both the mean and variance tests were obtained through an iterative process to provide a reasonable degree of discrimination.

The third test recorded the point at which the first AT&T x was marked and determined what particular rule caused that point to be marked. It also recorded the last point at which an x was marked. This test was included to see whether or not a pattern or sets of patterns could be recognized simply from the rule marking the first AT&T x.

The results of these tests can be found in Appendix A. From these results, four major conclusions were formulated. First, on the basis of the entire data set, the presence of a trend or a shift was consistently indicated by a significant change in the mean. All of the other patterns had means that remained within limits. Second, no conclusion or separation of patterns could be made on a significant change in the variance of the entire data set since there appeared to be no consistent pattern. Third, no conclusion could be made as to the type of pattern that existed based upon the AT&T run rule which identified the first sample point marked. Finally, the last point marked was reasonably accurate for identifying the true ending point of the unnatural pattern when the run length of the pattern was 45 points, but not very accurate at identifying the starting point. Nevertheless, the first and last points marked would provide a reasonable beginning point for identifying the location of the unnatural pattern.

At this point, two facts were established as the foundation of the knowledge base.

1. Confidence limits could be placed on the population mean of the entire data set. If the sample mean fell outside of these limits, then there was evidence that either a trend or a shift was present in the data set.
2. The first and last AT&T x's marked would be used to set initial bounds on the location of the unnatural pattern.

The second fact provided the ability to further develop the knowledge base. Even though the test of variances on the entire data set was unable to provide dependable identification of patterns, it was found through observation and underlying theory, that if the location of the unnatural pattern were known, the variance test would provide additional help in pattern recognition and separation. Therefore, all of the remaining tests were performed on only that data enclosed by the first and last AT&T x's marked. For ease of reference, this data will be henceforth referred to as the out-of-control window. Through study of pattern behavior and underlying distribution theory of each pattern, the knowledge base was completed and can be most easily understood by referring to the decision tree shown in Figure 25.

As can be seen, six additional facts were added to the knowledge base.

1. Once trend and shift had been isolated as the most

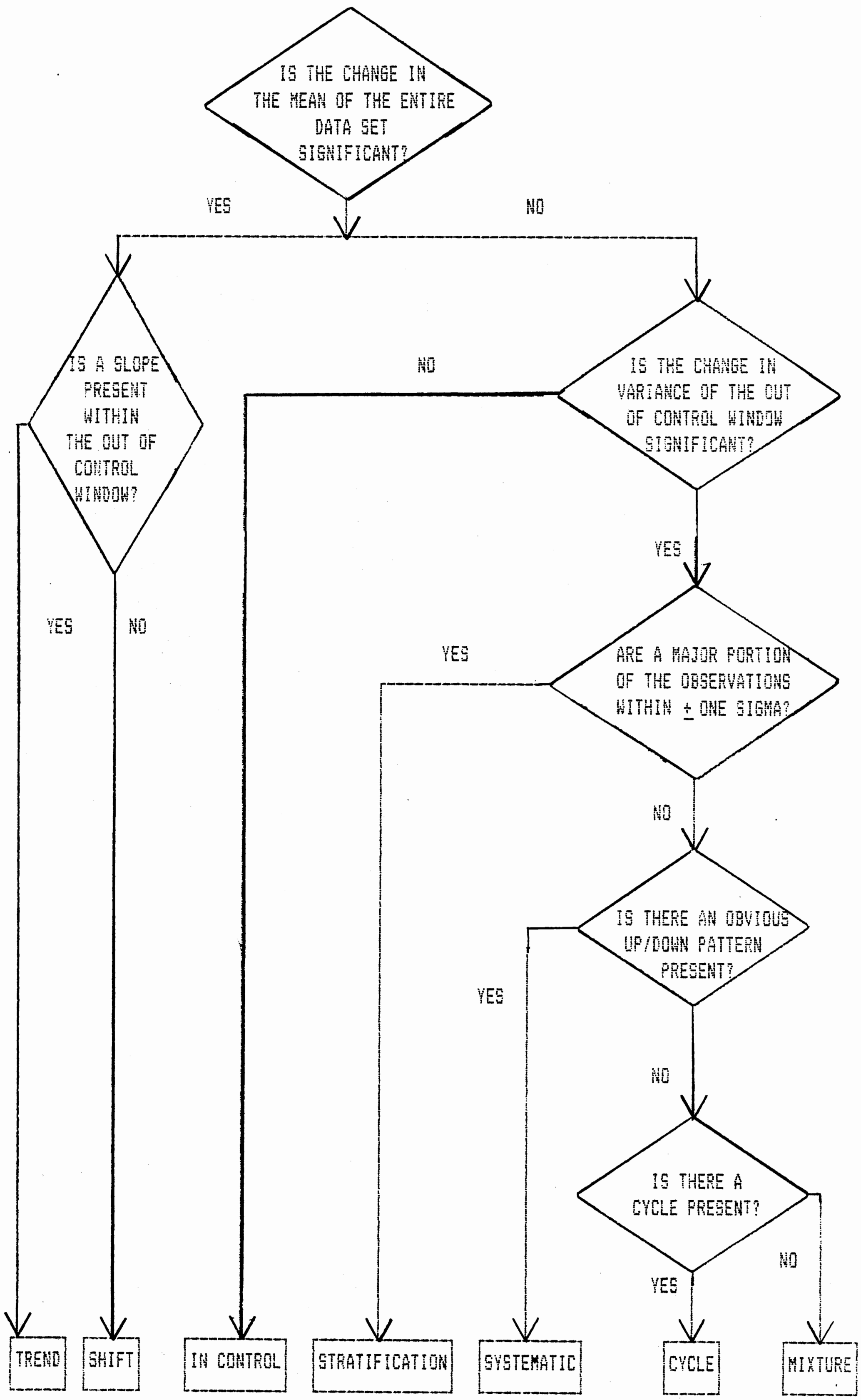


Figure 25. Knowledge Base Decision Tree

likely existing pattern, a test would be performed to determine whether a slope existed in the out-of-control window or not. If a slope did exist, then there was evidence that a trend was present. If a slope did not exist, then a shift was indicated.

2. With trend and shift eliminated as viable possibilities, a test was performed to separate an in-control process from the remaining unnatural patterns under study. A test would be performed to see if the variance in the out-of-control window was significantly different from the expected variance. If it was, then there was evidence that either a stratification, systematic, cycle or mixture pattern was present in the data. Otherwise, all of the possibilities had been eliminated and the data would then, for all practical purposes, be considered to be in-control.
3. If the variance was significant, then a count would be taken of the number of points within the out-of-control window that fell within plus or minus one in-control process standard deviation. From normal probability theory, only 68.27 percent of the data points should fall within these limits. If significantly more than this percentage was present, then there was evidence that a stratification pattern existed since its process standard deviation would be less than that of the

in-control process. Otherwise, either a systematic cycle or mixture pattern was present.

4. A test would be performed to determine if a continuous up/down pattern existed in the data of the out-of-control window. If such a pattern did exist, then there was evidence that the pattern was systematic. Otherwise, the pattern was either a cycle or mixture.
5. A test would then be done to determine if there was evidence of a cyclic pattern in the out-of-control window.
6. If the data did not have a cyclic nature, then the pattern was considered to be a mixture.

These facts made up the basic knowledge base from which the inference engine was to be designed.

4.2 Inference Engine

The inference engine was the control mechanism for branching through the knowledge base decision tree. The control mechanism would utilize such things as heuristics, analytical procedures, plausible reasoning and general rules of thumb to arrive at a solution.

Various heuristic parameters had to be determined. These parameters fell into three categories. The first category was that of sample sizes needed for various test windows. Second, discriminating alpha values were needed for a variety of hypothesis tests. Third, various discriminating probabilities were needed for the decision test procedures developed from the underlying unnatural pattern theory. The logic used to determine feasible values for these heuristic parameters are consistent within each of the three defined categories and can best be understood through illustration. Therefore, the logic used will be explained via an example from each category.

The first category was sample sizes for test windows. In general, a sample size was needed that allowed for a reasonably small alpha value. The sample size also needed to be fairly close to the smallest out-of-control window size used which in this research was five. Therefore, the starting point was an alpha value of 0.05 and a sample size of five. The example of determining the sample size and alpha value used in the variance test will best illustrate the logic of selection. This test determined the out-of-control window size by performing a test on whether the variance within the moving sample was greater than the population variance. For this test, it was decided that the alpha value of 0.05 would be held constant. Therefore, the sample size had to be adjusted accordingly. Using iterative testing for out-of-control run lengths of 5 and 45, samples sizes from five to eight were tested. Sample sizes of five and six caused the test variance limit to be too tight, thus causing the test to consistently identify too large of a window for the out-of-control window. A sample size of eight caused the test variance limit to be too loose, which often caused the test to miss finding the out-of-control condition. A sample size of seven generally eliminated the problem which occurred in the sample size of eight and modified the problem existing in smaller sample sizes to an acceptable level. This acceptable level was determined through an understanding of the underlying theory of the unnatural patterns of interest and the chi-square distribution and tests. Therefore, for this particular test an alpha value of 0.05 and sample size of seven were found to provide an acceptable level of discrimination. Through an iterative process such as this, the remaining sample sizes were determined.

The second category was the alpha test values which were used throughout the expert system. As illustrated in the above example, the value of alpha was initially set at 0.05. For the tests involving the F and Student t distributions, an even smaller value was generally appropriate. However, for the tests involving the chi-square distribution, a larger value usually had to be found. For example, it was desired to set confidence limits on the population variance and see if the sample variance fell within these limits. Low alpha values caused the test limits to be too wide and change in variance was often not identified. Therefore, various alpha values were tested against the four unnatural patterns which exhibit a change in variance (cycle, mixture, systematic and stratification) for both short and long out-of-control run lengths. After several iterations, an alpha value of 0.2 was found to be the smallest value that could be used to accurately identify a change in variance when it truly existed. Through a process such as this, the remaining alpha values were determined.

The third category was the discriminating probabilities used in the test sequences which were specifically designed for this research. For example, a test was needed to isolate stratification from the other change in variance patterns (cycle, mixture and systematic). Therefore, a special test had to be developed. By studying the underlying distributions associated with these four patterns, it was found that stratification would have a variance less than the population variance while the other three would have a variance greater than the population variance. An initial separation was made using a chi-square test to determine if the variance within the identified out-of-control window was less than the population variance. If it was, a final test was needed to determine if stratification truly existed. Therefore, from normal distribution theory, it was known that if no unnatural pattern was present (the process was in-control), one would theoretically expect 68.27 percent of the sample points to fall within plus or minus one population standard deviation. If stratification was present, a greater percentage of points would be expected within these limits. The question was, what value would accurately indicate that a stratification pattern existed? Various percentage levels were tested again using short and long out-of-control run lengths. A value of 75 percent was found to accurately discriminate in identifying the correct pattern. In a similar manner, the other discriminating probabilities were determined.

As has been illustrated, the choice of the heuristic parameters was made using iterative testing with the final decisions being made based upon an understanding of the associated underlying theories and the designer's experience. With a general understanding of how the heuristic parameters were determined, development of the inference engine can now be discussed.

The inference engine designed for this research can best be understood by stepping through the engine's flowchart which is shown in Figure 26.

I. The pattern generator and graphics package provided a control chart with the x's marked. The visual display was provided solely for the user's benefit so that the user had a physical representation of the situation under investigation.

II. The first and last AT&T x's marked were set as variables for use by the expert system. The first x marked was set equal to B and NB. The last x marked was set equal to F and NF. B and F were used as update variables; NB and NF were used as reference variables to be used in the final stages

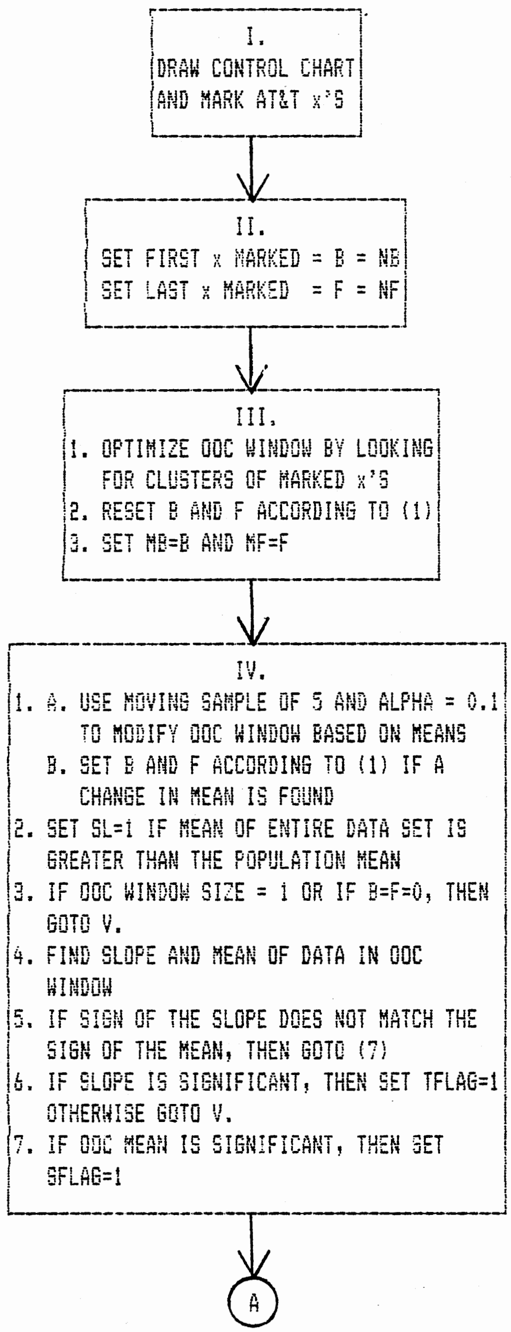


Figure 26. Inference Engine Flowchart

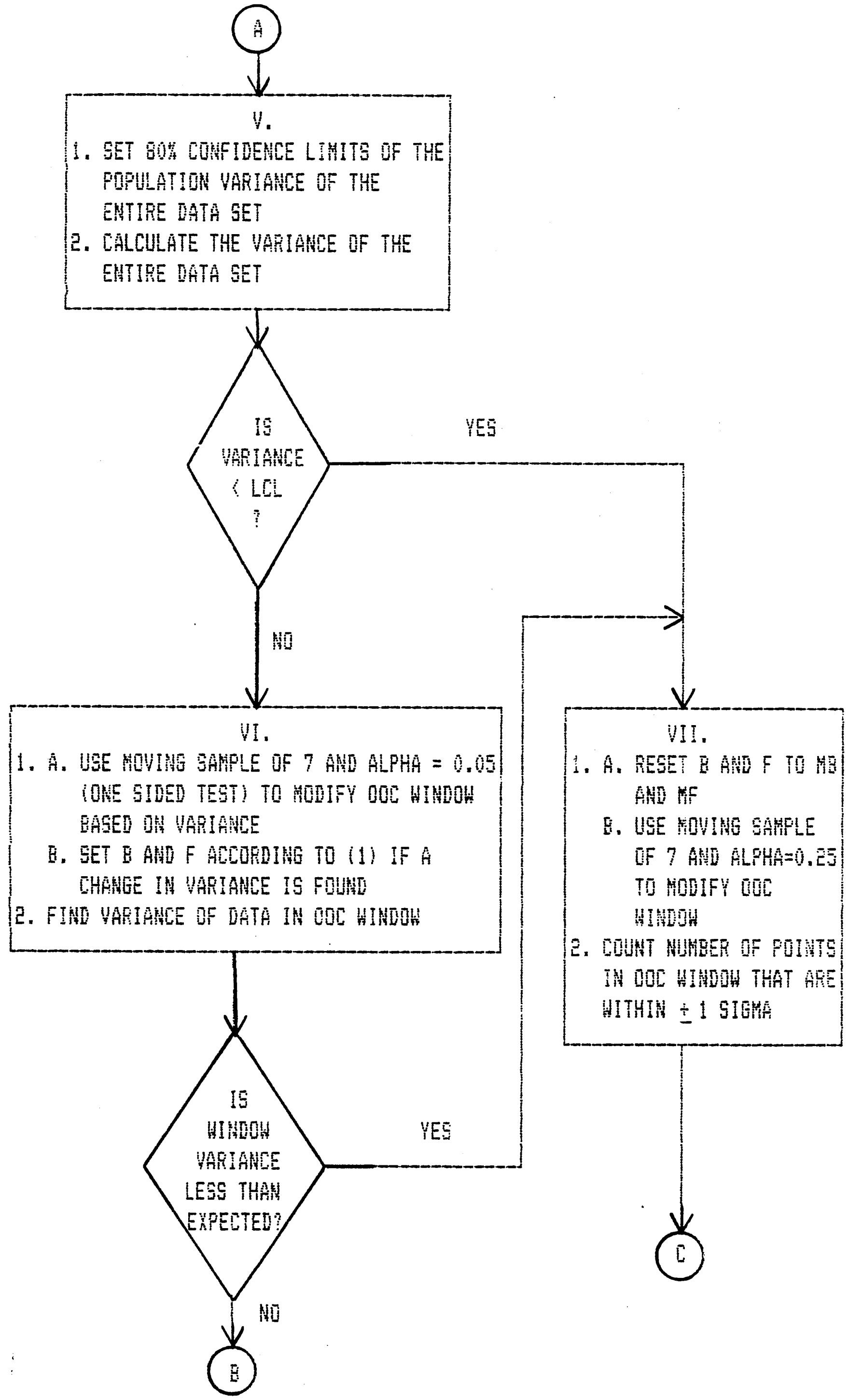


Figure 26. (Continued)

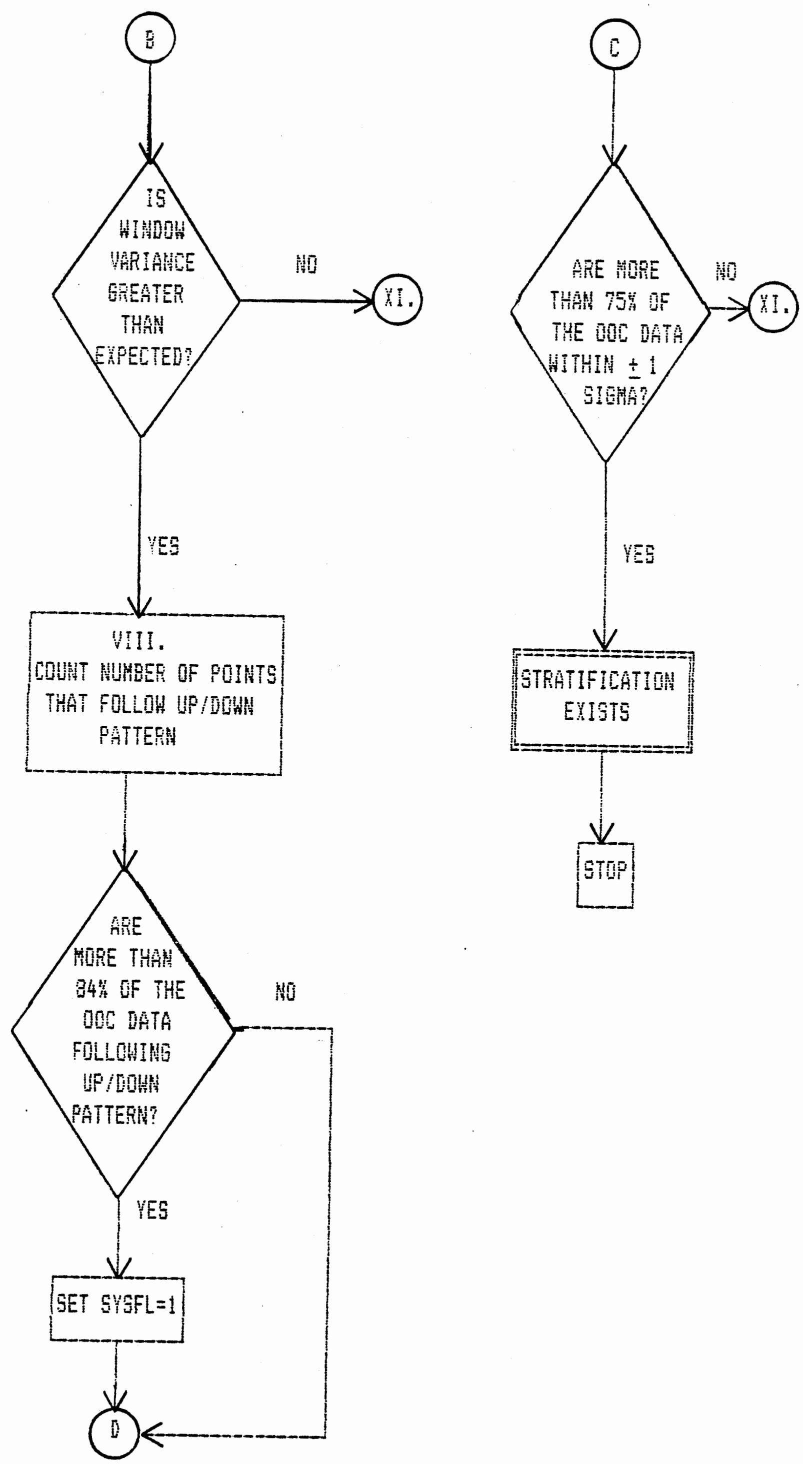


Figure 26. (Continued)

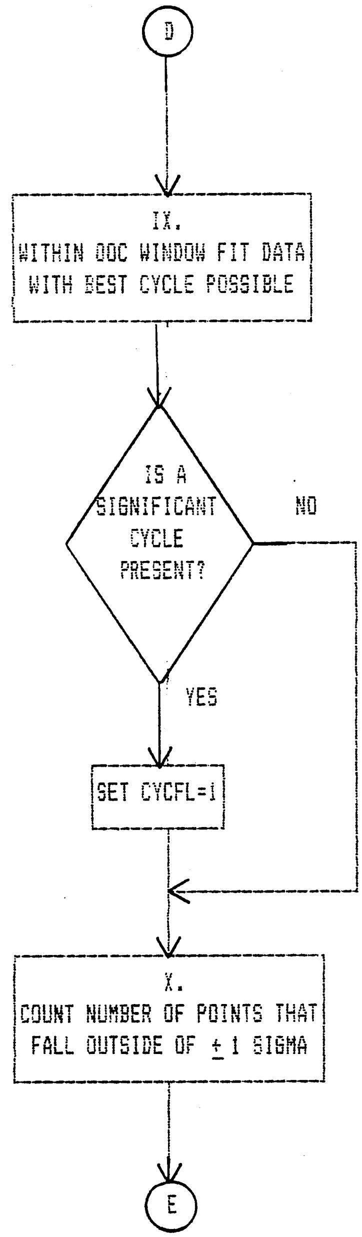


Figure 26. (Continued)

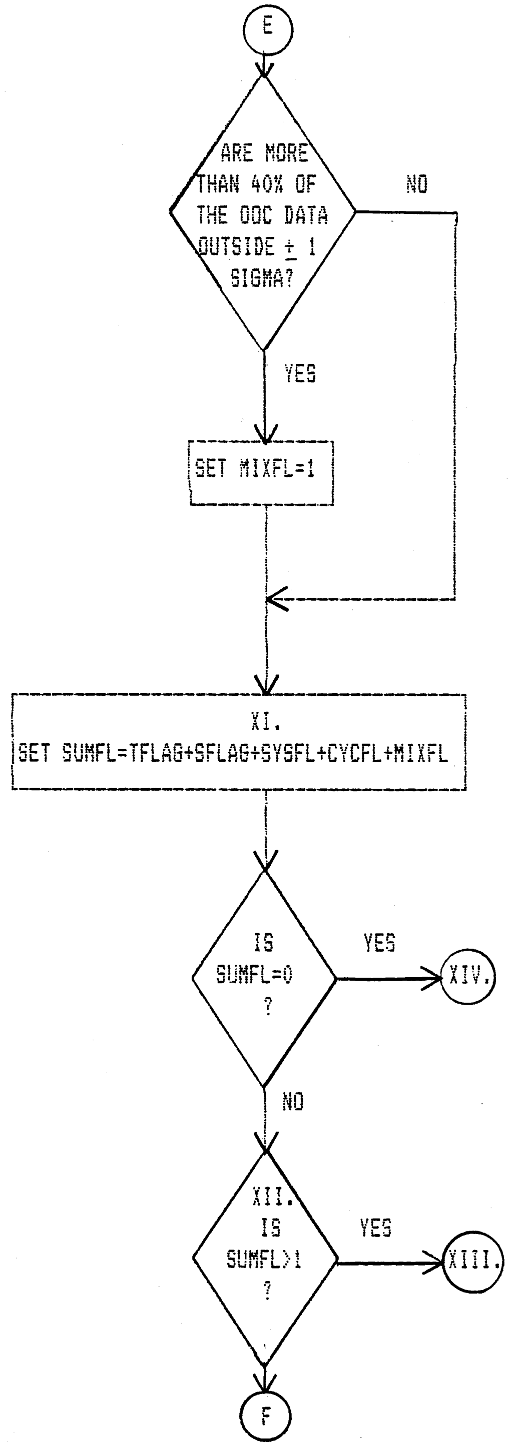


Figure 26. (Continued)

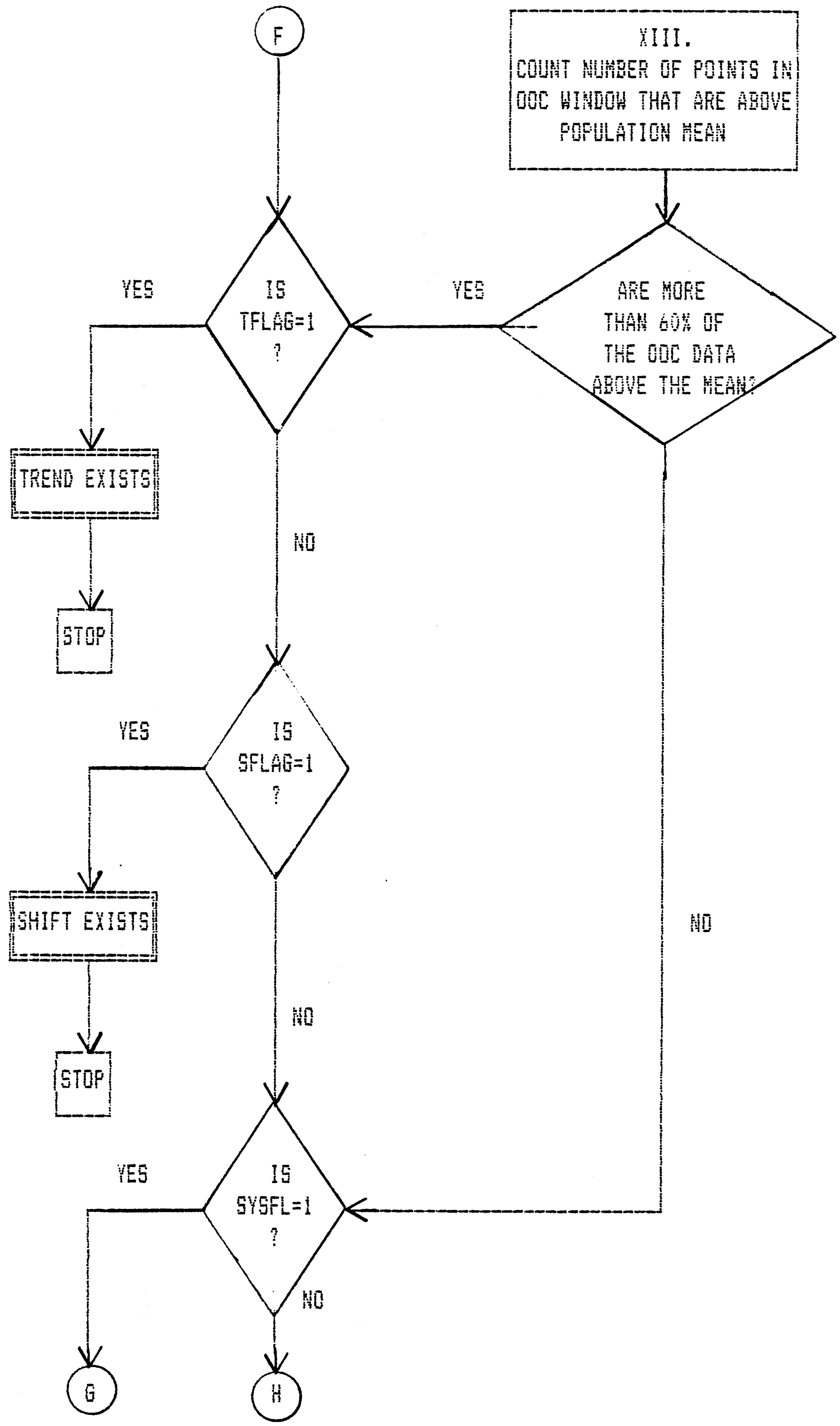


Figure 26. (Continued)

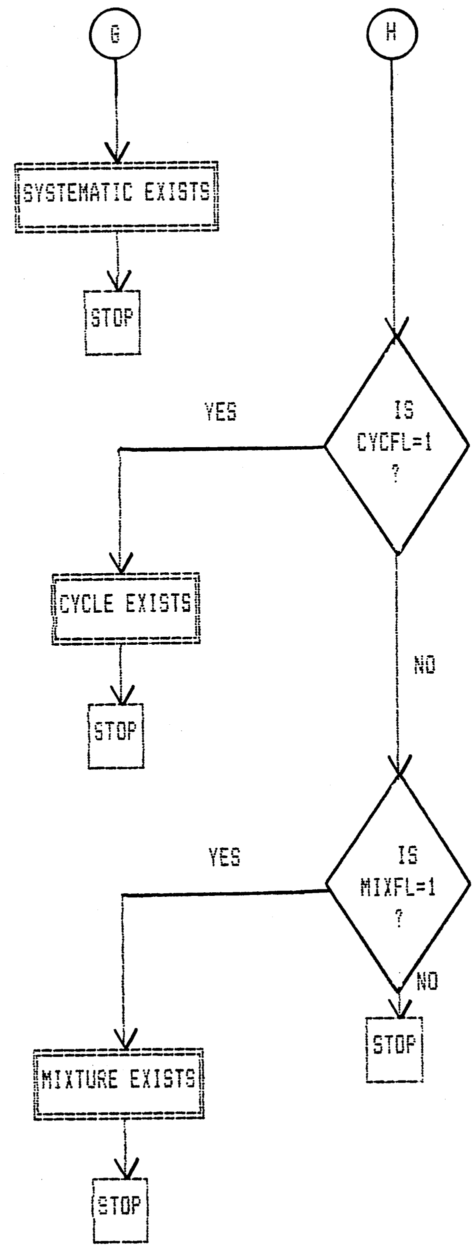


Figure 26. (Continued)

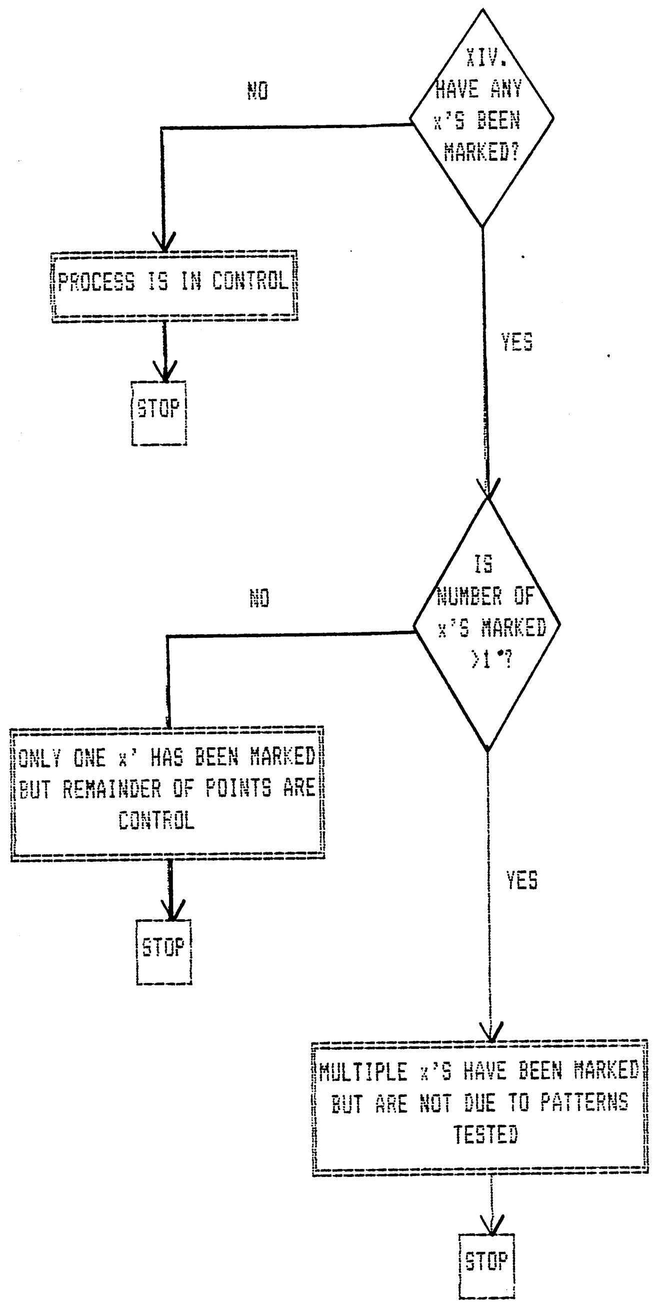


Figure 26. (Continued)

of the system. Therefore, the out-of-control window was initially bounded by B and F.

III. The out-of-control window was possibly modified by looking for clusters of x's. If two or more consecutive points were marked, then they remained within the defined window. However, if an outlier existed, then it was omitted from the window. This resulted in a possible reduction in the size of the out-of-control window. In addition to B and F being updated, these new beginning and ending points of the out-of-control window were set to MB and MF, respectively. This procedure was performed to provide a tighter, hopefully more accurate estimation of the location of the unnatural pattern.

IV.1. As described in the knowledge base decision tree, a test on the mean would be performed to separate trend and shift from the rest of the possible patterns. Through various iterations and changes, it was found that a test of the mean of the entire data set would not provide the most useful information. Instead, it was found that valuable information was obtained by using a moving sample of five throughout the data set. This meant that a sample of five points was taken starting with the first five; the mean was determined and tested for significance; the first point was truncated and the next point in the series added to make a new sample of five. This process continued until the entire data set had been tested.

The test performed was a basic hypothesis test on the mean.

$$H_0 : \mu = \mu_0$$

$$H_1 : \mu \neq \mu_0$$

where μ_0 was the known, population mean of the process. This test procedure used Z_0 as its test statistic, where

$$Z_0 = \frac{\bar{X} - \mu_0}{\sigma / \sqrt{n}}$$

$\bar{X}$ was the calculated mean of the sample set, n was the moving sample size and σ was the known, population standard deviation of the process. It follows that the distribution of Z_0 is N(0,1). The mean was found to be significantly different if $P(Z > |Z_0|) < \alpha$. After several trials, it was found that an alpha of 0.1 provided the best discrimination for reliable results.

The first time a significant mean was found in a moving sample, two things were done. First, the beginning point of the out-of-control window was set to the position of the first point in that moving sample plus two. Second, the ending point of the out-of-control window was set to the position of the last, or fifth, point in that moving sample. The next sample was then tested. If the sample means remained significant, the ending point of the out-of-control window was updated to be equal to the last point in that moving sample minus one. (The plus two and minus one were done to compensate for the averaging being done with a sample of five.) As soon as a mean was found to be insignificant, then it was found that the unnatural pattern had most probably ended. Therefore, this process had, independent of the results of steps II and III, established initial bounds for the out-of-control window.

These bounds were then modified to reflect the most accurate estimate of the beginning and ending points of the unnatural pattern. This modification had two major components. First, if the moving sample mean test did not find any significant means, then the bounds found in step III had to be used. If B=0 and F=0, then the process went to step V. Otherwise, B was adjusted based upon what rule caused that point to be marked. (Recall that B and F were set in II as the first and last points marked according to the AT&T run rules.) This adjustment was as follows. If rule one caused the point to be marked, then B was left alone. IF rule two was the cause, B was set equal to B-1. If rule three was the cause, B was set equal to B-3. If rule four was the cause, B was set equal to B-7. These adjustments were made based on the fact that the AT&T rules mark the last point in a series and the expert system required the beginning point. Second, if significant means had been found, then the beginning and ending points found using the moving sample mean test were compared to those found in step III. If they were outside of those set in step III, then B and F were changed to these new values.

2. The sample mean of the entire data set was calculated. If the sample mean was greater than the population mean, then the flag SL was set equal to 1.
3. The size of the out-of-control window was found from the revised bounds. If the size was one or zero, then the system went to V since a window size of at least two was needed for the upcoming slope test.
4. The sample mean and the slope of the data within the out-of-control window were calculated.
5. A test was done to see if the sign of the slope matched the sign of the deviation of the sample mean from the population mean ($\bar{X}-\mu$). In other words, if the slope was positive (negative) and SL=1 (SL=0) then the system would proceed to step IV.6, otherwise, it would skip to step IV.7. The

logic behind this test resided in the fact that if a positive trend existed (slope>0), then the sample mean of the entire data set would be greater than or equal to the population mean of the process (SL=1) and visa versa.

6. A test was then performed to determine whether or not the slope was significant. The test performed was as follows.

$$H_0 : \beta_1 = 0$$

$$H_1 : \beta_1 \neq 0$$

The test statistic used to evaluate the null hypothesis was F_0, where

$$F_0 = \frac{MSR}{MSE}$$

where MSR was the mean square error due to regression and MSE was the residual mean square error. It follows that F_0 is distributed as the F distribution with 1 and n-2 degrees of freedom. Therefore, H_0 would be rejected if $P(F_0 > F) < \alpha$. Failing to reject H_0 indicated that there was no evidence of a slope in the data of the out-of-control window. For this test, n represented the size of the out-of-control window and an alpha value of 0.1 was found to provide the best discrimination.

If H_0 was rejected then there was evidence that a trend existed. In this case, TFLAG was set equal to 1 and the system proceeded to step V.

7. A test was performed to determine if the sample mean within the out-of-control window was significantly different from the population mean. The same hypothesis test that was used in step IV.1 was used here. The only difference was that n represented the number of data points in the out-of-control window and alpha was 0.05. If the sample mean was found to be significant, SFLAG was set to 1.

V. Confidence limits were placed on the variance of the entire data set. These limits were

$$\frac{(n-1)S^2}{\chi^2_{\alpha/2,n-1}} \leq \sigma^2 \leq \frac{(n-1)S^2}{\chi^2_{1-\alpha/2,n-1}}$$

where S^2 was the population variance, n was the number of sample points in the entire data set and alpha was 0.2. If the sample variance of the entire data set was less than the lower control limit, then the system went to step VII. Otherwise it proceeded to step VI. (If the sample variance was significantly less than expected, there was evidence that a stratification pattern was present.)

VI.1. A moving sample was used to modify the out-of-control window. The method used was the same as in step IV.1, except the moving sample size was equal to seven and the test performed was based on variance. In addition, the determination of the ending point of the out-of-control window was based on the last moving sample which was significant. This contrasted with step IV.1 which determined the out-of-control window when the first insignificant variance was located. The test used was

$$H_0 : \sigma^2 \leq \sigma_0^2$$
$$H_1 : \sigma^2 > \sigma_0^2$$

A one-sided test was appropriate, since at this point the system was trying to determine if a cycle, mixture or systematic pattern was present. It was found that all three of these patterns would have a variance greater than the in-control process. The test statistic used was

$$X_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$$

where σ_0^2 was the population variance, S^2 was the variance within the moving sample and n was the size of the moving sample. It follows that the distribution of X_0^2 is chi-square with n-1 degrees of freedom. If $P(X_{n-1}^2 > X_0^2) < 0.05$, then the variance of the moving sample was defined to be significant. As in step IV.1, the B and F values were possibly modified to provide a more accurate determination of the out-of-control window.

2. The sample variance within the newly defined out-of-control window was calculated. This value was tested using

$$H_0 \; : \; \sigma^2 = \sigma_0^2$$
$$H_1 \; : \; \sigma^2 \neq \sigma_0^2$$

with the same test statistic as in step VI.1 , except S^2 was the sample variance within the out-of-control window and n was the number of points within the same window. If $P(\chi^2_{n-1} > \chi^2_0) < \alpha$ then the system went to step VIII. If $P(\chi^2_{n-1} < \chi^2_0) < \alpha$ then the system proceeded to step VII. This step was performed as a double check for the possible occurrence of stratification. If the sample variance did not appear to be significant, the system went to step XI. An alpha value of 0.2 was used.

VII.1. As in step VI.1, a moving sample of seven with alpha equal to 0.25 was used to modify the out-of-control window. The test used was

$$H_0 \; : \; \sigma^2 \geq \sigma_0^2$$
$$H_1 \; : \; \sigma^2 < \sigma_0^2$$

2. Within the newly defined out-of-control window, a count was made of the number of points that fell within plus or minus one standard deviation of the in-control process. If no unnatural pattern existed and the data was from the established in-

control process, one would theoretically expect only 68.27 percent of the points to fall within plus or minus one process standard deviation. With stratification, as discussed in Chapter 3, section 2.5, the resulting pattern causes the points defining this pattern to hug the centerline. In other words, more points than would normally be expected would fall within the plus or minus one standard deviation limits.

3. If 75 percent or more of the points within the out-of-control window fell within plus or minus one process standard deviation, then the system concluded that a stratification pattern existed. The 75 percent value was determined through heuristic testing to be the most discriminating. If at least 75 percent did not fall within these limits, then the system went to step XI.

VIII. A test was performed to see if a systematic pattern was present. This test determined if an up/down pattern existed within the out-of-control window established in step VI.1 (reference Chapter 3, section 2.7). This test was performed by keeping a count of the number of times a low point was followed by a high point. For example, in Figure 27, if point A was greater than point B, then point

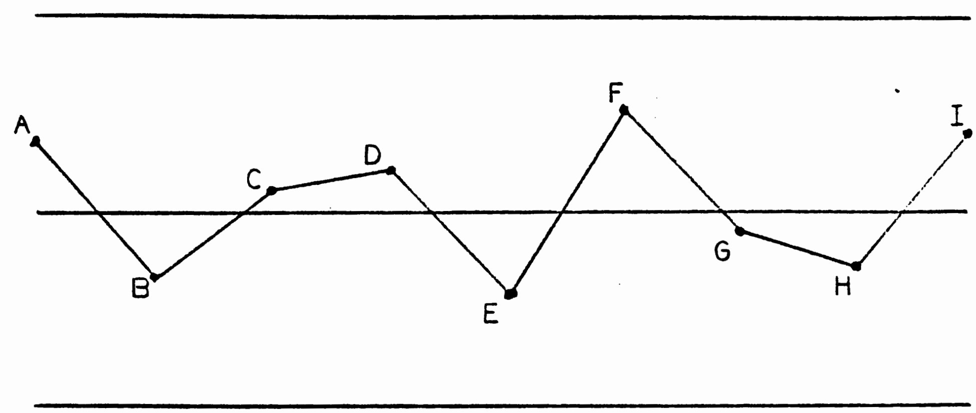


Figure 27. Test Pattern

point A would be given a value of 1. Otherwise, it would be given a value of 0. Therefore, points A through H were given values in the following manner assuming points A through I represented the out-of-control window.

$A>B$ then $A=1$

$B \not> C$ then $B=0$

$C \not> D$ then $C=0$

$D>E$ then $D=1$

$E \not> F$ then $E=0$

$F>G$ then $F=1$

$G>H$ then $G=1$

$H \not> I$ then $H=0$

"I" was not given a value since the system was only interested in how the points within the out-of-control window behaved with respect to each other.

With all of the points assigned a value, a test was done to see if the sum of two successive values was equal to 1. If it was, then the reference count was incremented by one. Otherwise, the reference count remained unchanged. This procedure is illustrated on the sample data.

	COUNT=0
A+B=1+0=1	COUNT=0+1=1
B+C=0+0=0	COUNT=1
C+D=0+1=1	COUNT=1+1=2
D+E=1+0=1	COUNT=2+1=3
E+F=0+1=1	COUNT=3+1=4
F+G=1+1=2	COUNT=4
G+H=1+0=1	COUNT=4+1=5

If the count value was equal to or greater than 84 percent of the window size, then the system concluded that a systematic pattern was present and SYSFL was set to 1. The 84 percent was determined through iterative testing to provide a dependable, accurate result.

IX. A test was performed to see if a cycle pattern was present. A trignometric function of the form

$$y(t) = a + b \sin\left(\frac{2\pi t}{P}\right)$$

was used where a was the intercept, b was the amplitude and P was the number of points within the cycle (Biegel, 1971). This function was fit to the data within the defined out-of-control window. Using this function, a significance test was done on all possible combinations of period and lag within the defined window. The test performed was

$$H_0 : \beta = 0$$

$$H_1 : \beta \neq 0$$

The test statistic used was

$$t_0 = \sqrt{\frac{(n-2)SSREG}{SSRES}}$$

where n was the number of points within the out-of-control window and SSREG and SSRES were the sum of squares due to regression and residuals, respectively. It follows that the distribution of t_0 is the Student t with n-2 degrees of freedom. The maximum absolute value of t that existed within the defined window was found and was tested against $t_{n-2, 1-\alpha/2}$ where alpha was 0.01. If $P(t_{n-1} > |t_0|) < \alpha$, then the system concluded that a cycle pattern existed and CYCFL was set to 1.

X. A test was performed to determine if a mixture pattern was present. Using the knowledge that a mixture came from two separate distributions shifted away from the in-control population process mean (Chapter 3, section 2.6), a test for mixture was developed. If no unnatural pattern existed and the data was from the established in-control process, one would theoretically expect 31.73 percent of the points to fall outside of plus or minus one in-control process standard deviation. The test performed consisted of counting the number of points in the out-of-control window that were outside of plus or minus one standard deviation. If this number exceeded 40 percent of the window size, then the system concluded that a mixture was present and MIXFL was set equal to 1.

XI. At this point, the system had determined if a pattern existed in the data. The system now had to determine whether the identified pattern was a trend, shift, cycle, systematic, mixture or no pattern. Recall, that step VIII made a final conclusion on the presence of stratification. The final decision concerning a possible pattern was made based upon what flag had been raised. Since some of the patterns under study had similar characteristics (e.g. mixture and systematic patterns both came from distributions that had been shifted from the center-line) and the identification process was not perfect, more than one identifying flag could have been raised. Therefore, a testing of the flags had to be performed. The initial test summed all of the flags. If the sum was equal to zero, the system went to step XIV. Otherwise, the system proceeded to step XII.

XII. A test was done to determine if the sum of flags was equal to 1. If not, this indicated that more than one pattern had been identified and the system went to step XIII to perform a hierarchical test. If only one flag had been raised, the identified pattern was noted as

1. TFLAG=1 (trend present)
2. SFLAG=1 (shift present)
3. SYSFL=1 (systematic present)
4. CYCFL=1 (cycle present)
5. MIXFL=1 (mixture present)

Once proper identification had been made, the system would inform the user and terminate the program.

XIII. If the sum of flags was greater than one, then more than one pattern had been indicated. Therefore, a test was developed to separate the possibilities into two groups. The first group consisted of the trend and shift patterns. The second group consisted of the systematic, cycle and mixture patterns. The reason for this separation was based on how these patterns were originally identified. Trend and shift were originally separated based on a change in mean. The other patterns were based on a change in variance.

The test developed consisted of counting the number of points within the defined out-of-control window that fell above the expected mean of the in-control process. Through heuristics, it was found that if more that 60 percent fell above this centerline, then a trend or shift was present. Since the trend flag and shift flag could not both be equal to one (step IV.6 and 7), the system tested to see which of these flags had been set, informed the user of its conclusion and terminated the program.

If less than 60 percent were found to be above the centerline, then either a systematic, cycle or mixture pattern existed. It was important to test the flags in the following order.

1. SYSFL=1 ?
2. CYCFL=1 ?
3. MIXFL=1 ?

This ordering was important since in the case of systematic and mixture patterns, both had similar underlying distributions (Chapter 3, sections 2.6 and 2.7) and both flags were generally set. However, since the systematic flag was set based on a test specifically designed to identify that pattern, SYSFL=1 superseded MIXFL=1 resulting in the system concluding that a systematic pattern existed. The cycle flag was tested next since depending on the period and amplitude, the mixture flag could also have been set in step X. Once the system identified the pattern, the system reported this to the user and terminated the program.

XIV. If the sum of flags equaled zero, then the system was unable to match a pattern to the data. Therefore, there were three possibilities remaining based upon the number of points marked by the AT&T run rules. First, if no points had been marked, the system reported that the process appeared to be in-control. Second, if only one point had been marked, the system reported that only one x had been marked with the remainder of points appearing to be in-control. Finally, if more than one point had been marked, the system reported that multiple points had been marked but the cause did not appear to be due to the six patterns tested for by the system.

Through the use of heuristics and statistically based tests, the knowledge based expert system was successfully implemented. The actual coding for the inference engine can be found in Appendix B.

CHAPTER V

PRESENTATION AND ANALYSIS OF RESULTS

5.1 Test Design

In order to evaluate the system described in Chapter 4, a test procedure was designed. It was determined that the quality of pattern recognition was a function of both the total length of the unnatural pattern and the magnitude of change present within the unnatural pattern. Therefore, a two-dimensional test matrix was designed with one parameter being the size of the out-of-control window and the other parameter being the magnitude of change. The pattern generated for each of these tests had sixty total points with the first out-of-control point beginning at point eight. The total length of the out-of-control pattern was varied from five points to forty-five points in increments of five. This procedure maintained the assumption that the pattern to be analyzed would first be in-control, then out-of-control and then back in-control (Chapter 1). Selection of the magnitude-of-change-test-points was made as follows. For all patterns, it was felt that tests should be made on changes in magnitude varying from insignificant to significant. For the shift, mixture and systematic patterns, a change in magnitude represented a shift in the population mean of the process. The shift was generated using a multiple, δ , of the in-control process population variation (Chapter 3). Therefore, the test designed for these three patterns required that δ vary from 0.5 (insignificant shift) to 3.0 (significant shift) in increments of 0.5. The cycle pattern had two generating parameters, δ and T, amplitude and period, respectively. Since amplitude was similar to the shift in the previous three patterns, δ was varied as described above. However, this test had to be performed for various cycle periods. Therefore, the period T was set to 4, 8 and 12. The defining parameter for the trend pattern was the slope. Therefore, the slope was varied from 0.25 (insignificant) to 1.25 (significant). The identifying parameter for the stratification pattern was the standard deviation. This pattern generated its variation as a fractional multiple, γ , of the in-control process population variation. Therefore, γ was varied from 0.2 (significant) to 0.8 (insignificant).

A total of ten independent runs was made at each cell of the matrix. For each independent run, two main items were provided (Figure 28). Part A provided information on the true nature of the control chart in question. It stated (1) what pattern was actually being generated; (2) where it actually started and stopped ; and (3) what the true magnitude of change was. Part B provided information

1 2

A MIXTURE PATTERN WITH A SHIFT OF 2.5 AND 45 OUT OF CONTROL POINTS STARTING AT 8 AND ENDING AT 52 .
THE TWO MEANS OF THE MIXTURE SHOULD BE AT 112.5 AND 87.5 .

4 3 5

B PATTERN IS A MIXTURE WITH OUT OF CONTROL BEGINNING AT 8 AND ENDING AT 52 .
THE TWO MEANS OF THE MIXTURE ARE AT 112.4677 AND 87.53232 .

6

1 2

A SYSTEMATIC PATTERN WITH A SHIFT OF 3 AND 10 OUT OF CONTROL POINTS STARTING AT 8 AND ENDING AT 17 .
THE TWO MEANS ASSOCIATED WITH THIS PATTERN SHOULD BE AT 115 AND 85 .

3

4 5

B PATTERN IS SYSTEMATIC WITH OUT OF CONTROL STARTING AT 8 AND ENDING AT 17 .
THE TWO MEANS ASSOCIATED WITH THIS PATTERN ARE AT 114.4021 AND 85.59794 .

6

Figure 28. Sample Outputs

related to what the expert system determined was happening. It stated (4) what pattern (if any) was found in the data; (5) where this pattern was observed to start and stop; and (6) what the estimated magnitude of change was. A complete summary of this output can be found in Appendix C.

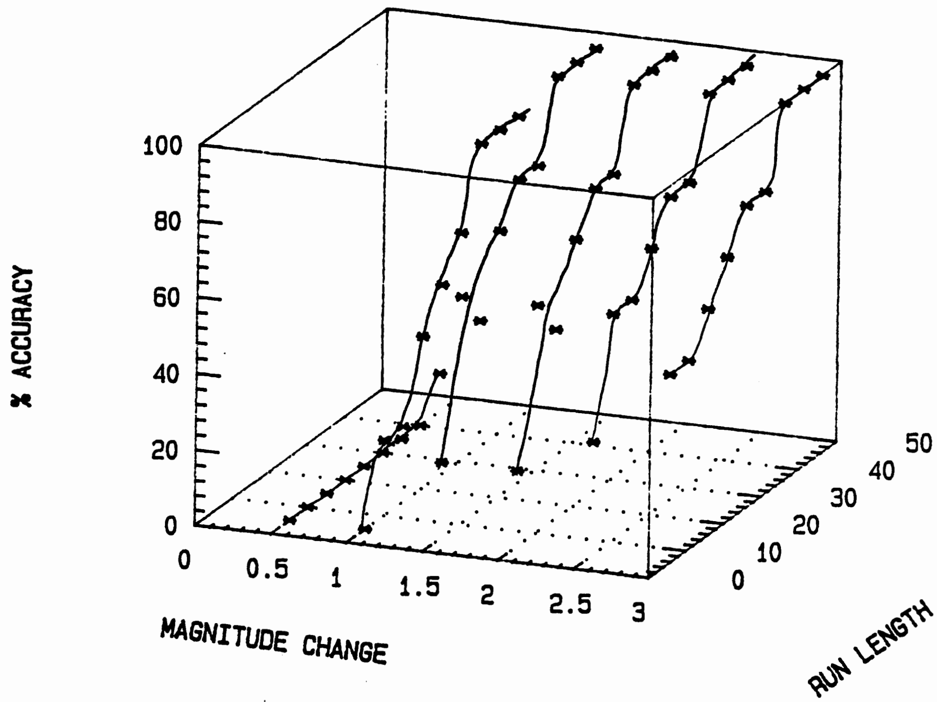
From the objectives outlined in Chapter 1, three items were of particular interest. First, how good was the system at recognizing the correct pattern? Second, how well did the system identify the starting and stopping points? Third, how well did the system estimate the magnitude of change?

5.2 Identification Accuracy

Tables I through VIII present the percent accuracy of correct identification in the test matrix format as well as a three dimensional representation of the data. For example, point A in Table I says that for a systematic pattern with a run length of 25 points and a magnitude of change of 2.0, the system was able to identify the systematic pattern 80 percent of the time. As can be seen from these tables, the identification accuracy increases as the run length increases and as the magnitude of change becomes more severe. However, this relationship did not appear to be quite linear in the variables run length and magnitude of change. Therefore, multiple regression was performed on the data in Tables I through VIII. In order to reduce bias in the regression analysis, each data set

TABLE I

PERCENT IDENTIFICATION ACCURACY FOR A SYSTEMATIC PATTERN

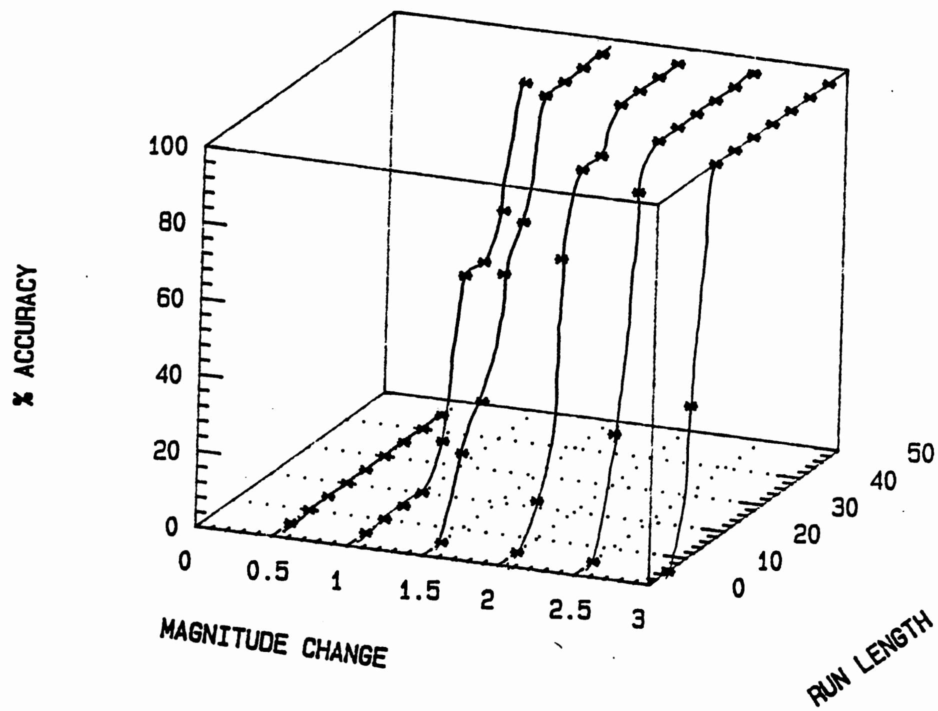


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	-	-	-	-	-	-	-	10
1.0	-	20	20	40	50	60	80	80	80
1.5	20	60	50	70	A 80	80	100	100	100
2.0	20	60	50	70	80	80	100	100	100
2.5	30	60	60	70	80	80	100	100	100
3.0	50	50	60	70	80	80	100	100	100

TABLE II

PERCENT IDENTIFICATION ACCURACY FOR A CYCLE PATTERN (PERIOD=4)

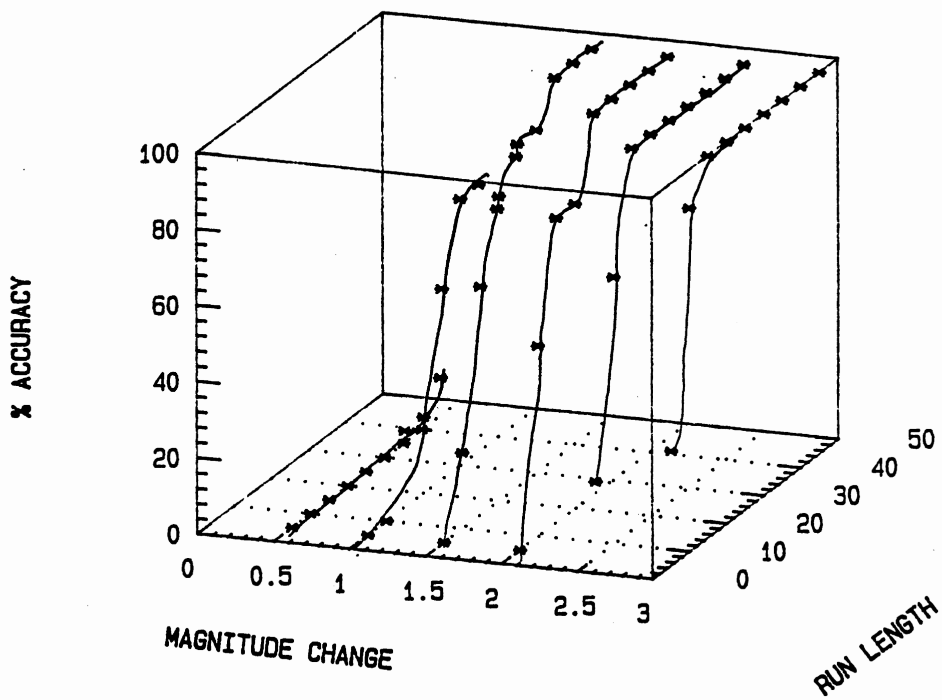


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	-	-	-	-	-	-	-	-
1.0	-	-	-	-	10	50	50	60	90
1.5	-	20	30	60	70	100	100	100	100
2.0	-	10	70	90	90	100	100	100	100
2.5	-	30	90	100	100	100	100	100	100
3.0	-	40	100	100	100	100	100	100	100

TABLE III

PERCENT IDENTIFICATION ACCURACY FOR A CYCLE PATTERN (PERIOD=8)

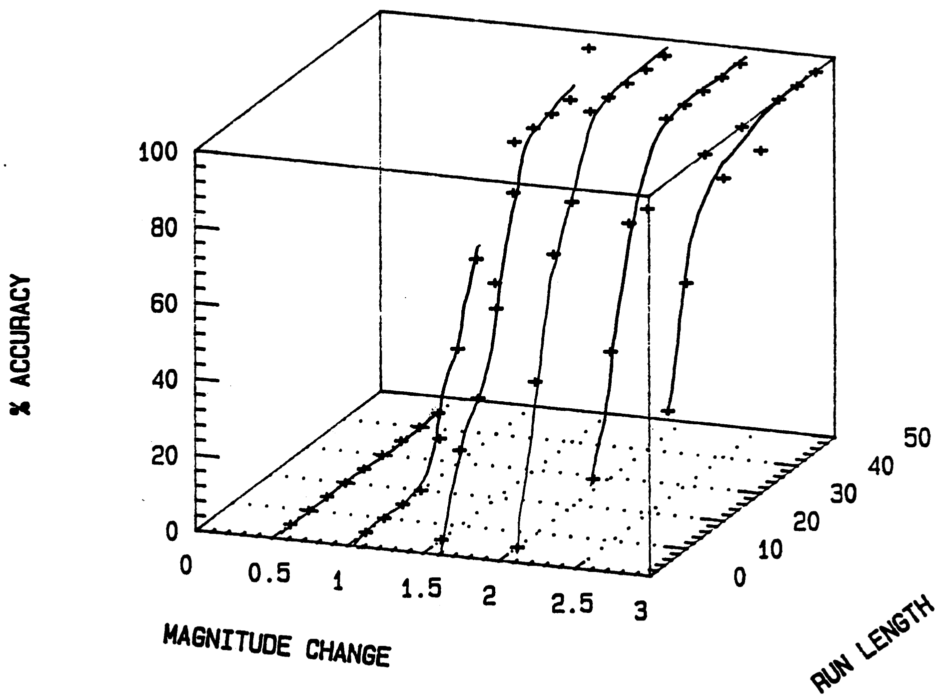


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	-	-	-	-	-	-	-	10
1.0	-	-	20	20	50	70	70	60	70
1.5	-	20	60	80	90	90	100	100	100
2.0	-	50	80	80	100	100	100	100	100
2.5	20	70	100	100	100	100	100	100	100
3.0	30	90	100	100	100	100	100	100	100

TABLE IV

PERCENT IDENTIFICATION ACCURACY FOR A CYCLE PATTERN (PERIOD=12)

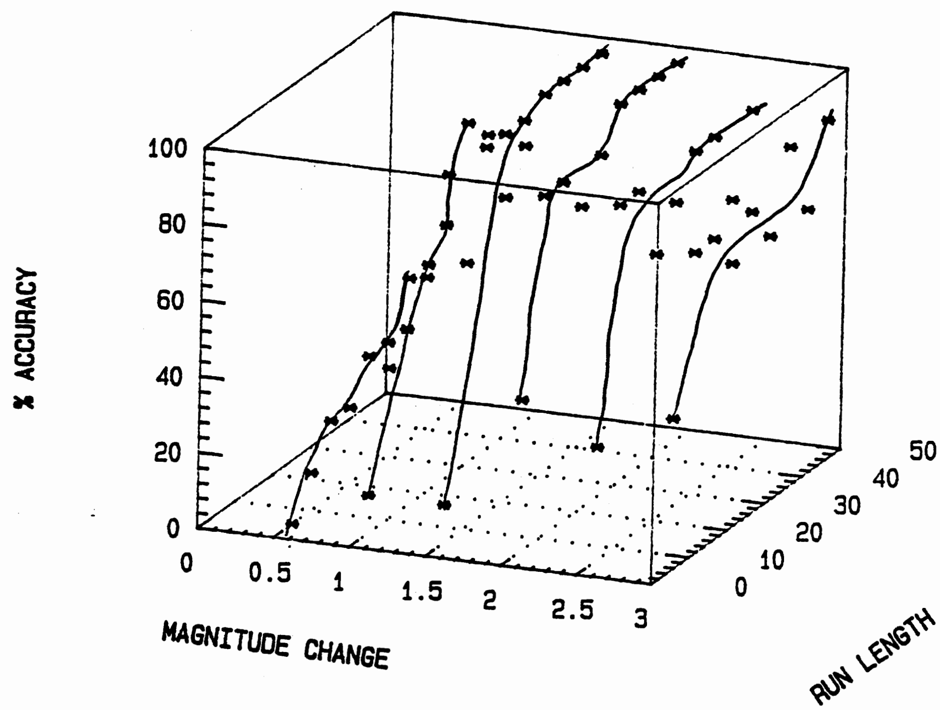


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	-	-	-	-	-	-	-	-
1.0	-	-	-	-	10	30	50	40	60
1.5	-	20	30	50	90	90	90	90	100
2.0	-	40	70	80	100	100	100	100	100
2.5	20	50	80	80	100	100	100	100	100
3.0	40	70	100	90	100	90	100	100	100

TABLE V

PERCENT IDENTIFICATION ACCURACY FOR A SHIFT PATTERN

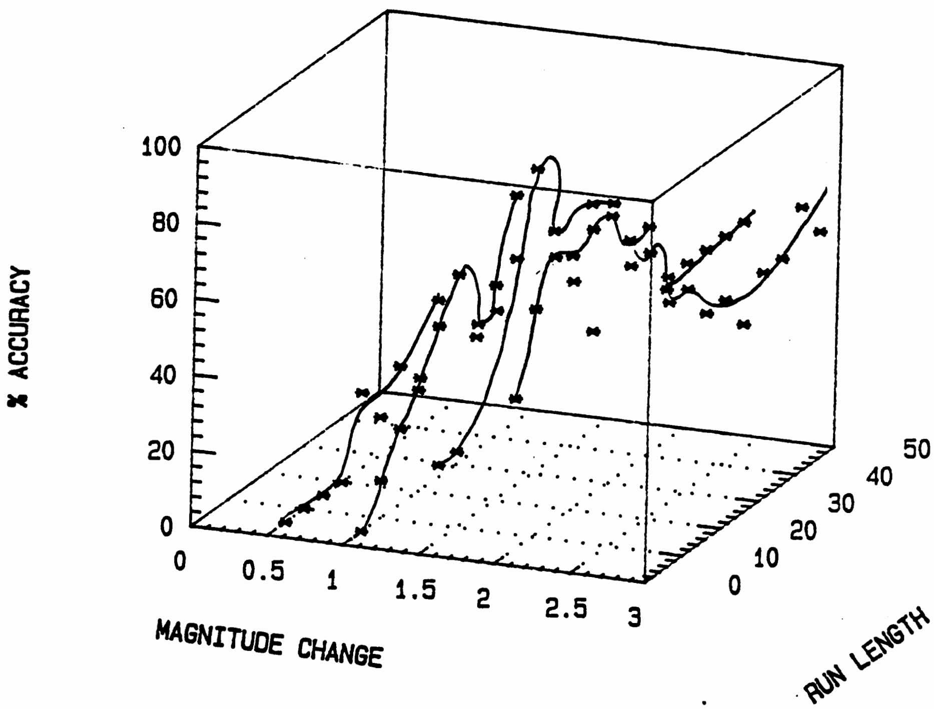


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	10	20	20	30	30	30	40	50
1.0	10	40	60	60	30	90	80	80	80
1.5	10	70	100	80	90	100	100	100	100
2.0	40	90	90	30	90	100	100	100	100
2.5	30	90	90	70	80	90	90	70	90
3.0	40	80	80	70	80	70	90	70	90

TABLE VI

PERCENT IDENTIFICATION ACCURACY FOR A MIXTURE PATTERN

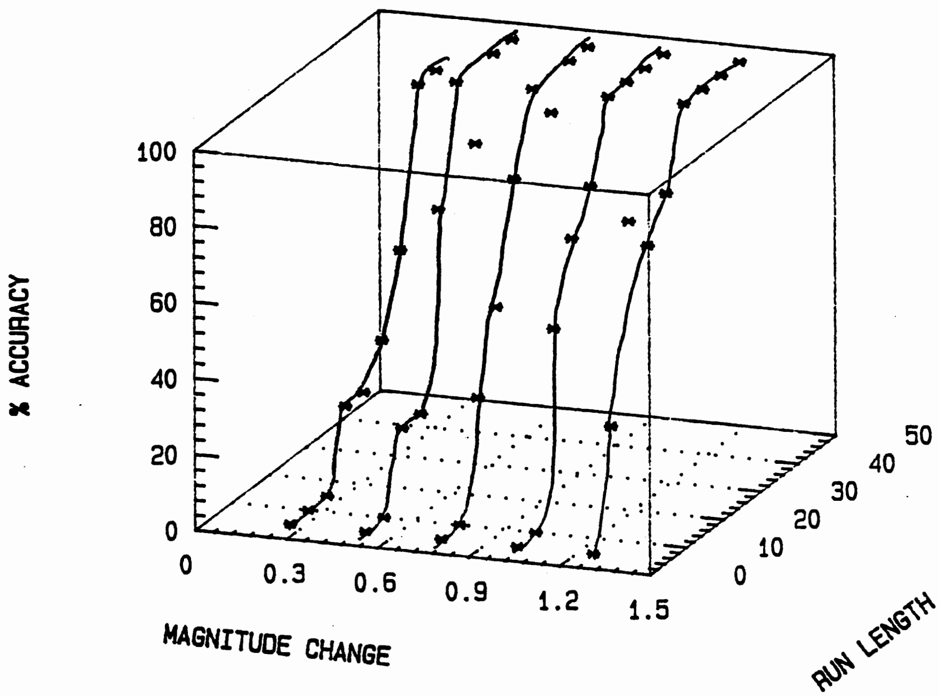


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.5	-	-	-	-	20	10	20	10	30
1.0	-	10	20	30	40	50	30	40	60
1.5	20	20	50	50	60	80	60	50	60
2.0	40	60	70	60	70	70	60	60	40
2.5	60	90	70	70	60	60	60	60	60
3.0	70	70	60	60	50	60	60	70	60

TABLE VII

PERCENT IDENTIFICATION ACCURACY FOR A TREND PATTERN

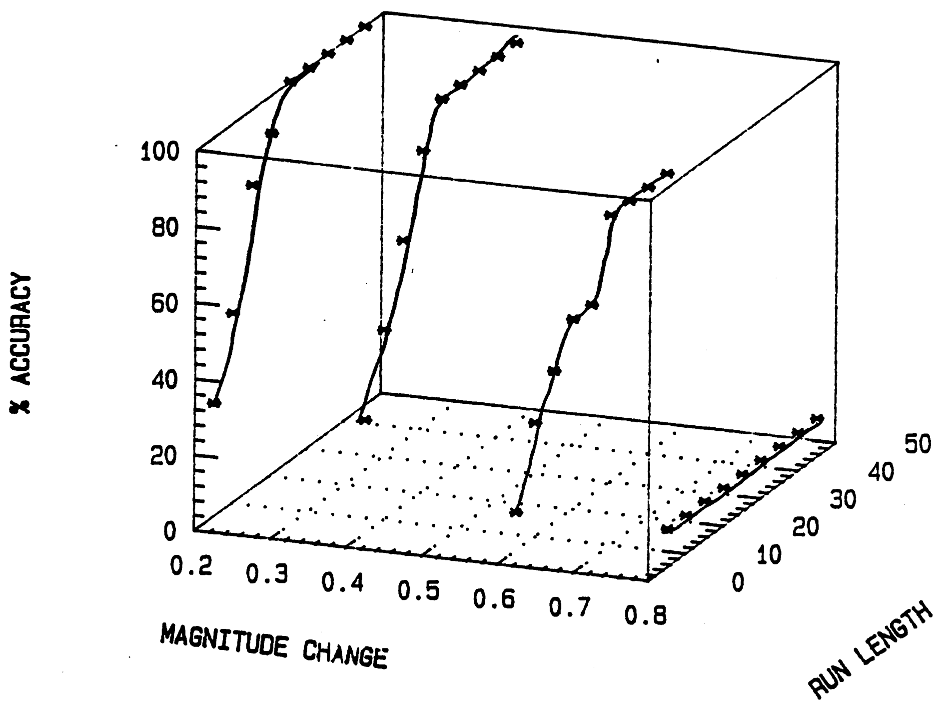


OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.25	-	-	-	20	20	30	50	90	90
0.50	-	-	20	20	70	100	80	100	100
0.75	-	-	30	50	80	100	90	100	100
1.00	-	-	50	70	80	100	100	100	100
1.25	-	30	80	70	80	100	100	100	100

TABLE VIII

PERCENT IDENTIFICATION ACCURACY FOR A STRATIFICATION PATTERN



OUT-OF-CONTROL PATTERN LENGTH

MAGNITUDE OF CHANGE	5	10	15	20	25	30	35	40	45
0.2	30	50	80	90	100	100	100	100	100
0.4	30	50	70	90	100	100	100	100	100
0.6	10	30	40	50	50	70	70	70	70
0.8	10	10	10	10	10	10	10	10	10

NOTE: 0.2 is the most severe magnitude of change for a stratification pattern.

was reduced to a minimum based upon the following guidelines.

1. If any boundary row or column contained the same percentage, a statement would be added to that pattern's dependability rules and that row or column would be eliminated. For example, in Table II, row 1 (0.5) and column 1 (5) contained all dashes which was the same as predicting the correct pattern zero percent of the time. Therefore, the following statement would be added to the cycle (period=4) pattern's dependability rules.

   A. At a run length of up to 5 and for all magnitudes of change up to 3.0, the probability of the expert system correctly identifying the pattern is zero. It is likewise true, for a magnitude of change of up to 0.5 and a run length of up to and including 45 points.

2. If any cell in the matrix was surrounded (horizontally and vertically) by cells with the same value, then the dependability rules were updated and this data value was eliminated from the regression data set.

With this reduced data set, a least squares equation was determined using a backward regression technique with an alpha equal to 0.05. The initial variables being tested were

1. VAR2 (run length)
2. VAR3 (magnitude of change)
3. VAR2 TIMES VAR3
4. VAR2 TIMES VAR2
5. VAR3 TIMES VAR3

Once the significant variables were determined, an analysis of variance for the full regression was performed. It was desired to obtain an adjusted R-squared value greater that 80 percent since the adjusted R-squared value, unlike the unadjusted R-squared value, would decrease if variables were entered into the model which did not add significantly to the fit. The standard error of estimate represented a measure of the unexplained variability in the dependent variable which in this case was the predicted probability. Since the dependent variable had maximum and minimum values of 0 and 100, respectively, it was desired to try and keep the standard error of estimate less than 15. This value would not leave too large a portion of the dependent variable's variability unexplained. Since each pattern resulted in an unique equation, each probability estimation equation will be discussed separately.

5.2.1 Systematic Probability Estimation

Table IX provides the results from the analysis. The dependability rules were as follows.

1. At a run length of up to 5 and a magnitude of change of up to 0.5, the probability of the expert

system correctly identifying the pattern is zero.

2. For run lengths of 40 to 45 and a magnitude of change of 2.0 up to 3.0, the probability of the expert system correctly identifying the pattern is 100 percent.

3. The following regression equation explains 87.17 percent of the total variation.

PROB(VAR2,VAR3) = -71.51 + .99*VAR2 + 101.03*VAR3 + 0.45*VAR2*VAR3 - 23.76 VAR3^2

TABLE IX

SYSTEMATIC REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-71.512753	12.353469	-5.7889	.0000
VAR2	0.986991	0.33722	2.9269	.0053
VAR3	101.030091	11.902824	8.4879	.0000
VAR2 TIMES VAR3	0.451409	0.193637	2.3312	.0242
VAR3 TIMES VAR3	-23.756927	2.892902	-8.2121	.0000

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	46005.849	4	11501.462	79.128	.000
ERROR	6104.7896	42	145.3521		
TOTAL (CORR.)	52110.638	46			

R-SQUARED = 0.882849
R-SQUARED (ADJ. FOR D.F.) = 0.871692
STND. ERROR OF EST. = 12.0562

5.2.2 Cycle (Period=4) Probability Estimation

Table X provides the results from the analysis.

TABLE X

CYCLE (PERIOD=4) REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-177.938169	29.113657	-6.1118	.0000
VAR2	5.805746	1.425672	4.0723	.0004
VAR3	121.581231	29.961701	4.0579	.0004
VAR2 TIMES VAR2	-0.055309	0.026507	-2.0866	.0469
VAR3 TIMES VAR3	-20.366063	7.922118	-2.5708	.0162

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	31248.739	4	7812.185	33.753	.000
ERROR	5092.0015	22	231.4546		
TOTAL (CORR.)	36340.741	26			

R-SQUARED = 0.859882
R-SQUARED (ADJ. FOR D.F.) = 0.834406
STND. ERROR OF EST. = 15.2136

The dependability rules were as follows.

1. At a run length of up to 45 and a magnitude of change of up to 0.5, the probability of the expert

system correctly identifying the pattern is zero.

2. At a run length of up to 5 and a magnitude of change of up to 3.0, the probability of the expert system correctly identifying the pattern is zero.
3. For run lengths of 35 to 45 and magnitude of changes of 2.0 up to 3.0, the probability of the expert system correctly identifying the pattern is 100.
4. For run lengths of 30 to 35 and a magnitude of change of 2.5 to 3.0, the probability is 100. It is likewise true for run lengths of 20 to 30 and magnitude of change of 3.0.
5. The following regression equation explains 83.44 percent of the total variation.

$$PROB(VAR2,VAR3) = -177.94 + 5.81*VAR2 + 121.58*VAR3 - 0.06*VAR2^2 - 20.37*VAR3^2$$

5.2.3 Cycle (Period=8) Probability Estimation

Table XI provides the results from the analysis. The dependability rules were as follows.

1. For run lengths of up to 10 and magnitude of change of up to 0.5, the probability of the expert system correctly identifying the pattern is zero. Likewise, it is true for run lengths of up to 5 and a magnitude of change up to 1.0.
2. For run lengths of 35 to 45 and a magnitude of change of 2.0 to 3.0, the probability is 100.

3. For run lengths of 25 to 35 and a magnitude of change of 2.5 to 3.0, the probability is 100. Likewise, it is true for run lengths of 20 to 25 and a magnitude of change of 3.0.

4. The following regression equation explains 91.76 percent of the total variation.

$$PROB(VAR2,VAR3) = -105.34 + 4.54*VAR2 + 67.26*VAR3 + 1.12*VAR2*VAR3 - 0.07*VAR2\hat{\ }2 - 10.83*VAR3\hat{\ }3$$

TABLE XI

CYCLE (PERIOD=8) REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-105.343278	27.394652	-3.8454	.0005
VAR2	4.53868	1.31831	3.4428	.0015
VAR3	67.263677	21.963072	3.0626	.0041
VAR2 TIMES VAR3	1.115223	0.431258	2.5860	.0139
VAR2 TIMES VAR2	-0.073825	0.017453	-4.2299	.0002
VAR3 TIMES VAR3	-10.832653	4.63714	-2.3361	.0252

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	53168.510	5	10633.702	81.223	.000
ERROR	4058.5173	31	130.9199		
TOTAL (CORR.)	57227.027	36			

R-SQUARED = 0.92908
R-SQUARED (ADJ. FOR D.F.) = 0.917642
STND. ERROR OF EST. = 11.442

5.2.4 Cycle (Period=12) Probability Estimation

Table XII provides the results from the analysis. The dependability rules were as follows.

1. At a run length of up to 45 and a magnitude of change of up to 0.5, the probability of the expert system correctly identifying the pattern is zero. Likewise, it is true a run length of up to 5 and a magnitude of change of up to 1.0.
2. For a run length of 45 and a magnitude of 2.0 to 3.0, the probability is 100.
3. For a run length of 40 to 45 and a magnitude of change of 2.5 to 3.0, the probability is 100. Likewise, it is true for a run length of 35 to 40 and a magnitude of change of 2.5.
4. The following regression equation explains 87.87 percent of the total variation.

   PROB(VAR2,VAR3) = -170.56 + 4.95*VAR2 + 134.89*VAR3
   - 0.05*VAR2^2 - 24.89*VAR3^2

5.2.5 Shift Probability Estimation

Table XIII provides the results from the analysis. The dependability rules were as follows.

1. The following regression equation explains 78.12 percent of total variation.

   PROB(VAR2,VAR3) = -65.67 + 3.71*VAR2 + 98.17*VAR3
   - 0.05*VAR2^2 - 23.33*VAR3^VAR3

TABLE XII

CYCLE (PERIOD=12) REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-170.558346	20.571816	-8.2909	.0000
VAR2	4.945336	0.760518	6.5026	.0000
VAR3	134.893682	20.043585	6.7300	.0000
VAR2 TIMES VAR2	-0.05476	0.015628	-3.5040	.0012
VAR3 TIMES VAR3	-24.89223	4.948692	-5.0301	.0000

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	44260.594	4	11065.148	67.986	.000
ERROR	5370.9852	33	162.7571		
TOTAL (CORR.)	49631.579	37			

R-SQUARED = 0.891783
R-SQUARED (ADJ. FOR D.F.) = 0.878666
STND. ERROR OF EST. = 12.7576

TABLE XIII

SHIFT REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-65.674603	10.633607	-6.1761	.0000
VAR2	3.707937	0.651147	5.6945	.0000
VAR3	98.174603	10.649819	9.2184	.0000
VAR2 TIMES VAR2	-0.052381	0.012701	-4.1242	.0001
VAR3 TIMES VAR3	-23.333333	2.978655	-7.8335	.0000

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	36003.651	4	9000.913	48.309	.000
ERROR	9129.6825	49	186.3201		
TOTAL (CORR.)	45133.333	53			

R-SQUARED = 0.797718
R-SQUARED (ADJ. FOR D.F.) = 0.781205
STND. ERROR OF EST. = 13.6499

5.2.6 Mixture Probability Estimation

Table XIV provides the results from the analysis. The dependability rules were as follows.

1. At a run length of up to 5 and a magnitude of change of up to 0.5, the probability of the expert system correctly identifying the pattern is zero.
2. The following regression equation explains 81.08 percent of the total variation.

$$\begin{aligned}PROB(VAR2,VAR3) = &-75.31 + 2.89*VAR2 + 84.71*VAR3 \\ &- 0.66*VAR2*VAR3 - 0.03*VAR2^2 \\ &- 13.18*VAR3^2\end{aligned}$$

TABLE XIV

MIXTURE REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-75.31006	11.162375	-6.7468	.0000
VAR2	2.886264	0.575478	5.0154	.0000
VAR3	84.712053	9.050899	9.3595	.0000
VAR2 TIMES VAR3	-0.65947	0.132742	-4.9681	.0000
VAR2 TIMES VAR2	-0.025794	0.009707	-2.6573	.0104
VAR3 TIMES VAR3	-13.179008	2.255544	-5.8429	.0000

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	23274.069	5	4654.814	45.565	.000
ERROR	4801.4031	47	102.1575		
TOTAL (CORR.)	28075.472	52			

R-SQUARED = 0.828982
R-SQUARED (ADJ. FOR D.F.) = 0.810789
STND. ERROR OF EST. = 10.1073

5.2.7 Trend Probability Estimation

Table XV provides the results from the analysis. The dependability rules were as follows.

1. At a run length of up to 5 and a magnitude of change of up to 1.25, the probability of the expert system correctly identifying the pattern is zero. Likewise, it is true for run lengths of up to 10 and a magnitude of change of up to 0.25.
2. For run lengths of 45 and a magnitude of change of 0.75 to 1.25, the probability is 100.
3. For run lengths of 40 to 45 and a magnitude of change of 1.0 to 1.25, the probability is 100. Likewise, it is true for run lengths of 35 to 40 and a magnitude of change of 1.25.
4. The following regression equation explains 86.16 percent of the total variation.

   $$PROB(VAR2,VAR3) = -89.49 + 5.76*VAR2 + 56.33*VAR3 - 0.05*VAR2^2$$

5.2.8 Stratification Probability Estimation

Table XVI provides the results from the analysis. The dependability rules were as follows.

1. At a run length of up to 45 and a magnitude of change of 0.8, the probability of the expert system correctly identifying the pattern is 10.
2. For a run length of 30 to 45 and a magnitude of change of up to 0.2, the probability is 100.

3. The following regression equation explains 99.41 percent of the total variation.

$$PROB(VAR2,VAR3) = 4.96*VAR2 + 138.50*VAR3 - 0.07*VAR2^2 - 285.44*VAR3^2$$

TABLE XV

TREND REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
CONSTANT	-89.488929	15.526647	-5.7636	.0000
VAR2	5.762172	1.195586	4.8195	.0000
VAR3	56.333243	7.333825	7.6813	.0000
VAR2 TIMES VAR2	-0.048066	0.02235	-2.1506	.0392

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	36373.386	3	12124.462	67.429	.000
ERROR	5214.4930	29	179.8101		
TOTAL (CORR.)	41587.879	32			

R-SQUARED = 0.874615
R-SQUARED (ADJ. FOR D.F.) = 0.861644
STND. ERROR OF EST. = 13.4093

TABLE XVI

STRATIFICATION REGRESSION ANALYSIS RESULTS

MODEL FITTING RESULTS

VARIABLE	COEFFICIENT	STND. ERROR	T-VALUE	PROB(>|T|)
VAR2	4.957764	0.378258	13.1068	.0000
VAR3	138.498258	23.26438	5.9532	.0000
VAR2 TIMES VAR2	-0.066624	0.007488	-8.8980	.0000
VAR3 TIMES VAR3	-285.435314	31.871927	-8.9557	.0000

ANALYSIS OF VARIANCE FOR THE FULL REGRESSION

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	PROB(>F)
MODEL	120885.07	4	30221.27	933.78	.00
ERROR	614.92592	19	32.36452		
TOTAL	121500.00	23			

R-SQUARED = 0.994939
R-SQUARED (ADJ. FOR D.F.) = 0.99414
STND. ERROR OF EST. = 5.68898

5.2.9 In-Control Identification Accuracy

In order to validate the expert system's ability to distinguish whether a pattern existed or not, a test was performed on data that had no pattern present. This test determined if the system was capable of recognizing an in-control process. As in the other test matrices, ten test runs were made. Since there was no "out-of-control window" available, the entire data set (60 points) was generated as in-control. The expert system analyzed these ten data sets and found nine of them in-control and the remaining data set had one x marked due to the AT&T run rules. Therefore, it was concluded that the expert system could indeed recognize when no pattern was present.

5.3 Start/Stop Point Accuracy

Tables XVII through XXIV present the average estimated starting and stopping points for the out-of-control window. These averages were calculated only from data obtained when a correct pattern identification had been made. As can be observed, the beginning point was located with reasonable consistency. Identification of the ending point was not nearly as accurate. This was found to be directly related to the heuristics used. As stated in Chapter 4, the ending point was identified using either the moving sample mean test or the moving sample variance test in conjunction with the AT&T run rules. It was found that these tests could be modified by changing the alpha value or by altering how it terminated its testing to provide either a conservative estimate (small out-of-control window) or an optimistic estimate (large out-of-control window). The conservative approach resulted in the conclusion that a pattern did not exist anywhere when it actually did exist (Type I error). The optimistic

TABLE XVII

START/STOP AVERAGES FOR A SYSTEMATIC PATTERN

OUT-OF-CONTROL PATTERN WINDOW

MAGNITUDE OF CHANGE		8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
0.5	START	-	-	-	-	-	-	-	-	31.0
	STOP	-	-	-	-	-	-	-	-	55.0
1.0	START	-	9.0	9.0	10.3	9.6	10.3	10.8	10.8	10.8
	STOP	-	15.5	16.5	24.3	34.0	33.3	42.0	44.3	46.6
1.5	START	7.5	8.0	8.2	8.0	7.6	7.6	7.7	7.7	7.7
	STOP	13.0	16.2	19.6	28.0	34.5	38.3	44.7	47.3	51.7
2.0	START	6.0	6.8	7.2	6.9	6.6	6.6	6.7	6.7	6.7
	STOP	13.0	17.0	20.8	29.7	36.1	39.4	45.4	49.0	52.8
2.5	START	6.0	6.0	6.0	6.0	5.9	5.9	5.9	5.9	5.9
	STOP	12.3	17.5	22.3	30.0	36.8	40.0	45.8	49.2	53.0
3.0	START	6.0	5.8	5.8	5.7	5.8	5.6	5.8	5.7	5.8
	STOP	12.8	17.6	22.7	30.3	37.0	40.4	46.1	49.4	53.2

TABLE XVIII

START/STOP AVERAGES FOR A CYCLE PATTERN (PERIOD=4)

OUT-OF-CONTROL PATTERN WINDOW

MAGNITUDE OF CHANGE		8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
0.5	START	-	-	-	-	-	-	-	-	-
	STOP	-	-	-	-	-	-	-	-	-
1.0	START	-	-	-	-	11.0	13.8	13.4	16.7	17.0
	STOP	-	-	-	-	33.0	44.6	40.4	44.5	50.0
1.5	START	-	7.0	9.7	9.7	9.6	9.0	9.3	9.3	9.3
	STOP	-	55.0	42.3	42.0	42.1	41.6	43.6	46.0	50.1
2.0	START	-	5.0	7.9	7.2	7.8	7.7	7.7	7.7	7.7
	STOP	-	17.0	38.9	35.4	40.1	42.0	44.9	47.7	52.5
2.5	START	-	6.0	7.2	7.2	7.1	7.1	7.2	7.2	7.1
	STOP	-	26.3	34.8	35.0	39.6	42.0	45.6	47.9	52.1
3.0	START	-	5.5	6.4	6.4	6.6	6.6	6.4	6.4	6.6
	STOP	-	24.0	33.5	35.9	40.0	42.3	45.8	44.3	52.8

TABLE XIX

START/STOP AVERAGES FOR A CYCLE PATTERN (PERIOD=8)

MAGNITUDE OF CHANGE	OUT-OF-CONTROL PATTERN WINDOW									
	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52	
0.5	-	-	-	-	-	-	-	-	23.0	START
	-	-	-	-	-	-	-	-	55.0	STOP
1.0	-	-	10.0	8.5	12.6	13.9	13.9	13.7	13.9	START
	-	-	23.0	23.0	35.0	43.0	42.3	44.5	43.3	STOP
1.5	-	6.0	7.8	9.3	9.9	9.9	10.6	10.6	10.6	START
	-	36.5	32.7	37.8	38.9	40.8	43.3	42.9	44.7	STOP
2.0	-	6.8	8.0	8.0	9.0	9.0	9.0	9.0	9.0	START
	-	37.4	37.3	38.4	38.5	40.7	46.2	46.3	50.6	STOP
2.5	6.0	6.4	7.1	7.3	7.1	7.1	7.3	7.1	7.1	START
	53.0	37.0	34.2	35.3	38.8	41.9	46.2	46.7	51.3	STOP
3.0	5.7	6.3	6.2	6.8	6.3	6.3	6.8	6.2	6.4	START
	50.3	32.8	34.2	39.0	39.5	42.6	48.1	47.8	51.6	STOP

TABLE XX

START/STOP AVERAGES FOR A CYCLE PATTERN (PERIOD=12)

MAGNITUDE OF CHANGE	OUT-OF-CONTROL PATTERN WINDOW									
	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52	
0.5	-	-	-	-	-	-	-	-	-	START
	-	-	-	-	-	-	-	-	-	STOP
1.0	-	-	-	-	12.0	10.0	20.0	13.8	19.0	START
	-	-	-	-	51.0	38.7	48.8	50.0	49.5	STOP
1.5	-	6.5	8.3	9.4	11.7	9.7	11.6	13.2	12.5	START
	-	36.0	42.3	40.2	38.9	39.9	44.0	45.0	50.0	STOP
2.0	-	7.0	7.6	8.1	8.4	8.4	8.4	8.4	8.4	START
	-	44.5	35.3	37.5	37.5	43.3	44.7	46.5	51.4	STOP
2.5	7.0	6.8	6.9	6.9	7.2	7.3	7.2	7.3	7.2	START
	55.0	44.8	37.4	38.8	38.9	43.8	45.4	48.9	52.4	STOP
3.0	6.5	6.4	6.5	6.4	6.4	6.4	6.4	6.5	6.4	START
	51.5	36.8	37.9	38.1	39.1	45.3	45.8	50.1	53.0	STOP

TABLE XXI

START/STOP AVERAGES FOR A SHIFT PATTERN

MAGNITUDE OF CHANGE	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52	
	OUT-OF-CONTROL PATTERN WINDOW									
0.5	- -	8.0 18.0	9.5 22.5	9.5 22.5	13.7 25.3	13.7 25.3	13.7 25.3	12.0 30.5	12.0 35.2	START STOP
1.0	10.0 15.0	8.5 16.0	9.7 20.8	10.0 23.3	8.8 27.8	8.7 30.3	8.8 38.5	8.8 43.3	8.8 48.0	START STOP
1.5	9.0 15.0	7.9 17.9	7.9 22.0	7.5 24.5	7.7 32.0	7.9 36.2	7.9 41.9	7.9 46.4	7.9 51.2	START STOP
2.0	7.0 12.3	7.6 17.3	7.6 20.4	7.1 27.1	7.2 32.6	7.4 37.0	7.4 43.6	7.6 46.7	7.4 52.6	START STOP
2.5	6.7 12.3	7.1 17.6	7.1 22.7	6.9 27.6	6.9 32.6	7.0 37.0	7.0 43.9	7.1 46.7	7.1 52.7	START STOP
3.0	6.5 12.0	7.0 17.5	7.0 22.8	6.6 27.6	6.6 32.6	7.0 37.1	6.8 43.9	6.9 46.7	6.9 52.7	START STOP

TABLE XXII

START/STOP AVERAGES FOR A MIXTURE PATTERN

MAGNITUDE OF CHANGE	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52	
	OUT-OF-CONTROL PATTERN WINDOW									
0.5	- -	- -	- -	- -	34.0 44.0	18.0 46.0	21.5 41.5	25.0 55.0	23.0 47.0	START STOP
1.0	- -	7.0 14.0	10.0 20.5	11.0 37.0	11.5 40.8	9.2 38.4	11.0 41.7	12.0 46.8	11.1 48.2	START STOP
1.5	7.0 15.0	8.5 34.5	9.2 33.4	8.6 39.0	9.0 37.7	7.9 39.1	9.0 42.8	8.8 46.8	9.2 49.3	START STOP
2.0	6.5 22.8	7.0 22.0	7.3 36.3	6.8 45.5	7.4 37.1	6.6 39.6	7.2 42.0	6.8 48.2	7.5 51.0	START STOP
2.5	6.0 20.0	6.4 36.9	6.4 36.7	6.6 44.9	6.2 40.0	5.8 41.7	6.3 42.3	6.3 43.8	6.5 52.0	START STOP
3.0	5.7 18.9	5.9 37.6	5.3 39.0	5.7 44.2	5.2 39.4	5.2 41.7	5.3 42.7	5.3 49.0	5.7 52.3	START STOP

TABLE XXIII

START/STOP AVERAGES FOR A TREND PATTERN

OUT-OF-CONTROL PATTERN WINDOW

MAGNITUDE OF CHANGE		8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
0.25	START	-	-	-	12.0	6.5	8.7	9.8	14.1	13.3
	STOP	-	-	-	26.5	32.0	37.3	40.4	46.3	52.0
0.50	START	-	-	6.5	11.0	11.7	12.0	11.5	12.0	12.0
	STOP	-	-	24.0	26.0	32.1	37.0	42.9	46.7	52.3
0.75	START	-	-	7.7	11.0	12.1	11.4	10.9	11.4	11.4
	STOP	-	-	23.3	26.2	32.1	37.0	43.2	46.3	52.3
1.00	START	-	-	9.8	10.9	11.1	10.6	10.6	10.6	10.6
	STOP	-	-	22.6	26.1	32.1	37.0	43.6	46.7	52.4
1.25	START	-	7.7	9.1	9.7	9.4	9.1	9.1	9.1	9.1
	STOP	-	16.3	22.1	26.4	32.1	37.0	43.6	46.7	52.4

TABLE XXIV

START/STOP AVERAGES FOR A STRATIFICATION PATTERN

OUT-OF-CONTROL PATTERN WINDOW

MAGNITUDE OF CHANGE		8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
0.2	START	4.3	4.4	5.3	5.3	6.0	6.0	6.0	6.0	6.0
	STOP	12.3	16.0	19.6	23.7	30.1	35.8	42.0	46.1	50.6
0.4	START	4.3	4.4	5.9	5.9	6.1	6.1	6.1	6.1	6.1
	STOP	12.2	16.0	19.0	25.6	29.8	35.2	41.7	46.0	50.1
0.6	START	4.0	5.7	6.3	6.2	6.2	6.3	6.3	6.3	6.3
	STOP	13.0	15.7	17.8	25.2	30.6	31.6	33.9	34.4	37.3
0.8	START	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	STOP	11.0	15.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0

approach concluded that a pattern existed, but this conclusion sometimes defined an out-of-control window which included data which was not part of the unnatural pattern (Type II error). The optimistic approach was determined to be the best alternative for two reasons. First, the conservative estimate was redundant since a small window had already been located. Recall from Chapter 4, section 2.III that a small window was obtained when the expert system tested for clusters of marked x's. Second, since the information provided would generally be refined through human endeavor no matter how it was arrived at, the approach providing the most information was preferable. In this case, that meant using the optimistic approach. For these reasons, it was concluded that the start/stop points identified by the system were quite acceptable.

5.4 Magnitude of Change Estimation

Tables XXV through XXXII provide the averages of the parameter estimates. In addition these tables provide the percent error of these estimates. As can be seen, these percentages are not consistent or predictable. However, the discrepancies were found to be related to the accuracy of the start/stop point identification. This problem occurred because the change of magnitude was estimated from the data within the defined start/stop window. The more accurate the identification of the start/stop points,

TABLE XXV

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A SYSTEMATIC PATTERN

OUT-OF-CONTROL PATTERN LENGTH

LOCATION OF SHIFTED MEAN	5	10	15	20	25	30	35	40	45
102.5	- -	- -	- -	- -	- -	- -	- -	- -	104.0 1.5
105.0	- -	108.4 3.2	108.3 3.1	106.3 1.2	105.2 0.2	105.2 0.2	105.0 0	105.0 0	105.4 0.4
107.5	110.4 2.7	108.3 0.7	108.4 0.8	107.8 0.3	107.4 0.1	107.4 0.1	107.4 0.1	107.5 0	107.8 0.3
110.0	111.4 1.3	110.4 0.4	110.6 0.6	110.0 0	109.7 0.3	109.9 0.1	109.9 0.1	110.1 0.1	110.4 0.4
112.5	111.8 0.6	112.2 0.2	112.1 0.4	112.1 0.4	111.8 0.6	112.0 0	112.2 0.2	112.4 0.1	112.6 0.1
115.0	112.5 2.2	114.1 0.8	114.0 0.9	113.9 1.0	113.6 1.2	113.9 1.0	114.1 0.8	114.3 0.6	114.5 0.4

AVE PARAMETER ESTIMATE
PERCENT ERROR

TABLE XXVI

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A CYCLE PATTERN (PERIOD=4)

OUT-OF-CONTROL PATTERN LENGTH

AMPLITUDE	5	10	15	20	25	30	35	40	45
2.5	- -	- -	- -	- -	- -	- -	- -	- -	- -
5.0	- -	- -	- -	- -	7.0 40.0	5.0 0	5.8 16.0	6.2 24.0	6.1 22.0
7.5	- -	3.1 58.7	5.6 25.3	5.9 21.3	6.8 9.3	6.8 9.3	7.3 2.7	7.6 1.3	7.8 4.0
10.0	- -	8.9 11.0	7.0 30.0	8.3 17.0	8.5 15.0	9.0 10.0	9.6 4.0	10.0 0	10.2 2.0
12.5	- -	9.0 28.0	9.5 24.0	9.9 20.8	10.4 16.8	11.0 12.0	11.8 5.6	12.2 2.4	12.8 2.4
15.0	- -	11.7 22.0	11.0 26.7	11.5 23.3	12.3 18.0	13.1 12.7	13.9 7.3	14.4 4.0	15.1 0.7

TABLE XXVII

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A CYCLE PATTERN (PERIOD=8)

OUT-OF-CONTROL PATTERN LENGTH

AMPLITUDE	5	10	15	20	25	30	35	40	45
2.5	- -	- -	- -	- -	- -	- -	- -	- -	8.0 220
5.0	- -	- -	10.5 110	8.0 60.0	6.3 26.0	5.4 8.0	5.8 16.0	6.6 32.0	6.4 28.0
7.5	- -	6.7 10.7	7.3 2.7	7.3 2.7	7.2 4.0	7.6 1.3	7.5 0	8.0 6.7	8.2 9.3
10.0	- -	6.3 37.0	8.1 19.0	8.8 12.0	9.1 9.0	9.4 6.0	9.4 6.0	10.2 2.0	10.1 1.0
12.5	3.6 71.2	7.8 37.6	9.8 21.6	10.6 15.2	10.4 16.8	11.0 12.0	11.5 8.0	12.2 2.4	12.3 1.6
15.0	3.6 76.0	10.1 32.7	11.3 31.3	11.1 26.0	12.2 18.7	10.8 28.0	11.9 20.7	14.3 4.7	14.5 3.3

TABLE XXVIII

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A CYCLE PATTERN (PERIOD=12)

OUT-OF-CONTROL PATTERN LENGTH

AMPLITUDE	5	10	15	20	25	30	35	40	45
2.5	- -	- -	- -	- -	- -	- -	- -	- -	- -
5.0	- -	- -	- -	- -	4.5 10.0	5.2 4.0	6.0 20.0	5.8 16.0	6.8 36.0
7.5	- -	5.6 25.3	5.1 32.0	5.7 24.0	6.3 16.0	6.8 9.3	7.5 0	8.1 8.0	8.1 8.0
10.0	- -	5.7 43.0	7.4 26.0	7.2 28.0	8.2 18.0	8.2 18.0	9.3 7.0	9.9 1.0	10.0 0
12.5	3.8 69.6	6.2 50.4	8.1 35.2	9.1 27.2	10.2 18.4	10.3 17.6	11.5 8.0	12.0 4.0	12.2 2.4
15.0	3.8 74.7	9.2 38.7	9.4 37.3	10.8 28.0	12.1 19.3	12.0 20.0	13.8 8.0	14.1 6.0	14.4 4.0

TABLE XXIX

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A SHIFT PATTERN

OUT-OF-CONTROL PATTERN LENGTH

LOCATION OF SHIFTED MEAN	5	10	15	20	25	30	35	40	45
102.5	- -	103.6 1.1	104.1 1.6	104.5 2.0	105.2 2.6	105.2 2.6	105.2 2.6	104.5 2.0	104.3 1.8
105.0	104.7 0.3	106.1 1.1	105.9 0.9	105.8 0.8	105.9 0.9	105.7 0.7	105.5 0.5	105.6 0.6	105.6 0.6
107.5	105.6 1.8	107.1 0.4	107.1 0.4	107.1 0.4	107.4 0.1	107.5 0	107.4 0.1	107.5 0	107.5 0
110.0	108.6 1.3	108.7 1.2	109.3 0.6	109.2 0.7	109.6 0.4	109.8 0.2	109.6 0.4	109.9 0.1	109.3 0.2
112.5	110.2 2.0	110.7 1.6	111.4 1.0	111.2 1.2	111.9 0.5	112.2 0.3	111.9 0.5	112.5 0	112.2 0.3
115.0	111.9 2.7	112.6 2.1	113.3 1.5	113.4 1.4	114.2 0.7	114.3 0.6	114.2 0.7	114.9 0.1	114.5 0.4

TABLE XXX

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION FOR A MIXTURE PATTERN

OUT-OF-CONTROL PATTERN LENGTH

LOCATION OF SHIFTED MEAN	5	10	15	20	25	30	35	40	45
102.5	- -	- -	- -	- -	105.8 3.2	103.6 1.1	104.9 2.3	103.9 1.4	103.8 1.3
105.0	- -	103.6 1.3	105.9 0.9	104.6 0.4	104.7 0.3	105.3 0.3	105.3 0.3	105.5 0.5	105.1 0.1
107.5	104.9 2.4	106.0 1.4	106.4 1.0	106.5 0.9	106.4 1.0	107.2 0.3	106.8 0.7	107.7 0.2	107.7 0.2
110.0	107.2 2.6	108.9 1.0	107.3 2.5	106.8 2.9	109.0 0.9	109.5 0.5	109.3 0.6	109.8 0.2	109.3 0.7
112.5	108.8 3.3	107.3 4.6	109.1 3.0	109.0 3.1	110.9 1.4	111.4 1.0	111.8 0.6	112.1 0.4	112.0 0.4
115.0	110.6 3.8	108.8 3.3	110.2 4.2	110.9 3.6	112.8 1.9	113.3 1.5	113.7 1.1	114.1 0.8	114.0 0.8

TABLE XXXI

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION
FOR A TREND PATTERN

OUT-OF-CONTROL PATTERN LENGTH

SLOPE	5	10	15	20	25	30	35	40	45
0.25	- -	- -	- -	.73 192	.49 96.0	.36 44.0	.31 24.0	.26 4.0	.23 8.0
0.50	- -	- -	.49 2.0	.89 78.0	.54 8.0	.45 10.0	.42 16.0	.49 2.0	.46 8.0
0.75	- -	- -	.70 7.1	1.09 45.3	.64 14.7	.69 8.0	.57 24.0	.74 13.0	.69 8.0
1.00	- -	- -	1.03 3.0	1.06 6.0	.91 9.0	.95 5.0	.73 27.0	.99 1.0	.93 7.0
1.25	- -	1.53 2.6	1.19 4.8	1.16 7.2	1.15 3.0	1.20 4.0	.94 24.8	1.23 1.6	1.17 6.4

TABLE XXXII

AVERAGE AND PERCENT ERROR OF PARAMETER ESTIMATION
FOR A STRATIFICATION PATTERN

OUT-OF-CONTROL PATTERN LENGTH

STANDARD DEVIATION	5	10	15	20	25	30	35	40	45
1.0	2.1 110	1.7 70.0	1.5 50.0	1.3 30.0	1.3 30.0	1.2 20.0	1.3 30.0	1.2 20.0	1.2 20.0
2.0	2.5 25.0	2.2 10.0	2.0 0	2.0 0	2.0 0	2.0 0	2.0 0	1.9 5.0	2.0 0
3.0	2.7 10.0	2.8 6.7	2.5 16.7	2.7 10.0	2.7 10.0	2.7 10.0	2.6 13.3	2.6 13.3	2.7 10.0
4.0	3.3 175	2.8 30.0	3.1 22.5	3.1 22.5	3.1 22.5	3.1 22.5	3.1 22.5	3.1 22.5	3.1 22.5

NOTE: 1.0 is the most severe magnitude of change for a stratification pattern.

the more accurate the estimation of the change in magnitude was. However, as discussed in 5.3, this parameter estimation would only be used as a "best" starting point of investigation for the user. Therefore, the estimation provided by the system was found to be acceptable.

5.5 Dependability Of Expert System

A single numerical value can not be given to the dependability of this system's performance. This is due largely to the system's heuristic nature and the variety of confidence levels being used within the system. However, by using the probability estimation equations derived in 5.2, the user can determine an estimate of the system's probability of success at a given run length and magnitude of change for these six patterns.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to develop procedures in the form of a knowledge based expert system for identifying and analyzing unnatural patterns which might exist in control chart data. This research concentrated on recognizing six unnatural patterns. They were shift, trend, stratification, systematic, cycle and mixture. Four specific goals were established in Chapter 1 to accomplish this purpose. The conclusions resulting from this research will be discussed in the context of these four goals.

6.1 Control Chart Development

This goal required two things. First, a pattern generator capable of emulating the six unnatural control chart patterns of interest was desired. Second, a graphics package capable of plotting the control chart and marking the AT&T run rule x's was needed. Both of these subgoals were achieved to slightly different degrees. The plotting of the control chart and marking of the AT&T x's worked extremely well on data provided by the pattern generator as well as data provided by an outside source.

The pattern generator capability was a function of the random number seed used. This was due to the IBM PC (or any digital computer for that matter) being able to only generate pseudo-random numbers. The numbers generated by these computers are statistically correct. However, the ability of the seed to emulate a given distribution changes as the random number seed changes. One of the main causes of this inability to emulate a pattern was the fact that only sixty numbers were being generated. Since a sample of only sixty was needed for this research, random number seeds that were as dependable as possible were desired. Once ten dependable seeds were found, the pattern generator performed successfully.

6.2 Interactive Expert System

This goal required the development of a knowledge base and the design of the inference engine to accurately identify the unnatural pattern present. The development of the knowledge base is documented in Chapter 4, section 1. The development of this knowledge base was quite successful and proved to be the key element in designing the present expert system.

The design of the inference engine proved to be a challenging and informative endeavor. It was originally planned to design this portion using one of the AI languages that were available. But after reviewing these languages, it was found that they were developed to be used primarily for object-oriented programming. Basically, object-oriented programming is based on the idea that objects are defined in terms of other objects. Operations are performed on these defined objects by testing and combining them with other objects. This is one reason that at the present time, any programming that is done using an AI language, is done on situations with well-defined, narrow domains that do not require a great deal of mathematical manipulation. This is not to say that the AI languages cannot perform mathematical manipulation. However, if a great deal of manipulation is required, it is more efficient to use one of the more conventional programming languages at this time. With this in mind, the inference engine was designed using BASIC on the IBM PC which was highly supportive for this type of heuristic testing. As can be seen in Tables I through VIII, this expert system performed quite well in identifying the pattern present in a given set of data.

6.3 System Validation

This goal required the development of a test sequence which would provide the ability to make judgements concerning the expert system's ability to identify a pattern. The actual test matrix can be found in Chapter 5. From the results provided in Tables I through VIII, it was felt that the test matrix provided sufficient evidence that the expert system performed at a consistently high level of accuracy. The original objective of developing an expert system that was "demonstrably superior to currently available pattern recognition procedures" was not fully achieved, due to the absences of an accessible test group.

6.4 System Effectiveness Evaluation

This goal required an evaluation of the system's ability to accurately identify the start/stop points and estimate the magnitude of change present. Even though the estimation of the magnitude of change was dependent upon how accurately the start/stop points had been identified, the estimation proved to be reasonable (Tables XXV through XXXII). As shown in Tables XVII through XXIV, the system proved to be fairly consistent and accurate at identifying the starting point. However, the system was not quite as proficient at identifying the ending point. It was felt that accurate identification of the ending point was not nearly as critical as identifying the starting point. The reason for this conclusion was that this system was designed to be an aid for the user in evaluating control charts. As such, the values provided by this system should not be taken as absolute, but should instead be used as initial starting points for further human investigation. Therefore, this system was felt to perform well in identifying the start/stop points and estimating the magnitude of change.

6.5 Parameter Optimization

The "proper" values of the heuristic parameters (e.g. alpha for significance, n for moving sample size, etc.) were determined experimentally, recognizing at each step that several model factors had to be balanced simultaneously. The choice of the specific values in this research permitted the complete development and validation of the pattern recognition system. These values represent a feasible test environment for general process control. It is recognized that for a specific process these parameter values will probably change. Due to the structure and the heuristic nature of this system, there is no one, optimal set of parameters, but depending upon the needs of the user, many feasible sets of parameters exist.

6.6 Concluding Remarks

This expert system is a first step towards a new generation of computer assisted quality control methodologies. Even though the computer will never replace the quality control engineer, it can definitely make the individual more productive. Systems such as this pattern analysis should be receiving increased acceptance as the requirement for better quality continues.

This research has developed an initial phase for the development of quality control expert systems; however, there are tremendous possibilities for expansion. Future research areas could include:

1. Expand the experimental base by having humans examine and analyze the various control chart patterns that have been analyzed by this expert system. This would provide additional measures of performance on the expert system's capability.
2. Expand the number of unnatural patterns to include the remaining nine as defined by AT&T (1956).
3. Allow the user to input information concerning the process and the type of chart being used. With this information it would be possible to further aid the user by providing more detailed information about the cause of the out-of-control situation.
4. Allow for more than one pattern to be present in the data, either consecutively or concurrently.

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APPENDIXES

APPENDIX A

SUMMARY OF RESULTS OF TESTS MADE FOR INITIAL DETERMINATION OF KNOWLEDGE BASE PARAMETERS

TABLE XXXIII

RESULTS FOR A SYSTEMATIC PATTERN

LOCATION OF SHIFTED MEAN	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
	–	–	–	S	S
	3	27	27	S	S
102.5	–	–	–	S	S
	3	48	53	S	S
	2	14	48	S	S
	3	15	17	S	D
	2	23	23	S	D
105.0	3	20	22	S	D
	2	15	53	S	D
	2	14	14	S	D
	2	13	53	S	D
	1	12	52	S	D
110.0	1	9	52	S	D
	1	13	53	S	D
	2	11	54	S	D
	2	11	53	S	D
	1	8	54	S	D
115.0	1	9	58	S	D
	1	8	53	S	D
	1	8	54	S	D

NOTE: S indicates the mean (or variance) of the test pattern does not differ significantly from the population mean (or variance). Therefore, they are relatively the <u>s</u>ame.

D indicates the mean (or variance) of the test pattern does <u>d</u>iffer significantly from the population mean (or variance).

TABLE XXXIV

RESULTS FOR A CYCLE PATTERN (PERIOD=4)

AMPLITUDE		RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
	5.0	1	14	14	S	D
		-	-	-	S	S
		-	-	-	S	D
		3	48	48	S	D
		4	54	54	S	S
	10.0	1	14	53	S	D
		1	12	52	S	D
		1	12	38	S	D
		1	22	53	S	D
		1	12	48	S	D
	15.0	1	10	53	S	D
		1	8	52	S	D
		1	12	50	S	D
		1	8	53	S	D
		1	8	52	S	D

TABLE XXXV

RESULTS FOR A CYCLE PATTERN (PERIOD=8)

AMPLITUDE	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
5.0	2	14	31	S	D
	2	21	21	S	D
	3	19	19	S	S
	-	-	-	S	S
	-	-	-	S	S
10.0	1	13	38	S	D
	2	9	46	S	D
	2	17	33	S	D
	2	13	48	S	D
	2	18	50	S	D
15.0	1	9	52	S	D
	2	9	46	S	D
	2	14	58	S	D
	2	9	53	D	D
	2	9	50	S	D

TABLE XXXVI

RESULTS FOR A CYCLE PATTERN (PERIOD=12)

AMPLITUDE	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
5.0	3	17	51	S	S
	-	-	-	S	S
	3	35	42	S	D
	2	46	48	S	D
	3	47	50	S	S
10.0	1	14	51	S	D
	1	9	37	S	D
	4	12	47	S	D
	3	10	52	S	D
	3	12	50	S	D
15.0	1	9	52	S	D
	2	9	51	S	D
	1	10	58	S	D
	1	9	52	S	D
	3	11	52	S	D

TABLE XXXVII

RESULTS FOR A SHIFT PATTERN

LOCATION OF SHIFTED MEAN	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
102.5	4	29	32	D	S
	4	18	42	D	S
	3	19	37	D	S
	3	27	53	D	S
	2	14	54	D	D
105.0	4	22	46	D	S
	4	13	44	D	S
	3	17	53	D	S
	4	12	59	D	S
	2	14	54	D	S
110.0	3	12	54	D	D
	2	9	54	D	D
	4	12	53	D	D
	2	9	59	D	S
	3	11	54	D	D
115.0	1	9	54	D	D
	1	8	54	D	D
	2	10	53	D	D
	1	8	53	D	D
	1	8	54	D	D

TABLE XXXVIII

RESULTS FOR A MIXTURE PATTERN

LOCATION OF SHIFTED MEAN	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
	-	-	-	S	S
	-	-	-	S	S
102.5	3	13	46	S	S
	4	28	29	S	D
	3	22	23	S	S
	1	20	53	S	D
	-	-	-	S	S
105.0	3	13	49	S	D
	3	27	27	S	S
	4	10	30	S	D
	1	13	51	S	D
	3	19	44	S	D
110.0	2	11	51	S	D
	1	12	52	S	D
	2	13	50	S	D
	3	12	51	S	D
	1	8	51	S	D
115.0	1	8	52	D	D
	2	9	52	S	D
	2	9	52	S	D

TABLE XXXIX

RESULTS FOR A TREND PATTERN

SLOPE	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
0.25	3	25	54	D	D
	4	19	54	D	D
	2	19	53	D	D
	2	26	59	D	D
	4	19	54	D	D
0.5	4	22	54	D	D
	4	18	54	D	D
	3	18	53	D	D
	4	23	59	D	D
	2	14	54	D	D
0.75	3	19	54	D	D
	3	16	54	D	D
	3	18	53	D	D
	3	20	53	D	D
	2	14	54	D	D
1.0	3	18	54	D	D
	3	13	54	D	D
	3	16	53	D	D
	4	18	53	D	D
	2	14	54	D	D
1.25	1	16	54	D	D
	3	13	54	D	D
	1	12	53	D	D
	4	18	53	D	D
	2	14	54	D	D

TABLE XL

RESULTS FOR A STRATIFICATION PATTERN

STANDARD DEVIATION	RULE	FIRST POINT	LAST POINT	MEANS	VARIANCES
	-	-	-	S	D
	-	-	-	S	D
1.0	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
2.5	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
3.5	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	D
	-	-	-	S	S
	-	-	-	S	S
5.0	-	-	-	S	S
	-	-	-	S	D
	-	-	-	S	S

APPENDIX B

COMPUTER LISTING

```
10 REM ****************************************************************************
20 REM * THIS PROGRAM PLOTS THE CONTROL CHART AND PLOTS THE x'S ACCORDING TO  *
30 REM * THE AT&T RUN RULES. THE DATA PLOTTED CAN EITHER BE INPUT MANUALLY OR *
40 REM * IT CAN BE GENERATED BY THE COMPUTER.  IF THE USER CHOOSES TO HAVE    *
50 REM * THE COMPUTER GENERATE THE DATA, THE USER CAN CHOOSE FROM 7 DIFFERENT *
60 REM * PATTERNS.  THEY ARE (1) TREND ; (2) CYCLE ; (3) MIXTURE ; (4) SHIFT; *
70 REM * (5) SYSTEMATIC; (6) STATIFICATION ; AND (7) IN CONTROL.              *
80 REM * ONCE THE x'S HAVE BEEN MARKED THE PROGRAM ANALYZES THE DATA AND      *
90 REM * DETERMINES WHETHER A PATTERN EXISTS.  IF ONE DOES, THE USER IS       *
91 REM * NOTIFIED AND THE PROGRAM TERMINATES.                                 *
92 REM ****************************************************************************
93 REM
94 REM
140 REM ***************************************************************************
142 REM * THE VARIABLES USED IN THIS PROGRAM ARE DEFINED AS FOLLOWS:          *
144 REM *   A(I)       = ARRAY OF RUN RULES WHICH IDENTIFIES WHAT RULE MARKED  *
146 REM *                THE x'S IN B(I)                                       *
148 REM *   A$         = VARIABLE FOR CHARACTER DATA ENTRY                     *
150 REM *   A2(I)      = TABLE OF A2 VALUES FOR USE IN CALCULATING UCL AND LCL *
152 REM *                FOR AN X BAR CHART                                    *
154 REM *   ALINE      = 3 SIGMA LINE PLOTTED ON SCREEN CONTROL CHART          *
156 REM *   ALPHA      = MULTIPLE OF SIGMA BY WHICH MEAN IS SHIFTED FROM THE   *
158 REM *              = MEAN DURING EACH SAMPLE INTERVAL DURING THE OOC       *
160 REM *              = CONDITION (TREND)                                     *
162 REM *   ASM        = VARIABLE FOR CONTROL OF PRINTOUT OF SCREEN TO PRINTER *
164 REM *   B(I)       = ARRAY OF POINTS WHERE x'S ARE MARKED                  *
166 REM *   B          = STARTING POINT UPDATE VARIABLE                        *
168 REM *   BB         = STARTING POINT OF OOC CONDITION FOUND IN MEAN TEST    *
170 REM *   BLINE      = 2 SIGMA LINE PLOTTED ON SCREEN CONTROL CHART          *
172 REM *   BS & FIR   = BASE POINT VARIABLE FOR MOVING WINDOW                 *
174 REM *   CHI        = TEST STATISTIC USED IN MOVING WINDOW VARIANCE TEST    *
176 REM *   CLINE      = MEAN OF X BAR CHART                                   *
178 REM *   COUNT      = RUNNING SUM OF THE NUMBER OF POINTS VIOLATING A       *
180 REM *                GIVEN RULE                                            *
182 REM *   CYCFL      = FLAG, WHICH WHEN SET, SIGNALS THAT A CYCLE EXISTS     *
184 REM *   D          = NUMERICAL VALUE OF A$                                 *
186 REM *   DE         = MULTIPLE OF SIGMA THE MEANS OF THE SYSTEMATIC         *
188 REM *                DISTRIBUTIONS SHIFT FROM THE IN-CONTROL MEAN          *
190 REM *   DEL        = AMPLITUDE OF THE CYCLE                                *
192 REM *   DELT       = MULTIPLE OF SIGMA THE MEANS OF THE MIXTURE            *
194 REM *                DISTRIBUTIONS SHIFT FROM THE IN-CONTROL MEAN          *
196 REM *   DEV        = STANDARD DEVIATION OF X BAR CHART                     *
198 REM *   DOW        = NUMBER OF POINTS BELOW IN-CONTROL MEAN                *
200 REM *   DS         = DEGREE OF SLOPE                                       *
202 REM *   ED         = STOPPING POINT OF OOC CONDITION FOUND IN MEAN TEST    *
204 REM *   FF         = FIRST POINT IN MOVING WINDOW                          *
206 REM *   F          = STOPPING POINT UPDATE VARIABLE                        *
208 REM *   F0         = TEST STATISTIC FOR SLOPE SIGNIFICANCE TEST            *
210 REM *   F1(I)      = LOOK UP TABLE FOR F VALUES (ALPHA=0.1)                *
212 REM *   FN NRD     = NORMAL RANDOM NUMBER GENERATOR                        *
214 REM *   FSIZE      = DEGREES OF FREEDOM ASSOCIATED WITH F TEST             *
216 REM *   G          = IDENTIFIES THE RULE WHICH MARKED AN x (GOES INTO A(I))*
```

```
218 REM *   GAM       = MULTIPLE OF SIGMA THAT BECOMES STRATIFICATION LIMITS  *
220 REM *   H & G     = REFERENCE POSITION USED IN DRAWING THE x'S ONTO THE   *
222 REM *               SCREEN CONTROL CHART ABOVE AND BELOW A GIVEN POINT    *
224 REM *   HH        = SCREEN REFERENCE POINTS FOR IDENTIFYING OOC CONDITION *
226 REM *   HI        = SET UPPER BOUND OF IN-CONTROL MEAN + ONE SIGMA        *
228 REM *   I,J,K     = STANDARD FOR/NEXT VARIABLES                           *
230 REM *   L         = LAST POINT TO BE OUT OF CONTROL (SET)                 *
232 REM *   L         = TEST LAG OF CYCLE                                     *
234 REM *   LA        = STOPPING POINT OF OOC CONDITION FOUND IN VARIANCE TEST*
236 REM *   LL & LAS  = LAST POINT IN MOVING WINDOW                           *
238 REM *   LCHI(I)   = LOOK UP TABLE FOR LOWER LIMIT CHI-SQUARE VALUES       *
240 REM *               (ALPHA=0.1)                                           *
242 REM *   LCL       = LOWER CONTROL LIMIT ON X BAR CHART                    *
244 REM *   LLV       = LOWER LIMIT FOR VARIANCE ON ENTIRE DATA SET           *
246 REM *   LOW       = SET LOWER BOUND OF IN-CONTROL MEAN - ONE SIGMA        *
248 REM *   LOWZ      = LOWER Z VALUE USED IN MEAN TEST                       *
250 REM *   M & MN    = REFERENCE POINTS USED IN DRAWING THE CONTROL CHART    *
252 REM *               TO THE SCREEN                                         *
254 REM *   MB & MF   = MODIFIED STARTING/STOPPING POINTS                     *
256 REM *   MEAN      = CALCULATED MEAN OF ALL POINTS IN ENTIRE DATA SET      *
258 REM *   MIN/MAX   = MIN AND MAX VALUES OF DATA ENTERED BY POINT USED TO   *
260 REM *               DETERMINE THE RANGES                                  *
262 REM *   MIXFL     = FLAG, WHICH WHEN SET, SIGNALS THAT A MIXTURE EXISTS   *
264 REM *   MOVMU     = MEAN OF MOVING WINDOW                                 *
266 REM *   MOVSUM    = SUM OF POINTS IN MOVING WINDOW                        *
268 REM *   MSE       = MEAN SQUARE ERROR                                     *
270 REM *   MSR       = MEAN SQUARE DUE TO REGRESSION                         *
272 REM *   MSTD      = STANDARD DEVIATION OF MOVING WINDOW (VARIANCE TEST)   *
274 REM *   MVAR      = VARIANCE OF MOVING WINDOW                             *
276 REM *   MVSUM     = SUM OF VARIANCES IN MOVING WINDOW                     *
278 REM *   N         = SAMPLE SUBGROUP SIZE                                  *
280 REM *   NB & NF   = LOCATION OF WHERE FIRST AND LAST x'S WERE MARKED      *
282 REM *   NC        = NUMBER OF POINS SET TO BE IN-CONTROL AT BEGINNING     *
284 REM *   NCC       = FIRST OOC POINT                                       *
286 REM *   OC        = TOTAL NUMBER OF POINTS TO BE OOC                      *
288 REM *   OOC       = OUT OF CONTROL CONDITION                              *
290 REM *   OSIG      = ONE SIGMA LIMIT USED IN AT&T RUN RULE 3               *
292 REM *   P         = TEST PERIOD OF CYCLE                                  *
294 REM *   P(I)      = DATA POINT I IN SAMPLE SUBGROUP                       *
296 REM *   PER       = PERIOD OF THE CYCLE                                   *
298 REM *   PI        = DEFINED VARIABLE                                      *
300 REM *   Q$        = CHARACTER VARIABLE FOR QUERY TO USER WANTING A        *
302 REM *               PRINTOUT OF THE CHART                                 *
304 REM *   R(I)      = RANGES OF SAMPLE SET I                                *
306 REM *   RBAR      = MEAN OF R CHART                                       *
308 REM *   RD(TRD)   = TABLE OF RANDOM NUMBER SEEDS FOR USE IN COMPILED      *
310 REM *               PROGRAM ONLY (TRD = 1 TO 10)                          *
312 REM *   SFLAG     = FLAG, WHICH WHEN SET, SIGNALS THAT A SHIFT EXISTS     *
314 REM *   SHIFT     = MULTIPLE OF SIGMA BY WHICH THE OOC MEAN IS SHIFTED    *
316 REM *               FROM THE IN-CONTROL MEAN (SHIFT)                      *
318 REM *   SIZE      = SIZE OF OOC WINDOW FOUND IN MEAN TEST                 *
320 REM *   SLOPE     = SLOPE OF POINTS IN OOC WINDOW                         *
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322 REM *   SL        = FLAG, WHICH WHEN SET, SIGNALS THAT THE MEAN OF THE    *
324 REM *               POINTS IN THE OOC WINDOW ARE > IN-CONTROL MEAN        *
326 REM *   SMEAN     = MEAN OF POINTS IN OOC WINDOW                          *
328 REM *   SMUL/SMLL = LOCATION OF UPPER AND LOWER MEANS OF THE DISTRIBUTIONS*
330 REM *               FOUND IN THE MIXTURE AND SYSTEMATIC PATTERNS          *
332 REM *   SSREG     = SUM OF SQUARES DUE TO REGRESSION (CYCLE TEST)         *
334 REM *   SSRES     = SUM OF SQUARES DUE TO RESIDUALS (CYCLE TEST)          *
336 REM *   ST        = STARTING POINT OF OOC CONDITION FOUND IN VARIANCE TEST*
338 REM *   STD       = STANDARD DEVIATION OF ENTIRE DATA SET                 *
340 REM *   STDSTR    = STRATIFICATION STANDARD DEVIATION                     *
342 REM *   STRVAR    = STRATIFICATION VARIANCE                               *
344 REM *   SUM       = CONTROL VARIABLE FROM PRINTOUT OF SCREEN TO PRINTER   *
346 REM *   SUMFL     = SUM OF PATTERN FLAGS                                  *
348 REM *   SUMR      = SUM OF THE RANGES                                     *
350 REM *   SUMYB     = SUM OF THE MEANS                                      *
352 REM *   SX        = SUM OF X1'S IN OOC WINDOW (CYCLE TEST)                *
354 REM *   SXX       = CORRECTED SUM OF SQUARES OF THE X'S IN OOC WINDOW     *
356 REM *   SXX       = SUM OF X1 SQUARES IN OOC WINDOW (CYCLE TEST)          *
358 REM *   SXY       = CORRECTED SUM OF SQUARES OF THE X*YT(I) IN OOC WINDOW *
360 REM *   SY        = SUM OF YT(I) IN OOC WINDOW                            *
362 REM *   SYS       = SUM OF X1*YT(I) IN OOC WINDOW (CYCLE TEST)            *
364 REM *   SYY       = SUM OF YT(I) SQUARED IN OOC WINDOW (VARIANCE TEST)    *
366 REM *   SYY       = CORRECTED SUM OF SQUARES OF THE YT(I) IN OOC WINDOW   *
368 REM *               (MEAN TEST)                                           *
370 REM *   SYSFL     = FLAG, WHICH WHEN SET, SIGNALS THAT A SYSTÈMATIC EXISTS*
372 REM *   T & TMAX  = TEST STATISTIC USED IN CYCLE t TEST                   *
374 REM *   T(I)      = LOOK UP TABLE FOR STUDENT T VALUES (ALPHA=0.01)       *
376 REM *   TCSS      = TOTAL CORRECTED SUM OF SQUARES IN OOC WINDOW          *
378 REM *   TEST      = TEST STATISTIC USED IN STRATIFICATION TEST            *
380 REM *   TFLAG     = FLAG, WHICH WHEN SET, SIGNALS THAT A TREND EXISTS     *
382 REM *   TSIG      = TWO SIGMA LIMIT USED IN AT&T RUN RULE 2               *
384 REM *   TUP       = NUMBER OF POINTS ABOVE IN-CONTROL MEAN                *
386 REM *   UCHI(I)   = LOOK UP TABLE FOR UPPER CHI-SQUARE VALUES (ALPHA=0.1) *
388 REM *   UCL       = UPPER CONTROL LIMIT ON X BAR CHART                    *
390 REM *   ULV       = UPPER LIMIT FOR VARIANCE ON ENTIRE DATA SET           *
392 REM *   UPZ       = UPPER LIMIT Z VALUE USED IN MEAN TEST                 *
394 REM *   VAR       = VARIANCE OF ENTIRE DATA SET                           *
396 REM *   VLN       = SIZE OF OOC WINDOW FOUND IN VARIANCE TEST             *
398 REM *   VSUM      = SUM OV VARIANCES OVER ENTIRE DATA SET                 *
400 REM *   WCHI      = TEST STATISTIC USED IN SIGNIFICANCE TEST ON VARIANCE  *
402 REM *               WITHIN OOC WINDOW                                     *
404 REM *   WIN       = SIZE OF MOVING WINDOW                                 *
406 REM *   WVAR      = VARIANCE IN OOC WINDOW FOUND IN VARIANCE TEST         *
408 REM *   X         = NUMBER OF SAMPLE SETS                                 *
410 REM *   XX1 & XX2 = REFERENCE POSITIONS FOR PLOTTING THE SCREEN POINTS    *
412 REM *   XSQ       = SUM OF X SQUARES IN OOC WINDOW (MEAN TEST)            *
414 REM *   XSUM      = SUM OF X'S IN OOC WINDOW (MEAN TEST)                  *
416 REM *   XY        = SUM OF X*YT(I) IN OOC WINDOW (MEAN TEST)              *
418 REM *   YY1 & YY2 = REFERENCE POSITIONS FOR PLOTTING THE SCREEN POINTS    *
420 REM *   YSQ       = SUM OF YT(I) SQUARES IN OOC WINDOW (MEAN TEST)        *
422 REM *   YSUM      = SUM OF YT(I) IN OOC WINDOW (MEAN TEST)                *
424 REM *   YT(I)     = MEAN OF SAMPLE SET I (OR X BAR POINTS)                *
```

```
426 REM *   Z0        = TEST STATISTIC USED IN MOVING WINDOW MEAN TEST        *
428 REM ************************************************************************
430 DIM P(10),R(100),YT(100),A2(10),F1(100),B(100),T(100),IS(100),UCHI(100),
    LCHI(100),R D (100),A(100)
432 REM ************************************************************************
434 REM *                THIS IS A LOOK UP TABLE FOR A2 VALUES                  *
436 REM ************************************************************************
438 FOR I=2 TO 10:READ A2(I):NEXT
440 DATA 1.88,1.023,.729,.577,.483,.419,.373,.337,.308
442 REM ************************************************************************
444 REM * THIS IS A LOOK UP TABLE FOR A ONE SIDED F TEST WITH ALPHA = 0.1      *
446 REM ************************************************************************
448 FOR I=1 TO 30:READ F1(I):NEXT
450 DATA 39.86,8.53,5.54,4.54,4.06,3.78,3.59,3.46,3.36,3.29,3.23,3.18,3.14,3.1,
    3.07,3.05,3.03,3.01,2.99,2.97,2.96,2.95,2.94,2.93,2.92,2.91,2.9,2.89,2.89,
    2.88
452 FOR I=31 TO 40:F1(I)=2.86:NEXT
454 FOR I=41 TO 60:F1(I)=2.815:NEXT
456 FOR I=61 TO 100:F1(I)=2.77:NEXT
458 REM ************************************************************************
460 REM * THIS IS A LOOK UP TABLE FOR A TWO SIDED t TEST WITH ALPHA = 0.01     *
462 REM ************************************************************************
464 FOR I=1 TO 30:READ T(I):NEXT
466 DATA 63.657,9.925,5.841,4.604,4.032,3.707,3.499,3.355,3.25,3.169,3.106,
    3.055,3.012,2.977,2.947,2.921,2.898,2.878,2.861,2.845,2.831,2.819,2.807,
    2.797,2.787,2.779,2.7 7 1,2.763,2.756,2.75
468 FOR I=31 TO 40:T(I)=2.727:NEXT
470 FOR I=41 TO 60:T(I)=2.682:NEXT
472 FOR I=61 TO 100:T(I)=2.638:NEXT
474 REM ************************************************************************
476 REM * THIS IS A LOOK UP TABLE FOR A ONE SIDED CHI-SQUARE TEST ALPHA=0.1    *
478 REM ************************************************************************
480 FOR I=1 TO 30:READ UCHI(I):NEXT
482 DATA
482 DATA 2.71,4.61,6.25,7.78,9.24,10.65,12.02,13.36,14.68,15.99,17.28,18.55,
    19.81,21.06,22.31,23.54,24.77,25.99,27.2,28.41,29.62,30.81,32.01,33.2,
    34.28,35.56,36.74,37.9 2 ,39.09,40.26
484 FOR I=31 TO 40:UCHI(I)=46.03:NEXT
486 FOR I=41 TO 50:UCHI(I)=57.49:NEXT
488 FOR I=51 TO 60:UCHI(I)=68.79:NEXT
490 FOR I=61 TO 70:UCHI(I)=79.97:NEXT
492 FOR I=71 TO 80:UCHI(I)=91.06:NEXT
494 FOR I=81 TO 90:UCHI(I)=102.08:NEXT
496 FOR I=91 TO 100:UCHI(I)=113.04:NEXT
498 REM ************************************************************************
500 REM * THIS IS A LOOK UP TABLE FOR A ONE SIDED CHI-SQUARE TEST ALPHA=0.1    *
502 REM ************************************************************************
504 FOR I=1 TO 30:READ LCHI(I):NEXT
506 DATA .02,.21,.58,1.06,1.61,2.2,2.83,3.49,4.17,4.87,5.58,6.3,7.04,7.79,8.55,
    9.31,10.09,10.87,11.65,12.44,13.24,14.04,14.85,15.66,16.47,17.29,18.11,
    18.94,19.77,20.6
508 FOR I=31 TO 40:LCHI(I)=24.83:NEXT
```

```
510 FOR I=41 TO 50:LCHI(I)=33.37:NEXT
512 FOR I=51 TO 60:LCHI(I)=42.08:NEXT
514 FOR I=61 TO 70:LCHI(I)=50.9:NEXT
516 FOR I=71 TO 80:LCHI(I)=59.81:NEXT
518 FOR I=81 TO 90:LCHI(I)=68.79:NEXT
520 FOR I=91 TO 100:LCHI(I)=77.83:NEXT
522 REM ************************************************************************
524 REM * THIS INPUTS A SET OF RANDOM NUMBER SEEDS FOR USE IN COMPILED TEST.  *
526 REM ************************************************************************
528 FOR I=1 TO 10:READ RD(I):NEXT
530 DATA 47570.58,47682.35,55555,65890,0,67890,2000,666666,495,4785
532 KEY OFF:LPRINT CHR$(15):WIDTH "LPT1:",132
534 DEF FN NRD=SQR(-2*LOG(RND))*COS(2*PI*RND)
536 PI=3.1415926#
538 FOR TRD=1 TO 10
540 I=RND(-RD(TRD))
542 GOTO 556
544 LPRINT TFLAG,SFLAG,SYSFL,CYCFL,MIXFL
546 LPRINT  " "
548 LPRINT  " "
550 NEXT TRD
552 END
554 REM ************************************************************************
556 REM * INITIALIZATION OF SELECTED VARIABLES AND FIRST USER PROMPT          *
558 REM ************************************************************************
560 A=0:B=0:F=0:NB=1E+20:NF=0:FOR I=1 TO 100:B(I)=0:A(I)=0:NEXT
562 TFLAG=0:SFLAG=0:SYSFL=0:CYCFL=0:MIXFL=0
564 SCREEN 0:WIDTH 80
566 COLOR 0,7,9
568 CLS
570 'ASM=0:SUB=VARPTR(ASM):POKE SUB,&HCD:POKE SUB+1,&H5:POKE SUB+2,&HCB
572 LOCATE 10,25:PRINT "SELECT DATA ENTRY TYPE"
574 LOCATE 11,25:PRINT "  1. BY HAND"
576 LOCATE 12,25:PRINT "  2. COMPUTER GENERATED"
578 LOCATE 13,25:PRINT "  3. END PROGRAM"
580 LOCATE 14,30:PRINT "(1,2 OR 3)";
582 A$=INKEY$:IF A$="" GOTO 582 ELSE IF A$<"1" OR A$>"3"  THEN BEEP:GOTO 582
    ELSE D=VAL(A$)
584 IF D=2 THEN GOTO 980
586 IF D=3 THEN END
588 CLS
590 LOCATE 12,25:PRINT "1. DATA ENTERED BY POINT"
592 LOCATE 13,25:PRINT "2. DATA ENTERED BY MEAN"
594 LOCATE 14,32:PRINT "(1 OR 2)"
596 A$=INKEY$:IF A$="" GOTO 596 ELSE IF A$<"1" OR A$>"2"  THEN BEEP:GOTO 596
    ELSE D=VAL(A$)
598 IF D=2 THEN GOTO 664
600 REM ************************************************************************
602 REM *       THIS SECTION ALLOWS FOR DATA ENTERED BY POINT                 *
604 REM ************************************************************************
606 CLS
608 LOCATE 12,25:INPUT "ENTER THE NUMBER OF SAMPLE SETS";X
```

```
610 LOCATE 13,25:INPUT "ENTER THE SAMPLE SUBGROUP SIZE";N
612 CLS
614 FOR I=1 TO X
616 PT=0
618 FOR J=1 TO N
620 LOCATE 13,25:PRINT "SAMPLE";I;": DATA POINT";J;:INPUT "IS ",P(J)
622 PT=PT + P(J)
624 NEXT J
626 MIN=P(1):MAX=P(1)
628 FOR K=2 TO N
630 IF P(K)<MIN THEN MIN=P(K):GOTO 634
632 IF P(K)>MAX THEN MAX=P(K)
634 NEXT K
636 R(I)= MAX-MIN
638 YT(I)=PT/N
640 SUMYB=SUMYB + YT(I)
642 SUMR=SUMR+R(I)
644 NEXT I
646 CLINE=SUMYB/X
648 RBAR = SUMR/X
650 UCL=CLINE + A2(N)*RBAR
652 LCL=CLINE - A2(N)*RBAR
654 GOSUB 686
656 GOTO 968
658 REM ***********************************************************************
660 REM *       THIS SECTION ALLOWS FOR DATA ENTERED BY MEAN                 *
662 REM ***********************************************************************
664 CLS
666 LOCATE 12,25:INPUT "ENTER THE NUMBER OF SAMPLE SETS";X
668 LOCATE 13,25:INPUT "ENTER SAMPLE SUBGROUP SIZE";N
670 CLS
672 FOR I=1 TO X
674 LOCATE 12,25:PRINT "THE MEAN OF SAMPLE SET";I;"IS";:INPUT YT(I)
676 LOCATE 13,25:PRINT "THE RANGE OF SAMPLE SET";I;"IS";:INPUT R(I)
678 SUMYB = SUMYB + YT(I)
680 SUMR = SUMR + R(I)
682 NEXT I
684 GOTO 646
686 REM ***********************************************************************
688 REM * THIS SECTION ALLOWS THE USER TO SAVE THE DATA GENERATED TO A DISK  *
690 REM ***********************************************************************
692 'LOCATE 13,20:PRINT "PLEASE ENTER THE FILE NAME YOU WOULD LIKE TO SAVE THE
    DATA UNDER."
694 'INPUT N$:N$=N$+".dat"
696 'OPEN "b:"+N$ FOR OUTPUT AS #1
698 'FOR I=1 TO X:PRINT #1,YT(I):NEXT
700 'CLOSE
702 REM ***********************************************************************
704 REM *    THIS SECTION DRAWS THE CONTROL CHART GRAPH TO THE SCREEN
706 REM ***********************************************************************
708 SCREEN 2
710 CLS
```

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712 PSET (80,15):DRAW "D150R565"
714 FOR I=1 TO X
716 PSET (80+565/(X+1)*I,165):DRAW "U3"
718 NEXT I
720 M=UCL*1.2-.2*LCL
722 MN=LCL*1.2-.2*UCL
724 PSET (80,165-150*(LCL-MN)/(M-MN)):DRAW "R565"
726 ALINE=165-150*(CLINE-2*DEV-MN)/(M-MN):BLINE=165-150*(CLINE-DEV-MN)/(M-MN)
728 LINE (80,BLINE)-(645,BLINE):',,,&HF0F0
730 LINE (80,ALINE)-(645,ALINE):',,,&HF0F0
732 PSET (80,165-150*(UCL-MN)/(M-MN)):DRAW "R565"
734 ALINE=165-150*(CLINE+2*DEV-MN)/(M-MN):BLINE=165-150*(CLINE+DEV-MN)/(M-MN)
736 LINE (80,BLINE)-(645,BLINE):',,,&HF0F0
738 LINE (80,ALINE)-(645,ALINE):',,,&HF0F0
740 PSET (80,165-150*(CLINE-MN)/(M-MN)):DRAW "R565"
742 LOCATE 19,6:PRINT INT(LCL)
744 LOCATE 5,6:PRINT INT(UCL)
746 LOCATE 12,6:PRINT INT(CLINE)
748 HH=10:GG=80+565/(X+1)*NCC:PSET(GG,HH)
750 HH=10:GG=80+565/(X+1)*L:PSET(GG,HH)
752 REM ***************************************************************************
754 REM *      THIS SECTION PLOTS THE POINTS ONTO THE CONTROL CHART            *
756 REM ***************************************************************************
758 FOR I=1 TO X-1
760 XX1=80+565/(X+1)*I
762 XX2=80+565/(X+1)*(I+1)
764 YY1=165-150*(YT(I)-MN)/(M-MN)
766 YY2=165-150*(YT(I+1)-MN)/(M-MN)
768 LINE (XX1,YY1)-(XX2,YY2)
770 NEXT I
772 REM ***************************************************************************
774 REM * THIS SECTION APPLIES RULE ONE OF THE AT&T RUN RULES.  TESTS TO SEE *
776 REM * IF ANY POINTS FALL OUTSIDE OF THE 3 SIGMA LIMITS.  IF IT DOES, AN  *
778 REM * x IS PLACED ABOVE OR BELOW THAT POINT.                              *
780 REM ***************************************************************************
782 FOR I=1 TO X
784 IF  YT(I)>UCL THEN G=1:GOSUB 942:GOSUB 914:GOTO 788
786 IF YT(I)<LCL THEN G=1:GOSUB 942:GOSUB 928
788 NEXT
790 REM ***************************************************************************
792 REM * THIS SECTION APPLIES RULE TWO OF THE AT&T RUN RULES.  IT TESTS TO  *
794 REM * SEE IF TWO OUT OF THREE SUCCESSIVE POINTS FALL OUTSIDE OF THE TWO  *
796 REM * SIGMA LIMITS.  ONLY THE SECOND POINT IS MARKED WITH AN x.          *
798 REM ***************************************************************************
800 TSIG=CLINE+2*DEV
802 COUNT=0
804 FOR I=1 TO X
806 IF YT(I)>TSIG THEN GOTO 810
808 IF COUNT = 0 THEN GOTO 814 ELSE COUNT=COUNT-1:GOTO 814
810 COUNT=COUNT+2
812 IF COUNT>2 THEN G=2:GOSUB 942:GOSUB 914:COUNT=2
814 NEXT I
```

```
816 TSIG=CLINE-2*DEV
818 COUNT=0
820 FOR I=1 TO X
822 IF YT(I)<TSIG THEN GOTO 826
824 IF COUNT = 0 THEN GOTO 830 ELSE COUNT=COUNT-1:GOTO 830
826 COUNT=COUNT+2
828 IF COUNT>2 THEN G=2:GOSUB 942:GOSUB 928:COUNT=2
830 NEXT I
832 REM ***************************************************************************
834 REM * THIS SECTION APPLIES RULE THREE OF THE AT&T RUN RULES.  IT TESTS   *
836 REM * TO SEE IF FOUR OUT OF FIVE SUCCESSIVE POINTS FALL OUTSIDE OF THE   *
838 REM * ONE SIGMA LIMITS.  ONLY THE FOURTH POINT IS MARKED WITH AN x.      *
840 REM ***************************************************************************
842 OSIG=CLINE + DEV
844 COUNT=0
846 FOR I=1 TO X
848 IF YT(I)>OSIG THEN COUNT=COUNT+1
850 IF COUNT<>4 THEN GOTO 860
852 IF YT(I)>OSIG AND YT(I-1)>OSIG AND YT(I-2)>OSIG AND YT(I-3)>OSIG THEN GOSUB
    942:GOSUB 914: GOTO 858
854 IF YT(I)>OSIG AND YT(I-1)>OSIG AND YT(I-3)>OSIG AND YT(I-4)>OSIG THEN GOSUB
    942:GOSUB 914: GOTO 858
856 IF YT(I)>OSIG AND YT(I-2)>OSIG AND YT(I-3)>OSIG AND YT(I-4)>OSIG THEN GOSUB
    942:GOSUB 914: GOTO 858
858 COUNT=3
860 NEXT I
862 OSIG=CLINE - DEV
864 COUNT=0
866 FOR I=1 TO X
868 IF YT(I)<OSIG THEN COUNT=COUNT+1
870 IF COUNT<>4 THEN GOTO 880
872 IF YT(I)<OSIG AND YT(I-1)<OSIG AND YT(I-2)<OSIG AND YT(I-3)<OSIG THEN GOSUB
    942:GOSUB 928: GOTO 878
874 IF YT(I)<OSIG AND YT(I-1)<OSIG AND YT(I-3)<OSIG AND YT(I-4)<OSIG THEN GOSUB
    942:GOSUB 928: GOTO 878
876 IF YT(I)<OSIG AND YT(I-2)<OSIG AND YT(I-3)<OSIG AND YT(I-4)<OSIG THEN GOSUB
    942:GOSUB 928: GOTO 878
878 COUNT=3
880 NEXT I
882 REM ***************************************************************************
884 REM * THIS SECTION APPLIES THE FOURTH RULE OF THE AT&T RUN RULES.  IT    *
886 REM * TESTS TO SEE IF EIGHT SUCCESSIVE POINTS FALL ON ONE SIDE OF THE    *
888 REM * CENTER LINE.  ONLY THE EIGHTH POINT IS MARKED WITH AN x.           *
890 REM ***************************************************************************
892 COUNT=0
894 FOR I=1 TO X
896 IF YT(I)>CLINE THEN COUNT=COUNT + 1 ELSE COUNT=0:GOTO 900
898 IF COUNT=8 THEN G=4:GOSUB 942:GOSUB 914:COUNT=7
900 NEXT I
902 COUNT=0
904 FOR I=1 TO X
906 IF YT(I)<CLINE THEN COUNT=COUNT + 1 ELSE COUNT=0:GOTO 910
```

```
908 IF COUNT=8 THEN G=4:GOSUB 942:GOSUB 928:COUNT=7
910 NEXT I
912 RETURN
914 REM ************************************************************************
916 REM *             THIS SECTION DRAWS AN x ABOVE THE POINT                 *
918 REM ************************************************************************
920 H=160-150*(YT(I)-MN)/(M-MN)
922 G=80+565/(X+1)*I
924 PSET (G,H):DRAW "NE2 NF2 NG2 H2"
926 RETURN
928 REM ************************************************************************
930 REM *             THIS SECTION DRAWS AN x BELOW THE POINT                 *
932 REM ************************************************************************
934 H=170-150*(YT(I)-MN)/(M-MN)
936 G=80+565/(X+1)*I
938 PSET (G,H):DRAW "NE2 NF2 NG2 H2"
940 RETURN
942 REM ************************************************************************
944 REM * THIS SECTION IDENTIFIES WHICH RUN RULE AND AT WHAT POINT IN THE     *
946 REM * PROCESS THE FIRST "MARKED x" OCCURRED.  IT ALSO IDENTIFIES WHEN     *
948 REM * THE LAST "MARKED x" OCCURRED.                                       *
950 REM ************************************************************************
952 IF I>NF THEN NF=I
954 B(I)=1:A(I)=G
956 IF I<NB THEN NB=I
958 RETURN
960 REM ************************************************************************
962 REM * THIS SECTION ALLOWS THE USER TO PRINT THE CONTROL CHART SHOWN ON   *
964 REM * THE USERS SCREEN TO THE PRINTER.                                    *
966 REM ************************************************************************
968 GOTO 1322:'LOCATE 24,4:PRINT "WOULD YOU LIKE A PRINTOUT OF THIS CHART?
    (Y/N)";
970 Q$=INPUT$(1)
972 IF Q$<> "Y" AND Q$<>"y" THEN 1322
974 LOCATE 24,4:PRINT SPACE$(50);
976 'SUB=VARPTR(ASM):CALL SUB
978 GOTO 1322
980 REM ************************************************************************
982 REM * THIS SECTION GENERATES THE DATA FOR 7 DIFFERENT PATTERNS            *
984 REM * AUTOMATICALLY.                                                      *
986 REM ************************************************************************
988 X=60:CLINE=100:UCL=115:LCL=85:DEV=5
990 'NC=INT(RND*11+5)
992 NC=7:NCC=NC+1
994 CLS
996 LOCATE 9,15:PRINT "WHAT TYPE OF PATTERN WOULD YOU LIKE TO SEE?"
998 LOCATE 10,27:PRINT "1. TREND"
1000 LOCATE 11,27:PRINT "2. CYCLE"
1002 LOCATE 12,27:PRINT "3. MIXTURE"
1004 LOCATE 13,27:PRINT "4. SHIFT"
1006 LOCATE 14,27:PRINT "5. SYSTEMATIC"
1008 LOCATE 15,27:PRINT "6. STRATIFICATION"
```

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1010 LOCATE 16,27:PRINT "7. NORMAL"
1012 LOCATE 17,27:PRINT "(1,2,3,4,5,6 OR 7)"
1014 A$=INKEY$:IF A$="" GOTO 1014 ELSE IF A$<"1" OR A$>"7"  THEN BEEP:GOTO 1014
     ELSE D=VAL(A$)
1016 IF D=7 THEN GOTO 1074
1018 CLS
1020 LOCATE 13,7:PRINT "PLEASE ENTER THE NUMBER OF POINTS YOU WOULD LIKE TO BE
     OUT OF CONTROL"
1022 LOCATE 14,12:INPUT "NUMBER MUST BE A MULTIPLE OF 5 AND BETWEEN 0 AND
     45";OC
1024 IF OC<0 OR OC>45 THEN SOUND 450,6:GOTO 1020
1026 L = NC+OC
1028 ON D GOTO 1042,1146,1184,1106,1268,1226
1030 REM ***********************************************************************
1032 REM * THIS SECTION GENERATES DATA FOR THE TREND PATTERN.  THE USER MUST  *
1034 REM * ENTER THE VALUE OF ALPHA (THE MULTIPLE OF SIGMA BY WHICH THE MEAN  *
1036 REM * IS SHIFTED FROM THE CENTERLINE EACH SAMPLE INTERVAL DURING THE OOC *
1038 REM * CONDITION).                                                        *
1040 REM ***********************************************************************
1042 CLS
1044 LOCATE 12,12:PRINT "WHAT MULTIPLE OF SIGMA WOULD YOU LIKE THE MEAN SHIFTED
     BY?"
1046 LOCATE 13,22:INPUT "TYPE A VALUE BETWEEN (.05 AND .25)";ALPHA
1048 IF ALPHA<.05 OR ALPHA>.25 THEN SOUND 450,6:GOTO 1044
1050 LPRINT "TREND PATTERN WITH A SLOPE OF";ALPHA*DEV;"AND";OC;"OUT OF CONTROL
     POINTS STARTING AT";NCC;"AND ENDING AT";L;CHR$(29);"."
1052 FOR K=1 TO NC
1054 YT(K)=CLINE+FN NRD*DEV
1056 NEXT K
1058 NCC=NC+1
1060 FOR I= NCC TO L
1062 YT(I)=CLINE + FN NRD*DEV + ALPHA*(I-NC)*DEV
1064 NEXT I
1066 IF L=X THEN GOTO 1070
1068 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1070 GOSUB 686
1072 GOTO 968
1074 REM ***********************************************************************
1076 REM * THIS SECTION GENERATES A REGULAR INCONTROL PROCESS CHART            *
1078 REM ***********************************************************************
1080 NCC=0:L=0
1082 CLS
1084 LPRINT "IN CONTROL PROCESS WITH 0 OUT OF CONTROL POINTS."
1086 FOR I= 1 TO X
1088 YT(I)=CLINE+FN NRD*DEV
1090 NEXT I
1092 GOSUB 686
1094 GOTO 968
1096 REM ***********************************************************************
1098 REM * THIS SECTION GENERATES THE DATA FOR THE SHIFT PATTERN.  THE USER   *
1100 REM * MUST INPUT THE VALUE OF DELTA (THE MULTPLE OF SIGMA BY WHICH THE   *
1102 REM * MEAN IS SHIFTED FROM THE CENTERLINE DURING THE OOC CONDITION).     *
```

```
1104 REM ****************************************************************************
1106 CLS
1108 LOCATE 12,7:PRINT "PLEASE ENTER THE MULTIPLE OF SIGMA YOU WOULD LIKE THE
     MEAN SHIFTED."
1110 LOCATE 13,24:INPUT "TYPE A VALUE BETWEEN (.5 TO 3)";SHIFT
1112 IF SHIFT <.5 OR SHIFT>3 THEN SOUND 450,6:GOTO 1108
1114 LPRINT "SHIFT PATTERN WITH EXPECTED MEAN OF";CLINE+SHIFT*DEV;"AND";OC;"OUT
     OF CONTROL POINTS STARTING AT";NCC;"AND ENDING AT";L;CHR$(29);"."
1116 FOR I=1 TO NC
1118 YT(I)=CLINE+FN NRD*DEV
1120 NEXT
1122 NCC=NC + 1
1124 FOR I=NCC TO L
1126 YT(I)=CLINE+ SHIFT*DEV + FN NRD*DEV
1128 NEXT I
1130 IF L=X THEN GOTO 1134
1132 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1134 GOSUB 686
1136 GOTO 968
1138 REM ****************************************************************************
1140 REM * THIS SECTION GENERATES THE DATA FOR THE CYCLE PATTERN.  THE USER   *
1142 REM * MUST INPUT THE VALUE OF DELTA.                                      *
1144 REM ****************************************************************************
1146 CLS
1148 LOCATE 11,12:PRINT "PLEASE ENTER THE PERIOD YOU WOULD LIKE THE CYCLE TO
     TAKE."
1150 LOCATE 12,28:INPUT "(4, 8 OR 12).";PER
1152 IF PER<>4 AND PER<>8 AND PER<>12 THEN SOUND 450,6:GOTO 1148
1154 LOCATE 14,5:PRINT "PLEASE ENTER THE MULTIPLE OF SIGMA YOU WOULD LIKE THE
     AMPLITUDE TO TAKE."
1156 LOCATE 15,30:INPUT "(.5 TO 3).";DEL
1158 IF DEL<.5 OR DEL>3 THEN SOUND 450,6:GOTO 1154
1160 LPRINT "CYCLE WITH A PERIOD OF";PER;"AND AMPLITUDE
     OF";DEL*DEV;"WITH";OC;"OUT OF CONTROL POINTS STARTING AT";NCC;"AND ENDING
     AT";L;CHR$(29);"."
1162 FOR K=1 TO NC
1164 YT(K)=CLINE+FN NRD*DEV
1166 NEXT K
1168 NCC=NC+1
1170 FOR I=NCC TO L
1172 YT(I)=CLINE + FN NRD*DEV + DEL*SIN(2*PI*(I-NC)/PER)*DEV
1174 NEXT I
1176 IF L=X THEN GOTO 1180
1178 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1180 GOSUB 686
1182 GOTO 968
1184 REM ****************************************************************************
1186 REM * THIS SECTION GENERATES THE DATA FOR THE MIXTURE PATTERN.  THE USER *
1188 REM * MUST INPUT THE VALUE OF DELTA.                                      *
1190 REM ****************************************************************************
1192 CLS
```

```
1194 LOCATE 12,9:PRINT "PLEASE ENTER THE MULTIPLE OF SIGMA YOU WOULD LIKE THE
     MEANS"
1196 LOCATE 13,9:PRINT "OF THE MIXTURE DISTRIBUTIONS TO SHIFT FROM THE NORMAL
     MEAN"
1198 LOCATE 14,34:INPUT "(.5 TO 3)";DELT
1200 IF DELT<.5 OR DELT>3 THEN SOUND 450,6:GOTO 1194
1202 LPRINT "MIXTURE PATTERN WITH A SHIFT OF";DELT;"AND";OC;"OUT OF CONTROL
     POINTS STARTING AT";NCC;"AND ENDING AT";L;CHR$(29);".":LPRINT "THE TWO
     MEANS OF THE MIXTURE SHOULD BE AT";CLINE+DELT*DEV;"AND";CLINE-
     DELT*DEV;CHR$(29);"."
1204 FOR I=1 TO NC
1206 YT(I)=CLINE + FN NRD*DEV
1208 NEXT I
1210 NCC=NC+1
1212 FOR I=NCC TO L
1214 IF RND<.5 THEN YT(I)=CLINE+FN NRD*DEV+DELT*DEV ELSE YT(I)=CLINE+FN NRD*DEV
     - DELT*DEV
1216 NEXT I
1218 IF L=X THEN GOTO 1222
1220 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1222 GOSUB 686
1224 GOTO 968
1226 REM ***************************************************************************
1228 REM * THIS SECTION GENERATES THE DATA FOR THE STRATIFICATION PATTERN. THE*
1230 REM * USER MUST INPUT THE VALUE OF GAMMA (THE MULTIPLE OF SIGMA DESIRED  *
1232 REM * WHEN IN THE OOC CONDITION).                                        *
1234 REM ***************************************************************************
1236 CLS
1238 LOCATE 12,13:PRINT "PLEASE ENTER THE MULTIPLE OF SIGMA YOU WOULD LIKE"
1240 LOCATE 13,13:INPUT "THE STRATIFICATION LIMITS TO BECOME (.2 TO 1)";GAM
1242 IF GAM<.2 OR GAM>1 THEN SOUND 450,6:GOTO 1238
1244 LPRINT "STRATIFICATION PATTERN WITH STD. DEV =";GAM*DEV;"AND";OC;"OUT OF
     CONTROL POINTS STARTING AT";NCC;"AND ENDING AT";L;CHR$(29);"."
1246 FOR I=1 TO NC
1248 YT(I)=CLINE + FN NRD*DEV
1250 NEXT I
1252 NCC=NC+1
1254 FOR I=NCC TO L
1256 YT(I)=CLINE + FN NRD*DEV*GAM
1258 NEXT I
1260 IF L=X THEN GOTO 1264
1262 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1264 GOSUB 686
1266 GOTO 968
1268 REM ***************************************************************************
1270 REM * THIS SECTION GENERATES THE DATA FOR THE SYSTEMATIC PATTERN.  THE   *
1272 REM * USER MUST INPUT THE VALUE OF DELTA.                                 *
1274 REM ***************************************************************************
1276 CLS
1278 LOCATE 12,8:PRINT "PLEASE ENTER THE MULTIPLE YOU WOULD LIKE THE MEANS OF
     THE TWO"
```

```
1280 LOCATE 13,8:INPUT "DISTRIBUTIONS TO SHIFT AWAY FROM THE NORMAL MEAN (.5 TO
     3)";DE
1282 IF DE<.5 OR DE>3 THEN SOUND 450,6:GOTO 1278
1284 LPRINT "SYSTEMATIC PATTERN WITH A SHIFT OF";DE;"AND";OC;"OUT OF CONTROL
     POINTS STARTING AT";NCC;"AND ENDING AT";L;CHR$(29);".":LPRINT "THE TWO
     MEANS ASSOCIATED WITH THIS PATTERN SHOULD BE AT";CLINE+DE*DEV;"AND";CLINE-
     DE*DEV;CHR$(29);"."
1286 FOR I=1 TO NC
1288 YT(I)=CLINE + FN NRD*DEV
1290 NEXT I
1292 NCC=NC+1
1294 FOR I=NCC TO L
1296 YT(I)=CLINE + FN NRD*DEV + ((-1)^I)*DE*DEV
1298 NEXT I
1300 IF L=X THEN GOTO 1304
1302 FOR I=L+1 TO X:YT(I)=CLINE+FN NRD*DEV:NEXT I
1304 GOSUB 686
1306 GOTO 968
1308 REM ************************************************************************
1310 REM * THIS SECTION SETS A 95% CONFIDENCE LIMIT ON THE EXPECTED MEAN OF    *
1312 REM * THE ENTIRE DATA SET.  IT THEN CALCULATES THE MEAN OF THE ENTIRE     *
1314 REM * DATA SET AND DETERMINES IF THIS MEAN IS OUTSIDE OF THE EXPECTED     *
1316 REM * LIMITS.  IF IT IS, THEN THERE IS EVIDENCE THAT EITHER A TREND OR    *
1318 REM * A SHIFT PATTERN IS PRESENT.                                         *
1320 REM ************************************************************************
1322 SUM=0
1324 FOR I=1 TO X
1326 SUM=SUM+YT(I)
1328 NEXT
1330 MEAN=SUM/X
1332 ULM=CLINE+((1.96*DEV)/SQR(X))
1334 LLM=CLINE-((1.96*DEV)/SQR(X))
1336 REM ************************************************************************
1338 REM * THIS SECTION OPTIMIZES THE OUT OF CONTROL WINDOW BY LOOKING FOR     *
1340 REM * CLUSTERS OF MARKED x'S.  IF OUTLIERS EXIST, THEY ARE OMITTED FROM   *
1342 REM * THE WINDOW.  THIS REDUCES THE WINDOW TO ITS SMALLEST SIZE, THUS     *
1344 REM * ALLOWING IT TO BE MODIFIED IN LATER SECTIONS.                       *
1346 REM ************************************************************************
1348 COUNT=0
1350 FOR I=1 TO X
1352 IF B(I)=1 THEN GOTO 1356
1354 IF COUNT=0 THEN GOTO 1360 ELSE COUNT=COUNT-1:GOTO 1360
1356 COUNT=COUNT+2
1358 IF COUNT>2 THEN B=I+COUNT-5:I=X
1360 NEXT I
1362 COUNT=0
1364 FOR I=X TO 1 STEP -1
1366 IF B(I)=1 THEN GOTO 1370
1368 IF COUNT=0 THEN GOTO 1374 ELSE COUNT=COUNT-1:GOTO 1374
1370 COUNT=COUNT+2
1372 IF COUNT>2 THEN F=I-COUNT+5:I=1
1374 NEXT
```

```
1376 MF=F:MB=B
1378 REM ************************************************************************
1380 REM * THIS SECTION FURTHER DEFINES THE SIZE OF THE OUT OF CONTROL          *
1382 REM * WINDOW BY COMPUTING THE MEAN WITH A MOVING WINDOW SIZE OF 5. THE     *
1384 REM * SLOPE OF THE DATA SET WITHIN THIS WINDOW IS CALCULATED AND A TEST    *
1386 REM * DONE TO DETERMINE IF THE SLOPE IS SIGNIFICANTLY DIFFERENT THAN       *
1388 REM * ZERO. IF THE SLOPE IS SIGNIFICANT( ALPHA=0.1), THEN A TREND EXISTS.*
1390 REM * IF SLOPE IS NOT SIGNFICANT, THEN A SHIFT HAS POSSIBLY OCCURRED.      *
1392 REM ************************************************************************
1394 BS=0:BB=0:ED=0:UPZ=1.64:LOWZ=-1.64
1396 MOVSUM=0:FF=BS+1:LL=BS+5:WIN=LL-FF+1
1398 IF LL=X+1 THEN GOTO 1426
1400 FOR I=FF TO LL:MOVSUM=MOVSUM+YT(I):NEXT I
1402 BS=BS+1
1404 MOVMU=MOVSUM/WIN
1406 ZO=(MOVMU-CLINE)/(DEV/SQR(WIN))
1408 IF ZO>LOWZ AND ZO<UPZ THEN GOTO 1396
1410 BB=FF+2:ED=LL
1412 MOVSUM=0:FF=BS+1:LL=BS+5:WIN=LL-FF+1
1414 IF LL=X+1 THEN GOTO 1426
1416 FOR I=FF TO LL:MOVSUM=MOVSUM+YT(I):NEXT I
1418 BS=BS+1
1420 MOVMU=MOVSUM/WIN
1422 ZO=(MOVMU-CLINE)/(DEV/SQR(WIN))
1424 IF ZO<LOWZ OR ZO>UPZ THEN ED=LL-4:GOTO 1412
1426 IF BB=0 THEN GOTO 1434
1428 IF B=0 AND F=0 THEN B=BB:F=ED:GOTO 1442
1430 IF ED>F THEN F=ED
1432 IF BB<B THEN B=BB:GOTO 1442 ELSE GOTO 1436
1434 IF F=0 AND B=0 THEN GOTO 1490
1436 IF A(B)=2 THEN B=B-1
1438 IF A(B)=3 THEN B=B-3
1440 IF A(B)=4 THEN B=B-7
1442 F=F-1:SIZE=F-B+1:TSB=B:TSF=F
1444 IF SIZE<=5 THEN GOTO 1490
1446 XSQ=0:XSUM=0:YSQ=0:Y=0:XY=0:YSUM=0
1448 IF MEAN>CLINE THEN SL=1 ELSE SL=0
1450 FOR I=B TO F
1452 YSQ=YSQ+YT(I)^2
1454 YSUM=YSUM+YT(I)
1456 XY=XY+YT(I)*I
1458 XSUM=XSUM+I
1460 XSQ=XSQ+I^2
1462 NEXT
1464 SXX=XSQ-((XSUM^2)/SIZE)
1466 SXY=XY-((YSUM*XSUM)/SIZE)
1468 SYY=YSQ-((YSUM^2)/SIZE)
1470 SMEAN=YSUM/SIZE
1472 SLOPE=SXY/SXX
1474 IF (SL=1 AND SLOPE<0) OR (SL=0 AND SLOPE>0) THEN GOTO 1488
1476 DS=ATN(SLOPE)*180/PI
1478 MSR=SLOPE*SXY
```

```
1480 MSE=(SYY-SLOPE*SXY)/(SIZE-2)
1482 F0=MSR/MSE
1484 FSIZE=SIZE-2
1486 IF F0>F1(FSIZE) THEN TFLAG=1:GOTO 1490
1488 IF ABS(CLINE-SMEAN)*SQR(SIZE)/DEV>1.96 THEN SFLAG=1
1490 REM ************************************************************************
1492 REM * THIS SECTION SETS A 80% CONFIDENCE LIMIT ON THE EXPECTED VARIANCE  *
1494 REM * OF THE ENTIRE DATA SET.  IT THEN CALCULATES THE VARIANCE OF THE    *
1496 REM * ENTIRE DATA SET AND DETERMINES IF THIS VALUE IS OUTSIDE OF THE     *
1498 REM * EXPECTED LIMITS.                                                    *
1500 REM ************************************************************************
1502 VSUM=0
1504 FOR I=1 TO X
1506 VSUM=VSUM + (YT(I)-MEAN)^2
1508 NEXT
1510 VAR=VSUM/(X-1)
1512 STD=SQR(VAR)
1514 ULV=DEV^2*(X-1)/46.46
1516 LLV=DEV^2*(X-1)/74.4
1518 IF VAR<LLV THEN GOTO 1750
1520 REM ************************************************************************
1522 REM * THIS SECTION DETERMINES THE OUT OF CONTROL WINDOW SIZE BY DOING A  *
1524 REM * HYPOTHESIS TEST ON WHETHER THE VARIANCE IS GREATER THAN 25, USING  *
1526 REM * A MOVING WINDOW OF 7 WITH ALPHA=.05.  THIS WILL SEPERATE MIXTURE,  *
1528 REM * SYSTEMATIC AND CYCLE FROM IN CONTROL.                              *
1530 REM ************************************************************************
1532 F=MF:B=MB:FI=0:LA=0:ST=0
1534 MVSUM=0:FIR=ST+1:LAS=ST+7:WIN=LAS-FIR+1
1536 IF LAS=X+1 THEN GOTO 1568
1538 FOR I= FIR TO LAS:MVSUM=MVSUM+ (YT(I)-MEAN)^2:NEXT I
1540 ST=ST+1
1542 MVAR=MVSUM/(WIN-1)
1544 MSTD=SQR(MVAR)
1546 CHI=(WIN-1)*MVAR/DEV^2
1548 IF CHI<12.59 THEN GOTO 1534
1550 FI=FIR+3:LA=LAS
1552 MVSUM=0:FIR=ST+1:LAS=ST+7:WIN=LAS-FIR+1
1554 IF LAS=X+1 THEN GOTO 1568
1556 FOR I= FIR TO LAS:MVSUM=MVSUM+ (YT(I)-MEAN)^2:NEXT I
1558 ST=ST+1
1560 MVAR=MVSUM/(WIN-1)
1562 MSTD=SQR(MVAR)
1564 CHI=(WIN-1)*MVAR/DEV^2
1566 IF CHI<12.59 THEN GOTO 1552 ELSE LA=LAS-5:GOTO 1552
1568 IF FI=0 THEN GOTO 1576
1570 IF B=0 AND F=0 THEN B=FI:F=LA:GOTO 1584
1572 IF LA>F THEN F=LA
1574 IF FI<B THEN B=FI:GOTO 1584 ELSE GOTO 1578
1576 IF F=0 AND B=0 THEN GOTO 1706
1578 IF A(B)=2 THEN B=B-1
1580 IF A(B)=3 THEN B=B-3
1582 IF A(B)=4 THEN B=B-7
```

```
1584 VARB=B:VARF=F
1586 VLN=F-B+1:IF VLN<=5 THEN GOTO 1706
1588 SY=0:SYY=0:FOR I=B TO F:SY=SY+YT(I):SYY=SYY+YT(I)*YT(I):NEXT
1590 WVAR=(SYY-SY*SY/VLN)/(VLN-1)
1592 SMUL=CLINE+DEV*((3.24*SQR(WVAR))-(3*DEV))/(DEV+(.46*SQR(WVAR)))
1594 SMLL=CLINE-DEV*((3.24*SQR(WVAR))-(3*DEV))/(DEV+(.46*SQR(WVAR)))
1596 WCHI=(VLN-1)*WVAR/(DEV*DEV)
1598 IF WCHI<LCHI(VLN-1) THEN GOTO 1810
1600 IF WCHI<UCHI(VLN-1) THEN GOTO 1706
1602 REM ***********************************************************************
1604 REM * THIS SECTION DETERMINES WHETHER A SYSTEMATIC PATTERN EXISTS.        *
1606 REM ***********************************************************************
1608 FOR I=B TO F-1
1610 IF YT(I)>=YT(I+1) THEN IG(I)=1 ELSE IG(I)=0
1612 NEXT
1614 SUU=0
1616 FOR I=B TO F-1
1618 IF IG(I)+IG(I+1)=1 THEN SUU=SUU+1
1620 NEXT
1622 STEST=INT(.84*(F-B+1))
1624 IF SUU>=STEST THEN SYSFL=1
1626 REM ***********************************************************************
1628 REM * THIS SECTION TRIES TO DETERMINE IF A CYCLE IS PRESENT IN THE DATA. *
1630 REM ***********************************************************************
1632 SY=0:SYY=0
1634 W=F-B+1:IF W<12 THEN GOTO 1680
1636 FOR I=B TO F
1638 SY=SY+YT(I)
1640 SYY=SYY+YT(I)^2
1642 NEXT
1644 U=SY/W
1646 TCSS=SYY-((SY^2)/W):TMAX=0
1648 FOR P=3 TO 12
1650 FOR L=0 TO P/2-.1
1652 SYS=0:SX=0:SXX=0
1654 FOR I=B TO F
1656 X1=SIN(2*PI*(I+L-B+1)/P)
1658 SYS=SYS+YT(I)*X1
1660 SX=SX+X1
1662 SXX=SXX+X1*X1
1664 NEXT I
1666 V=(SYS-SX*SY/W)/(SXX-SX*SX/W)
1668 SSREG=V*(SYS-SX*SY/W)
1670 SSRES=TCSS-SSREG
1672 T=SQR((W-2)*SSREG/SSRES)
1674 IF T>TMAX THEN TMAX=T:PMAX=P:LMAX=L:UMAX=U:VMAX=V
1676 NEXT L:NEXT P
1678 IF TMAX>T(W-2) THEN CYCFL=1
1680 REM ***********************************************************************
1682 REM * THIS SECTION DETERMINES WHETHER A MIXTURE PATTERN EXISTS            *
1684 REM ***********************************************************************
1686 COUNT=0:HI=0:LOW=0
```

```
1688 HI=CLINE+DEV:LOW=CLINE-DEV
1690 FOR I=B TO F
1692 IF YT(I)>HI OR YT(I)<LOW THEN COUNT=COUNT+1
1694 NEXT
1696 TEST=.4*VLN
1698 IF COUNT>TEST THEN MIXFL=1
1700 REM ************************************************************************
1702 REM * THIS SECTION USES THE FLAGS TO OPTIMIZE PATTERN IDENTIFICATION.     *
1704 REM ************************************************************************
1706 SUMFL=0
1708 SUMFL=TFLAG+SFLAG+SYSFL+CYCFL+MIXFL
1710 IF SUMFL=0 THEN GOTO 1828
1712 IF SUMFL<>1 THEN GOTO 1740
1714 IF TFLAG=1 THEN LPRINT "PATTERN IS A TREND WITH A SLOPE
     OF";SLOPE;"OR";DS;"DEGREES WITH OUT OF CONTROL BEGINNING AT";TSB;"AND
     ENDING AT";TSF;CHR$(29);".":GOTO 544
1716 IF SFLAG=1 THEN LPRINT "PATTERN IS A SHIFT WITH A MEAN OF";SMEAN;"WITH OUT
     OF CONTROL BEGINNING AT";TSB;"AND ENDING AT";TSF;CHR$(29);".":GOTO 544
1718 IF SYSFL=1 THEN LPRINT "PATTERN IS SYSTEMATIC WITH OUT OF CONTROL STARTING
     AT";VARB;"AND ENDING AT";VARF;CHR$(29);".":LPRINT "THE TWO MEANS
     ASSOCIATED WITH THIS PATTERN ARE AT";SMUL;"AND";SMLL;CHR$(29);".":GOTO 544
1720 IF CYCFL=1 THEN LPRINT "PATTERN IS A CYCLE WITH A PERIOD OF";PMAX;"AND AN
     AMPLITUDE OF";ABS(VMAX);"WITH OUT OF CONTROL BEGINNING AT";VARB;"AND
     ENDING AT";VARF;CHR$(29);"." ELSE GOTO 1730
1722 Y=UMAX+VMAX*SIN(2*PI*(LMAX+1)/PMAX):PSET (80+565/(X+1)*B,165-150*(Y-
     MN)/(M-MN))
1724 FOR I=B+1 TO F:Y=UMAX+VMAX*SIN(2*PI*(I+LMAX-B+1)/PMAX)
1726 LINE -(80+565/(X+1)*I,165-150*(Y-MN)/(M-MN)):NEXT
1728 GOTO 544
1730 IF MIXFL=1 THEN LPRINT "PATTERN IS A MIXTURE WITH OUT OF CONTROL BEGINNING
     AT";VARB;"AND ENDING AT";VARF;CHR$(29);".":LPRINT "THE TWO MEANS OF THE
     MIXTURE ARE AT";SMUL;"AND";SMLL;CHR$(29);".":GOTO 544
1732 REM ************************************************************************
1734 REM * THIS SECTION MAKES THE FINAL DETERMINATION ON PATTERN                *
1736 REM * IDENTIFICATION IF MORE THAN ONE FLAG HAS BEEN SET.                   *
1738 REM ************************************************************************
1740 TUP=0:DOW=0
1742 FOR I=B TO F
1744 IF YT(I)>CLINE THEN TUP=TUP+1 ELSE DOW=DOW+1
1746 NEXT
1748 IF TUP>.55*VLN THEN GOTO 1714 ELSE GOTO 1718
1750 REM ************************************************************************
1752 REM * THIS SECTION DETERMINES WHETHER A STRATIFICATION PATTERN EXISTS     *
1754 REM ************************************************************************
1756 F=MF:B=MB:FI=0:LA=0:ST=0
1758 MVSUM=0:FIR=ST+1:LAS=ST+7:WIN=LAS-FIR+1
1760 IF LAS=X+1 THEN GOTO 1792
1762 FOR I= FIR TO LAS:MVSUM=MVSUM+ (YT(I)-MEAN)^2:NEXT I
1764 ST=ST+1
1766 MVAR=MVSUM/(WIN-1)
1768 MSTD=SQR(MVAR)
1770 CHI=(WIN-1)*MVAR/DEV^2
```

```
1772 IF CHI>3.45 THEN GOTO 1758
1774 FI=FIR+3:LA=LAS
1776 MVSUM=0:FIR=ST+1:LAS=ST+7:WIN=LAS-FIR+1
1778 IF LAS=X+1 THEN GOTO 1792
1780 FOR I= FIR TO LAS:MVSUM=MVSUM+ (YT(I)-MEAN)^2:NEXT I
1782 ST=ST+1
1784 MVAR=MVSUM/(WIN-1)
1786 MSTD=SQR(MVAR)
1788 CHI=(WIN-1)*MVAR/DEV^2
1790 IF CHI<3.45 THEN LA=LAS-5:GOTO 1776
1792 IF FI=0 THEN GOTO 1800
1794 IF B=0 AND F=0 THEN B=FI:F=LA:GOTO 1808
1796 IF LA>F THEN F=LA
1798 IF FI<B THEN B=FI:GOTO 1808 ELSE GOTO 1802
1800 IF F=0 AND B=0 THEN GOTO 1706
1802 IF A(B)=2 THEN B=B-1
1804 IF A(B)=3 THEN B=B-3
1806 IF A(B)=4 THEN B=B-7
1808 VLN=F-B+1:IF VLN<=5 GOTO 1706
1810 COUNT=0
1812 HI=CLINE+DEV:LOW=CLINE-DEV
1814 FOR I=B TO F
1816 IF YT(I)<HI AND YT(I)>LOW THEN COUNT=COUNT+1
1818 NEXT
1820 TEST=.75*VLN
1822 SY=0:SYY=0:FOR I=B TO F:SY=SY+YT(I):SYY=SYY+YT(I)*YT(I):NEXT
1824 STRVAR=(SYY-SY*SY/VLN)/(VLN-1):STDSTR=SQR(STRVAR)
1826 IF COUNT>=TEST THEN LPRINT "STRATIFICATION PATTERN EXISTS WITH STD. DEV.
     =";STDSTR;"AND OUT OF CONTROL STARTING AT";B;"AND ENDING
     AT";F;CHR$(29);".":GOTO 544 ELSE GOTO 1706
1828 REM ***********************************************************************
1830 REM * THIS SECTION DETERMINES WHETHER PROCESS IS IN CONTROL.             *
1832 REM ***********************************************************************
1834 IF NB=1E+20 AND NF=0 THEN LPRINT "PROCESS IS IN CONTROL.":GOTO 544
1836 IF NB=NF THEN LPRINT "ONLY ONE x HAS BEEN MARKED WITH THE REMAINDER OF THE
     PROCESS APPEARING TO BE IN CONTROL.":GOTO 544
1838 LPRINT "MULTIPLE POINTS HAVE BEEN MARKED ACCORDING TO THE AT&T RULES.
     HOWEVER, THE CAUSE IS NOT DUE TO ANY OF THE PATTERNS TESTED."
1840 GOTO 544
```

APPENDIX C

DATA SUMMARY

TABLE XLI

SYSTEM IDENTIFICATION RESULTS FOR A SYSTEMATIC PATTERN

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW								
	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=8 1X=2	NC=7 1X=3 MX=1	NC=7 1X=3	NC=6 1X=3	NC=6 1X=4 MX=2 CYC=1	NC=5 1X=2 MX=3 CYC=1	NC=6 1X=1 CYC=1 MIX=1	NC=6 MX=2 CYC=2 SYS=1	NC=5 MX=2
1	NC=9 1X=1	NC=5 1X=3 SYS=2 MIX=2 SYS=2	NC=3 1X=2 CYC=1 MIX=3 SYS=4	NC=1 1X=1 CYC=1 MIX=2 SYS=5	NC=1 1X=1 CYC=1	MIX=4 SYS=6	MIX=2 SYS=8	MIX=2 SYS=8	MIX=2 SYS=8
1.5	NC=5 1X=3 SYS=2	NC=1 MX=1 MIX=2 SYS=6	NC=1 MIX=4 SYS=5	MIX=3 SYS=7	MIX=2 SYS=8	MIX=2 SYS=8	SYS=10	SYS=10	SYS=10
2	NC=3 1X=1 MX=3 MIX=1 SYS=2	MX=2 MIX=2 SYS=6	MIX=5 SYS=5	MIX=3 SYS=7	MIX=2 SYS=8	MIX=2 SYS=8	SYS=10	SYS=10	SYS=10
2.5	1X=1 MX=4 MIX-2 SYS=3	MX=1 MIX=3 SYS=6	MIX=4 SYS=6	MIX=3 SYS=7	MIX=2 SYS=8	MIX=2 SYS=8	SYS=10	SYS=10	SYS=10
3	MX=4 MIX=1 SYS=5	MX=2 MIX=3 SYS=5	MIX=4 SYS=6	MIX=3 SYS=7	MIX=2	SYS=8	SYS=10	SYS=10	SYS=10

TABLE XLII

SYSTEM IDENTIFICATION RESULTS FOR A CYCLE PATTERN (PERIOD=4)

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=9 1X=1	NC=9 1X=1	NC=8 1X=2	NC=7 1X=2 MX=1	NC=6 1X=2 MX=2	NC=6 1X=2 MX=2	NC=6 1X=2 MX=2	NC=5 1X=3 MX=2	NC=2 1X=3 MX=4 MIX=1
1	NC=9 1X=1	NC=8 1X=2	NC=7 1X=3	NC=6 1X=4 MX=1	NC=4 1X=2 MX=2 MIX=1 CYC=1	NC=3 1X=1 CYC=5	NC=3 MX=1 MIX=1 CYC=5	NC=2 MX=1 MIX=1 CYC=6	1X=1 CYC=9
1.5	NC=6 1X=4	NC=3 1X=3 MIX=2 CYC=2	NC=2 1X=2 MX=1 MIX=2 CYC=3	NC=1 1X=1 MIX=2 CYC=6	NC=1 1X=1 MIX=1 CYC=7	CYC=10	CYC=10	CYC=10	CYC=10
2	NC=5 1X=3 MIX=2	NC=2 1X=2 MX=2 MIX=3 CYC=1	MIX=3 CYC=7	MIX=1 CYC=9	MIX=1 CYC=9	CYC=10	CYC=10	CYC=10	CYC=10
2.5	NC=2 1X=3 MX=1 MIX=4	1X=1 MX=3 MIX=3 CYC=3	MX=1 CYC=9	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10
3	NC=1 1X=1 MX=3 MIX-5	MX=3 MIX=3 CYC=4	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10

TABLE XLIII

SYSTEM IDENTIFICATION RESULTS FOR A CYCLE PATTERN (PERIOD=8)

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=9 1X=1	NC=9 1X=1	NC=9 1X=1	NC=8 1X=1 MX=1	NC=8 1X=1 MX=1	NC=7 1X=1 MX=2	NC=6 1X=2 MX=2	NC=5 1X=4 MX=1	NC=6 1X=2 NX=1 CYC=1
1	NC=9 1X=1	NC=5 1X=4 MX=1	NC=4 1X=2 MX=2 CYC=2	NC=3 1X=2 MX=2 SHIFT=1 CYC=2	NC=2 1X=3 MX=1 CYC=5	NC=1 1X=1 MIX=1 CYC=7	1X=2 MIX=1 CYC=7	NC=2 1X=1 MIX=1 CYC=6	NC=1 1X=1 MIX=1 CYC=7
1.5	NC=8 1X=1 SYS=1	NC=5 1X=1 TREND=1 MIX=1 CYC=2	NC=3 1X=1 CYC=6	NC=1 1X=1 CYC=8	NC=1 CYC=9	NC=1 CYC=9	C6C=10	CYC=10	CYC=10
2	NC=6 1X=2 MX=1 MIX=1	NC=2 MIX=3 CYC=5	SYS=1 MIX=1 SHIFT=1 CYC=8	SYS=10 MIX=1 CYC=8	CYC=10	CYC=10	CYC-10	CYC=10	CYC=10
2.5	NC=5 MX=1 MIX=2 CYC=2	MIX=3 CYC=7	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10	CYC=10
3	NC=2 1X=1 MIX=4 CYC=3	MIX=1 CYC= 9	CYC=10	CYC= 10	CYC=10	CYC=(10)	CYC=10	CYC=10	CYC=10

TABLE XLIV

SYSTEM IDENTIFICATION RESULTS FOR A CYCLE PATTERN (PERIOD=12)

	OUT-OF-CONTROL WINDOW								
MAGNITUDE OF CHANGE	8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=7 1X=1 MX=1 STRAT=1	NC=7 1X=2 STRAT=2	NC=8 1X=2	NC=7 1X=3	NC=6 1X=4	NC=5 1X=3 MIX=2	NC=4 TREND=1 1X=3 MX=2
1	NC=8 MX=1 SHIFT=1	NC=7 1X=2 MX=1	NC=6 SHIFT=2 1X=1 MX=1	NC=6 1X=1 MX=1 SHIFT=2	NC=6 1X=2 MX=1 CYC=1	NC=4 1X=2 MX=1 CYC=3	NC=4 MX=1 CYC=5	NC=3 MX=1 MIX=2 CYC=4	NC=2 1X=1 MIX=1 CYC=6
1.5	NC=4 1X=3 MX=2 SHIFT=1	NC=3 1X=2 MX=1 TREND=1 MIX=1 CYC=2	NC=1 1X=3 MX=1 MIX=1 TREND=1 CYC=3	NC=1 1X=1 MX=2 MIX=1 CYC=5	MIX=1 CYC=9	MIX=1 CYC= 9	MIX=1 CYC= 9	SHIFT=1 CYC=9	CYC= 10
2	NC=2 1X=3 MX=4 SHIFT=1	NC=1 1X=1 MIX=3 SYS=1 CYC=4	NC=1 MIX=1 SYS=1 CYC=7	MIX=1 CYC=8	CYC=10	CYC= 10	CYC=10	CYC=10	CYC=10
2.5	1X=3 MX=3 SHIFT=1 MIX=1 CYC=2	SYS=1 MIX=4 CYC=5	SYS=1 MIX=1 CYC=8	SHIFT CYC=8	CYC=10	CYC= 10	CYC=10	CYC= 10	CYC=10
3	TREND=1 SHIFT=1 MX=2 MIX=2 CYC=4	TREND=1 SHIFT=1 MIX=1 CYC=7	CYC= 10	SHIFT=1 CYC=9	CYC=10	SHIFT=1 CYC=9	CYC=10	CYC= 10	CHC= 10

TABLE XLV

SYSTEM IDENTIFICATION RESULTS FOR A SHIFT PATTERN

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=8 1X=1 STRAT=1	NC=7 1X=1 MX=1 SHIFT=1	NC=4 1X=2 STRAT=2 SHIFT=2	NC=4 1X=2 STRAT=1 SHIFT=2	NC=4 1X=2 MX=1 SHIFT=3	NC=2 1X=3 MX=1 SHIFT=3 STRAT=1	NC=1 1X=3 MX=1 SHIFT=3	1X=3 MX=3 SHIFT=4	1X=2 MX=3 SHIFT=5
1	NC=7 1X=1 MX=1 SHIFT=1	NC=4 1X=1 MIX=1 SHIFT=4	NC=1 1X=2 SHIFT=6 CYCLE=1	NC=1 1X=1 TREND=1 CYCLE-1	1X=1 TREND=1 SHIFT=8	TREND=1 SHIFT=9	TREND=2 SHIFT=8	TREND=2 SHIFT=8	TREND=2 SHIFT=8
1.5	NC=2 1X=4 MX=3 SHIFT=1	NC=2 TREND=1 SHIFT=7	SHIFT=10	TREND=2 SHIFT=8	TREND=1 SHIFT=9	SHIFT=10	SHIFT=10	SHIFT=10	SHIFT=10
2	1X=2 MX=1 MIX=2 CYC=2 SHIFT=4	TREND=1 SHIFT-9	TREND=1 SHIFT=9	TREND=2 SHIFT=8	TREND=1 SHIFT=9	SHIFT=10	SHIFT=10	TREND-1 SHIFT=9	SHIFT-10
2.5	MX=1 MIX=1 CYC=3 TREND=2 SHIFT=3	TREND=1 SHIFT=9	TREND=1 SHIFT=9	TREND=3 SHIFT=7	TREND=2 SHIFT=8	TREND=1 SHIFT=9	TREND=1 SHIFT=9	TREND=3 SHIFT=7	TREND=1 SHIFT=9
3	MX=1 MIX=1 CYC=2 TREND=2 SHIFT=4	TREND=1 SHIFT=8 MIX=1	TREND=2 SHIFT=8	TREND=3 SHIFT=7	TREND=2 SHIFT=8	TREND=3 SHIFT=7	TREND=1 SHIFT=9	TREND=3 SHIFT=7	TREND=1 SHIFT=9

TABLE XLVI

SYSTEM IDENTIFICATION RESULTS FOR A MIXTURE PATTERN

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.5	NC=4 1X=3 STRAT=2 TREND=1	NC-6 1X=3 STRAT=1	NC=3 1X=4 MX=1 TREND=1 STRAT=1	NC=5 1X=4 CYCLE=1	NC=4 1X=1 MX=3 MIX=2	NC=4 1X=3 MX=2 MIX-1	NC-3 1X=3 MX=2 MIX=2	NC=3 1X=1 MX=2 CYC=3 MIX=1	NC=4 1X=1 STRAT=1 CYC=1 MIX=3
1	NC=4 1X=3 STRAT=1 TREND=1 SHIFT=1	NC=5 1X=3 CYC=1 MIX=1	NC=2 1X=1 MX=1 CYC=2 STRAT=1 MIX=2	NC=3 1X=1 MX=1 CYC=2 MIX=3 SYS=1	NC=2 CYC=3 SYS=1 MIX=4	NC=2 SHIFT=1 CYC=1 SYS=1 MIX=5	NC=2 1X=1 SHIFT=1 CYC=3 MIX=3	NC=2 SHIFT=1 CYC=3 MIX=4	NC=2 CYC=2 MIX=6
1.5	NC=2 1X=2 MX=3 STRAT=1 MIX=2	NC=3 1X=3 CYC=2 MIX=2	NC=1 MX=1 CYC=3 MIX=5	NC=1 CYC=4 MIX=5	CYC=4 MIX=6	CYC=2 MIX=8	TREND=1 CYC=3 MIX=6	TREND=1 CYC=4 MIX=5	TREND=1 CYC=3 MIX=6
2	NC=3 MX=1 CYC=2 MIX=4	CYC=4 MIX=6	CYC=3 MIX=7	SHIFT=1 CYC=3 MIX=6	CYC=3 MIX=7	SHIFT=2 CYC=1 MIX=7	CYC=4 MIX=6	CYC=4 MIX=6	CYC=6 MIX=4
2.5	1X=2 CYC=2 MIX=6	CYC=1 MIX=9	CYC=3 MIX=7	SHIFT=1 CYC=2 MIX=7	SHIFT=1 CYC=3 MIX=6	SHIFT=2 CYC=2 MIX=6	CYC=4 MIX=6	CYC=4 MIX=6	CYC=4 MIX=6
3	1X=1 CYC=2 MIX=7	SHIFT=1 CYC=2 MIX=7	CYC=4 MIX=6	SHIFT=1 CYC=3 MIX=6	SHIFT=1 CYC=4 MIX=5	SHIFT=2 CYC=2 MIX=6	CYC=4 MIX=6	CYC=3 MIX=7	SHIFT=1 CYC=3 MIX=6

TABLE XLVII

SYSTEM IDENTIFICATION RESULTS FOR A TREND PATTERN

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.05	NC=8 1X=1 STRAT=1	NC=8 1X=2	NC=4 1X=2 MX=2 SHIFT=1 STRAT=1	NC-2 1X=2 MX=2 SHIFT=2 TREND=2	1X=3 MX=1 SHIFT-4 TREND=3	MX=1 SHIFT=6 TREND=3	SHIFT=5 TREND=5	SHIFT=1 TREND=9	SHIFT=1 TREND=9
.10	NC=8 1X=1 STRAT=1	NC=5 1X=1 SHIFT=2	1X=2 MIX=13 SHIFT=5 TREND=2	CYCLE=1 SHIFT=7 TREND=2	SHIFT=3 TREND=7	TREND=10	SHIFT=2 TREND=8	TREND=10	TREND=10
.15	1X=1 STRAT=1	NC=5 1X=1 MIX=1 SHIFT=3	SHIFT=7 TREND=3	SHIFT=5 TREND=5	MIX=1 SHIFT=1 TREND=8	TREND=10	SHIFT=1	TREND=10	TREND=10
.20	NC=9 1X=1	NC=2 1X=2 MIX=1 MX=1 SHIFT=4	MIX=1 SHIFT=4 TREND=5	SHIFT=3 TREND=7	MIX=1 SHIFT=1 TREND=8	TREND=10	TREND=10	TREND=10	TREND=10
.25	NC=8 1X=1 MX=1	1X=2 MX=1 SHIFT=4 TREND=3	SHIFT=1 MIX=1 TREND=8	MIX=1 SHIFT=2 TREND=7	MIX=1 SHIFT=2 TREND=8	TREND=10	TREND=10	TREND=10	TREND=10

TABLE XLVIII

SYSTEM IDENTIFICATION RESULTS FOR A STRATIFICATION PATTERN

MAGNITUDE OF CHANGE	OUT-OF-CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
.2	NC=6 1X=1 STRAT=3	NC=4 1X=1 STRAT=5	NC=1 1X=1 STRAT=8	1X=1 STRAT=9	STRAT=10	STRAT=10	STRAT=10	STRAT=10	STRAT=10
.4	NC=6 1X=1 STRAT=3	NC=4 1X=1 STRAT=5	NC=2 1X=1 STRAT=7	1X=1 STRAT=9	STRAT=10	STRAT=10	STRAT=10	STRAT=10	STRAT=10
.6	NC=8 1X=1 STRAT=1	NC=6 1X=1 STRAT=3	NC=5 1X=1 STRAT=4	NC=4 1X=1 STRAT=5	NC=4 1X=1 STRAT=5	NC=3 STRAT=7	NC=3 STRAT=7	NC=3 STRAT=7	NC=3 STRAT=7
.8	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1	NC=8 1X=1 STRAT=1

TABLE XLIX

PARAMETER ESTIMATION SUMMARY FOR A SYSTEMATIC PATTERN

LOCATION OF SHIFTED MEAN	OUT OF CONTROL WINDOW								
	0-12	0-17	0-22	0-27	0-32	0-37	0-42	0-47	0-52
102.5 97.5	-	-	-	-	-	-	-	-	104/96 31-55
105.0 95.0		108.3/91.7 9-16 108.4/91.6 9-15	108.4/91.6 9-15 108.2/91.8 9-18	106.6/93.4 9-26 107.7/92.3 9-19 105.2/94.8 10-27 105.7/94.3 13-25	103.4/96.6 7-55 106.6/93.4 9-26 105.6/94.4 9-33 105.2/94.8 10-2 105.1/94.9 13-29	104.4/95.6 7-55 106.6/93.4 9-26 103.1/96.9 14-37 106.7/93.9 9-23 104.9/95.1 10-28 105.7/94.3 13-31	105.2/94.8 7-55 103.4/96.6 12-51 104.8/95.2 10-45 105.3/94.7 12-55 105.2/94.8 9-34 103.5/96.5 14-42 105.7/94.3 13-31 106.7/93.3 9-23	105.8/94.2 7-55 103.8/96.2 12-51 105.1/94.9 10-46 105.6/94.4 12-55 105.2/94.8 9-34 106.7/93.3 9-23 103.5/96.5 14-42 104.6/95.4 13-48	106/94 7-55 104.9/95.2 12-55 106.1/93.9 12-55 105.1/94.9 10-55 105.2/94.8 9-34 104.3/95.7 14-42 106.7/93.9 9-23 105/95 13/55
107.5 92.5	110.3/89.7 8-13 110.4/89.6 7-13	106.1/93.9 6-17 110.5/89.5 8-17 107.9/92.1 10-15 109.5/90.5 7-17 106.6/93.4 7-15 108.9/91.1 10-16	106.1/93.9 6-21 110.6/89.4 8-18 108/92 10-18 109.4/90.6 7-19 107.8/92.2 10-22	105.5/94.5 8-45 107.1/92.9 6-26 109.5/90.5 8-26 107.8/92.2 10-19 108.7/91.3 7-26 108.1/91.9 7-27 108/92 10-27	105.5/94.5 5-55 106.7/93.3 8-45 107.1/92.9 6-26 109.5/90.5 8-27 106.1/93.9 10-27 108.2/91.8 7-33 107.8/92.2 7-32 108.2/91.8 10-31	106.7/93.9 5-55 107/93 8-45 106.2/93.8 6-33 108.5/91.5 8-36 106.2/93.8 10-38 108.2/91.8 7-33 107.8/92.2 7-32 108.1/91.9 10-34	107.6/92.4 5-55 106.4/93.6 7-51 107.7/92.3 8-45 107.8/92.2 9-55 106.6/93.4 6-40 108.4/91.6 8-39 107.8/92.2 7-37 106.6/93.4 10-42 107.3/92.7 7-43 107.6/92.4 10-40	108.4/91.6 5-55 107/93 7-51 108.2/91.8 8-47 108.2/91.8 9-55 106.4/93.6 6-46 108.1/91.9 8-41 106.5/93.5 10-45 107.5/92.5 7-42 107.5/92.5 7-43 107.5/92.5 10-48	108.8/91.2 5-55 107.8/92.2 7-51 108.2/91.8 8-51 108.8/91.2 9-55 107.1/92.9 6-55 107.6/92.4 8-51 107.3/92.7 10-53 107.4/92.6 7-44 107.3/92.7 7-52 107.8/92.2 10-53
110.0 90.0	111.1/88.9 6-13 111.7/88.3 6-13	109.1/90.9 5-17 112/88 6-17 110.1/89.9 9-16 111.5/88.5 6-17 108.6/91.4 5-18 111.1/88.8 10-17	109.1/90.9 5-21 112/88 6-19 110.2/89.8 9-20 111.2/88.8 6-22 110.7/89.3 10-22	107.6/92.4 7-45 110/90 5-27 111.5/88.5 6-27 109.1/90.9 9-27 111.1/88.9 6-27 110.2/89.8 5-28 110.8/89.2 10-27	107.7/92.3 5-55 108.9/91.1 7-45 109.4/90.6 5-32 111.2/88.8 6-30 108.8/91.2 9-30 110.6/89.4 6-33 110.2/89.8 5-32 110.8/89.2 10-32	109/91 5-55 109.5/90.5 7-45 109.2/90.8 5-36 110.9/89.1 6-36 109.1/90.9 9-38 110.5/89.5 6-36 110.1/89.9 5-34 110.8/89.2 10-35	110/90 5-55 109.1/90.9 7-51 110.2/89.8 7-45 109.9/90.1 7-55 109.4/90.6 5-41 110.8/89.2 6-40 110.2/89.8 6-40 109.9/90.1 5-43 110.4/89.6 10-42	110.8/89.2 5-55 109.8/90.2 7-51 110.6/89.4 7-48 110.5/89.5 7-55 109.5/90.5 5-48 110.4/89.6 6-46 109.9/90.1 6-46 110/90 5-46 110.3/89.7 10-48	111.3/88.7 5-55 110.5/89.5 7-53 110.8/89.2 7-52 111.1/88.9 7-55 109.9/90.1 5-52 110.3/89.7 6-53 109.4/90.6 6-53 109.9/90.1 5-52 110.5/89.5 10-53
112.5 87.5	113/87 6-13 108.9/91.1 6-11 113.4/86.5 6-13	111.4/88.6 5-17 113.6/86.4 6-18 111.7/88.3 6-17 113.2/86.8 6-18 110.9/89.1 5-18 112.2/87.8 8-17	111.2/88.8 5-22 113/87 6-23 111.9/88.1 6-21 113.3/86.7 6-22 111.2/88.8 5-23 112.1/87.9 8-23	109.6/90.4 6-45 112/88 5-28 113.7/86.3 6-27 111.3/88.7 6-27 113/87 6-28 112.4/87.6 5-28 112.6/87.4 8-27	109.7/90.3 5-55 110.9/89.1 6-45 111.6/88.4 5-33 113.2/86.8 6-31 111.1/88.9 6-32 112.9/87.1 6-33 112.2/87.8 5-33 112.7/87.3 8-32	111/89 5-55 111.6/88.4 6-45 111.6/88.4 5-37 113/87 6-37 111.5/88.5 6-38 112.6/87.4 6-37 112.4/87.6 5-34 112.6/87.4 8-37	112.1/87.9 5-55 111.3/88.7 6-51 112.4/87.6 6-45 111.9/88.1 6-55 111.8/88.2 5-42 112.9/87.1 6-42 111.9/88.8 6-42 112.5/87.5 6-41 112.2/87.8 5-43 112.5/87.5 8-42	112.9/87.1 5-55 112/88 6-51 112.8/87.2 6-48 112.5/87.5 6-55 111.9/88.1 5-48 112.7/87.3 6-47 111.8/88.2 6-47 112.4/87.6 6-47 112.3/87.7 5-46 112.5/87.5 8-48	113.4/86.6 5-55 112.7/87.3 6-52 112.9/87.1 6-53 113.2/86.8 6-51 112.2/87.7 5-55 112.7/87.3 6-53 112.2/87.8 6-53 111.9/88.1 6-53 112.1/87.9 5-54 112.6/87.4 8-52
115.0 85.0	110.6/89.4 5-13 113.9/86.1 5-13 110.8/89.2 6-12 115.2/84.8 6-13 112/88 8-13	113.4/86.6 5-17 114.9/85.4 5-18 112.8/87.2 5-18 114.9/85.1 6-18 114.4/85.6 8-17	113.1/86.9 5-23 114.5/85.5 5-23 113.7/86.3 6-22 115.2/84.8 6-22 113.2/86.8 5-23 114.2/85.8 8-23	114.4/85.6 8-28 111.4/88.6 6-45 114/86 5-28 115/85 5-28 113.2/86.8 5-27 115/85.1 6-28 114.3/85.7 5-28	111.4/88.6 5-55 112.8/87.2 6-45 113.6/86.4 5-33 114.8/85.2 5-32 113.3/86.7 6-32 114.8/85.2 6-33 114.2/85.8 5-33 114.5/85.5 8-33	112.8/87.2 5-55 113.5/86.5 6-45 113.6/86.4 5-37 114.8/85.2 5-37 113.4/86.6 5-38 114.6/85.4 6-37 114/86 5-37 114.6/85.4 8-37	113.8/86.2 5-55 113.3/86.7 6-51 114.3/85.7 6-45 113.7/86.3 6-55 113.7/86.3 5-43 114.7/85.3 5-42 114/86 6-42 114.4/85.6 6-42 114.2/85.8 5-43 114.4/85.6 8-43	114.7/85.3 5-55 114/86 6-51 114.8/85.2 6-48 114.3/85.7 6-55 113.9/86.1 5-48 114.5/85.5 5-47 113.7/86.3 5-47 114.3/85.7 6-48 114.2/85.7 5-47 114.5/85.5 8-48	115.2/84.8 5-55 114.6/85.4 6-55 114.9/85.1 6-52 115/85 6-55 114.2/85.8 5-53 114.4/85.6 5-53 114.2/85.8 6-52 114/86 5-53 114.2/85.8 5-53 114.6/85.4 8-53

TABLE L

PARAMETER ESTIMATION SUMMARY FOR A CYCLE PATTERN (PERIOD=4)

AMPLITUDE	OUT OF CONTROL WINDOW 0-12	0-17	0-22	0-27	0-32	0-37	0-42	0-47	0-52
2.5	-	-	-	-	-	-	-	-	-
5.0	-	-	-	-	7.0 11-33	3.4 11-55 4.4 20-45 3.7 12-55 6.8 15-31 6.9 11-37	5.5 20-45 6.8 15-31 7.1 15-31 5.3 11-33 4.1 11-55	4.5 11-55 7.3 33-51 5.9 20-45 6.9 15-44 7.1 10-39 5.3 11-33	5.2 11-55 9.4 33-53 3.9 20-56 5.5 12-55 6.9 15-45 6.8 33-49 7.4 11-39 3.9 7-47 6.1 11-53
7.5	-	2.9 5-55 3.2 9-55	3.5 13-51 3.2 9-55 10.0 7-21	3.3 5-55 4.3 13-51 4.4 13-45 3.7 9.55 10.0 7-21 9.9 11-25	4.2 5-55 5.5 13-51 5.8 13-45 4.6 9.55 8.4 7-31 9.2 9-33 9.9 11-25	4.8 5-55 6.3 13-51 6.7 13-45 5.3 9-55 8.6 7-33 6.1 9-35 7.1 11-37 9.2 9-37 9.0 6-35	5.7 5-55 7.4 13-55 8.1 13-45 6.3 9-55 8.5 7-39 6.1 9-35 7.1 11-43 9.6 9-39 6.0 6-35 8.4 11-39	6.3 5-55 8.2 13-51 8.6 13-45 6.9 9-55 8.8 7-45 6.1 9-35 7.4 11-45 9.5 9-43 5.9 6-47 8.4 11-39	7.2 5-55 9.7 13-53 6.7 13-56 7.9 9-55 9.0 7-47 6.1 9-35 7.6 11-53 9.5 9-43 5.9 6-51 8.6 11-53
10.0	-	8.9 5-17	3.5 5-55 4.1 11-51 4.9 9-45 3.8 9-55 11.3 5-23 10.0 7-23 11.6 9-20	4.3 5-55 5.1 11-51 6.0 9-45 4.6 9-55 11.3 5-23 10.0 7-23 11.5 9-23 9.8 5-19 12.5 10-25	5.5 5-55 6.6 11-51 7.7 9-45 6.0 9-55 10.1 5-31 9.3 7-31 11.7 9-33 7.7 5-31 11.6 10-29	6.3 5-55 7.6 11-51 8.8 9-45 6.8 9-55 10.7 5-35 8.9 7-35 10.0 7-37 11.7 9-37 8.3 5-35 10.9 10-35	7.5 5-55 9.1 11-51 10.5 9-45 8.1 9-55 10.5 5-41 9.0 7-39 10.0 7-43 11.8 9-40 8.0 5-41 11.1 10-39	8.3 5-55 10.1 11-51 11.0 9-45 9.0 9-55 11.0 5-47 9.0 7-42 10.2 7-45 8.3 5-47 10.9 10-45 11.9 9-45	9.5 5-55 11.7 11-53 9.1 9-56 10.3 9-55 11.1 5-49 8.9 7-47 10.3 7-53 8.3 5-51 11.2 10-53 11.6 9-53
12.5	-	4.2 8-45 11.0 5-17 11.7 5-17	4.3 5-55 4.8 11-51 6.2 8-45 4.5 9-55 13.6 5-23 12.5 7-23 13.6 8-21 12.0 5-19 13.8 7-21	5.3 5-55 6.1 11-51 7.5 8-45 5.6 9-55 12.7 5-24 11.6 7-23 12.5 7-23 13.2 8-26 10.6 5-23 14.0 7-25	6.8 5-55 8.0 11-51 9.4 8-45 7.3 9-55 12.6 5-33 11.0 7-31 11.8 7-31 13.9 7-33 10.2 5-33 13.3 7-29	7.8 5-55 9.2 11-51 10.8 8-45 8.3 9-55 13.1 5-35 11.4 7-35 12.5 7-37 10.6 5-35 12.8 7-35 13.9 7-27	9.3 5-55 11.1 11-51 12.8 8-45 10.1 9-55 12.9 5-43 11.5 7-41 12.5 7-43 10.4 7-43 13.1 7-39 14.3 8-43	10.3 5-55 12.3 11-51 13.1 8-46 11.1 9-55 13.3 5-47 11.5 7-43 12.7 7-45 12.7 7-45 13.0 7-45 14.3 8-45	11.8 5-55 14.2 11-53 13.4 8-45 12.7 9-55 13.3 5-50 11.2 7-51 12.8 7-53 12.8 7-51 13.4 7-53 13.9 7-53
15.0	-	4.8 7-45 13.1 5-17 15.0 5-17 13.8 5-17	5.1 5-55 5.6 11-51 7.2 7-45 5.4 7-55 15.8 5-23 13.2 5-21 12.6 5-23 16.1 7-21 12.7 5-20 16.3 7-21	6.3 5-55 7.1 11-51 8.8 7-45 6.7 7-55 15.0 5-26 13.1 5-25 12.4 5-25 15.7 7-27 12.9 5-25 16.5 7-25	8.1 5-55 9.3 11-51 11.1 7-45 8.5 7-55 14.9 5-33 12.9 5-31 14.2 7-31 16.4 7-33 12.5 5-33 15.0 7-33	9.3 5-55 10.8 11-51 12.7 7-45 9.8 7-55 15.4 5-35 13.4 5-36 15.0 7-37 16.5 7-37 12.9 5-37 15.3 7-35	11.1 5-55 13.1 11-51 13.1 11-51 11.7 7-55 15.3 5-43 13.5 5-43 13.8 5-43 12.7 5-41 15.4 7-41 16.8 7-43	12.3 5-55 14.6 11-51 15.6 7-46 12.9 7-55 15.7 5-47 15.7 5-47 13.9 5-47 16.9 7-47 13.1 5-47 15.5 7-47	14.1 5-55 16.7 11-53 15.4 7-49 14.8 7-55 15.7 5-51 15.7 5-51 15.3 7-53 16.5 7-53 13.4 5-33 15.9 7-53

TABLE LI

PARAMETER ESTIMATION SUMMARY FOR A CYCLE PATTERN (PERIOD=8)

AMPLITUDE	OUT OF CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
2.5	-	-	-	-	-	-	-	-	5.7 23-53
5.0	-	-	7.3 14-25 6.9 6-21	6.9 6-21 9.7 11-25	3.5 11-51 4.8 20-45 7.3 15-27 6.2 6-27 9.7 11-25	3.2 11-55 4.2 11-51 5.1 20-45 5.7 23-55 7.3 15-27 6.2 6-27 5.8 11-41	3.8 11-55 4.9 11-51 4.8 20-45 6.3 23-55 7.3 15-27 5.0 6-41 8.5 11-22	4.2 11-55 5.4 11-51 7.7 20-33 6.8 23-55 5.6 6-48 9.7 11-25	4.8 11-55 6.3 11-49 4.8 20-50 7.4 23-55 7.3 15-27 5.7 6-45 8.5 11-22
7.5	-	3.7 6-55 9.6 6-18	3.6 6-55 3.9 9-51 7.8 6-25 8.9 10-23 8.9 6-21 10.9 10-21	3.6 6-55 4.4 9-51 5.1 14-45 5.6 13-55 9.6 6-18 9.7 10-26 11.4 10-26	3.9 6-55 5.3 9-51 5.7 14-45 6.1 13-55 7.4 6-29 6.9 15-33 8.2 6-27 11.4 10-26	4.9 6-55 6.3 9-51 5.9 14-45 6.9 13-55 7.8 6-34 8.8 10-38 8.4 6-29 11.4 10-26	5.6 6-55 7.2 9-51 6.5 14-45 7.8 13-55 8.0 6-41 6.1 17-37 9.4 17-37 7.6 6-42 9.0 10-39	6.2 6-55 7.9 9-51 9.4 14-34 8.5 13-55 8.0 6-42 5.9 17-38 9.4 10-34 8.0 6-48 9.1 10-38	7.0 6-55 9.0 9-49 7.5 14-51 9.4 13-55 8.1 6-48 9.4 10-34 7.6 15-34 8.4 6-46 9.1 10-38
10.0	-	4.1 5-55 3.4 7-51 4.2 10-45 3.4 7-51 4.2 10-45 11.6 6-18 8.3 6-18	3.9 5-55 4.7 7-51 5.1 10-45 5.6 12-55 9.8 6-25 11.7 9-23 13.4 9-22 10.9 6-22	4.4 5-55 5.5 7-51 5.9 10-45 6.3 12-55 11.0 6-22 12.3 9-26 14.1 9-26 10.7 6-27	4.9 5-55 6.7 7-51 6.6 10-45 6.9 12-55 10.0 6-31 9.9 15-29 12.4 9-30 9.0 11-33 10.8 6-29 14.1 9-27	6.1 5-55 8.1 7-51 7.6 10-45 8.2 12-55 10.2 6-34 9.9 15-29 11.3 9-38 9.8 11-34 10.5 6-33 11.9 9-33	7.1 5-55 9.2 7-51 9.0 10-45 9.4 12-55 9.9 6-44 9.4 15-43 8.8 9-48 9.4 11-39 11.8 9-39 10.0 6-43	7.8 5-55 10.2 7-51 11.7 10-39 10.3 12-55 10.4 6-46 9.4 15-43 11.6 9-38 9.1 11-42 10.4 6-48 11.3 9-46	8.3 5-55 11.4 7-49 10.1 10-51 11.5 12-55 9.9 6-[illegible] 9.1 1[illegible]-49 10.1 9-48 8.7 11-53 10.9 6-47 11.3 9-46
12.5	3.6 5-55 3.5 7-51	4.5 5-55 4.1 7-51 4.8 7-45 4.9 10-55 11.1 5-18 10.6 5-18 14.9 6-17	5.6 7-51 6.2 7-45 6.0 10-55 10.2 5-25 11.5 10-21 12.8 6-23 13.9 10-22 13.0 5-23 14.4 6-22 4.6 5-55	6.7 7-51 7.2 8-45 6.8 10-55 13.3 6-23 11.5 10-21 13.0 6-27 13.9 10-22 12.8 5-27 15.3 6-27 5.3 5-55	8.1 7-51 7.8 7-45 8.1 10-55 10.6 5-31 11.2 10-30 13.9 6-31 11.4 10-33 13.0 5-31 14.1 6-30 6.1 5-55	7.6 5-55 9.8 7-51 9.7 7-45 9.8 10-55 11.2 5-36 10.4 10-34 13.0 6-38 12.5 5-34 13.3 6-37 12.4 10-34	8.9 5-55 11.2 7-51 11.3 8-45 11.2 10-55 12.3 6-44 11.1 10-43 10.6 6-48 12.0 10-39 12.4 5-43 13.6 6-39	9.8 5-55 12.4 7-51 13.9 7-39 12.3 10-55 11.7 5-46 11.1 10-43 13.4 6-38 11.7 10-45 12.6 5-48 13.3 6-47	11.1 5-55 13.9 7-49 12.5 7-51 13.7 10-55 11.3 5-53 11.2 10-50 11.7 6-50 11.2 10-53 13.2 5-47 12.9 6-50
15.0	3.8 5-55 3.7 6-51 3.3 6-45	4.8 5-55 4.6 6-51 5.0 6-45 5.2 10-55 13.0 5-18 15.6 6-17 12.4 5-18 17.2 6-17 12.7 8-19	5.3 5-55 6.3 6-51 7.0 6-45 6.5 10-55 12.3 5-25 13.3 6-21 14.7 7-22 14.7 7-22 15.1 5-23 16.8 6-22	7.8 7-51 8.1 7-45 7.7 10-55 13.1 5-25 13.5 7-23 15.7 6-27 15.0 5-27 15.0 5-27 17.6 6-27 6.2 5-55	7.4 5-55 9.3 6-51 9.1 6-45 9.3 10-55 13.1 5-32 13.5 7-30 13.2 7-33 13.2 7-33 14.0 5-33 16.5 6-30	9.1 5-55 11.3 6-51 11.2 6-45 11.3 10-55 13.5 5-37 13.0 7-37 14.5 5-37 14.5 5-37 15.7 6-37 14.3 7-34	10.6 5-55 13.3 7-51 13.6 7-45 13.0 10-55 13.3 5-44 13.6 7-43 10.4 10-55 10.4 10-55 14.7 5-43 15.8 6-42	11.8 5-55 14.3 6-51 15.7 6-39 14.3 10-55 14.1 5-47 13.4 6-45 13.9 7-46 13.9 7-46 14.9 5-48 15.7 6-47	13.3 5-55 16.0 6-49 14.5 6-51 16.0 10-55 13.5 5-53 13.7 7-51 13.3 8-53 13.3 8-53 15.1 5-49 15.4 6-50

TABLE LII

PARAMETER ESTIMATION SUMMARY FOR A CYCLE PATTERN (PERIOD=12)

AMPLITUDE	OUT OF CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
2.5	-	-	-	-	-	-	-	-	-
5.0	-	-	-	-	4.5 12-51	5.2 12-51 5.8 12-37 4.6 6-28	4.8 31-55 6.0 12-51 4.3 14-55 8.9 31-45 6.2 12-38	5.1 17-55 6.7 12-51 4.9 14-55 6.8 23-55	6.7 34-55 7.0 12-51 9.7 31-46 5.3 14-55 6.6 12-39 5.3 11-15
7.5	-	3.3 7-55 7.8 6-17	3.9 7-55 3.6 12-55 7.8 6-17	4.4 7-55 4.9 11-51 3.5 12-55 7.8 6-17 7.8 11-23	4.9 7-55 5.7 11-51 6.3 29-45 4.2 12-55 6.5 7-29 6.4 12-29 7.9 10-33 6.8 6-29 8.3 11-29	6.7 11-51 8.0 29-45 5.2 12-55 6.4 8-29 6.4 12-29 6.5 6-34 7.9 11-37 8.3 11-24 5.6 7-55	7.9 11-51 10.8 29-45 6.0 12-55 6.5 7-29 7.3 12-42 7.2 11-41 8.3 9-42 6.8 6-36 6.4 7-55	8.9 11-51 12.0 29-46 6.4 8-40 8.8 12-48 7.0 19-46 6.8 6-36 8.8 11-42 7.2 11-41 7.2 12-55	9.4 11-51 12.0 29-46 7.9 12-55 7.4 19-47 6.1 7-53 6.8 6-36 8.8 12-52 7.8 11-53 7.3 11-52 7.9 7-55
10.0	-	3.7 6-55 4.6 7-51 4.5 9-55 10.1 6-17	4.6 6-55 5.6 7-51 4.2 9-55 8.3 6-21 11.1 9-20 10.2 6-18 7.5 10-27	5.3 6-55 6.5 7-51 5.9 12-45 4.7 9-55 7.9 6-19 8.4 9-23 8.6 6-28 10.4 10-24	6.1 6-55 7.6 7-51 7.2 12-45 5.6 9-55 8.4 6-29 9.6 9-29 8.9 10-29 9.5 9-33 9.2 6-29 9.7 10-28	8.8 7-51 9.0 12-45 6.6 9-55 8.3 6-31 9.6 9-29 9.3 10-37 8.7 6-38 8.5 10-37 6.6 9-55 6.9 6-55	8.0 6-55 10.3 7-51 10.7 12-45 7.9 9-55 8.4 6-40 8.5 9-40 9.8 10-42 10.8 9-42 9.2 6-36 9.5 10-41	9.1 6-55 11.4 7-51 11.3 12-47 9.1 9-55 8.3 6-41 9.0 9-47 11.1 10-48 10.8 9-43 9.2 6-36 9.4 10-42	10.0 6-55 12.0 7-52 11.3 12-47 10.0 9-53 8.2 6-53 9.0 9-48 11.1 10-53 10.0 9-52 8.1 6-48 9.5 10-53
12.5	3.1 6-55 4.4 8-55	4.3 6-55 5.3 7-51 4.7 7-45 4.8 8-55 12.1 6-18	5.4 6-55 6.5 7-51 6.0 7-45 4.6 8-55 10.5 6-22 12.5 8-21 9.7 6-23 9.8 7-27	6.3 6-55 7.7 7-51 7.4 7-45 5.5 8-55 9.5 6-26 12.5 8-25 10.8 6-28 13.1 7-25	7.2 6-55 9.0 7-51 8.9 7-45 6.7 8-55 10.8 6-30 12.1 9-30 12.0 8-30 11.7 8-33 11.8 6.31 12.2 7-29	8.3 6-55 10.5 7-51 10.6 7-45 8.1 8-55 10.8 6-36 12.1 9-30 12.1 8-37 11.1 6-38 11.2 7-37 8.1 9-55	9.6 6-55 12.3 7-51 12.7 7-45 9.7 8-55 10.9 6-40 10.8 9-41 12.6 8-43 13.3 8-42 11.5 6-40 12.0 7-42	11.0 6-55 13.8 7-51 13.3 7.47 10.9 6-45 11.5 9-47 13.6 8-48 11.2 9-55 11.5 6-40 12.1 7-46 11.1 8-55	12.1 6-55 14.5 7-51 12.3 7-53 12.3 8-55 10.5 6-50 11.5 9-48 13.7 8-52 12.4 8-53 10.9 6.52 11.3 7-53
15.0	3.3 5-55 3.9 7-51 3.3 7-45 4.5 7-55	4.7 5-55 6.0 7-51 5.3 7-45 4.9 7-55 15.0 6-17 14.8 7-18 13.9 6-17	6.0 5-55 7.4 7-51 7.1 7-45 11.3 6-23 14.8 7-22 11.9 6-23 11.6 6-37 5.6 7-55 12.5 7-23 5.3 7-55	8.8 7-51 8.7 7-45 6.6 7-55 12.0 6-28 12.7 7-28 14.8 7-25 13.0 6-28 13.2 6-28 7.1 5-55	8.1 5-55 10.4 7-51 10.5 7-45 8.0 7-55 13.2 6-31 14.1 7-31 13.9 6-30 14.0 7-33 14.2 6-31 14.5 6-29	9.5 5-55 12.2 7-51 12.6 7-45 13.2 6-35 14.5 7-37 13.5 6-37 13.5 6-38 9.4 7-55 9.7 7-55	11.1 5-55 14.4 7-51 15.1 7-45 11.6 7-55 13.3 6-42 13.3 7-42 14.7 6-43 15.8 7-42 13.8 6-41 14.4 6-42	12.6 5-55 16.1 7-51 15.8 7-47 13.1 6-47 13.9 7-48 16.1 7-48 12.8 6-48 14.3 6-47 13.3 7-55 13.3 7-55	14.0 5-55 17.0 7-51 14.8 7-53 12.9 6-53 15.0 6-53 13.2 6-52 13.6 6-53 14.8 7-53 13.9 7-52 14.7 7-55

TABLE LIII

PARAMETER ESTIMATION SUMMARY FOR A SHIFT PATTERN

LOCATION OF SHIFTED MEAN	OUT OF CONTROL WINDOW 8-12	8-17	8-22	8-27	8-32	8-37	8-42	8-47	8-52
102.5	-	103.6 8-18	103.8 8-18 104.4 11-27	103.9 8-18 105.1 11-27	103.9 8-18 105.1 11-27 106.5 22-31	106.5 22-31 103.9 8-18 105.1 11-27	106.5 22-31 103.9 8-18 105.1 11-27	106.5 22-31 103.9 8-18 102.4 7-46 105.1 11-27	106.5 22-31 103.9 8-18 102.6 7-47 1[illegible].5 12-53 105.1 11-27
105.0	104.7 10-15	106.0 7-18 106.1 10-16 106.9 10-18 105.3 7-12	104.1 17-26 106.4 7-18 106.9 10-22 107.5 10-18 105.2 7-19 105.0 7-22	106.4 7-18 106.9 10-23 104.6 7-26 106.9 10-21 105.2 7-19 104.8 7-33	106.4 7-18 105.7 10-36 104.4 7-32 106.9 10-21 105.2 7-19 107.3 10-31 105.1 12-32 105.8 7-33	106.4 7-18 106.4 10-36 104.4 7-35 106.9 10-21 105.2 7-15 107.2 10-36 105.2 12-34 103.6 8-39 106.2 7-35	105.4 7-41 106.4 10-36 104.4 7-35 104.9 10-46 104.6 7-43 106.9 10-38 105.2 12-34 106.2 7-35	105.4 7-43 106.4 10-36 104.8 7-46 105.5 10-46 104.9 7-45 106.9 10-38 104.9 12-45 105.7 7-47	105.4 7-43 105.8 10-52 105.1 7-47 105.8 12-53 104.9 7-45 106.9 10-38 105.1 12-55 105.6 7-51
107.5	105.6 9-15	108.1 7-18 107.8 8-19 105.9 7-17 108.6 9-18 106.5 9-20 106.4 8-16 106.6 7-17	104.9 10-26 108.7 7-18 108.7 8-22 106.1 7-22 108.9 9-21 106.9 6-19 107.7 9-27 106.5 8-21 105.3 8-22 107.4 7-22	108.7 7-18 107.5 8-28 106.9 7-26 108.4 9-26 106.9 6-19 106.2 8-24 105.3 8-22 106.7 7-33	107.5 7-29 107.5 8-36 106.9 7-32 107.9 9-28 106.7 6-32 108.9 9-33 107.2 8-32 105.6 8-33	107.2 10-36 107.5 7-29 108.5 8-36 106.7 7-38 107.4 9-37 106.6 6-37 109.5 9-36 107.1 8-37 105.9 8-39	107.2 10-36 107.8 7-41 107.8 8-44 107 7-39 107.1 9-46 106.8 6-43 108.9 9-43 106.7 8-45 106.3 8-41	106.9 10-46 107.7 7-44 108.2 8-46 107.2 7-46 107.9 9-46 106.9 6-47 108.5 9-49 107.4 8-46 106.4 8-47	106.7 10-48 107.7 7-44 108 8-52 107.4 7-52 108.1 9-53 106.9 6-52 108.9 9-51 107.3 8-55
110.0	109.4 6-11 109.3 7-12 108.8 6-11 107 9-15	106.3 9-15 109.6 6-18 109.4 7-19 108.1 6-17 110.8 9-18 108.1 8-20 108.9 8-16 107.8 8-17 108.9 7-17	107.2 9-26 109.9 6-21 110.7 7-22 111.5 9-21 108.4 6-22 109.3 8-27 109 8-21 107.8 8-22 109.7 7-22	109.9 6-26 109.6 7-28 109.2 6-26 110.9 9-26 108.6 6-26 108.8 8-26 107.8 8-26 108.6 7-33	109.3 6-31 109.5 7-36 109.2 6-32 110.6 9-31 108.9 6-32 111.1 8-33 109.7 8-32 107.9 8-33 110.4 7-33	109.8 9-36 109.5 6-37 110.8 7-36 108.9 6-38 110 9-37 108.9 6-37 111.8 8-36 109.6 8-37 108.3 8-39 110.8 7-37	109.2 9-43 110.0 6-41 110 7-44 108.7 6-47 109.4 9-46 109.1 6-43 111.1 8-43 109 8-45 108.8 8-41 110.2 7-73	109.5 9-46 109.6 6-46 110.5 7-46 110.4 9-46 109.3 6-47 110.8 8-49 109.9 8-46 108.9 8-47 110.5 7-47	109.2 9-53 109.3 6-53 110.4 7-52 109.8 6-52 110.5 9-53 109.3 6-52 111.2 8-51 109.6 8-55 108.9 8-51 110 7-54
112.5	111.1 6-11 110.5 6-11 109.2 8-15	109.3 8-16 111.6 6-18 111.3 7-19 110.2 6-17 113.2 8-18 110 8-20 110.1 7-16 109.4 7-17 111.2 7-17	108.9 8-26 112.1 6-21 113 7-22 110.6 6-22 114 8-21 111.1 8-27 110.7 7-21 109.7 7-22 112.1 7-22	112.2 6-26 111.8 7-28 113.4 8-26 110.1 6-28 110.7 7-26 109.8 7-26 110.4 7-33	111.6 6-31 111.5 7-36 111.5 6-36 113.2 8-31 111.3 6-32 110 7-33 112.8 7-33 113.5 8-33	112.1 8-36 111.9 6-37 113.2 7-36 111.2 6-38 112.5 8-37 111.2 6-37 114.3 8-36 110 7-39 113.2 7-37	111.5 8-43 112.4 6-41 112.3 7-44 110.8 6-47 111.7 8-46 111.4 6-43 113.5 8-43 110.9 7-45 112.6 7-43	111.9 8-46 112 6-46 112.9 7-46 112.9 8-46 111.6 6-47 113.1 8-49 112.9 7-47	111.5 8-53 111.6 6-53 112.8 7-52 113 8-53 111.7 6-52 113.8 8-51 111.7 7-55 111.1 7-51 112.4 7-54
115.0	112.8 6-11 112.2 6-11 110.7 8-15 111.7 6-11	111.8 8-16 112.5 6-19 112.3 6-17 115.5 8-18 111.9 8-20 112.3 7-16 111.7 7-17 112.8 6-17	110.9 8-26 114.2 6-21 112.8 6-22 116.5 8-21 113 8-27 113 7-21 112.1 7-22 113.9 6-22	114.4 6-26 113.6 6-28 115.9 8-26 112.3 6-28 113.1 7-26 112.2 7-26 112.1 6-33	113.9 6-31 113.3 6-36 113.8 6-32 115.7 8-31 113.6 6-32 115.9 8-33 112.3 7-33 114.7 6-33	114.6 8-36 114.3 6-37 113.5 6-38 114.9 8-37 113.6 6-37 116.8 8-36 112.6 7-39	113.9 8-43 114.8 6-41 114.3 6-44 112.9 6-47 113.9 8-46 113.7 6-43 116 8-43 113.2 7-45 114.7 6-43	114.4 8-46 114.4 6-46 115.1 6-46 115.4 8-46 114 6-47 115.5 8-49 115.2 6-47	113.9 8-53 113.9 6-53 115 6-52 115.5 8-53 114.1 6-52 116.3 8-51 114 7-55 113.6 7-51 114.5 6-54

TABLE LIV

PARAMETER ESTIMATION SUMMARY FOR A MIXTURE PATTERN

LOCATION OF SHIFTED MEAN

	OUT OF CONTROL WINDOW 0-12	0-17	0-22	0-27	0-32	0-37	0-42	0-47	0-52
102.5 97.5	–	–	–	–	105.0/94.6 50-55 105.7/94.3 10-33	103.6/96.4 10-46	103.9/96 25-51 105.9/94.1 10-32	103.9/96.1 25-55	103.8/96.2 27-41 104.8/95.2 25-47 102.7/97.3 17-53
105.0 95		105.6/94.4 7-14	104.6/95.4 10-18 107.1/92.9 10-23	105.5/94.5 7-25 103.8/96.2 10-51 104.4/95.6 16-35	105.3/94.7 13-40 103.7/96.3 16-49 106.5/93.5 10-33 103.3/96.7 7-41	105.7/94.3 6-36 105.4/94.6 7-37 105/95 10-45 105.8/94.2 16-33 104.7/95.3 7-41	105.7/94.3 10-40 105.4/94.6 16-44 104.7/95.3 7-41	105/95 15-46 106/94 7-55 105.6/94.4 10-44 105.3/94.7 16-42	104.3/95.7 15-53 104.4/95.6 12-47 106.4/93.6 7-50 105.8/94.2 10-45 105.3/94.7 16-42 104.2/95.8 10-52
107.5 92.5	105.5/94.5 6-12 104.3/95.7 8-18	108.4/91.6 9-14 103.6/96.4 8-55	109.3/90.7 11-21 103.8/96.2 9-53 109.5/90.5 8-23 105.3/94.7 12-22 104/96 6-48	105.5/94.5 9-38 108.6/91.4 7-25 105.9/94.1 8-51 106.9/93.1 14-35 105.7/94.3 5-46	104.2/95.8 6-32 107.6/92.4 9-40 109.2/90.8 8-33 105.9/94.1 14-49 105.3/94.7 12-31 105.9/94.1 5-41	107.4/92.6 11-38 103.9/96 6-55 105.9/94.1 9-35 108.6/91.4 5-36 108.1/91.9 7-38 109.2/90.8 7-32 107.3/92.7 6-41 107.1/92.9 12/38	107.4/92.6 11-53 105.2/94.8 6-35 105.7/94.3 9-41 106.5/93.5 8-43 108.2/91.8 14-44 107.5/92.5 6-41	108.2/91.8 11-46 105.7/94.3 9-41 108.6/91.4 7-55 108.2/91.8 5-46 107.7/92.3 12-46	108.0/92 11-47 105.6/94.4 9-47 107.5/92.5 4-52 109.3/90.7 7-52 107.7/92.3 12-48 107.8/92.2 12-50
110.0 90.0	108.2/91.8 6-12 109.2/90.8 8-13 102.8/97.2 6-55 108.4/91.6 6-11	111.1/88.9 10-15 108.4/91.6 5-12 110.9/89.1 8-15 109.4/90.6 6-13 104.7/95.3 6-55	111.5/88.5 10-22 103.6/96.4 6-36 105.3/94.7 6-53 111.2/88.8 6-23 108.6/91.4 10-22 105.7/94.3 5-48 105.3/94.7 8-50	103.5/96.5 6-55 106.9/93.1 6-44 106.2/93.8 9-42 107.5/92.5 5-51 107.7/92.3 5-46 108.7/91.3 10-35	110.4/89.6 10-30 107.2/92.8 6-33 110.7/89.3 5-34 107.9/92.1 10-49 108.6/91.4 10-33 109.9/90.1 6-40 108.4/91.6 5-41	109.9 90 10-38 109.9/90 6-55 108.5/91.5 6-36 111.1/88.9 5-36 110.8/89.2 4-33 109.9/90.1 10-38 109.7/90.3 5-41	109.9/90 10-43 108/92 6-39 108.5/91.5 6-41 109.1/90.9 6-43 110.3/89.7 10-44 110/90 5-42	110.8/89.2 10-46 108.2/91.8 6-50 108.5/91.5 6-45 110.8/89.2 5-55 110.4/89.6 4-47 110.1/89.9 10-46	110.4/89.6 10-51 108.1/91.9 6-52 108.4/91.6 6-51 110.4/89.6 8-50
112.5 87.5	110/89.9 5-13 109.8/90.2 6-13 103.7/96.3 6-55 110/90 6-13 111/89 5-13 108.3/91.7 8-13	111.8/88.2 9-17 109.6/90.4 5-14 112/88 6-17 105.5/94.5 6-37 104.6/95.4 6-55 106.1/93.9 5-55 105.1/94.9 8-40 104.6/95.4 8-46 106.3/93.7 5-51	113.2/86.8 10-23 106.8/93.2 6-53 113.1/86.9 5-23 110/90 8-23 107.5/92.5 5-48 106.2/93.8 5-36 106.8/93.2 6-51	113.4/86.6 9-25 105.7/94.3 5-55 108.9/91.1 6-44 108.6/91.4 8-42 109.3/90.7 5-51 107.8/92.2 8-41 109.6/90.4 5-46	109.1/90.1 6-48 111.9/88.1 5-40 112.7/87.3 5-34 10[illegible].9/90.1 8-49 110.9/89.1 8-33 110.7/89.3 5-41	112.4/87.6 10-38 108.5/91.5 5-55 110.8/89.2 6-39 113.1/86.9 5-37 111.8/88.2 4-40 111.9/88.1 5-41	112.4/87.6 10-43 110.6/89.4 5-41 110.9/89.1 6-42 112.4/87.6 4-42 112.4/87.6 8-44 112.3/87.7 5-42	112.9/87.1 10-47 110.7/89.3 5-50 111.1/88.9 6-46 112.8/87.2 5-55 112.5/87.5 4-47 112.3/87.7 8-48	112.7/87.3 9-51 110.7/89.3 5-52 111.1/88.9 6-52 112.5/87.5 6-52 112.2/87.8 8-53 112.9/87.1 5-52
115.0 85.0	111.8/88.2 5-13 112/88 6-13 104.4/95.6 5-55 112.1/87.9 6-13 112.7/87.3 5-13 109.2/90.8 6-13 111.7/88.3 7-12	113.2/86.8 7-17 114/86 6-17 107/93 5-37 107.4/92.6 5-55 106.5/93.5 6-40 106.1/93.9 7-46 107.6/92.4 5-51	108.2/91.8 5-53 114.9/85.1 5-23 112/88 7-23 109.2/90.8 5-48 108.3/91.7 5-36 108.5/91.5 6-51	114.4/85.6 7-27 107.6/92.4 5-55 110.5/89.5 5-44 110.5/89.5 7-42 111/89 5-51 111.3/88.7 5-46	110.9/89.1 5-48 113.6/86.4 5-41 114.3/85.7 4-34 113/87 7-33 112.6/87.4 5-41	113.9/86.1 7-38 110.5/89.5 5-55 112.8/87.2 5-39 115/85 5-37 113.6/86.4 4-40 113.8/86.2 5-41	112.9/87.1 5-42 114.2/85.8 4-42 114.1/85.9 6-44 114.1/85.9 5-43 114/86 7-43 112.8/87.2 5-42	114.5/85.5 7-47 112.9/87.1 5-50 113.1/86.9 5-47 115.2/84.8 5-48 114.2/85.8 4-48 114.1/85.9 6-48 114.5/85.0 5-55	114.4/85.6 7-52 112.9/87 5-52 113.2/86.8 5-52 114.4/85.6 6-53 114/86 6-53 114.8/85.2 5-52

TABLE LV

PARAMETER ESTIMATION SUMMARY FOR A TREND PATTERN

SLOPE	OUT OF CONTROL WINDOW 0-12	0-17	0-22	0-27	0-32	0-37	0-42	0-47	0-52
.25	-	- -	-	0.65 6-26 0.81 10-27	0.65 6-31 0.32 7-33	0.42 6-36 0.35 13-39 0.31 7-37	0.42 6-36 0.26 8-41 0.22 15-43 0.40 13-41 0.23 7-41	0.31 6-46 0.19 8-46 0.18 17-46 0.27 23-46 0.24 13-46 0.23 15-47 0.31 25-46 0.35 13-47 0.24 7-47	0.25 6-53 0.16 8-53 0.18 17-52 0.28 23-52 0.25 13-53 0.24 15-52 0.17 18-51 0.32 13-51 0.24 7-51
.50	-	-	0.5 6-26 0.47 7-22	0.89 6-26 0.89 16-26	0.9 6-31 0.25 8-31 0.44 16-32 0.34 12-33 0.78 15-32 0.57 18-33 0.52 7-33	0.66 6-36 0.42 8-37 0.51 12-36 0.29 16-38 0.21 12-37 0.35 14-37 0.55 12-36 0.58 15-37 0.41 18-39 0.56 7-27	0.5 6-43 0.51 8-41 0.25 12-44 0.39 14-43 0.36 12-43 0.27 15-45 0.65 18-41 0.41 7-43	0.56 6-46 0.44 8-46 0.43 12-46 0.61 16-47 0.45 12-46 0.47 14-47 0.29 12-49 0.59 15-46 0.59 18-47 0.49 7-47	0.47 6-53 0.38 8-53 0.44 12-52 0.55 16-52 0.43 12-53 0.47 14-52 0.46 12-51 0.36 15-55 0.55 18-51 0.49 7-51
.75	-	-	0.55 6-26 0.82 11-22 0.72 7-22	1.14 6-26 0.55 8-26 1.14 16-26 1.05 11-27 0.59 14-26	0.50 8-31 0.69 16-32 0.44 12-31 0.65 13-32 0.53 11-33 0.98 14-32 0.58 16-33 0.72 7-33	0.91 6-36 0.67 8-37 0.79 11-36 0.46 16-38 0.46 12-37 0.65 13-37 0.80 11-36 0.82 14-37 0.48 16-39 0.81 7-37	0.71 6-43 0.76 8-41 0.44 11-44 0.21 12-46 0.61 13-43 0.57 11-43 0.38 14-45 0.84 16-41 0.62 7-43	0.81 6-46 0.69 8-46 0.71 11-46 0.86 16-47 0.70 12-42 0.74 13-47 0.47 11-49 0.83 14-46 0.81 16-47 0.74 7-47	0.69 6-53 0.59 8-53 0.70 11-52 0.80 16-52 0.64 12-53 0.74 13-52 0.71 11-51 0.50 14-55 0.78 16-51 0.74 7-51
1.0	-	-	0.61 6-26 1.07 11-22 1.09 13-22 1.43 12-21 0.97 7-22	1.39 6-26 0.80 9-26 1.47 13-26 0.68 11-26 1.30 11-27 0.85 12-26 0.91 15-26	0.75 8-31 1.09 13-32 0.80 11-31 0.98 12-32 0.71 11-33 1.17 12-32 0.84 15-33 0.91 7-33	1.16 6-36 0.92 8-37 1.04 11-36 0.79 13-38 0.76 11-37 0.95 12-37 1.05 11-36 1.05 12-37 0.67 15-39 1.06 7-37	0.92 6-43 1.01 8-41 0.60 11-44 0.33 13-47 0.35 11-46 0.85 12-43 0.77 11-43 0.53 12-45 1.13 15-41 0.83 7-43	1.05 6-46 0.94 8-46 0.96 11-46 1.14 13-47 0.97 11-46 1.01 12-47 0.64 11-49 1.07 12-46 1.09 15-47 0.9 7-47	0.91 6-53 0.81 8-53 0.95 11-52 1.08 13-52 0.88 11-53 1.01 12-52 0.97 11-52 0.67 12-55 1.05 15-51 0.99 7-51
1.25	-	1.20 6-16 2.42 10-16 0.90 7-17	0.66 6-26 1.28 10-22 1.03 7-22 1.30 10-21 1.52 10-21 0.99 10-21 1.55 11-22 1.22 7-22	1.05 8-26 0.61 10-28 1.33 7-26 1.06 10-26 1.56 10-27 1.1 12-26 1.41 11-26	1.00 8-31 1.24 7-32 1.11 10-31 1.21 10-32 0.95 10-33 1.42 12-32 1.17 11-33 1.11 7-33	1.41 6-36 1.17 8-37 1.27 10-36 1.02 7-38 1.06 10-37 1.19 10-37 1.32 10-36 1.30 12-37 0.97 11-39 1.31 7-37	1.13 6-43 1.26 8-41 0.78 10-44 0.58 7-47 0.50 10-46 1.06 10-43 1.00 10-43 0.65 12-43 1.42 11-41 1.04 7-43	1.31 6-46 1.19 8-46 1.20 10-46 1.33 7-47 1.24 10-46 1.25 10-47 0.85 10-49 1.32 12-46 1.38 11-47 1.24 7-47	1.13 6-53 1.03 8-53 1.20 10-52 1.30 7-52 1.11 10-53 1.25 10-52 1.23 10-52 0.82 12-55 1.34 11-51 1.24 7-51

TABLE LVI

PARAMETER ESTIMATION SUMMARY FOR A STRATIFICATION PATTERN

STANDARD DEVIATION	OUT OF CONTROL WINDOW 0-12	0-17	0-22	0-27	0-32	0-37	0-42	0-47	0-52
1.0	1.71 5-12	1.43 4-18	1.44 4-19	0.94 9-25	1.44 4-32	1.42 4-33	1.49 4-44	1.25 4-45	1.23 4-47
	2.12 4-12	1.60 5-13	1.00 9-20	1.29 5-27	1.00 9-31	0.95 9-34	1.00 9-40	1.01 9-46	1.37 9-55
	2.39 4-13	2.10 4-14	1.30 5-23	2.07 6-28	1.21 5-31	1.13 5-36	1.52 5-50	1.34 5-50	1.10 5-50
		2.05 4-17	2.17 6-21	1.77 4-28	1.85 6-30	1.72 6-35	1.62 6-40	1.58 6-45	1.57 6-47
		1.34 5-18	1.83 4-20	1.07 9-24	1.55 4-29	1.74 4-41	2.06 4-50	1.29 4-49	1.26 4-53
			1.12 9-18	1.76 6-28	1.03 9-29	0.98 9-37	.96 9-40	0.96 9-46	0.96 9-49
			2.05 4-17	1.65 4-26	1.06 6-30	1.03 6-37	1.03 6-37	1.02 6-43	1.03 6-49
			1.11 5-19	0.98 5-27	1.59 4-34	1.50 4-34	1.43 4-38	1.38 4-44	1.36 4-52
					0.98 5-27	1.06 5-38	0.97 5-42	0.96 5-44	1.21 5-55
					0.82 8-28	0.85 8-33	0.96 8-39	1.02 8-49	0.93 8-49
2.0	2.37 5-12	1.92 4-18	1.93 4-18	2.08 4-24	2.17 4-32	2.16 4-33	2.12 4-44	1.97 4-45	1.94 4-47
	2.49 4-12	2.21 5-13	1.91 10-20	1.89 10-23	1.93 10-31	1.88 10-32	1.96 10-40	1.99 10-46	2.13 10-55
	2.52 4-13	2.59 4-14	2.01 5-23	2.03 5-27	1.93 5-31	1.92 5-32	2.13 5-50	2.02 5-50	1.88 5-50
		2.31 4-17	2.36 4-19	2.40 6-28	2.32 6-30	2.18 6-35	2.15 6-39	2.17 6-45	2.23 6-47
		1.92 5-18	1.86 9.17	2.33 4-28	2.16 4-29	2.22 4-41	2.42 4-50	1.98 4-49	1.87 4-53
			2.31 4-17	2.12 9-23	2.03 9-28	1.97 9-37	1.94 9-39	1.91 9-46	1.92 9-49
			1.75 5-19	1.66 6-24	1.88 6-28	1.84 6-37	1.84 6-37	1.80 6-42	1.90 6-49
				2.03 4-26	2.05 4-34	1.99 4-34	1.91 4-38	1.96 4-44	2.06 4-52
				1.63 5-27	1.63 5-27	1.81 5-38	1.74 5-42	1.73 5-44	1.84 5-50
					1.64 8-28	1.70 8-33	1.86 8-38	1.91 8-49	1.86 8-49
3.0	2.74 4-13	3.17 5-12	1.49 11-17	2.86 11-22	2.93 11-31	2.86 11-32	2.82 11-32	2.82 11-35	3.01 11-55
		2.68 4-17	3.13 5-19	2.87 5-27	2.75 5-31	2.75 5-31	2.75 5-32	2.75 5-32	2.75 5-32
		2.62 5-18	2.69 4-17	2.85 6-24	2.93 6-30	2.77 6-35	2.77 6-35	2.83 6-36	2.83 6-36
			2.54 5-18	2.55 4-26	2.65 4-34	2.34 6-22	2.34 6-22	2.34 6-22	2.34 6-22
				2.36 5-27	2.36 5-27	2.62 4-34	2.53 4-38	2.56 4-39	2.56 4-39
						2.62 5-38	2.55 5-42	2.55 5-44	2.55 5-44
						2.70 8-29	2.55 8-33	2.55 8-33	2.55 8-33
4.0	3.30 4-11	2.81 4-15	3.14 4-17	3.14 4-17	3.14 4-17	3.14 4-17	3.14 4-17	3.14 4-17	3.14 4-17

VITA

Jill Anne Swift

Candidate for the Degree of

Doctor of Philosophy

Thesis: DEVELOPMENT OF A KNOWLEDGE BASED EXPERT SYSTEM FOR CONTROL CHART PATTERN RECOGNITION AND ANALYSIS

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Memphis, Tennessee, November 12, 1959, the daughter of Gary and Sharon Green. Married to Dr. Fred W. Swift on June 12, 1987.

Education: Graduated from Briarcrest High School, Memphis, Tennessee, in May, 1977; received Bachelor of Science degree in Mechanical Engineering from Memphis State University, Memphis, Tennessee, in May, 1981; received Master of Science degree in Mechanical Engineering from Memphis State University, Memphis, Tennessee, in May, 1982; completed requirements for the Doctor of Philosophy degree, with a major in Industrial Engineering and Management, at Oklahoma State University in December, 1987.

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