AN EXPERT ADVISOR FOR OFF-LINE QUALITY IMPROVEMENT

by

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CHAPTER 1

INTRODUCTION

1.1 Background

Quality control programs have been recognized by industries in the United States of America as being crucial to the survival of the firm. Techniques such as statistical process control have achieved greater popularity in the U.S. as their success is made known. Some [Ishikawa 1984, Whitney 1988, Clausing and Simpson 1990] argue that more emphasis must be placed on designing quality into the product and process rather than inspecting quality in once the product/process has been developed.

1.2 Purpose of the Research

The purpose of this research is to develop an off-line quality control system that can assist in the search for continual process improvement. The system will capture knowledge about a process or product, suggest an appropriate experimental design, and measure the effectiveness of the revisions suggested by the experimental outcomes.

1.3 Discussion

Designing quality into a product or process may be achieved through the application of off-line quality techniques. Japanese engineer Genichi Taguchi has advanced a methodology for off-line quality improvement that has renewed interest in industrial experimentation during the

past decade. The Taguchi method can be segmented into Taguchi strategy and Taguchi tactics. Pignatiello [1988, pp. 247-248] writes:

> The Taguchi strategy is a systematic application of the design and analysis of experiments for the purpose of designing and improving product and process quality. The strategy involves the empirical minimization of an expected loss function to determine the *best* product design.

A similar bifurcation is expressed by Hunter [1985, p. 218]:

> Of particular importance is a careful separation of philosophy and practice. Taguchi has contributed tremendously to the increased application of statistical methods in product design and manufacture... His philosophy starts with the recognition that the greatest improvement in product quality begins with product design.
>
> There can be little argument with the expressed purpose of ongoing empirical determination of the best product and process design.

Deming [1986, pp. 23-24] begins and ends his *Fourteen Points* with this idea. Points one and fourteen, respectively, are: (1) Create constancy of purpose toward improvement of product and service with the aim to become competitive and to stay in business, and to provide jobs; and (14) Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job. Deming [1986, p. 26] elaborates on point number one: "Constantly improve design of product and service. This obligation never ceases."

Deming's [1986, p. 23] fifth point addresses the theme of continual improvement as well, stating: "Improve

constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs." The Deming cycle is his framework for the pursuit of continual process improvement. Composed of the steps plan, do, check, and act, the cycle calls for an improvement plan to be developed and implemented on a small scale, with results monitored prior to implementation for the entire system.

The Deming cycle adapted to experimental investigation is articulated by Box and Draper [1987] in their discussion of the iterative nature of the experimental learning process. The experimental learning process consists of repeated use of the four-step sequence conjecture, design, experiment, and analysis. Box and Draper [1987, p. 8] elaborate:

> By "design" we mean the synthesis of a suitable experiment to test, estimate, and develop a current conjectured model. By "analysis" we mean the treatment of the experimental results, leading either to verification of a postulated model and the working out of its consequences, or to the forming of a new or modified conjecture. These complementary processes are used many times during an investigation and, by their intelligent alternation, the experimenter's knowledge of the system becomes steadily greater.

Gitlow et al. [1989, pp. 15-16] write: "An organization's mission statement, operating philosophy, and goals should provide a framework for consistent action on a day-to-day and long-term basis."

A metric for process capability is the process capability index, of which several formulations exist. Kane [1989, p. 266] writes: "Continuous improvement requires constantly improving process capability."

The Taguchi tactics, most prominently his advocacy of signal to noise ratios and fractional factorial designs, have received considerable criticism from among statistical circles. Box [1985, p. 189] writes: "It is, I believe, very important to separate, on the one hand quality engineering ideas and, on the other statistical techniques for putting these ideas into practice." Several researchers have proposed alternative experimental design tactics to those favored by Taguchi. Huang [1987] adopts a nonparametric approach for small sample-size experiments involving factors with two and three levels. Ritchie [1988] uses minimum bias central composite designs to determine the settings of the parameters where observations are to be taken. Others concentrate on techniques that minimize the number of experimental runs required for a thorough analysis. Box [1985, p. 189] elaborates:

> These very important [quality] engineering ideas are however accompanied by proposed statistical procedures that are often unnecessarily complicated and inefficient, and sometimes naive. Specifically: (i) The sequential nature of investigation is not exploited; and (ii) an unnecessarily limited choice of designs and rationale for their use is offered in which interaction is not adequately dealt with.

Box and Jones [1992] minimize the number of runs and still meet performance criteria for various experimental objectives by conducting experiments in a split-plot mode. Kim [1988] investigates two-factor interactions using a sequential method that reduces the number of experimental runs needed to detect influential two-factor interactions.

Continual quality improvement in the form of increased process capability can be facilitated by automating the Taguchi method strategy for off-line quality so that it can be used by practitioners with limited exposure to these concepts. This research suggests a means of automating process capability improvement that is effected by a blend of the Taguchi method strategy with more classical experimental design strategies. Hunter [1985, p. 219] writes: "...the philosophy proposed by Taguchi, and modern statistical practices, go hand in hand. As students and practitioners our objectives must be to apply the best of both."

In this study, the Taguchi strategy and experimental design tactics recommendations were automated via an expert system that can analyze a process and suggest an empirical approach to improve process capability. The integration of these ideas was validated by implementation in the form of a working prototype that was used to analyze an existing process. The prototype system may be used in the two different capability improvement arenas of product design

improvement and total quality management (TQM) for process improvement.

The first of these areas, product design refinement, is the classical Taguchi method application. Once the Taguchi method had been applied and the product design had been changed, the effectiveness of the revisions was assessed by comparing pre- and post-analysis process capability indices. If the application is oriented towards TQM, process capability index comparisons may not be relevant. Instead, some other metric for process performance can be used to effect a comparison of both the pre- and post-analysis processes.

The application of expert systems to the field of statistics is not new, but surprisingly little work has been done in this area. Hand [1991, p. 1] writes: "The publication of the book Artificial Intelligence and Statistics, edited by Gale, in 1986 represented something like a doubling of the published material..." Liu [1989] identifies desirable design features for a statistical expert systems based upon a survey of one thousand American Statistical Association members. A similar study was presented by Hwang [1990], although this project focused on the evaluation, using the Analytic Hierarchy Process, of existing statistical expert systems. Platforms for the implementation of a statistical expert system are explored

by Kennedy [1990], who examines the programming aspects rather than the statistical analysis aspects of this arena.

Prototype systems have been implemented by O'Keefe [1982], Portier and Lai [1983], and Williams [1991]. Each of these systems has been targeted for a specific field of experimentation or addresses only one facet of continual process improvement.

1.4 Motivation for the Research

There has been a call from industry for research in the area of quality improvement. In an open letter, executives of six major companies (American Express, Ford Motor, IBM, Motorola, Proctor and Gamble, and Xerox) state the following [Robinson et al., 1991 pp. 94-95]:

> We believe business and academia have a shared responsibility to learn, to teach, and to practice total quality management. If the United States expects to improve its global competitive performance, business and academic leaders must close ranks behind an agenda that stresses the importance and value of TQM.
>
> Despite some successful collaboration between business and higher education in advancing total quality management, widespread adoption of TQM is moving too slowly to meet the challenge. For a variety of reasons, businesses are often hesitant to open their quality systems to academic scrutiny, thus hindering the study and understanding of TQM by the academic community. And because of the limited amount of scholarly research, many academic institutions have been slow to incorporate TQM into their core curriculum and their own administrative practices.
>
> The situation is bad for all of us. Business bears the burden of education and, in some sense, reeducating new hires. This not only represents an additional cost but also perpetuates a

> competitive disadvantage. And academic institutions that are slow to embrace TQM, at best, miss the opportunity to lead change and, at worse, run the risk of becoming less relevant to the business world.
>
> Our system of higher education is one of this country's most powerful competitive weapons. Working together, companies and institutions of higher education *must* accelerate the application of total quality management on our campuses if our education system and economy are to maintain and enhance their global positions.

The quality literature also recognizes a need for greater investigation in this area. Benton [1991] compares statistical process control and Taguchi methods, demonstrates their complementary nature, and suggests that Taguchi methods be incorporated into a total quality program. The method of incorporation is not proposed in his piece. Hunter [1985, p. 219] concludes that, "We are all involved in a learning process on behalf of product quality..." Freund [1985, p. 194] states, "Now it is essential to go through the adaptation stage to make ["off-line" quality control] fit into the mainstream of the quality effort." Kacker [1986, p. 28] agrees, and adds, "We should learn the wide implications of Taguchi's best ideas and combine them with the best engineering and statistical techniques we know."

Researchers in production and operations management (P/OM), Rao and Lingaraj [1988], Turban and Sepehri [1986], and Kempf [1985], have concluded that P/OM is faced with a number of problems that are well suited for an expert

systems approach. They segment P/OM into two major areas: strategic areas that ask what, how and when to produce; and tactical areas that deal with timing and quantity to be produced. The P/OM activity classification scheme (Table 1.1) of Rao and Lingaraj [1988] indicates that quality management programs exist in the tactical area.

Table 1.1 P/OM Activity Classification

STRATEGIC	TACTICAL
Aggregate Planning	Scheduling
Forecasting	Capacity Planning
Location	Layout
	Process and Product Design
	Quality Control
	Job Design
	Inventory Control
	Maintenance and Reliability

1.5 Contribution of the Research

The major contribution of this research lies in the formal merger of the Taguchi strategy for off-line quality control with universally accepted tactics for experimental design. A secondary contribution lies in the approach used by the experimental design module of the system. Third, a contribution is realized by validation of the prototype in a *real-world* manufacturing setting, which not only afforded the opportunity to test the system but also improved the manufacturing process at the test site. The success of this study should be replicable at numerous other manufacturing concerns.

1.6 Format of the Document

Chapter 2 of this dissertation reviews published literature regarding Taguchi methods, experimental design, computer-aided experimental design, process capability and expert systems. Chapter 3 describes the architecture of the off-line quality control expert system and the form and mechanics of the prototype system. Chapter 4 presents a validation and verification of the prototype expert system. Chapter 5 discusses the contributions, limitations, and possible future extensions of this research. Appendix A contains a partial listing of the expert system's code and Appendix B is an operating manual for the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Taguchi Methods

Ishikawa [1984] partitions the evolution of quality control efforts into three generations: (1) inspection, (2) manufacturing process control, and (3) product and process design improvement (Figure 2.1). The first two generations of quality control fall short because inspection does not improve the built-in quality of a product, and manufacturing process controls are costly. Product and process design methods as advocated by Taguchi build quality into the product and/or process, making the product (process) insensitive to variability in both the manufacturing environment and the product's use environment. In addition, improved product and process design reduces manufacturing and product lifetime costs. Kacker [1985] suggests that Taguchi's work is a major contribution in this quality control evolution.

While this approach is not solely attributable to Taguchi, he must be acknowledged as being primarily responsible for its renaissance. Earlier descriptions of similar approaches include Michaels' [1964, p. 223] description of what is essentially robust product design. Michaels writes:

> The thing which gives rise to Split-plot design, an old agricultural favorite, is the distinction between test products and environmental conditions

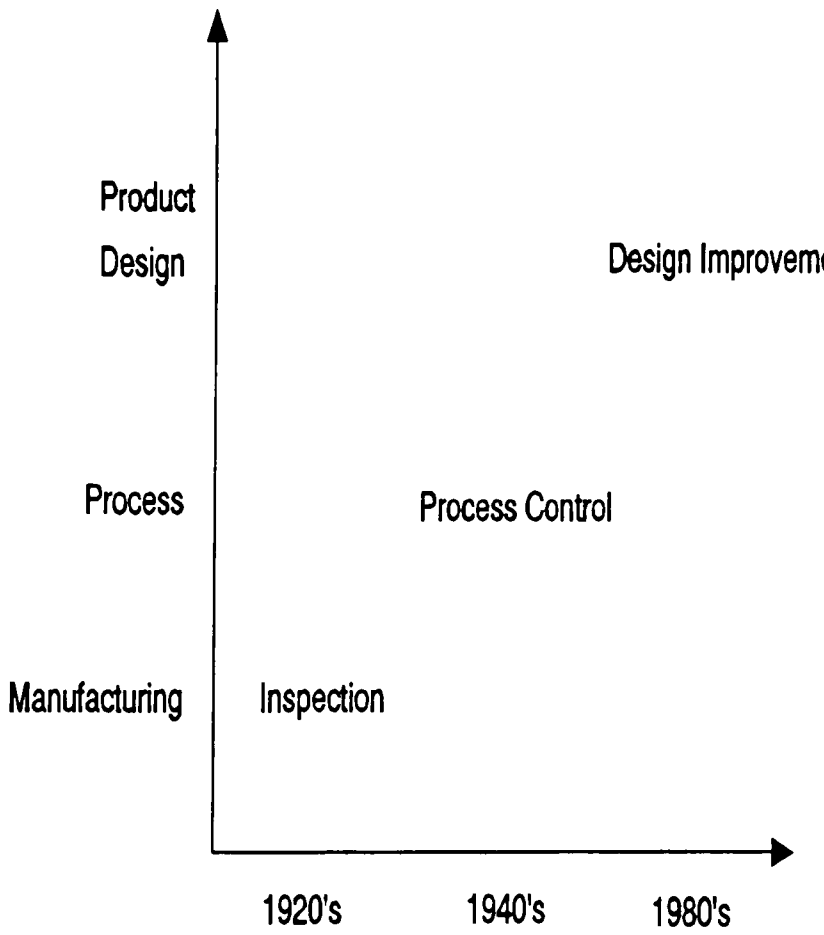

Figure 2.1 Evolution of Quality Control

> in R & D factorial experiments. Environmental factors, such as water hardness and washing techniques, are included in the experiment becausewe want to know if our products perform equally well vis-a-vis competition in all environments. In other words we want to know if there are any Product x Environmental interactions.

Earlier articles by Morrison [1957] and Zelen [1959] describe what is today called parameter design. Hitzleberger [1967] provides a case study exploring an application of parameter design. Since it is Taguchi who has resurfaced these ideas, a review of his methodology is presented in the remainder of this section. It bears repeating that the separation of strategy and tactics first delineated in section 1.3 is followed throughout the research. The strategies of Taguchi's parameter design are incorporated while the tactics are rejected in favor of mainstream approaches.

2.1.1 Parameter Design

The Taguchi method is an empirical method for statistically planned experiments for system design, parameter design, and tolerance design. Most of the literature on this method focuses on parameter design. Parameter design is a technique for finding product and/or process designs that are insensitive to noise such as manufacturing or environmental variability. León, Shoemaker, and Kacker [1987, p. 262] say, "Operationally, the objective of parameter design is to find the setting of

the product's [or the process's] design parameters that minimizes expected loss caused by noise."

2.1.2 Expected Loss

Taguchi and Wu [1985, p. 2] state, "Quality is the loss imparted to the society from the time a product is shipped." Expected loss can be thought of as the expected monetary loss a customer may experience by using a product whose performance characteristic deviates from its ideal level. Pignatiello [1988, p. 248] writes:

> [loss is meant to reflect the] loss (cost) that is incurred to society when the product's ultimate consumer uses a product whose quality characteristic deviates from the target value. This is a departure from the traditional thinking that the ultimate goal is to maximize one's own profit.

The following discussion, adapted from Phadke [1989] presents Taguchi's loss function that is used to quantify expected loss. The expected loss reflects the manufacturer's loss in market share for producing unreliable products of low quality. This loss is generally difficult to quantify but can often be approximated by a quadratic loss function. For example, let Y be a value of performance measure of interest and let m be the target value of Y. As Y deviates from m in the product's use environment, the product user experiences a loss. The actual form of the loss, denoted by L(Y) is unknown but can be approximated by a simple quadratic loss function: $L(Y) = k(Y - m)^2$ where k

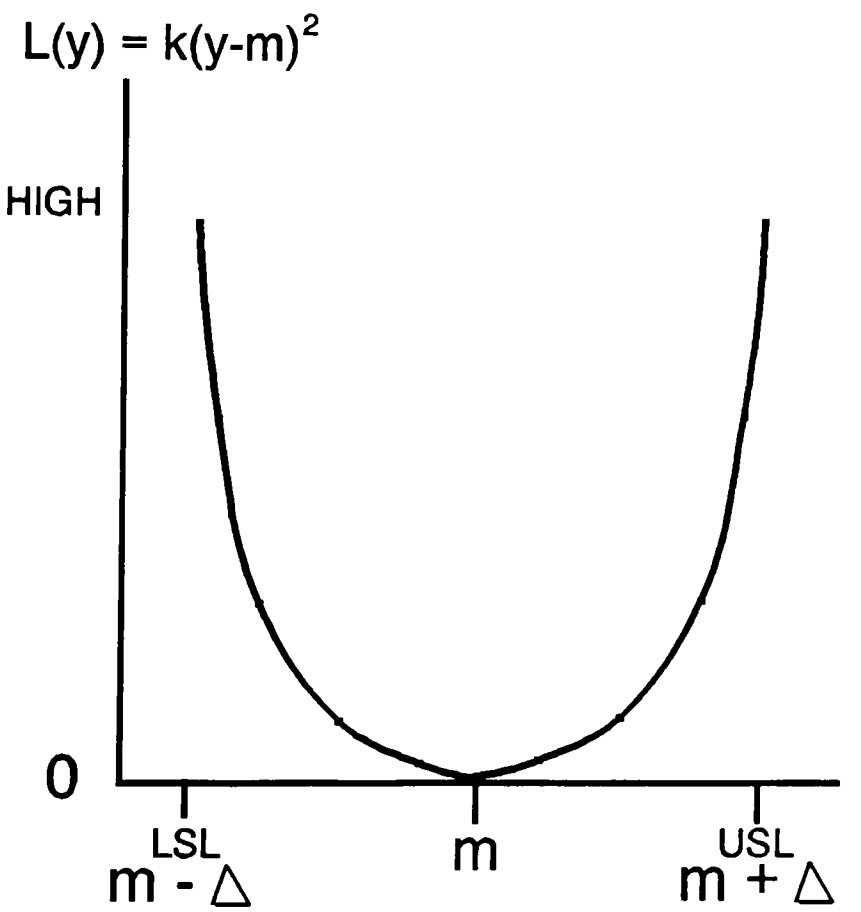

Figure 2.2 Taguchi Loss Function

is some proportionality constant. Figure 2.2 demonstrates the nature of this loss function.

The goal of Taguchi's method is to identify the optimal settings for the design variables, where the optimal settings are those for which expected loss is minimized. Phadke [1989, p. 19] notes:

> [the quadratic loss function] ...does not imply that every customer who receives a product with y as the value of the quality characteristic will incur a precise quality loss equal to L(y). Rather, it implies that the average quality loss incurred by those customers is L(y). The quality loss incurred by a particular customer will obviously depend on that customer's operating environment.

The quadratic loss function may be contrasted with the more traditional view of quality losses, which is characterized by the step function displayed as Figure 2.3.

2.1.3 Design Variables

The ultimate goal of parameter design (often referred to as secondary design) is to identify the settings of the product design characteristics that minimize expected loss. Taguchi [1985, p. 30] writes, "Secondary design is the most important step in developing stable and reliable products or manufacturing processes." Design variables are those that can be controlled by the designer, for example, material and ingredient mix.

The set of all possible combinations of values for the design variables is called the design space and is denoted by Θ. A subset of Θ is selected using statistical

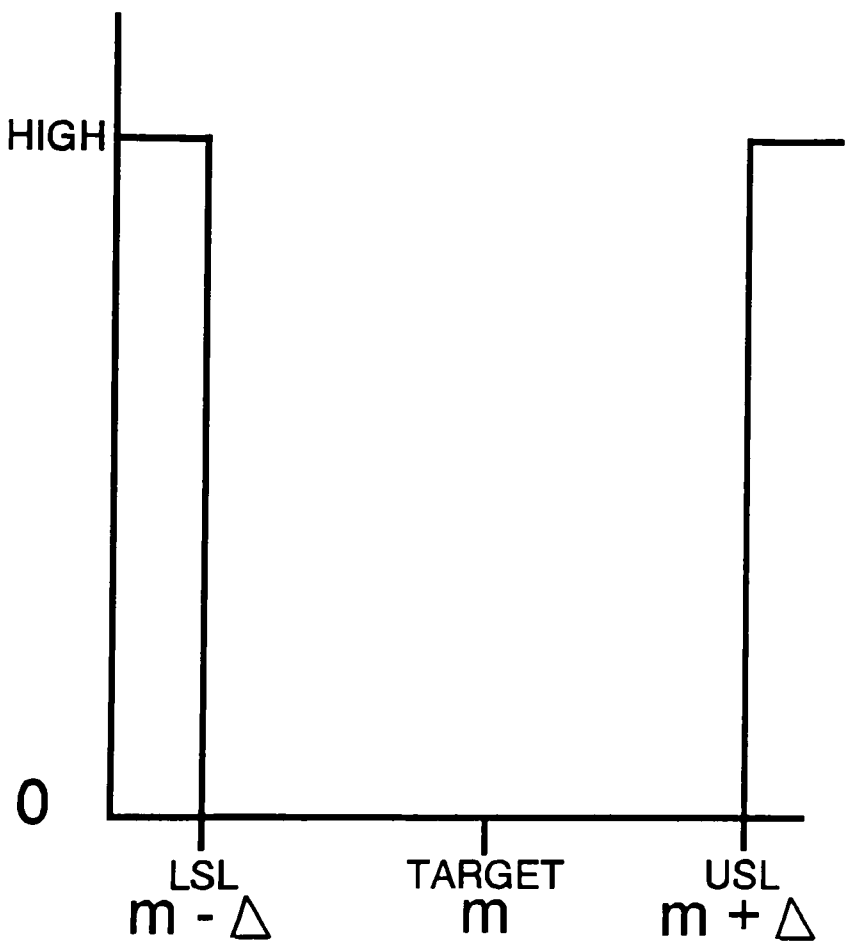

Figure 2.3 Classical View of Product Specifications

experimental design methods. This subset is called the design matrix (referred to as the inner array by Taguchi). A particular product design specification is defined by the vector of settings of the design variables $\Theta = (\Theta_1, \Theta_2, \ldots, \Theta_k)$ and the design matrix that is generated using design of experiment techniques is composed of M such product specifications as depicted by equation 2.1:

$$\boldsymbol{\theta} = \begin{array}{c|cccc} \overline{\theta^1}: & \theta_1^1 & \theta_2^1 & \cdots & \theta_k^1 \\ \overline{\theta^2}: & \theta_1^2 & \theta_2^2 & \cdots & \theta_k^2 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \overline{\theta^M}: & \theta_1^M & \theta_2^M & \cdots & \theta_k^M \end{array} \quad . \qquad 2.1$$

Each column of the design matrix represents a design variable and each entry in a column represents a setting level or value for the corresponding design variable. Each row of the matrix represents a product design.

2.1.4 Noise Variables

The sources of noise that can affect a product's performance are classified by Taguchi [1985, p. 29] as follows:

> Outer noise - the variation of environmental conditions such as temperature, humidity, dust, input voltage, etc.
>
> Inner noise - the deterioration of elements or materials comprising the circuit. For example, the resistance of a resistor increases by 10% in ten years, or the parameter of a transistor changes with time.

Variational noise between products - the variation between products resulting in different outputs.

Let Ω represent the noise space. It is impossible to include **all** possible sources of variability contained in the noise space, so the designer must select a subset of noise variables from the noise space that are believed to be responsible for most of the performance variation. Once levels for the noise variables have been determined, design of experiments techniques are used to construct a noise matrix, a subset of Ω. A particular noise condition specification is defined by a vector of the settings of the noise variables $w = (w_1, w_2, \ldots, w_l)$ and the noise matrix that is constructed using design of experiments techniques is composed of N such noise conditions as depicted in equation 2.2:

$$\boldsymbol{\omega} = \begin{array}{cccc} \overline{\omega^1}: & \overline{\omega^2}: & \cdots & \overline{\omega^N}: \\ \omega_1^1 & \omega_1^2 & \cdots & \omega_1^N \\ \omega_2^1 & \omega_2^2 & \cdots & \omega_2^N \\ \vdots & \vdots & \ddots & \vdots \\ \omega_l^1 & \omega_l^2 & \cdots & \omega_l^N \end{array} . \qquad 2.2$$

Each of the N columns of the noise matrix (referred to as the outer array by Taguchi [1986], Roy [1990]) represents a different combination of the levels of the noise variables and each row represents the noise variables and their settings.

2.1.5 Performance Measures

A complete parameter design is an M x N matrix, the M rows representing M design specifications and the N columns representing N noise conditions. Each of the M designs is run under each of the N noise conditions. A performance measure that reflects a quality characteristic of the product (process) is calculated for each design under each noise condition. Thus, for each design specification, the repeat observations on the performance measure include the effects of many possible levels of noise variables on the performance measure.

In order to determine a best design, i.e., a design that minimizes expected loss, a performance statistic must be constructed that reflects the variability introduced by the noise array as well as the effects of controllable variables on the performance measure or quality characteristic of interest.

If Y is the performance measure of interest for a certain product, then it is a function of both the control factors and noise factors. A performance statistic, $Z(\Theta)$, must be selected that reflects the effects of both of these factors. Taguchi [1972] refers to these performance statistics as signal to noise (S/N) ratios. Barker [1986] reports that Taguchi has identified over seventy such functions, the vast majority of which are industry-specific. The three most commonly reported are: (a) smaller is better;

(b) larger is better; and (c) nominal is best. Ratios expressing these relationships are contained in Phadke [1989].

León et al. [1987] criticize Taguchi for not providing a connection between the two optimization problems of maximizing the S/N ratio and minimizing expected loss. They found that if certain models for the product or process response are assumed then maximization of the S/N ratio does not lead to minimization of average squared error loss. For other models they have shown that maximization of the S/N ratio has nothing to do with minimizing the expected loss. Hunter [1987], Nelder [1992], and Wu [1992] warn that S/N ratios recommended by Taguchi should simply not be used as performance statistics. Hendrix [1991, p. 75] states, "Genichi Taguchi's signal-to-noise ratios are a wasted effort. They contribute nothing of value and confuse decision makers." Performance statistics other than Taguchi's S/N ratios have been proposed by Box [1988] and León et al. [1987].

It is agreed that the Taguchi strategy is a sound one. Researchers must, however, investigate better and more reliable tactics with which to implement Taguchi's strategy. Kacker [1985, p. 187] notes "Taguchi has given us an excellent starting point for further research in statistical methods for product design improvement as well as a stimulus for wider application of existing methods." One such

application lies within the realm of computer expert systems.

2.2 Design of Experiments

While it is generally acknowledged that the statistician Richard Fisher is the father of experimental design, his orientation was agricultural, as evidenced by an early paper [1926] and his book published in 1925. Leonard Tippett, a colleague of Fisher's, was the first to describe the application of these principles to manufacturing [1929]. Tippett's initial suggestion [1936, p. 32] that statistics be used as a quality improvement tool concludes with, "The need for the application of statistical methods to the control of quality in industry lies in the fact that all industrial products are subject to some degree of uncontrolled variation." Contemporary discussions in industrial experimentation center around the experimental efficiency that can be achieved through the deployment of fractional designs.

The orthogonal arrays promoted by Taguchi for the construction of industrial experiments have been well received by numerous engineers, most prominently in the automotive industry (American Supplier Institute [1984, 1985, 1986, 1989]). There is virtually no information available regarding Taguchi's method for construction of these orthogonal arrays. Kacker, Lagergren, and Filliben [1990, 1991] make great strides in explaining the fractional

factorial nature of the orthogonal arrays and the fractionated multi-level factorial nature of his mixed-element orthogonal arrays.

Fractional factorial designs were developed by Fisher [1926, 1935] and Yates [1935, 1937]. Fractional factorials are discussed at length in Rao [1947] and Raghavaro [1971]. These designs are appropriate for a number of situations (Kacker [1982, 1985], Taguchi [1976, 1977], Roy [1990]).

Orthogonal arrays are matrices of numbers whose columns have certain balancing properties, having evolved from factorial plans and Latin squares (e.g., Raktoe, Hedayat, and Federer [1981, p. 170]). Taguchi's mixed-level orthogonal arrays are based entirely on the method articulated by Bose and Bush [1952].

Taguchi receives perhaps his strongest criticism from critics of his statistically planned experimental design methodologies. Tribus and Szonyi [1989], Box [1985], Hunter [1985], Morris and Mitchell [1983], Lucas [1985], and Box and Bisgaard [1987] criticize slavish adhesion to this design methodology and suggest techniques for screening all variables to find those most important, and then analyzing the important variables using response surface methodology, central composite, rotatable, Box-Behnken [1960], or Box and Wilson [1951] designs. Their feelings are summarized by Tukey [1985, p. 207], who says:

> Taguchi has blurred the picture by ascribing confirmatory status to appearances [results of

> small orthogonal array experiments] that are exploratory either wholly or in large part. Perhaps [this has been done] by necessity, if engineers are to be persuaded to the try new [design of experiment methods] and learn that they really work. Over the next several years we can look forward to a clearer view of the place and nature of Taguchi-like small experiments.

Wu [1992], Box [1992], and Myers and Vining [1992] take issue with the use of limited experimentation followed by one or more confirmatory experiments. Wu [1992, p. 143] observes:

> Distinction should be made between traditional response-surface methodology, which commits more runs to regression model building and this approach, which commits more runs directly to confirmation. The former is preferred if it is important and affordable to understand the response relation and if the relation is not too complex. The latter is preferred if it is important to quickly identify a setting (rather than a whole surface) with a better performance. This latter scenario is commonly encountered in solving practical quality problems.

2.3 Computer-Aided Design of Experiments

Snee [1985, p. 222] writes:

> It does not appear to be widely recognized that a computer can be a useful aid in the design of experiments as well as in the analysis of data. The computer can be particularly useful in the administration of an experimental design program and in developing experimental plans for those situations in which the classic designs are not applicable.

Snee cites four primary advantages of computer-aided experimental design, among these being: increased quality of design, reduction in design coding mistakes, consideration of design factors unfamiliar to the experimenter, and time

savings. Hahn [1985] discusses the potential for intelligent computer-aided design of experiments, segmenting the field into three levels of increasing software sophistication:

(1) Computerized statistical answering and referral services;

(2) Expert guidance embedded in statistical programs; and

(3) Automated statistical consultation and data analysis.

The first level could address general questions in the area of statistics and applications, perhaps referring the user to the most appropriate reference material. This system is little more than a supplement to a good statistical library. Tung and Schuenmeyer [1991] discuss an expert system for statistical consulting that determines the data type and sampling method and then suggests an ANOVA routine and statistical software for the analysis. SETS (Statistical Expert Tutorial System) constructed by Prabhu [1989] suggests SAS and Minitab commands to use to perform a number of different descriptive or inferential statistical analyses. Carley [1990] has developed EG Network, an expert system that assists in the construction of SAS code by presenting examples by topic area.

Efforts to make statistical programs more intelligent are being pursued by several practitioners, notably Chambers [1981, p. 40] who writes:

> The approach that I believe to be most important tries to bring some of the functions served by expert consultation into the statistical package itself. Consultation with a statistician would then be supplemented by analysis and dialogue guided by the software.

Gale and Pregibon [1982, 1983] and Becker and Chambers [1984] detail development of such a package at AT&T Bell Laboratories.

The third system level provides both consulting services as well as data analysis of the agreed-upon design, and provides the most complete emulation of a statistical consultant. O'Keefe [1982] developed a prototype expert system called the Automated Statistical Analyst (ASA) and concluded that the ASA performed well "as an exercise in knowledge representation." He added that the system was insufficient in "communicating with a statistically naive client...[because] you have to know too much to use it" (Hahn [1985], p. 4).

Portier and Lai [1983] have developed a prototype menu driven system that aids in selection of the appropriate statistical technique. Hahn [1984] has provided a hypothetical example of a session with an Automated Statistical Consultant (ASC), but has yet to implement the system. Williams [1991] has developed the DESIGN EXPERT,

which specializes in model recognition and ANOVA construction of experiments common in the medical field.

Hahn [1985, p. 6] concludes his analysis of statistical expert systems with the observation:

> ...very few of the problems for which I have been asked to provide guidance over the past year could have been responded to effectively by an automated system. The prospects for developing an expert system in a specialized area may be somewhat brighter, though the market is smaller.

Jones [1980, p. 180] concurs with this position, adding "... a computer program is only likely to be able to give sound advice on a limited number of problems."

Algorithms developed for the computer-aided design of experiments may be classified as follows: generation of the candidate list of experiments; selection of the design points from the candidate list; and design evaluation. Experiment selection is addressed by Mitchell [1974] (DETMAX) and Snee and Marquardt [1974] (XVERT). DETMAX requires user specification of a model and then attempts to maximize the $|\mathbf{X'X}|$ criterion. The XVERT algorithm can be used to construct designs for mixture problems with the constraint that the situation is adequately addressed by a linear model.

Point generation is accomplished by the CONSIM algorithm (Snee [1979]), which generates vertices of regions defined by both single and multiple component constraints. The CADEX algorithm (Kennard and Stone [1969]) makes no assumptions about model form, requires a set of possible

points, and then suggests points that uniformly cover the region of interest. The ACED algorithm (Welch [1982, 1984, 1985]) requires specification of a model but can satisfy a user-specified criteria for region coverage.

Design evaluation is discussed by Hahn et al. [1976, 1978] and can be accomplished using the EXPLOR algorithm, which computes various collinearity statistics.

2.4 Process Capability Indices

Process capability indices provide a measure of the ability of an existing process to produce output that meets specifications. An excellent discussion of process capability indices and capability determination procedures may be found in Kane [1989, pp. 266-297]. Process capability in general is discussed by Gryna [1986, pp. 16.1-16.59]. Kane [1986] compares the variables process capability indices C_p, CPU, CPL, k, and C_{pk}, demonstrates their sampling distributions, and offers suggestions for the employment of multiple indices to describe more completely process capability. These process capability indices are defined as follows:

$$C_p = \frac{USL - LSL}{6\sigma}, \tag{2.3}$$

$$CPU = \frac{USL - \mu}{3\sigma}, \tag{2.4}$$

and

$$CPL = \frac{\mu - LSL}{3\sigma}, \qquad 2.5$$

$$k = \frac{|T - \mu|}{Min\{T - LSL, USL - T\}}, \qquad 2.6$$

$$C_{pk} = Min\{CPL, CPU\}, \qquad 2.7$$

where,

USL = upper specification limit,

LSL = lower specification limit,

σ = process standard deviation,

μ = process mean,

T = process target.

Kane [1986, pp. 44-45] indicates that the primary advantage cited by users of C_{pk} over C_p is that the former statistic provides a truer measure of process capability since the C_{pk} statistic takes into account process centering and natural limits, while the C_p statistic considers only natural limits. He writes:

> It is apparent that the C_p index measures potential process performance since only the process spread is related to the specification limits; the location of the process mean is not considered. Thus, only potential performance of a process is quantified by C_p and can only be attained for the process mean equal to the midpoint of the specification limits. The C_{pk} index is related to the C_p index, but utilizes the process mean and can be considered a measure of process performance.

Boyles [1991, p. 17] writes, "The C_p and C_{pk} indices are appropriate measures of progress for quality improvement paradigms in which *reduction of variability* is the guiding

principle and process yield is the primary measure of success."

Consistent with his goal of *reducing variation from the target value*, Taguchi [1985, 1986] has proposed an alternate formulation of C_p. Chan et al. [1988, p. 162] discuss this capability index under the designation C_{pm} and show that it "... assesses process capability and takes into account departures from the target value." Boyles [1991] extends this work by relaxing Chan et al's assumption that the process mean is the target value. Johnson [1992] relates the C_{pm} index to Taguchi's notion of squared error loss. For purposes of this proposed research, the Taguchi capability index shall be designated C_{pm} and is defined as:

$$C_{pm} = \frac{USL - LSL}{6\tau}, \qquad 2.8$$

where,

$$\tau^2 = E[(X - T)^2]. \qquad 2.9$$

Boyles demonstrates the advantage of the C_{pm} statistic through the use of plots in the (μ,σ) plane. C_{pk} is shown to increase without bound for fixed μ as $\sigma \to 0$, while C_{pm} is bounded above. The lack of responsiveness to off-target conditions makes C_{pk} an unacceptable measure of process capability in the context of a Taguchi strategy. Kushler and Hurley [1992, p. 189] write, "The principal distinction between C_{pk} and C_{pm} is in the relative importance attached

to the specification limits LSL and USL as opposed to the target T." A number of authors (Fabian [1987], Chan et al. [1988], Kane [1986], Johnson [1992], and Taguchi [1985, 1986]) discuss the need for process centering when judging process capability.

Kane cites the following pitfalls of using process capability indices:

(1) Determining capability of an out-of-control process;

(2) Dependence of capability on the sampling plan;

(3) Computational complexity; and

(4) Application to a nonnormal process.

There is some disagreement over the lower bound on the number of subgroups required to accurately determine a process capability. For a variables measurement, the highest minimum number of samples (one hundred) is suggested by Evans and Lindsay [1989, p. 239] and Gitlow et al. [1989, p. 431]. Gitlow et al. break the samples into three separate time periods of 50, 25, and 25 samples of size three to five units each. Kane's suggestion of 50 samples [1989, p. 285] is the lowest minimum amount. For an attributes measurement, Gitlow et al. [1989, p. 431] suggest three distinct sampling periods consisting of 20 to 25 samples of size 50 to 100 units.

2.5 Expert Systems

Expert systems are computer programs that perform the work of a human expert in a specific field. A human expert has been described by Johnson [1983, pp. 78-79] as:

> An expert is a person who, because of training and experience, is able to do things the rest of us cannot; experts are not only proficient but also smooth and efficient in the actions they take. Experts know a great many things and have tricks and caveats for applying what they know to problems and tasks; they are also good at plowing through irrelevant information to get at basic issues, and they are good at recognizing problems they face as instances of types with which they are familiar.

Hayes-Roth et al. [1983a,b] indicate that expert systems provide a standardized methodological approach to solving important, fairly complex tasks that require human expertise. Waterman [1986, p. 8] asserts that:

> The expert system is the collection of programs or computer software that solves problems in the domain of interest. It's called a system rather than just a program because it contains both a problem-solving component and a support component.

Problems an expert system can accommodate are currently limited to the domain in which the system has expertise, just as a human expert.

Expert systems are valuable in instances when there is no human expert available. There are many reasons for using an expert system instead of or in addition to the available human expertise. Some of the advantages accrued by relying upon computer expertise over that of a human are listed by Kaplan [1984] and displayed in Table 2.1.

Table 2.1 Advantages of Expert Systems

Human Expertise	Artificial Expertise
Perishable	Permanent
Difficult to Transfer	Easy to Transfer
Difficult to Document	Easy to Document
Unpredictable	Consistent
Expensive	Affordable

2.5.1 Appropriate Problems

Expert systems can be valuable tools in very specific domains. A number of researchers, including Hall and Kandel [1991] and Waterman [1986] provide guidelines for the suitability of a situation for an expert system. The more comprehensive list is produced by Waterman [1986] and rests on the three criteria of the expert system being possible, justified, and appropriate.

An expert system is possible if the following are true:

(1) The task does not require common sense;

(2) The task requires only cognitive skills;

(3) Experts can articulate their methods;

(4) Genuine experts exist;

(5) Experts agree on solutions;

(6) The task is not too difficult; and

(7) The task is not poorly understood.

An expert system is justified according to Waterman [1986] if any of the following items is true:

(1) The task solution has a high payoff;

(2) Human expertise is being lost;

(3) Human expertise is scarce;

(4) Expertise is needed in many locations; and

(5) Expertise is needed in a hostile environment.

The nature, complexity, and scope of the problem domain determine when an expert system is appropriate. Waterman [1986] feels that an expert system is appropriate if all of the following hold:

(1) The task requires symbol manipulation;

(2) The task requires heuristic solutions;

(3) The task is not too easy;

(4) The task has a practical value; and

(5) The task is of manageable size.

A review of the motivations for this research indicates that the problem of continual process improvement is well-suited to the expert system domain.

2.6 Summary and Conclusions

This chapter has presented a review of the literature pertinent to the field of product improvement via experimentation. This idea is not new, but has experienced a recent increase in attention due to Genichi Taguchi, whose methodology is examined in this chapter. While his nomenclature is used throughout the research, classical design of experiments tactics are adopted due to their rigor. Expert system automation of statistical consulting, and expert systems in general are discussed, and the field

of industrial experimental design is shown to be promising for such an application.

CHAPTER 3

THE OFF-LINE QUALITY IMPROVEMENT EXPERT SYSTEM

3.1 Introduction

The recent emphasis on improving manufacturing products and processes has necessitated the need for effective decision-aiding technologies and strategies. In the Taguchi method, we have an effective *strategy* for continual process improvement. Expert system technology can provide a medium for the deployment of the Taguchi method strategy.

One product of this research is a prototype expert system for automating the off-line quality improvement strategy proposed by Taguchi. The off-line quality improvement expert (OQIE) system is designed as an assistant that elicits process information from the user and then guides him or her through the steps of product assessment and improvement. The model provides a highly interactive environment for the analyst. This system takes the strategy and applies it to accepted experimental design techniques. Such a mix, as described in the remainder of this section, is new to the areas of quality control and production and operations management.

This research has implications for the ability of a firm to design quality into a product or process, placing the conversion process in a proactive, competitive mode. The alternative to this approach, the reactive mode for a firm, is to inspect quality into a product, which is

oftentimes inefficient and ineffective. Clausing and Simpson [1990], Whitney [1988], Ishikawa [1984], and Taguchi and Wu [1985] all present strong cases for the desirability of a proactive stance to quality products and processes.

A diagrammatic view of the architecture is displayed in Figure 3.1. The information flows between the three sources of input are depicted by arrows. Note that the user can directly query the experimental design knowledge base as well as the process capability knowledge base.

The knowledge bases are composed of rules representing a blend of the Taguchi strategy and classical industrial experimental design techniques. Figure 3.2 is a Venn diagram depicting the mix of the strategy and tactics. The diagram is composed of the sets representing the sum of the Taguchi method as contained in Taguchi and Wu [1985] and the array of industrial experimental designs as represented in Box and Draper [1987], Barker [1985], Davies [1967], Myers [1971], and Montgomery [1991]. The knowledge base of the OQIE is represented by the intersection of these two sets. Of those items captured by the OQIE, the notions of the Taguchi process capability index, parameter design, design variables, and noise variables are uniquely from the Taguchi method. The rules in the OQIE's knowledge base that pertain to these concepts are indicated next to each concept's listing. The remainder of the items represented in the OQIE

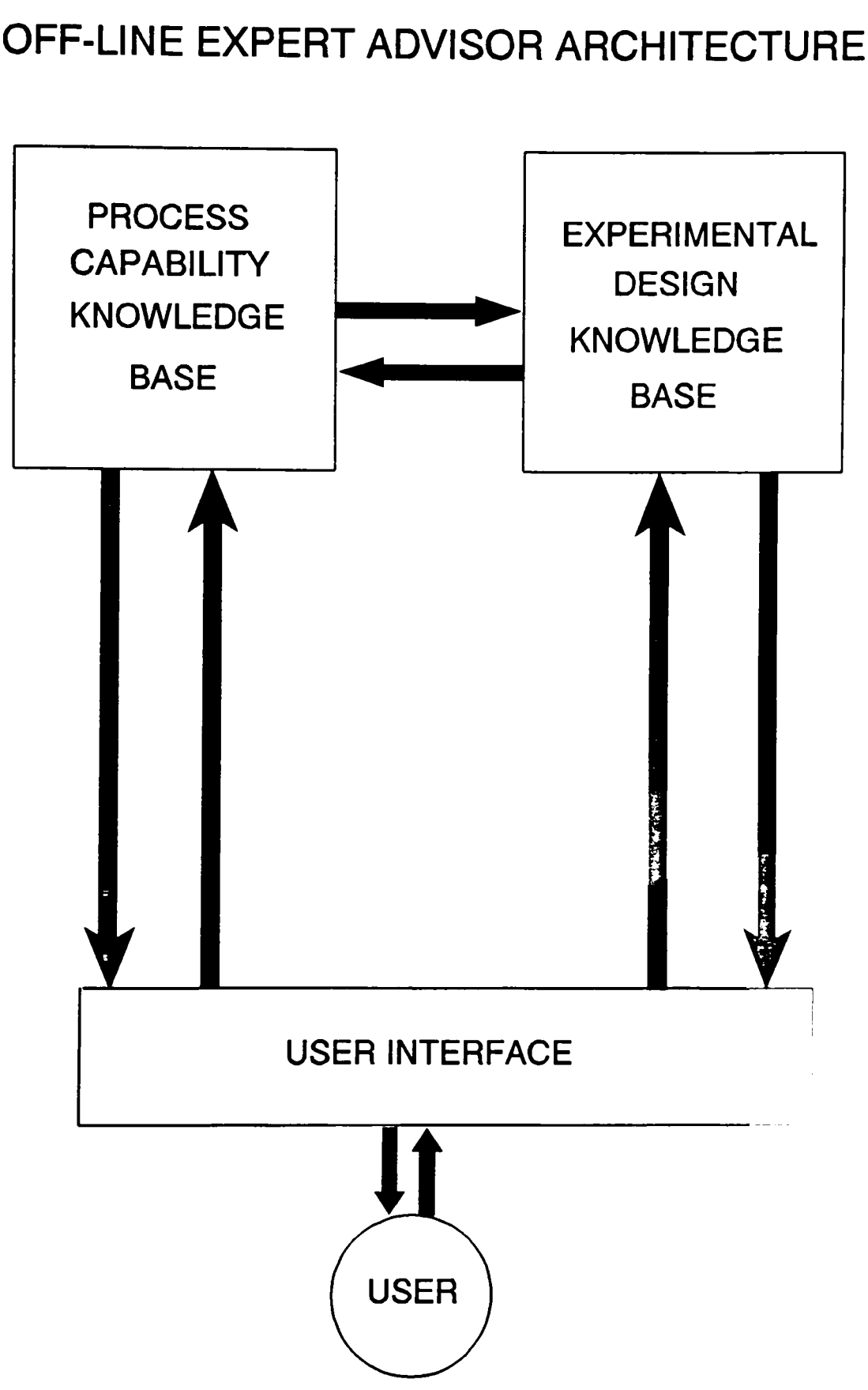

Figure 3.1 Off-Line Quality Improvement Expert System Architecture

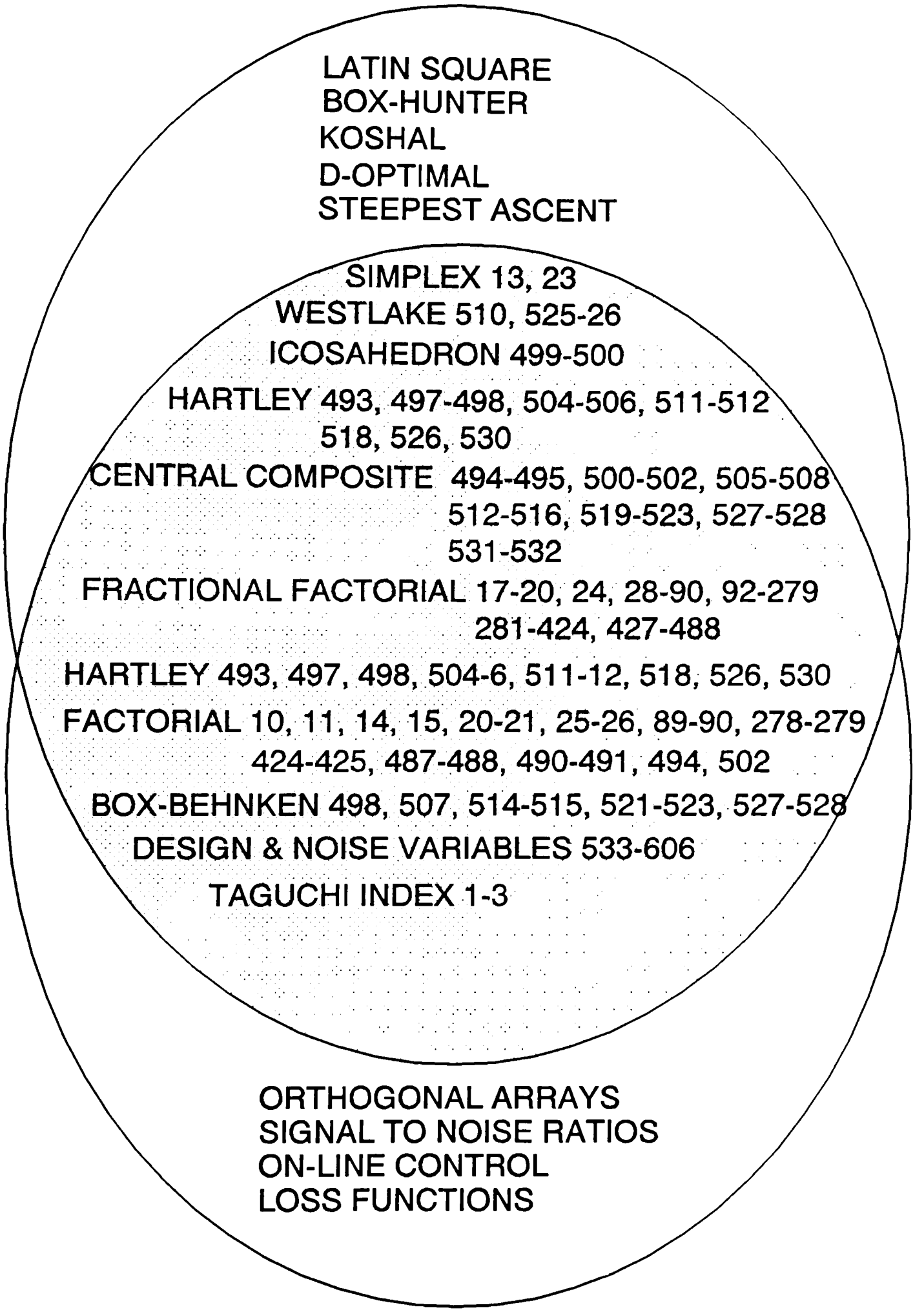

Figure 3.2 Strategy and Tactics Blend of OQIE

knowledge base come from the field of experimental design, particularly the niche of industrial experimental design. The rules pertaining to each of these designs are listed next to the design in the Venn diagram. A complete listing of the designs recommended by the OQIE, the rules in the OQIE's knowledge base that apply these designs, and the statistical literature references that describe these designs and their efficacy appears as Table 3.1. A complete listing of the rules and their references for the process capability knowledge base of the OQIE appears as Table 3.2.

3.2 Methodology

Numerous P/OM doctoral dissertations have built prototypes to substantiate their conceptual work. The works of Cheng [1989], Lin [1990], Eom [1992], and Liang [1993], as well as many others have included prototyping as a component of their research methods.

The testing of the prototype provides the opportunity to determine the system's accuracy in comparison with the conceptual development. The prototype design verification illustrates that the system does what it is designed to do and that it provides reasonable answers. The second component is the validation of the conceptual development.

Both of these questions are addressed by constructing the prototype system. Since the prototype was effectively implemented, it can be logically inferred that the design is valid, i.e., that the prototype adequately addresses the

Table 3.1 Rule Reference for OQIE Experimental Design Knowledge Base

Experimental Design Name	Rules	Reference
2^1 factorial	10	Barker [1985]
2^1 factorial w/replications	11	Barker [1985]
2^2 simplex	13	Myers [1971]
2^2 factorial	14	Barker [1985]
2^2 factorial w/replications	15	Barker [1985]
1/2 fraction 2^3 factorial	17 - 20	Barker [1985]
2^3 factorial	20, 21	Barker [1985]
2^3 factorial w/replications	21	Barker [1985]
2^4 simplex	23	Myers [1971]
1/2 fraction 2^4 factorial	24	Barker [1985]
2^4 factorial	25	Barker [1985]
2^4 factorial w/replications	26	Barker [1985]
1/4 fraction 2^5 factorial	28 - 88	Barker [1985]
1/2 fraction 2^5 factorial	88 - 90	Barker [1985]
2^5 factorial	89, 90	Barker [1985]
2^5 factorial w/replications	90	Barker [1985]
1/8 fraction 2^6 factorial	92 - 277	Barker [1985]
1/4 fraction 2^6 factorial	97 - 278	Barker [1985]
1/2 fraction 2^6 factorial	277 - 279	Barker [1985]
2^6 factorial	278, 279	Barker [1985]
2^6 factorial w/replications	279	Barker [1985]
1/16 fraction 2^7 factorial	281, 282	Barker [1985]
1/8 fraction 2^7 factorial	282 - 423	Barker [1985]
1/4 fraction 2^7 factorial	283 - 424	Barker [1985]

Table 3.1 Continued

Experimental Design Name	Rules	Reference
1/2 fraction 2^7 factorial	423 - 424	Barker [1985]
2^7 factorial	424, 425	Barker [1985]
2^7 factorial w/replications	425	Barker [1985]
1/16 fraction 2^8 factorial	427 - 484	Barker [1985]
1/8 fraction 2^8 factorial	428 - 486	Barker [1985]
1/4 fraction 2^8 factorial	485 - 488	Barker [1985]
1/2 fraction 2^8 factorial	486 - 488	Barker [1985]
2^8 factorial	487, 488	Barker [1985]
2^8 factorial w/replications	488	Barker [1985]
3^1 factorial	490	Barker [1985]
3^1 factorial w/replications	491	Barker [1985]
3^2 factorial	494	Barker [1985]
3^2 Hartley	493	Hartley [1959]
3^2 central composite	494	Box & Draper [1987]
3^2 central composite w/center point replications	495	Box & Draper [1987]
3^3 Hartley	497, 498	Hartley [1959]
3^3 icosahedron	499, 500	Myers [1971]
3^3 Box-Behnken	498	Box & Behnken [1960]
3^3 central composite	500	Box & Draper [1987]
3^3 central composite w/center point replications	501, 502	Box & Draper [1987]
3^3 factorial	502	Barker [1985]
3^4 Hartley	504 - 506	Hartley [1959]
1/2 fraction 3^4 central composite	505	Box & Draper [1987]

Table 3.1 Continued

Experimental Design Name	Rules	Reference
1/2 fraction 3^4 central composite w/center point replications	506	Box & Draper [1987]
3^4 Box-Behnken	507	Box & Behnken [1960]
3^4 central composite	507	Box & Draper [1987]
3^4 central composite w/center point replications	508	Box & Draper [1987]
3^5 Westlake	510	Westlake [1965]
3^5 Hartley	511, 512	Hartley [1959]
1/2 fraction 3^5 central composite	512	Box & Draper [1987]
1/2 fraction 3^5 central composite w/center point replications	513 - 514	Box & Draper [1987]
3^5 Box-Behnken	514 - 515	Box & Behnken [1960]
3^5 central composite	515	Box & Draper [1987]
3^5 central composite w/center point replications	516	Box & Draper [1987]
3^6 Hartley	518	Hartley [1959]
1/2 fraction 3^6 central composite	519	Box & Draper [1987]
1/2 fraction 3^6 central composite w/center point replications	520 - 523	Box & Draper [1987]
3^6 Box Behnken	521 - 523	Box & Behnken [1960]
3^6 central composite	522	Box & Draper [1987]
3^6 central composite w/center point replications	523	Box & Draper [1987]
3^7 Westlake	525 - 526	Westlake [1965]
3^7 Hartley	526	Hartley [1959]
3^7 Box Behnken	527 - 528	Box & Behnken [1960]

Table 3.1 Continued

Experimental Design Name	Rules	Reference
1/2 fraction 3^7 central composite	527	Box & Draper [1987]
1/2 fraction 3^7 central composite w/center point replications	528	Box & Draper [1987]
3^8 Hartley	530	Hartley [1959]
1/4 fraction 3^8 central composite	531	Box & Draper [1987]
1/4 fraction 3^8 central composite w/center point replications	532	Box & Draper [1987]

Table 3.2 Rule Reference for OQIE Process Capability Knowledge Base

Process Capability Outcome	Rule	Reference
$C_{pm} < 1.5$	1	Boyles [1991]
$1.5 \leq C_{pm} < 2.0$	2	Boyles [1991]
$2.0 \leq C_{pm}$	3	Boyles [1991]
$0.10 \leq p$	4	Evans & Lindsay [1993]
$0.01 \leq p < 0.10$	5	Evans & Lindsay [1993]
$0.01 > p$	6	Evans & Lindsay [1993]

questions of function and utility raised in the preceding paragraph. The best way of evaluating success is to manually analyze sample problems, by choosing representative problems from the quality literature, and then use the prototype to do the same. The degree to which these analyses are comparable can be taken as the measure for success in terms of the validation question. The ability of the prototype system to demonstrate objectively all of the functions specified for the system can be taken as a measure of success in terms of the verification question.

Newell and Simon [1976, p. 114] state:

> Computer science is an empirical discipline. We would have called it an experimental science, but like astronomy, economics, and geology, some of its unique forms of observation and experience do not fit a narrow stereotype of the experimental method. None the less, they are experiments. Each new machine that is built is an experiment. Actually constructing the machine poses a question to nature; and we listen for the answer by observing the machine in operation and analyzing it by all analytical and measurement means available. Each new program that is built is an experiment. It poses a question to nature, and its behavior offers clues to an answer.
>
> It [society] needs to understand that, as in any science, the gains that accrue from such experimentation and understanding pay off in the permanent acquisition of new techniques; and that it is these techniques that will create the instruments to help society in achieving its goals.

3.3 Implementation of the System

The expert system has been implemented in the expert system shell EXSYS PROFESSIONAL Version 3.0 (Huntington

[1991]), which is a rule-based format that uses English-like commands and permits chaining of distinct rule bases. The rule bases communicate with each other as well as two external programs via a blackboard system. A partial listing of the OQIE's rules appears as Appendix A.

The mechanics of the system's decisions are illustrated by the tree diagram of Figure 3.3. This tree is a macro view of the initial decisions required when using the OQIE. The system traverses the tree depending upon the user's responses to system inquiries. The major branches of the tree are the capability study, two-level experimental design, and three-level experimental design.

3.4 Process Capability Knowledge Base

The main menu of the OQIE provides an introduction to the program as well as the choice of a process capability study or an experimental design session. These possibilities are illustrated by the initial branching of the tree in Figure 3.3. Depending upon the process under consideration, the user will select a variables or attributes process capability study.

A process capability study should be selected prior to any planned experiment in order to provide a benchmark by which subsequent design modifications should be measured. As indicated by Kane [1986] in section 2.4, a process capability index is meaningful only when the process is

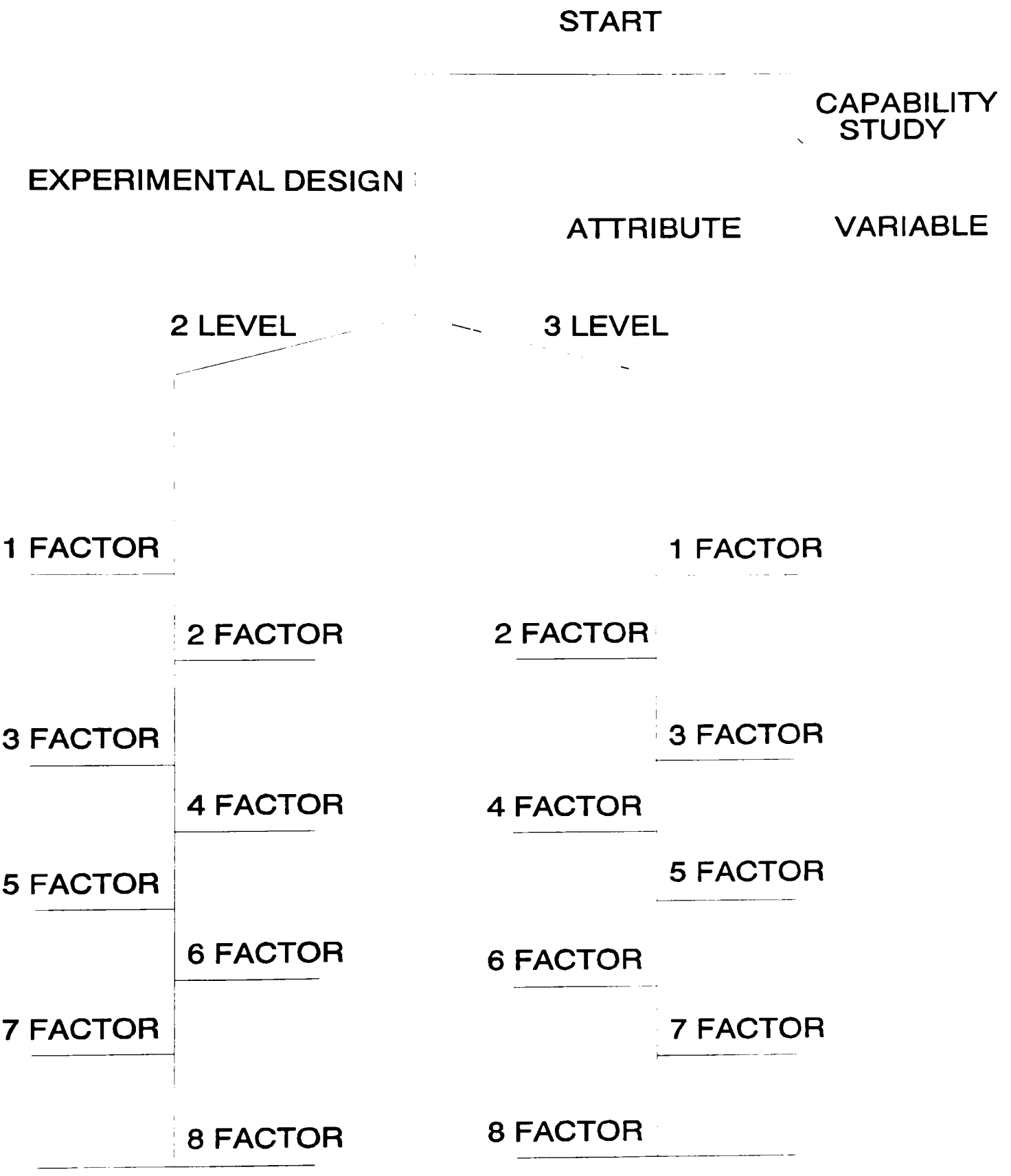

Figure 3.3 OQIE Decision Tree

stable. If the process is not in statistical control, then the ratio of the specification limits to the natural limits is not indicative of the process potential. An attributes process capability index (simple fraction defective) would be the best measure of an unstable process. Following adjustments to the unstable process, a follow-up attributes measure would reveal process improvement, and then a variables measure of capability would hold meaning.

A variables process capability study uses the C_{pm} index to perform a process capability determination. The system first asks the user some basic questions regarding the monitored process. The upper and lower process specification limits (USL and LSL), the target (T), and the subgroup size (n) must all be provided to the system.

Following initial setup the system will prompt the user for the results of 50 subgroups. The system then computes a Taguchi process capability index based upon the formulas presented in Chapter 2, section 4. This performance index should be manually recorded by the user for future reference.

For the attribute capability study, the system prompts the user for the results of 150 samples. The system will then compute the fraction defective process capability, which is expressed as a proportion. This process capability should be manually recorded by the user for future reference.

Finally, it should be noted that while the thrust of the OQIE is off-line quality improvement, and process capability studies are considered on-line techniques, their inclusion in the system provides a means by which the effectiveness of design modifications can be measured. Statistical examination of experimental results provides a more rigorous assessment of design changes, but the OQIE is at present incapable of performing these types of calculations.

3.5 Experimental Design Knowledge Base

The experimental design component controls the dialogue between the user and the experimental design manager. Figure 3.3 illustrates the first two experimental design decisions that the OQIE requires. The user must provide information describing the number and types of controllable variables. Figure 3.3 has been decomposed into two additional trees, displayed as Figures 3.4 and 3.5. Figure 3.4 shows the two-level experimental design branch of the tree in greater detail and Figure 3.5 shows the same information for the three-level experimental design branch. Taken together, paths represented in Figures 3.3, 3.4, and 3.5 comprise the majority of the rules displayed in Appendix A. Rules eight through five hundred thirty-one address the branches shown by those three figures.

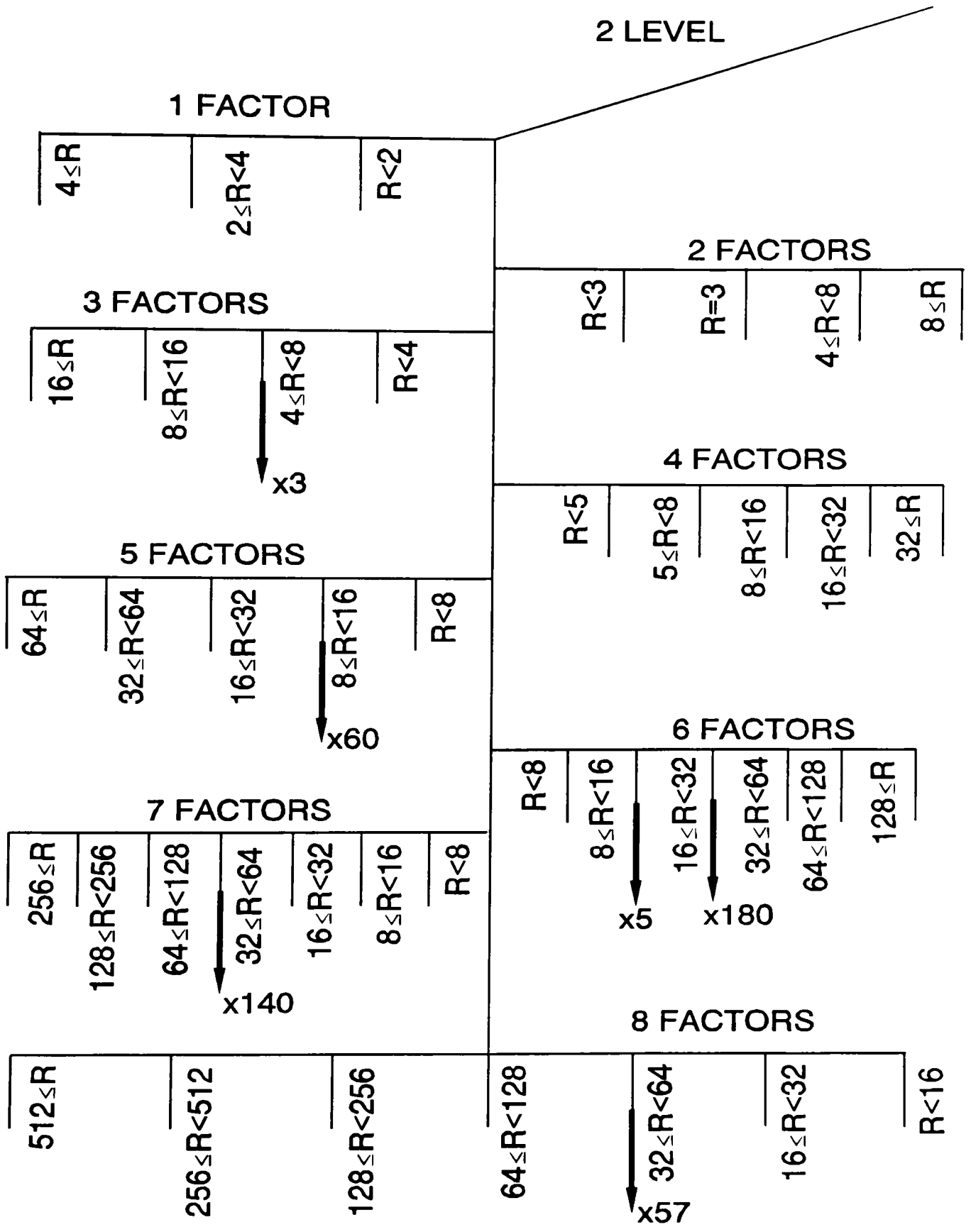

Figure 3.4 OQIE 2-Level Experimental Design Tree

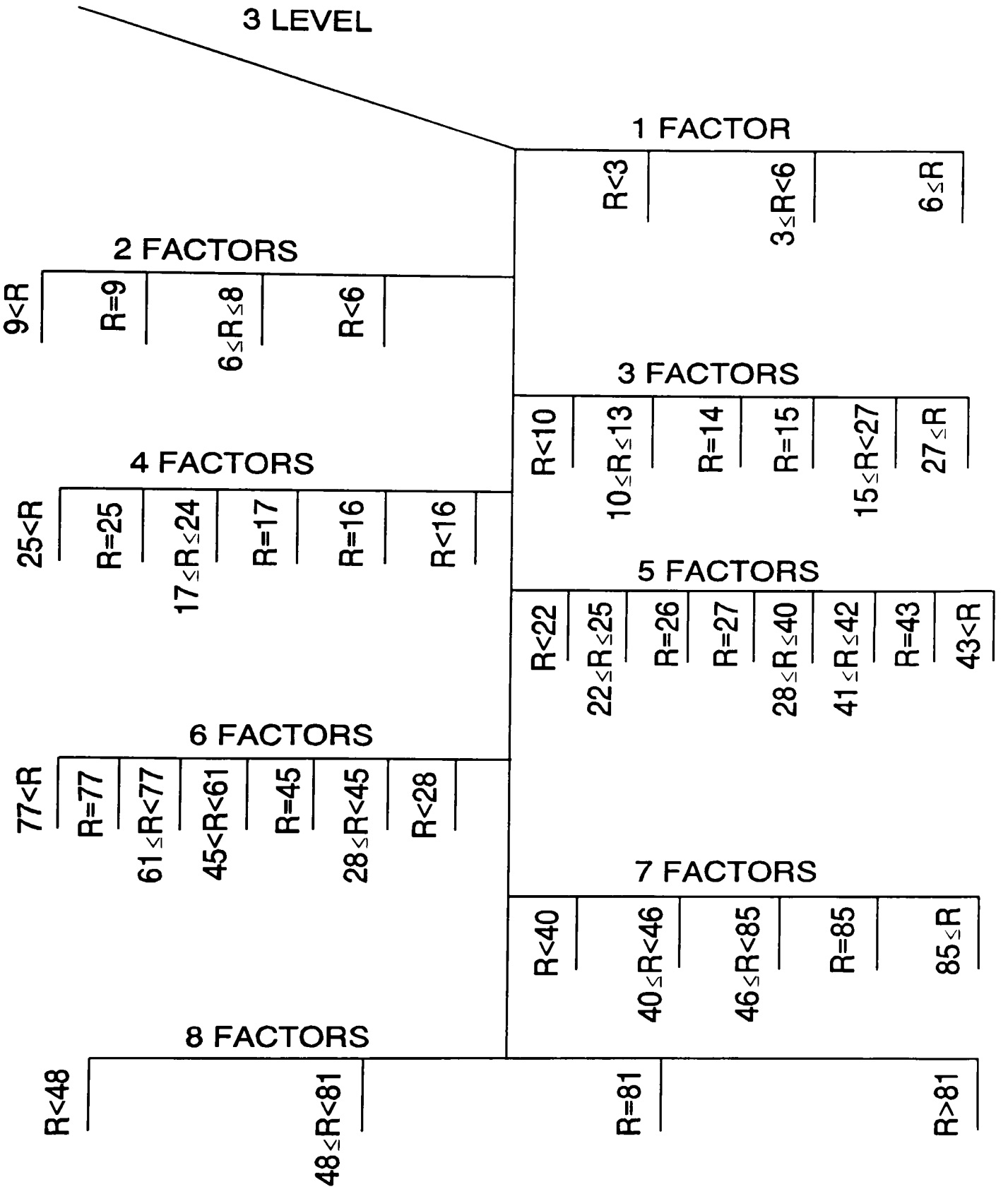

Figure 3.5 OQIE 3-Level Experimental Design Tree

In order to traverse the sections of the tree represented in Figures 3.4 and 3.5, the following information is elicited by the OQIE:

(1) Number of design variables and the levels of each;

(2) Number of noise variables and the levels of each;

(3) The cost, in both time and money, of making one observation at any combination of levels of the noise and design variables. These costs will be assumed constant at all possible levels; and

(4) Assumptions about the type of relationships existing between each of the design variables and the output.

Note that for each branch showing the number of factors in the experiment, there are between three and eight branches corresponding to different experimental trial budgets. In Figure 3.4, the branches corresponding to three factor, four to eight runs; five factor, eight to sixteen runs; six factor, eight to sixteen runs; six factor, sixteen to thirty-two runs; seven factor, thirty-two to sixty-four runs; and eight factor, thirty-two to sixty-four runs, terminate in arrows.

The designs recommended by the OQIE under these conditions involve considerable aliasing and require the user to specify preferences regarding the assignment of factors in order to allow estimation of certain interactions. The number next to each of the arrows symbolizes the number of different factor assignments that

can be made by the system. Each of these branches contains a subtree of the size indicated in Figure 3.4 that performs the factor assignment routine. Figures 3.6 and 3.7 illustrate two such factor assignment subtrees for the three factor, four to eight run as well as the six factor, eight to sixteen run designs, respectively. The general composition of the rules for each of these aliasing situations is the same within each distinct block. For example, all one hundred eighty rules within the six factor, sixteen to thirty-two runs design are the same, except for the assignments of labels to the factors. Since there is extensive duplication, only one rule from each of the aliasing situations is presented in Appendix A.

The factor names and level settings are collected and manipulated in the last seventy-five rules of the OQIE.Rules five hundred thirty-two through six hundred and six of Appendix A show the initial gathering of factor labelling information that may be reassigned later if the design involves aliasing.

The system will tell the user the maximum number of experimental runs given the stated time and financial constraints. A design that comes closest to maximizing the expenditure of the constraining resource will be suggested, along with a report that the specified model will require $X and take Y time to complete data collection. Designs

EXPERIMENTAL DESIGN

2 LEVEL

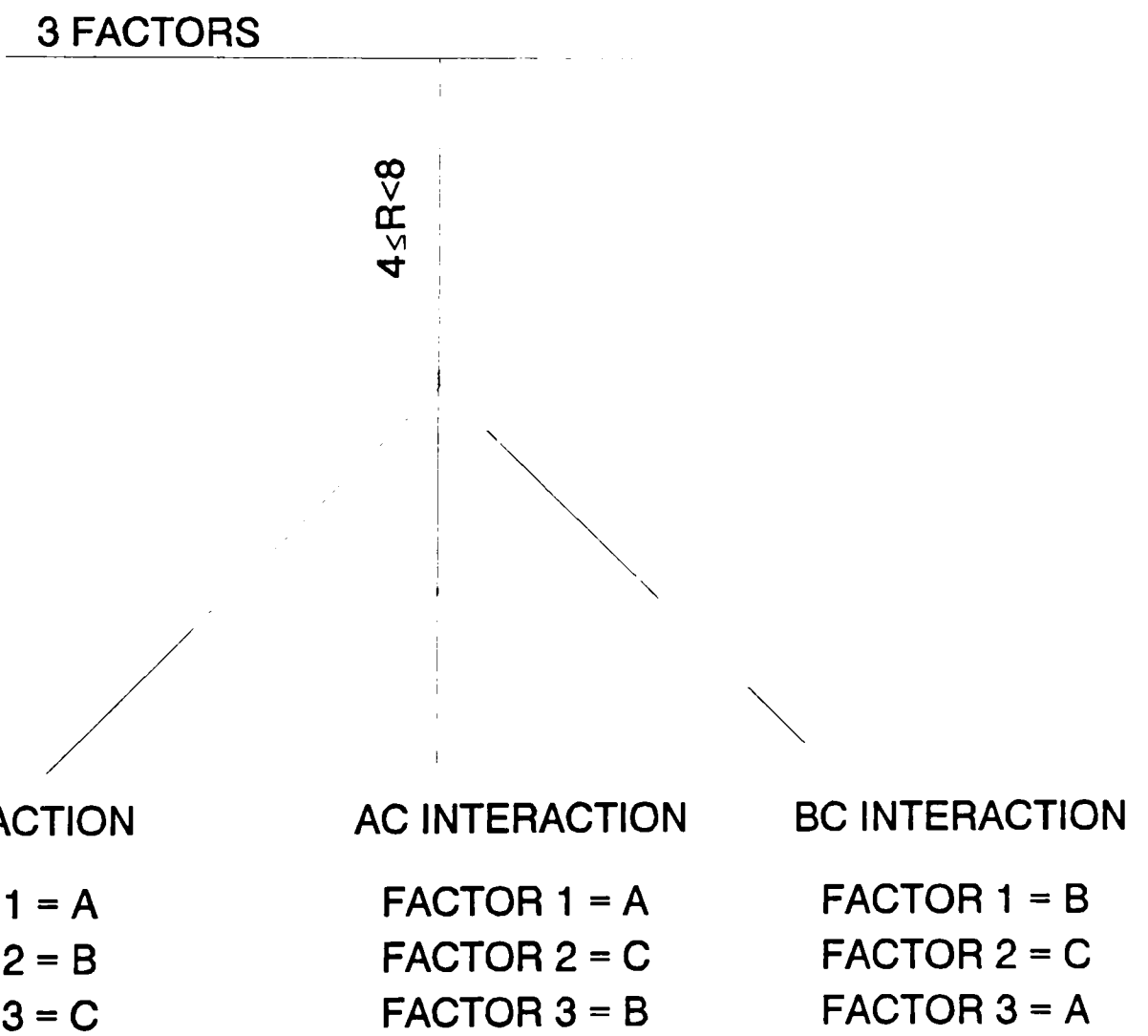

Figure 3.6 Half Fraction 2^3 Subtree

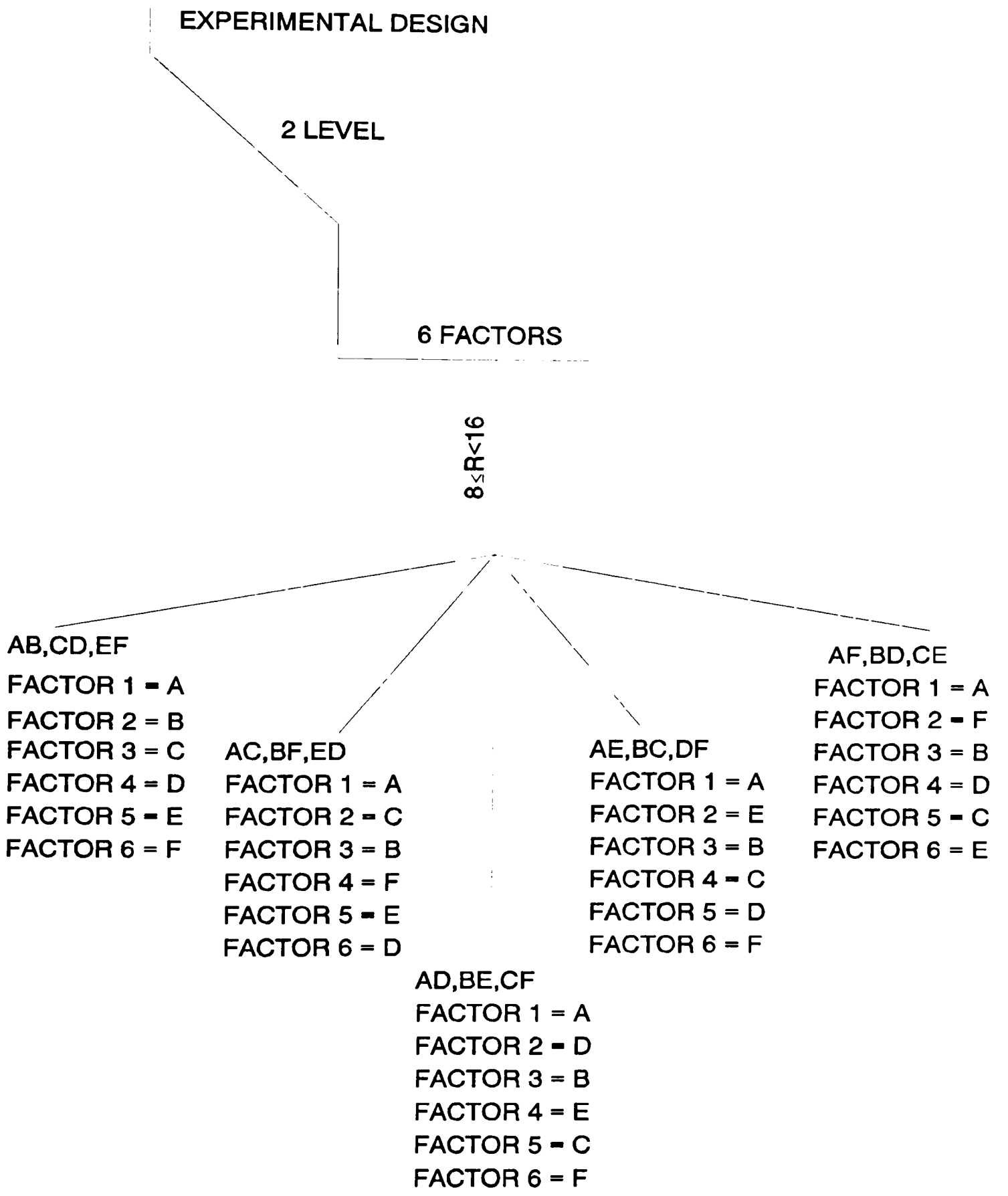

Figure 3.7 Eighth Fraction 2^6 Factorial Subtree

suggested by the OQIE are presented in summary form by Barker [1985, p. 68], Box and Draper [1987, p. 521], and Myers [1971, p. 153]. The designs indicated represent even region coverage for various combinations of the number of factors and the number of trials. Each combination has a single best design, although in general, for a given number of factors, the greater the number of experimental trials, the better the assessment of the situation. For that reason, the experimenter is usually better served by an experiment requiring more trials, but the OQIE takes into account the limitations of time and money that face experimenters operating in the real world.

Following a review of the information obtainable by the recommended design, the user may express satisfaction with the experimental design or choose to redefine his experimental objectives. If the experimenter feels that the depth of investigation is inadequate, then the situation may be reanalyzed with the assumption that additional financial or temporal resources are available. On the other hand, if the budget is known with certainty, the experimenter may drop factors from the analysis to permit a more thorough exploration of a vital few factors.

3.6 Comparison With Existing Architectures

No system currently available incorporates all of the process analysis and improvement capabilities present in the

Advisor. There are three existing software packages commercially available that possess varying levels of sophistication in the arena of design of experiments. The remainder of this section describes the features, advantages, and disadvantages of these software packages as well as the OQIE. This comparison is summarized in Table 3.3.

Of the commercial packages, each one uses what can be referred to as a generative approach to its experimental design module. In the generative approach, much as in the generative approach described in the computer-aided process planning literature, a computer algorithm is used to synthesize a design once it determines the number of factors and levels present, important relationships, and the number of experimental trials possible. The OQIE uses a variant approach, similar to the variant approach used in computer aided process planning. In the variant approach, a series of IF-THEN rules ascertains the situation and selects an appropriate design from a base of several stored plans.

The primary advantage of the generative approach is the reduction in storage space required to produce an experiment. As long as the number of factors is within range, the program can execute its algorithm and generate a suitable design. The variant approach requires the presence of a standard design for each possible situation already in the database or it will be unable to make any suggestion for

Table 3.3 Summary of System Comparison

	OQIE	Juse-Qcas	Catalyst	JMP
Experimental Design				
Classical	Y	Y	N	Y
Fractional Factorial	Y	N	Y	Y
D-Optimal	N	N	Y	Y
Sequential	Y	N	N	Y
Next Best	Y	N	N	N
Help Screens	Y	Y	Y	Y
Budget Limits	Y	N	N	Y
Calculations	N	N	N	N
Process Capability				
Cp	N	Y	N	N
Cpk	N	Y	N	N
Cpm	Y	N	N	N
Attributes	Y	N	N	N
Help	Y	N	NA	NA
Follow-up Study	Y	N	NA	NA

a design. The variant approach holds speed and ease of programming as its advantages over the generative approach.

One factor missing from Table 3.3 is a comparison of the speed of the three systems. A meaningful comparison is not possible due to the disparate presentations of information. The systems were tested with two different fractional factorial design situations and the JMP, Catalyst, and OQIE software all provided their full information within four seconds. Each one has a slightly different on-screen display, and the OQIE creates a file in addition to its visual display.

3.6.1 Design of Experiments with JUSE-QCAS

The JUSE-QCAS™ [Nissho Iwai, Inc. 1986] software was developed by the Japanese Union of Scientists and Engineers with the goal of bringing a quality control assisting system to an IBM compatible format. JUSE-QCAS has a design of experiments module that prompts the user for the number of factors and the levels of each. The package then takes this information and generates a full 2^k or 3^k design, depending upon the number of levels specified for each factor. No provision is made for limiting factors on the number of experimental trials possible, so the algorithm will without fail recommend a design that requires the experimenter to estimate all possible interactions among variables.

This is the only package that also provides for process capability assessment. The process capability indices

computed are C_p and C_{pk}. The indices are computed but no explanation is offered as to the meaning or interpretation of the process capability.

3.6.2 Design of Experiments Using Catalyst

BBN Software Products' Catalyst [BBN Software Products] package is also capable of designing experiments, although a Macintosh platform is required. The Catalyst cannot suggest classical experimental designs, but instead produces only D-optimal designs. The Catalyst produces these designs in a generative fashion, and provides little in the way of help to the user. The Catalyst has no provision for assessing the results of an experiment, does not exploit the sequential nature of experimentation, does not address the issue of experimental budget constraints, and does not measure process capability.

3.6.3 Design of Experiments Using JMP

SAS Institute Incorporated offers a design of experiments module called JMP Design® [SAS Institute Inc. 1992] as a companion to the standard JMP® package for the Macintosh. This package uses a generative approach to model building and is, in many respects, the equivalent of the OQIE in terms of the approach to experimental design suggestion.

JMP queries the user regarding the number of factors and levels of each and then presents the user with an array

of designs possible covering several different depths of investigation. The array of designs shows distinct breaks in numbers of trials, so the user must locate his number of trials level between two breakpoints, as opposed to the OQIE's automatic location. This manual depth of investigation decision addresses the same concerns as the OQIE's automatic budget constraint feature.

JMP's explanation facility is limited to design class-specific concerns, and it has no feature to assess process capability. The OQIE's feature of reporting the number of runs required to achieve the next best design may be mimicked in JMP by reading down the list of k factor designs to see what the next design is on the list. The aliasing information is presented in the same manner as the OQIE, but there is no automatic assignment of factors to identifiers.

3.7 Summary and Conclusions

This chapter has presented the design and architecture of the prototype expert system capable of realizing the hybrid approach to off-line quality improvement discussed in Chapter 1. The melding of the Taguchi strategy with mainstream statistical experimental design techniques has been illustrated in the form of a Venn diagram. The strategy for validation and verification is presented, along with a more detailed discussion of the capabilities of the system's two main modules. The sources for the derivations of all of the experimental design rules have been displayed

as a means of validating that segment of the knowledge base. The source for the Taguchi method confirms the validity of the rules directly associated with the Taguchi strategy. Finally, a comparison is made between the OQIE and three other software packages. The method taken in the experimental design module is shown to be a different approach from that taken by an existing stand-alone experimental design software package.

CHAPTER 4

SYSTEM VALIDATION AND VERIFICATION

4.1 Introduction

Quality concepts and verification and validation of conventional software has received much attention in the literature. Much of the work done in the area of software engineering is directly transferrable to the realm of expert system engineering. There are, however, many aspects of expert systems that have not been addressed by these studies. Several early works on expert systems have described quality characteristics of expert systems.

Gaschnig et al. [1983] provide the following list of criteria for expert system evaluation:

(1) The quality of the system's decisions and advice;

(2) The correctness of the reasoning techniques used;

(3) The quality of the human-computer interaction (both its content and the mechanical issues involved);

(4) The system's efficiency; and

(5) The system's cost-effectiveness.

Liebowitz [1986, 1988] incorporates these measures, along with those developed by Boehm et al. [1978] for software engineering into a set that covers all aspects of expert systems development.

Shannon [1975] provides sufficiency criteria as a basis for checking the overall validity of the prototype. Shannon's criteria for validation are:

(1) The prototype should be goal or purpose directed. The prototype is built for a purpose and should meet its functional specifications. This also implies that the system should have "representational sufficiency"--the concepts should be adequately represented;

(2) The prototype should be robust, in that it does not give absurd answers;

(3) The internal representation of the concepts should have "face validity" based on *a priori* knowledge, past research, and existing theory;

(4) The user interface should be appropriate. It should be easy for the user to control and manipulate; i.e., it should be easy to communicate with;

(5) The prototype should be adaptive and flexible, with an easy procedure to modify and update representations; and,

(6) The prototype must be complete on important issues.

Others have developed criteria for the validation and verification of specific elements of an expert system. Marcot [1987] addresses the evaluation of the knowledge base with a list of twenty different concerns. Kidd and Cooper [1985] offer guidelines for three different man-machine interface issues, knowledge acquisition, knowledge

representation, and communications interface. Giarratano and Riley [1989] examine the development process with their list of twenty criteria for quality systems.

O'Leary [1987, pp. 468-469] states, "Developing, designing, and implementing systems for making expert decisions requires analyzing the knowledge base and the decision-making capabilities of the system. That process, [is] referred to as validation. Smith and Kandel [1993, pp. 66-67] concur, and add:

> Verification and validation are complementary approaches for assessing and assuring the quality of expert systems. Evaluations, sans verification and validation, deals with the utility of the system, i.e., those aspects which are especially relevant to the intended user(s) of the expert system; for example, the ease of use, efficiency, usefulness of the results, and cost effectiveness are examined. Evaluation activities deal with the usability of the expert system while verification and validation deal with the accuracy and reliability of the expert system.

4.2 The Linear Model Process Model

Giarratano [1989] has proposed a process model he calls "The Linear Model" (Figure 4.1) to show the phases of expert systems development and the relationships between the phases. A discussion of the validation and verification activities for each of these phases is adapted from Smith and Kandel [1993].

4.2.1 Planning Phase

An initial analysis of the problem is undertaken to ensure that it is appropriate for an expert system approach.

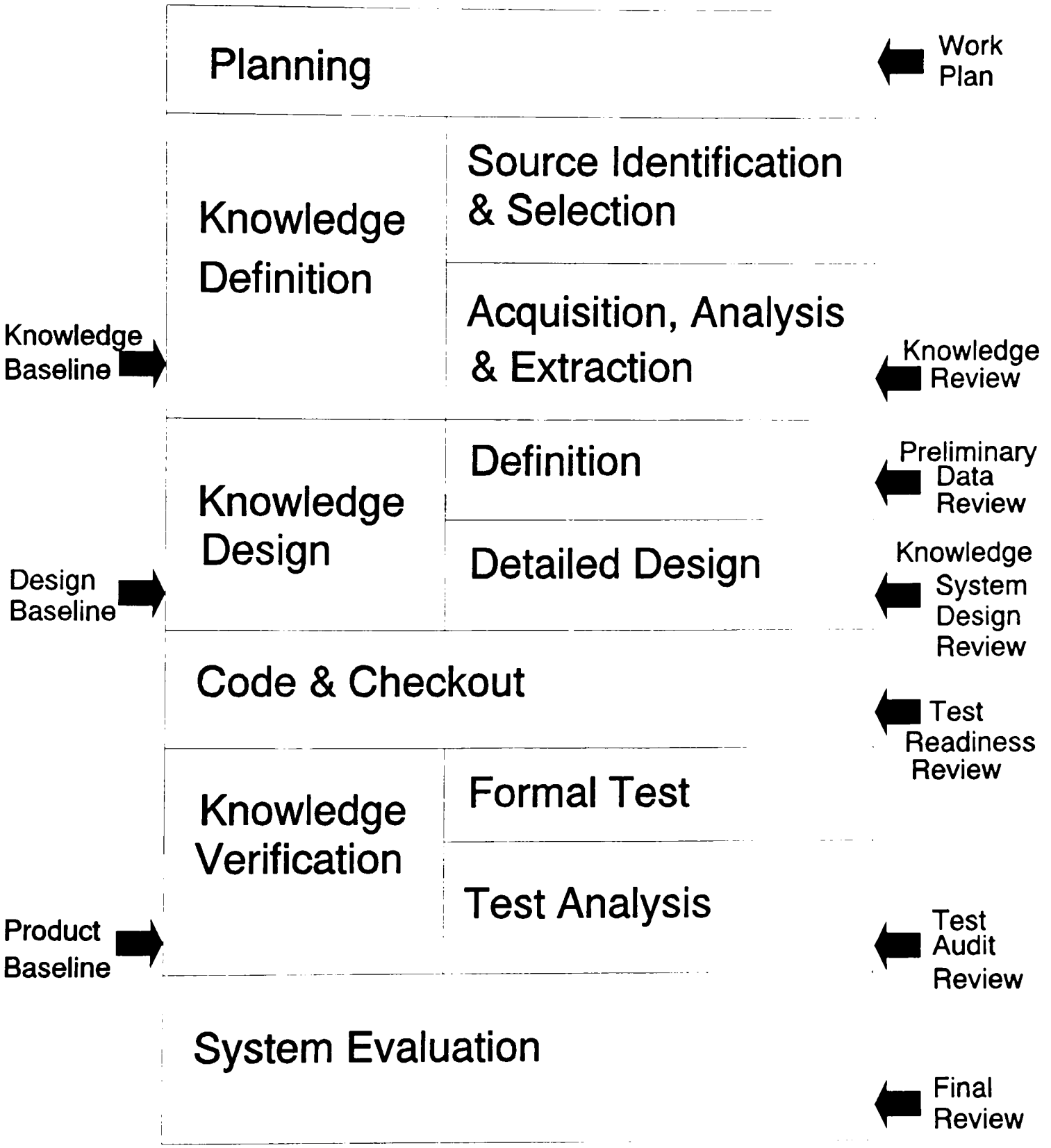

Figure 4.1 The Linear Model

Suitability of the topic of experimental design for such an approach was discussed in section 2.5.1 of this thesis. To recap, the nature, complexity, and scope of the problem domain determine when an expert system is appropriate. Waterman [1986] feels that an expert system is appropriate if all of the following hold:

(1) The task requires symbol manipulation;

(2) The task requires heuristic solutions;

(3) The task is not too easy;

(4) The task has a practical value; and

(5) The task is of manageable size.

The presentation of the OQIE in this chapter adequately addresses each of these items, thus completing the verification and validation for this phase of the research.

4.2.2 Knowledge Definition Phase

The knowledge definition phase involves identification of potential sources for the knowledge base as well as extraction of the knowledge. Verification of the knowledge entails a formal review of all sources or experts consulted. In the case of the OQIE, the sources include Box and Draper [1987], Barker [1985], Montgomery [1991], and Myers [1971]. The requirements specifications outlined in Chapter 3 describe the expected performance level of the system and serve as the validation activity.

4.2.3 Knowledge Design Phase

This phase requires detailed design of the expert system components. Decisions are made regarding the inference engine, knowledge representation, and user interface, in this case driven largely by the selection of EXSYS PROFESSIONAL as the tool. A test plan that covers all aspects of functional check-out is also formulated in this phase. Reviews of the design information and testing procedures constitute verification and validation in this phase. The design information is presented in Chapter 3 and the test plan is found in sections 3, 4, and 5 of this chapter.

4.2.4 Code and Checkout

Code realization, examination, and documentation are implemented in this phase. Major logic points of the code are contained in Appendix A. The code is certified as ready for thorough testing and the user manual appears as Appendix B of this dissertation.

4.2.5 Knowledge Verification

Knowledge verification involves implementation of the test plan for the developed code. The test plans covered in this chapter of the document are realized in sections 3, 4, and 5 and consist of a comparison of the OQIE's solutions to solved problems discussed in the statistical literature.

4.2.6 System Evaluation

In the final phase of the Linear Model, analysis of the detailed verification from the previous step, as well as an examination of the system's performance requirements as discussed in Chapter 3, provide for final verification and validation of the system. A final report on the conclusions of this activity appears in section 5 of this chapter, following presentation of the verifications of sections 3 through 5.

4.3 Analysis of Gear and Pinion Data

A project to investigate the geometric distortion of drive pinions and gears during a heat treatment process was performed at an axle plant [Taguchi 1987]. This project was successful in identifying operating conditions that significantly improved the quality of the produced parts. However, a large experiment using inner and outer arrays was performed, thus making the investigation very time-consuming and expensive. The same situation will be reanalyzed in order to demonstrate the efficacy of the OQIE.

4.3.1 Process Under Investigation

In automobile manufacturing, the drive pinion and gear system provides transmission of power from the vehicle drive shaft to the rear axle. The parts are heat treated to improve strength and wear characteristics. In a particular manufacturing plant, a quality problem arose from part

distortion during heat treatment, and a designed experiment was conducted in response.

The original experiment involved two sizes (7.5 in. and 8.5 in.) and several types of gears and pinions. The primary measures of distortion were stem runout (for the pinions), and dish, kink outer diameter, and kink inner diameter (for the gears). The experiment included carbon potential, operating mode, last zone temperature, quench oil temperature, and quench oil agitation as the five control factors. Furnace track, tooth size, and part positioning were the three noise factors for the experiment. Two levels were examined for each of the control and noise factors.

4.3.2 Original Experimental Setup

The original Taguchi approach called for a 16-run fractional factorial design of resolution V to be used as a control array. For this half-fraction the defining contrast was I=ABCDE. The confounding patterns are then set and it is possible to determine the confounding patterns by multiplying each side of the defining contrast by the same combination of letters. Multiplying through by ABC, and obeying the laws of modulo arithmetic results in the relationship ABC=DE, meaning the two-way interaction DE is mathematically equivalent to the three-way interaction ABC.

The noise array used a full 2^3 factorial design, which required eight runs to get all eight possible combinations of noise variables. Two replicates were performed for each

combination of settings, resulting in an experiment with a total of 256 trials.

4.3.3 OQIE Reanalysis With Imposed 128 Trial Limit

The same factors were provided to the OQIE to determine what improvements could be made upon the original experimental design. The procedure selected at the initial screen (Figure 4.2) was number of possible trials determination. Budgetary information was not available for the initial investigation so it was decided to limit the number of experimental trials to a fraction of the original 256 run experiment. The first analysis was begun with an imposed limit of 128 trials. The time and money available were both supplied as 128 while the time and money cost of each trial was input as 1. This resulted in the OQIE's assignment of the variable [RUNS] to 128, as displayed in Figure 4.3.

The OQIE then queried the user regarding the desired procedure and experimental design recommendation was selected as in Figure 4.4.

Selection of the experimental design recommendation option caused the OQIE to ask for the number of design variables and the number of noise variables. The number five was typed in response to the design variable question (Figure 4.5) and the system was informed that there were three noise variables as well.

THIS PROGRAM WILL COMPUTE A PROCESS CAPABILITY AND/OR DETERMINE THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS. IF YOU WISH TO CHECK ONLY PROCESS CAPABILITY, ENTER ZEROS FOR THE NUMBER OF DESIGN AND NOISE VARIABLES. IF YOU WISH TO DESIGN AN EXPERIMENT AND CHECK PROCESS CAPABILITY, THIS SCREEN WILL REAPPEAR, ALLOWING YOU TO SELECT THE OTHER PROCEDURE THE SECOND TIME THROUGH.

ENTER (P)ROCESS CAPABILITY OR (T)RIALS.
ENTER ANY OTHER CHARACTER TO RETURN TO THE EXPERT SYSTEM.

Figure 4.2 Procedure Determination

```
WHAT IS THE FINANCIAL BUDGET FOR THIS INVESTIGATION?  128
WHAT IS THE COST OF A SINGLE EXPERIMENTAL TRIAL?  1
HOW MUCH TIME DO YOU HAVE TO COMPLETE THIS INVESTIGATION?  128
HOW LONG DOES IT TAKE TO RUN ONE TRIAL?  1
THE DOLLAR CONSTRAINT IS 128 AND THE TIME CONSTRAINT IS 128
TIME AND MONEY BOTH LIMIT YOU TO 128 TRIALS

Press any key to continue...
```

Figure 4.3 Number of Trials Determination

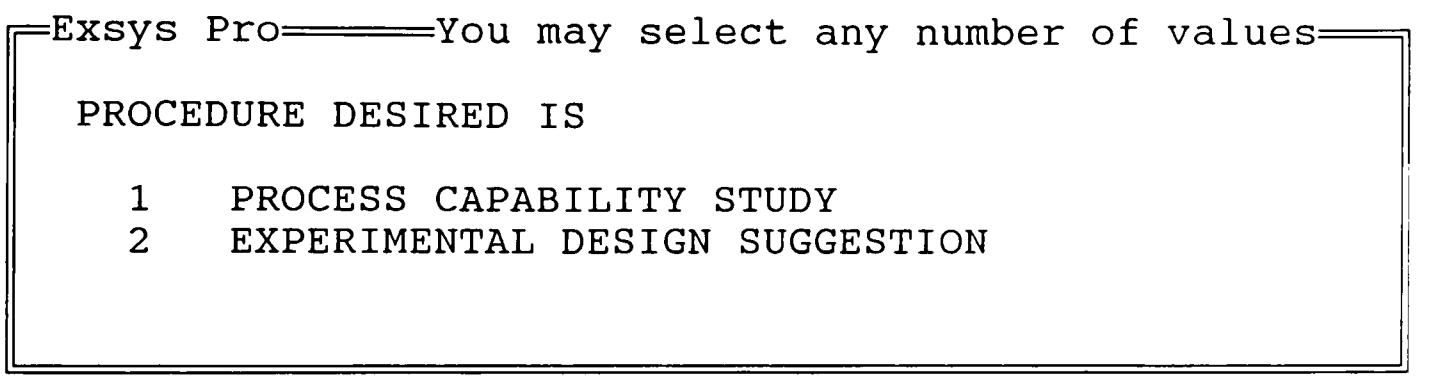

Figure 4.4 Procedure Selection

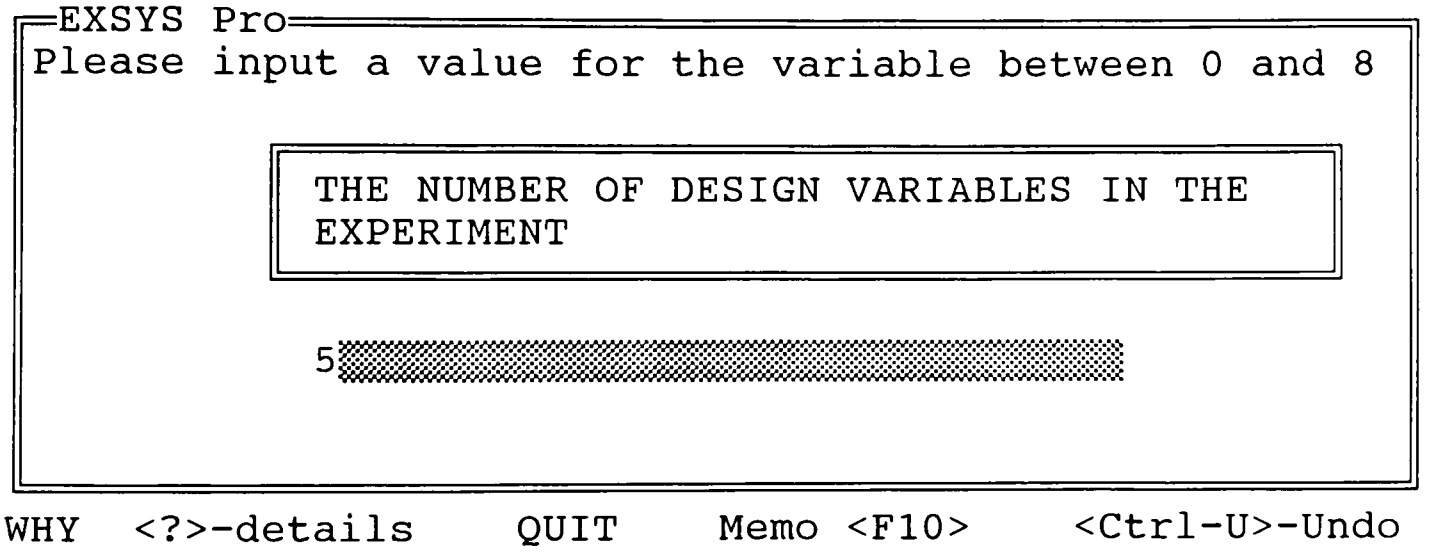

Figure 4.5 Number of Design Variables Screen in Pinion Experiment

The system then asked the user to specify the nature of the response, linear or quadratic, and was told that linearity would be assumed (Figure 4.6).

The OQIE then prompted the user for the names of the design variables, as well as the high and low levels of each. Sample screens for these inquiries are displayed a Figures 4.7 and 4.8, respectively. The original settings were not available for every design and noise variable, so responses to these questions assumed that the variables had already been coded +1 and -1.

The system then asked for the names of the noise variables as well as their high and low levels. Once again, the high and low levels were entered in coded form since the original settings were not available. The OQIE had all the information it required to suggest an experimental design and it produced the file DESIGN.DAT, which details the information provided, shows the variable assignments, and makes specific design recommendations. The DESIGN.DAT file for this investigation appears as Figure 4.9, which has been divided into two sections. Part I of the DESIGN.DAT file contains the information provided to the system, which includes the number of trials, design, and noise variables, as well as the names and levels of the design and noise variables. Part II shows the variable assignments made by the OQIE. In this case, there were a sufficient number of trials to achieve a resolution V design so the OQIE assigned

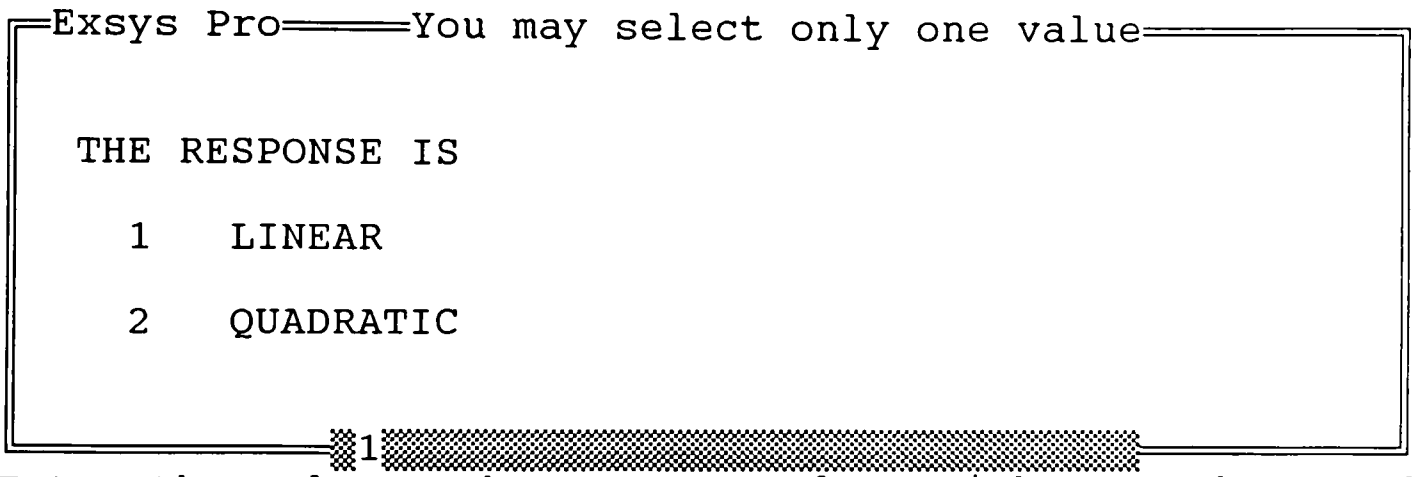

Figure 4.6 Response Variable Characteristic

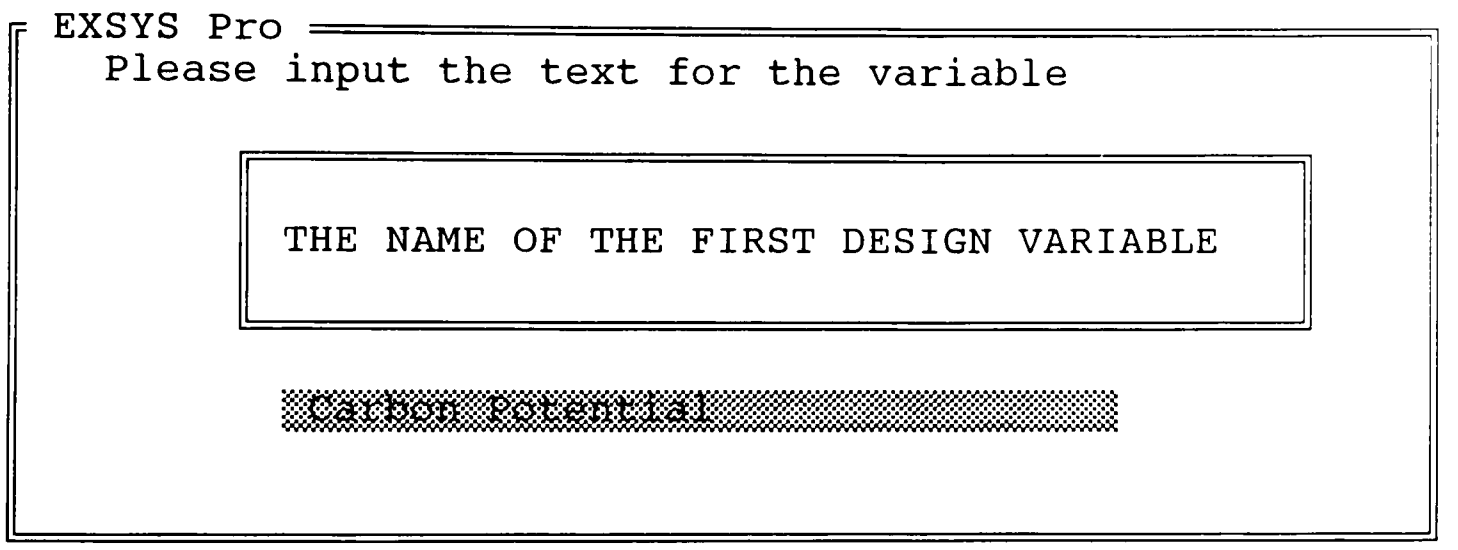

Figure 4.7 Variable Name Input Screen

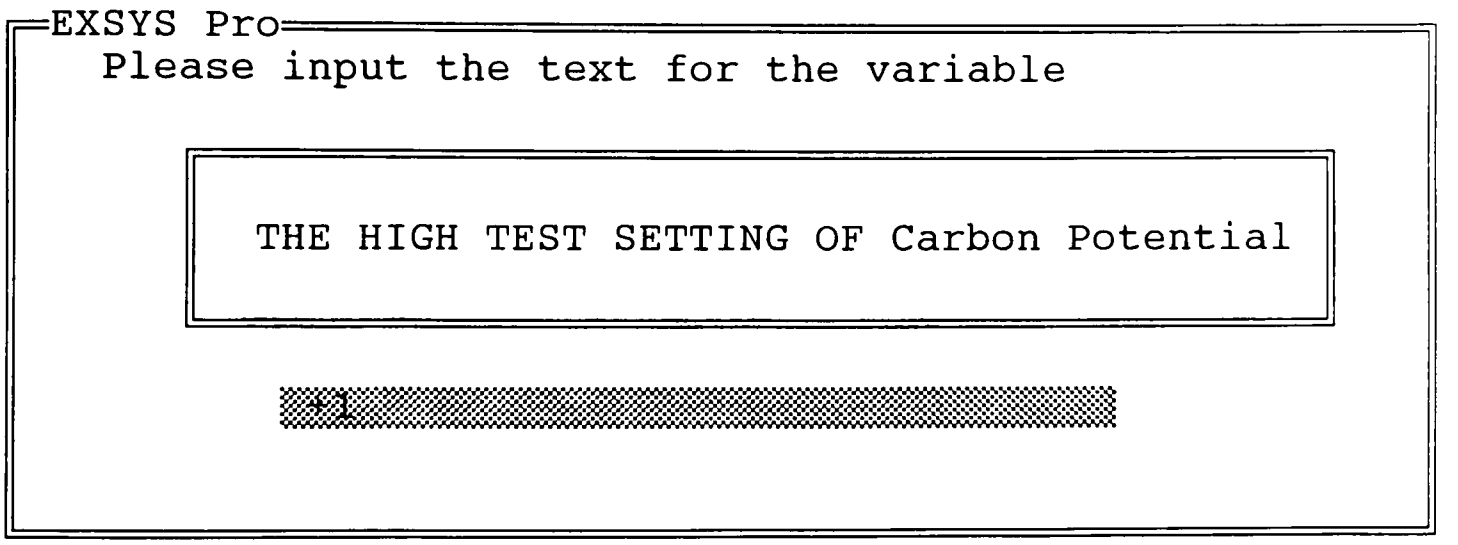

Figure 4.8 Variable Level Input Screen

I. YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 128

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 5

THE NAME OF THE FIRST DESIGN VARIABLE = Carbon potential

THE NAME OF THE SECOND DESIGN VARIABLE = Operating mode

THE NAME OF THE THIRD DESIGN VARIABLE = Last zone temperature

THE NAME OF THE FOURTH DESIGN VARIABLE = Quench oil temperature

THE NAME OF THE FIFTH DESIGN VARIABLE = Quench oil agitation

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 3

THE NAME OF THE FIRST NOISE VARIABLE = Furnace track

THE NAME OF THE SECOND NOISE VARIABLE = Tooth size

THE NAME OF THE THIRD NOISE VARIABLE = Part positioning

THE RESPONSE IS LINEAR

II. THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

FACTOR A OF THE DESIGN = Carbon potential
FACTOR B OF THE DESIGN = Operating mode
FACTOR C OF THE DESIGN = Last zone temperature
FACTOR D OF THE DESIGN = Quench oil temperature
FACTOR E OF THE DESIGN = Quench oil agitation
FACTOR F OF THE DESIGN = Furnace track
FACTOR G OF THE DESIGN = Tooth size
FACTOR H OF THE DESIGN = Part positioning

Figure 4.9 DESIGN.DAT File for 128 Run Pinion Experiment

III. DESIGN RECOMMENDATIONS

A. THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST SUITED FOR YOUR INDICATED SITUATION ARE LISTED BELOW:

1/4 FRACTION 2^8 FACTORIAL: Confidence=9/10
1/2 FRACTION 2^8 FACTORIAL: Confidence=8/10
1/8 FRACTION 2^8 FACTORIAL: Confidence=1/10

B. MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE THE LIST BELOW SHOWS THE NUMBER OF ADDITIONAL TRIALS REQUIRED IN ORDER TO EXTRACT MORE INFORMATION ABOUT THE SITUATION

THE NUMBER OF ADDITIONAL TRIALS REQUIRED TO ACHIEVE AN IMPROVED DESIGN = 128

IV. A BRIEF DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD AND H=ABEF AS DEFINING CONTRASTS. THIS DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS. THE 1/2 FRACTION OF THE 2^8 DESIGN PERMITS ESTIMATION OF ALL MAIN, TWO-WAY, AND THREE-WAY EFFECTS. THE DEFINING CONTRAST IS H=ABCDEFG. BY POOLING INSIGNIFICANT THREE-WAY INTERACTION TERMS, AN ESTIMATE OF EXPERIMENTAL ERROR VARIANCE MAY BE DEVELOPED. THE 1/8 FRACTION OF THE 2^8 FACTORIAL DESIGN ALLOWS ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS OF FACTORS A AND E TO BE ESTIMATED. IN ADDITION, THE FOLLOWING TWO-WAY ALIASES CAN BE ESTIMATED: BC=DH, BF=DG, BG=DF, BH=CD, CG=FH, CF=GH, AND BD=CH=FG. THESE ALIASED INTERACTIONS PERMIT ESTIMATION OF ALL COMBINATIONS OF B,C,D,F,G, OR H WITH EACH OF THE OTHER FACTORS.

V. THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN BE FOUND IN THIS SUBDIRECTORY IN THE FILE(S) LISTED BELOW:

Q28.DAT & H28.DAT & E28.DAT

THE INFORMATION ON THE FOLLOWING SCREEN IS A LESS PERMANENT REPEAT OF THIS REPORT (I.E., IT DISAPPEARS AFTER YOU PRESS RETURN). THIS INFORMATION IS CONTAINED IN THE DATA FILE DESIGN.DAT, WHICH IS AN ASCII TEXT FILE THAT HAS BEEN WRITTEN TO THE CURRENT DEFAULT DIRECTORY.

Figure 4.9 Continued

the variables were assigned factor names in the order in which they were entered.

The continuation of Figure 4.9 shows sections III, IV, and V of the DESIGN.DAT file, which contain design suggestions and background information.

Section III of the DESIGN.DAT file is composed of subsections A and B that, respectively, show the experiments possible given the information of Section I and show the number of additional resources needed to undertake the next better investigation.

Section A shows that although there were a sufficient number of trials to achieve a half-fraction 2^8 factorial design, based upon the confidence factors, the OQIE has listed it as a second choice to a quarter-fraction 2^8 factorial design. The confidence factors provide a monotonic scale for indicating the preference of one design to another given a specific design setting. The quarter-fraction design is listed as having a confidence of 9/10 and the half-fraction design is listed as having a confidence 8/10. Assignment of confidence factors is a subjective exercise when generalizing over the entire range of experiments that could possibly be conducted using this system. The term "confidence" is an unalterable entity in EXSYS PROFESSIONAL and may be misleading. A suitable synonym for "confidence" in this arena might be "generic desirability," since the information provided in section IV

should be reconciled with the *a priori* reasoning of the investigator regarding important interactions between design and noise factors. The OQIE has also indicated that an eighth-fraction 2^8 factorial design may be run, although the confidence assigned this option is only 1/10.

Section B reveals that the next step up in terms of design completeness requires that an additional 128 trials be conducted. This would bring the total number of trials to 256, which is the same number used in the original Taguchi investigation. An experiment of this size would permit all main effects and all possible interactions to be estimated, with the more complex and non-significant interactions possibly being pooled to form an error term.

Section IV of the report offers a brief discussion of the designs recommended in section III.A. It is noted that the half-fraction permits estimation of all main, two-way, and three-way interactions without aliasing, while the quarter-fraction permits estimation of all main effects but aliases some of the two-way interactions with three-way interactions. It is this information that should be used in conjunction with the researcher's *a priori* knowledge of the process to confirm or discount the confidence factors assigned in section III of the report. If the researcher believes that no three-way interactions are significant, then he or she may agree with the assessment of section III.A. that suggests a quarter-fraction factorial when

resources exist to run a half-fraction. If the researcher believes to the contrary, or does not know enough about the process to declare otherwise, the OQIE's assignment of confidence values in section III.A. may be overruled.

Section V of the DESIGN.DAT file displays the data files containing the factor setting information. An example of a data file is displayed in Figure A.13. The data file displays experimental trial factor settings in Yates algorithm order so it is up to the investigator to randomize the trials. Section V concludes with the indication that all of the information appears in the DESIGN.DAT file and that the identical information that appears on the subsequent computer screen will vanish once the review is concluded.

4.3.4 OQIE Reanalysis With Imposed 64 Trial Limit

A second investigation of the gear and pinion data was attempted with an imposed 64 trial resource limit. Since the entire experimental situation was identical to the previous execution of the OQIE, the Change/rerun option was selected at the OQIE's final screen (see Appendix B.7.2 for details) and the external program was recalled with limits of 64 supplied as time and money constraints. No interactions had to be selected so the OQIE proceeded directly to the creation of the DESIGN.DAT file and presentation of the final screen (Figure 4.10).

```
EXSYS Pro ========== **RESULTS ** ==========================
                                                VALUE   PREV.
1  1/4 FRACTION 2^8 FACTORIAL                     9       9
2  1/8 FRACTION 2^8 FACTORIAL                     3       1
3  1/2 FRACTION 2^8 FACTORIAL                    NONE     8
4  THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 5
5  THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 3
6  THE MAXIMUM NUMBER OF TRIALS POSSIBLE = 64
7  FACTOR A OF THE DESIGN = Carbon Potential
8  FACTOR B OF THE DESIGN = Operating mode
9  FACTOR C OF THE DESIGN = Last zone temperature
10 FACTOR D OF THE DESIGN = Quench oil temperature
11 FACTOR E OF THE DESIGN = Quench oil agitation
12 FACTOR F OF THE DESIGN = Furnace track
13 FACTOR G OF THE DESIGN = Tooth size
14 FACTOR H OF THE DESIGN = Part positioning
15 THE LOW TEST SETTING OF Carbon Potential = -1
16 THE HIGH TEST SETTING OF Carbon Potential = +1
17 THE LOW TEST SETTING OF Operating mode = -1
18 THE HIGH TEST SETTING OF Operating mode = +1

    ** MORE DATA **
```

All choices <A> only if >1 <G> Print <P> Change/rerun <C>
Rules used <line#> Quit/save <Q> Help <H> Memo <F10>
Done <D>

Figure 4.10 Final Screen of 64 Trial Pinion Experiment

As Figure 4.10 indicates, the only change from the first session with the OQIE is that the half-fraction of the full 2^8 factorial design is not possible, since there are insufficient resources for the requisite 128 trials. The quarter-fraction is still the best choice with a confidence assignment of 9/10, although the eighth-fraction receives mention with a confidence assignment of 3/10.

The DESIGN.DAT file, displayed in Figure 4.11 is virtually identical in all regards with the exception of the half-fraction 2^8 factorial experiment suggestion in section III and the discussion of that experiment in section IV.

The second half of the DESIGN.DAT file reflects the lack of experimental resources in the absence of any suggestion of the half-fraction 2^8 factorial arrangement.

4.3.5 Independent Analysis of Pinion Data

An analysis of the same gear and pinion data was performed by Miller, Sitter, Wu, and Long [1993, pp. 26-30] to demonstrate that a smaller experiment could arrive at the same conclusions as a large Taguchi-style experiment. Their discussion of the experimental setup follows.

> To ascertain what recommendations would have resulted from performing an experiment with fewer runs [than Taguchi's], selected half-fractions (one-half the original run size) and quarter-fractions (one-quarter the original run size) of the original experiment were reanalyzed. These fractions were carefully chosen in consideration of the confounding structure in the original design. To illustrate, we describe one half-fraction and one quarter-fraction.

I. YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 64

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 5

THE NAME OF THE FIRST DESIGN VARIABLE = Carbon Potential

THE NAME OF THE SECOND DESIGN VARIABLE = Operating mode

THE NAME OF THE THIRD DESIGN VARIABLE = Last zone temperature

THE NAME OF THE FOURTH DESIGN VARIABLE = Quench oil temperature

THE NAME OF THE FIFTH DESIGN VARIABLE = Quench oil agitation

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 3

THE NAME OF THE FIRST NOISE VARIABLE = Furnace track

THE NAME OF THE SECOND NOISE VARIABLE = Tooth size

THE NAME OF THE THIRD NOISE VARIABLE = Part positioning

THE RESPONSE IS LINEAR

II. THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

FACTOR A OF THE DESIGN = Carbon Potential
FACTOR B OF THE DESIGN = Operating mode
FACTOR C OF THE DESIGN = Last zone temperature
FACTOR D OF THE DESIGN = Quench oil temperature
FACTOR E OF THE DESIGN = Quench oil agitation
FACTOR F OF THE DESIGN = Furnace track
FACTOR G OF THE DESIGN = Tooth size
FACTOR H OF THE DESIGN = Part positioning

Figure 4.11 DESIGN.DAT File for 64 Run Pinion Experiment

III. DESIGN RECOMMENDATIONS

A. THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST SUITED FOR YOUR INDICATED SITUATION ARE LISTED BELOW:

1/4 FRACTION 2^8 FACTORIAL: Confidence=9/10
1/8 FRACTION 2^8 FACTORIAL: Confidence=3/10

B. MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE THE LIST BELOW SHOWS THE NUMBER OF ADDITIONAL TRIALS REQUIRED IN ORDER TO EXTRACT MORE INFORMATION ABOUT THE SITUATION

THE NUMBER OF ADDITIONAL TRIALS REQUIRED TO ACHIEVE AN IMPROVED DESIGN = 64

IV. A BRIEF DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD AND H=ABEF AS DEFINING CONTRASTS. THIS DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS. THE 1/8 FRACTION OF THE 2^8 FACTORIAL DESIGN ALLOWS ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS OF FACTORS A AND E TO BE ESTIMATED. IN ADDITION, THE FOLLOWING TWO-WAY ALIASES CAN BE ESTIMATED: BC=DH, BF=DG, BG=DF, BH=CD, CG=FH, CF=GH, AND BD=CH=FG. THESE ALIASED INTERACTIONS PERMIT ESTIMATION OF ALL COMBINATIONS OF B,C,D,F,G, OR H WITH EACH OF THE OTHER FACTORS.

V. THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN BE FOUND IN THIS SUBDIRECTORY IN THE FILE(S) LISTED BELOW:

Q28.DAT & E28.DAT

THE INFORMATION ON THE FOLLOWING SCREEN IS A LESS PERMANENT REPEAT OF THIS REPORT (I.E., IT DISAPPEARS AFTER YOU PRESS RETURN). THIS INFORMATION IS CONTAINED IN THE DATA FILE DESIGN.DAT, WHICH IS AN ASCII TEXT FILE THAT HAS BEEN WRITTEN TO THE CURRENT DEFAULT DIRECTORY.

Figure 4.11 Continued

1. The half-fraction defined by I=ABFG consists of the 128 runs [that contain the identical information as the original experiment]. We get I = ABFG x ABCDE = CDEFG.

2. The quarter fraction I = ABFG = ADGH consists of the 64 runs [with a complete defining relationship of] I = ABFG = ADGH = ABCDE = BDFH = BCEGH = CDEFG = ACEFH.

Using a single combined array for both the control and noise factors has two definite advantages over Taguchi's approach which calls for the use of an inner array crossed with an outer array. The former approach required a much smaller number of runs, and the combined array can be chosen in a flexible manner to accommodate the estimation of selected control-by-control and noise-by-noise interactions. Both of these advantages are clearly illustrated above. The above half-fraction would have required only half as many runs as the original experiment and still allowed estimation of all main effects and most of the 2-factor interactions if the 3-factor and higher-order interactions are negligible. The quarter-fraction, I=ABFG=ADGH, requires only one-quarter the number of runs and allows estimation of all main effects and selected 2-factor interactions.

We should note that some of the other half-fractions considered were resolution V designs (e.g., I=ABFGH) which allow all main effects and two-factor interactions to be estimated (assuming three-factor and higher order interactions are negligible) using half the original number of runs.

4.3.6 Comparison of Experimental Designs

The original experiment, conducted using crossed control and noise arrays, required 256 experimental trials to assess the effects of the eight factors under consideration. The results of the experiment showed that the last zone temperature and part position factors should be kept at their high level while operating mode should be

at its low level for the 7.5 in gear. The experiment is considered a success since quality was actually improved after implementation of the experimenters' findings.

The reanalysis (Miller et al. [1993]) involved combined arrays of two different sizes, both of which were smaller than the Taguchi experiment. The 128 experimental trial array was set up so that an alias structure identical to the original experiment was achieved. This resulted in identical results to the original experiment. The 64 experimental trial array "would have *yielded exactly the same recommendations*" (Miller et al. [1993, p. 35]) by capturing the large effects, although smaller effects would possibly be missed. The setting for operating mode is a smaller effect and might initially be missed with an initial quarter-fraction screening experiment but would have merited closer inspection if any subsequent testing was to be performed.

A reanalysis of the data using the designs suggested by the OQIE is not possible since the alias structure and subsequent experimental trial settings proposed are different than those that were reported. An inspection of the designs for reasonability is possible and it is evident that both the 128 and 64 trial designs are workable designs capable of uncovering the same kind of effects observed in the previous two analyses. The 128 trial design is a higher resolution investigation than either of its predecessors

since it can provide estimates of all main, two-way, and three-way interaction effects provided four-way and higher order interactions are negligible. The 64 trial experiment is a resolution V design, which means it permits estimation of all main and two-way interaction effects separate from each other if three-way and higher interactions are assumed negligible.

4.4 Analysis of Drilling Data

An investigation of the factors involved in drilling holes in an aluminum alloy was performed in the Machine Tool Laboratory as The University of Iowa. Mielnik [1993, p. 72] reports that "it has been conservatively estimated that over 100 million drills are used each year in the United States alone, so that the number of holes drilled annually runs into the billions." Despite the vast numbers of holes drilled, the drilling process is poorly understood due to its complex, multivariable nature.

4.4.1 Process Under Investigation

An aluminum alloy (7075-T6) was used in an experiment that checked the influence of drill diameter and feed rate on the thrust and torque required. A 24-inch Cincinnati-Bickford upright drilling machine set at 800 rpm was used throughout the experiment. Due to the softness of the alloy, and resultant lack of wear of the drill bits, the

bits were changed only when the experiment dictated a change in size.

4.4.2 Original Experiment

An experiment was performed that investigated the effects of drill diameter and feed rate assuming a quadratic response. The design selected was a two-factor central composite design, which is composed of a factorial design augmented with star points and central points. This design, rather than testing the two factors at only three levels as a 3^2 factorial, is more the nature of a 5^2 factorial design since the star points may be obtained by rotating the square described by a 2^2 factorial design by 45 degrees. The "extra" two levels of the factors are obtained by selecting levels $\pm\sqrt{2}$ times the level coded as 1. A diagram of the coded coordinates of the experiment adapted from Mielnik [1993] appears as Figure 4.12.

An error estimate for the experiment is provided by replicating the center point, labelled (0,0) in Figure 4.12, four times. The entire experiment consisted of twelve trials, one observation at each corner and star point and four replications of the center point.

4.4.3 OQIE Reanalysis Using Imposed 12 Trial Limit

The process was analyzed using the OQIE with an imposed size limitation of twelve trials. The DESIGN.DAT file appears as Figure 4.13.

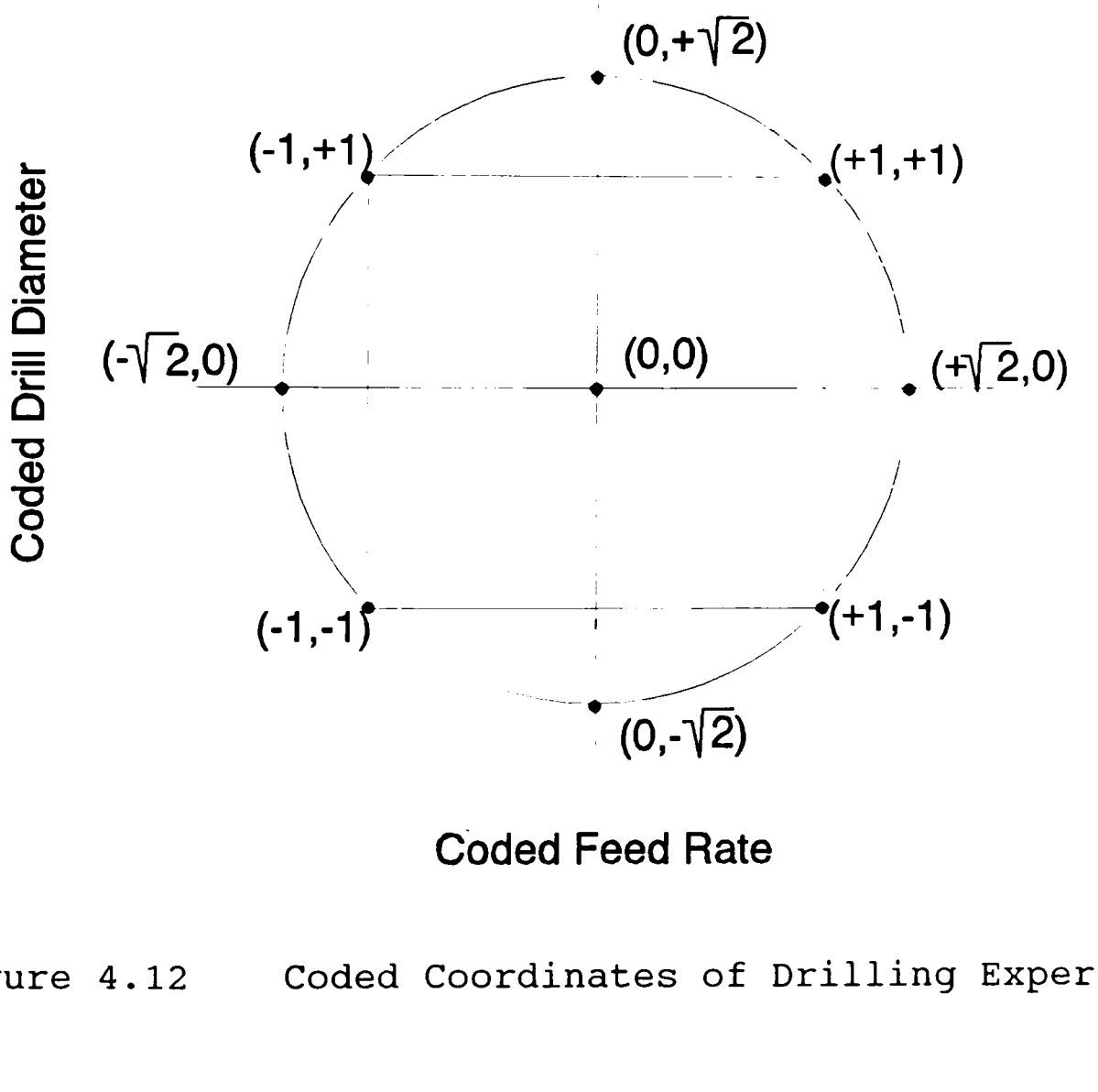

Figure 4.12 Coded Coordinates of Drilling Experiment

```
I.  YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 12

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 2

THE NAME OF THE FIRST DESIGN VARIABLE = Feed Rate
THE NAME OF THE SECOND DESIGN VARIABLE = Drill Diameter

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 0

THE RESPONSE IS QUADRATIC

II.  THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

FACTOR A OF THE DESIGN = Feed Rate
FACTOR B OF THE DESIGN = Drill Diameter

III. DESIGN RECOMMENDATIONS

     A.    THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST
           SUITED FOR YOUR INDICATED SITUATION ARE LISTED
           BELOW:

3^2 CENTRAL COMPOSITE W/CENTER POINT REPLICATED:
Confidence=9/10

     B.    MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE THE
           LIST  BELOW SHOWS THE NUMBER OF ADDITIONAL TRIALS
           REQUIRED IN ORDER TO EXTRACT MORE INFORMATION
           ABOUT THE SITUATION

THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES
PERMITS A THOROUGH INVESTIGATION
```

Figure 4.13 DESIGN.DAT File for Drill Data

IV. A BRIEF DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

THE CENTRAL COMPOSITE DESIGN IS COMPOSED BY ROTATING A 2^2 FACTORIAL DESIGN 90 DEGREES AND ADDING 4 ADDITIONAL POINTS (CALLED STAR POINTS) THAT ARE LOCATED A DISTANCE OF THE FOURTH ROOT OF FOUR (1.4142) AWAY FROM THE CENTER POINT OF THE DESIGN. THIS DESIGN ASSUMES THAT YOU CAN SELECT 5 DIFFERENT LEVELS FOR EACH OF THE VARIABLES UNDER INVESTIGATION. BY REPLICATING THE CENTER POINT OF THE DESIGN, EXPERIMENTAL ERROR MAY BE ESTIMATED.

V. THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN BE FOUND IN THIS SUBDIRECTORY IN THE FILE(S) LISTED BELOW:

32CCD.DAT

THE INFORMATION ON THE FOLLOWING SCREEN IS A LESS PERMANENT REPEAT OF THIS REPORT (I.E., IT DISAPPEARS AFTER YOU PRESS RETURN). THIS INFORMATION IS CONTAINED IN THE DATA FILE DESIGN.DAT, WHICH IS AN ASCII TEXT FILE THAT HAS BEEN WRITTEN TO THE CURRENT DEFAULT DIRECTORY.

Figure 4.13 Continued

The OQIE selected an experiment identical to the one proposed in the literature. All suggested data points are the same so analysis of the data will produce the sameresults and conclusions as the original investigation everything else, *ceteris paribus*.

4.5 Field Trial

The Custom Manufacturing Services Division of the Texas Instruments, Inc., production facility in Lubbock, Texas, manufactures a variety of consumer products, among them calculators and educational, computer-based toys. In July of 1993, Texas Instruments began producing four different models of printing desktop calculators. The model 8660 desktop calculator was the product selected for improvement in the field trial of the OQIE.

4.5.1 Process Under Investigation

The system represents a classical product layout capable of producing 2,000 items/day in one seven and one-half hour shift. Line flow is constant and each worker is authorized to stop the line if a problem with the manufacturing process is perceived. Texas Instruments uses 100% inspection, so the observed defect rates represent the actual population of production rather than an estimate.

System parameters were determined from historical data that have been collected using the Texas Instruments Real Time Tracking System (RTTS). Population parameters are

obtainable from the RTTS since it has been used to track defect rates since the line's inception. Propagation rates for the parameters displayed in Table 4.1 are maintained by the RTTS used at this facility.

These defects have been segmented by Texas Instruments into four categories: 2000 series defects are electrical in nature; 3000 series defects are mechanical in nature; 4000 series defects are cosmetic in nature; and 5000 series defects cover all other possibilities.

This part of the validation consisted of three phases, the first of which established a baseline process capability, called p_1, for one component of the original product design. The Texas Instruments process uses an attributes measure, so the process capability was expressed as a percentage of defects.

A pareto analysis of the RTTS data for the month of December 1993 is presented in Table 4.2. The defect rates are computed as a percentage of units produced during this run of length 22,503.

As Table 4.2 shows, the second most frequent error is a 2000 code involving the LED display for the unit, which has a tendency to crack during insertion, rendering it inoperable. During the December production run, a total of 224 LED displays cracked during insertion. The process engineer and line employees felt that the majority of display fractures were caused by the display leads being too

Table 4.1 Errors Tracked by the RTTS

ERROR #	DESCRIPTION
2000	Bad components, I.C's, transistors, etc.
2001	Solder, etch, and lead shorts
2002	Solder, etch, and lead opens
2003	Clipping of wrong resistors or wrong value inserted to get frequency within specifications
2004	Components marked with the wrong value
2005	Component reversal errors
2006	Foreign objects that could cause electrical failure
2007	Missing electrical components
2009	Insufficient solder
3000	Mechanical defect
3001	Parts bent mechanically out of specification
3002	Parts welded mechanically out of specification
3003	Loose objects in unit
3004	Missing
3005	Elastomers, components, or parts that are seated, but not seated properly
3006	Parts or components that are not connected, attached, or torqued
3007	Solder ball
3008	Parts that are warped out of specification
3009	Parts or components not physically conforming with the specifications
3010	Parts or components that do not fit physically together because of improper installation

Table 4.1 Continued

ERROR #	DESCRIPTION
4000	Generic cosmetic defect
4001	Chemical or foreign object that causes discoloration or deformation that do not affect the functionality or reliability of the unit
4002	Scratch
4003	Missing parts or components that do not affect the functionality or reliability of the unit
4004	Parts or components not properly inserted that do not affect the functionality or reliability of the unit
4005	Parts, components, display, labels, imprints, or other parts or components that do not physically line up as designed, but do not affect the functionality or reliability of the unit
5004	Mixed or wrong parts or components, out of sequence
5005	False failures
5006	Parts or components physically damaged.

Table 4.2 Component Failure Rankings

RANK	ITEM	PERCENTAGE	CUMULATIVE PERCENTAGE
(1)	Top Case	1.46%	1.46%
(2)	Vacuum Display	1.00%	2.46%
(3)	8 x 60 PCB	0.79%	3.25%
(4)	Keysets	0.71%	3.96%
(5)	Pretty Box	0.65%	4.61%
(6)	Display Spprt Brkt	0.53%	5.14%
(7)	Ribbon Printer	0.49%	5.63%
(8)	Disp Spprt Brkt Left	0.47%	6.10%
(9)	Male Header	0.46%	6.56%
(10)	Solid Jumper Wire	0.41%	6.97%
(11)	Slide Switch	0.40%	7.37%
(12)	Poly Bag	0.33%	7.70%
(13)	1N4148 Diode	0.30%	8.00%
(14)	IC Driver IR2422	0.30%	8.30%
(15)	100uF 35V Capacitor	0.28%	8.58%
(16)	Male Header	0.25%	8.83%
(17)	80x60 PCB	0.25%	9.08%
(18)	Display Window	0.24%	9.32%
(19)	Tax/Calc Label	0.19%	9.51%
(20)	1872 Transistor	0.18%	9.69%

short for display brackets, so it was decided to test the effect of displays with longer leads. It was felt that no other variables had a significant impact on the LED display cracking problem, so no other design or noise variables were included in the experiment.

4.5.2 Analysis With the OQIE

In step two of the field trial, an experiment was designed to test the effects of varying this single design variable. The OQIE was supplied with a single factor to test at two levels along with a trials constraint of two. The DESIGN.DAT file output by the system appears as Figure 4.14.

The third step of the field trial required execution of the experiment, with a fraction defective determination. A run of 13,016 units using displays with the longer leads revealed only thirty-four LED cracking errors, a fraction defective equal to 0.26%.

The index computed following the second study, p_2, was then compared by Texas Instrument process engineers to determine the process improvement. The process capability indices of the pre- and post-experimentation product designs have been compared to determine if any process improvement has taken place.

The hypothesis under examination tests the effectiveness of this application of the off-line quality

I. YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 2

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 1

THE NAME OF THE FIRST DESIGN VARIABLE = LEAD LENGTH

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 0

THE RESPONSE IS LINEAR

II. THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

FACTOR A OF THE DESIGN = LEAD LENGTH

III. DESIGN RECOMMENDATIONS

A. THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST SUITED FOR YOUR INDICATED SITUATION ARE LISTED BELOW:

2^1 FACTORIAL: Confidence=9/10

B. MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE THE LIST BELOW SHOWS THE NUMBER OF ADDITIONAL TRIALS REQUIRED IN ORDER TO EXTRACT MORE INFORMATION ABOUT THE SITUATION

THE NUMBER OF TRIALS NEEDED FOR THE NEXT BEST EXPERIMENT = 2

IV. A BRIEF DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

THIS DESIGN ALLOWS ONE MAIN EFFECT TO BE TESTED. TWO RUNS ARE THE ABSOLUTE MINIMUM TO DO THIS BUT LEAVES NO ROOM FOR ESTIMATION OF ERROR VARIANCE. A BETTER DESIGN WOULD REQUIRE ONLY TWO MORE RUNS.

V. THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN BE FOUND IN THIS SUBDIRECTORY IN THE FILE(S) LISTED BELOW:

21.DAT

Figure 4.14 DESIGN.DAT File for Texas Instruments Field Validation

improvement expert system. This effectiveness hypothesis is expressed as follows:

H_0: There is no difference between the process capability of the pre-experiment setup and the post-experiment setup.

H_a: The process capability of the post-experimental assembly line configuration is greater than that of the pre-experimental assembly line configuration.

The effectiveness hypothesis can be tested by a comparison of the first and second process capability indices using equations 4.1 through 4.3:

$$z = \frac{\hat{p}_1 - \hat{p}_2}{s_p(D)}, \qquad 4.1$$

where,

$$s_p(D) = \sqrt{\hat{p}(1 - \hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}, \qquad 4.2$$

and,

$$\hat{p} = \frac{X_1 + X_2}{n_1 + n_2}. \qquad 4.3$$

That is, can the system suggest designs that result in the improvement of the process capability of a manufacturing process? Equation 4.6 shows the results of this field study:

$$\hat{p} = \frac{224 + 34}{22,503 + 13,016} \qquad 4.4$$

$$\hat{p} = 0.0073$$

$$s_p(D) = \sqrt{0.0073(1 - 0.0073)\left(\frac{1}{22,503} + \frac{1}{13,016}\right)} \qquad 4.5$$

$$s_p(D) = 9.351 \times 10^{-4}$$

$$z = \frac{0.0099 - 0.0026}{9.351 \times 10^{-4}} \qquad 4.6$$

$$z = 7.8515.$$

This result reflects a high level of significance ($p < .001$). Since the null hypothesis is rejected, then there is evidence that the system can be considered effective for a real-world application.

A comparison cannot be made between use of the system in this situation and the use of manual experimental design techniques, since the system was used by the manufacturing firm employee responsible for designing an experiment on this particular line. Given the simplicity of this situation, it is likely that a similar experiment could have been suggested by the process engineer. A more complicated situation, beyond the expertise of the employee, would have allowed the OQIE to demonstrate its utility as a decision support system.

4.6 Summary and Conclusions

This chapter has demonstrated the validity of the architecture of the OQIE. First, the Linear Model of Giarratano [1989] was used as a vehicle to show internal validity. Next, the OQIE was presented with three different problems to solve. The first two problems, taken from the literature, were analyzed in a manner consistent with that of professionals in the area of experimental design. The third application consisted of a field trial during which a manufacturing professional familiar with the notion of off-line quality used the system to recommend a suitable experiment. The study suggested by the experiment was performed and the process capability as computed by the manufacturing firm's system was higher for the post-experiment manufacturing process than for the pre-experiment manufacturing process.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Purpose and Motivation Revisited

The purpose of this research was to develop a conceptual framework for an off-line quality control expert system that can assist in the search for continual process improvement.

It is well-documented that the United States no longer enjoys the competitive advantage it held during the first half of the twentieth century. Quality is a concern for both consumers and producers and it is one area where the United States has a perceived deficiency. Motivations for this research stem from two sources, industry and quality improvement researchers, both of whom indicate a need for increased research into the application of quality improvement techniques.

Of the three primary approaches to quality improvement, only robust design affects the built-in worth of a product in a cost-efficient manner. The other approaches, inspection and process controls, either fail to improve the built-in quality of a product or are costly, or both. Off-line product and process design methods build quality into the product and/or process, making the product (process) insensitive to variability in both the manufacturing environment and the product's use environment. In addition,

improved product and process design reduces manufacturing and product lifetime costs.

5.2 Methodology Revisited

A prototype system was developed to test the efficacy of fusing strategies repopularized by Taguchi with accepted procedures (classical design of experiments). The expert system that was developed determines the capability of a process, captures knowledge about important process or product parameter relationships, suggests an appropriate experimental design, and measures the effectiveness of the revisions suggested by the experimental outcomes. The system automates a blend of the Taguchi method strategy for off-line quality and classical industrial experimental design techniques so that this hybrid approach can be used by practitioners with limited exposure to either of these concepts.

The system tests presented in Chapter 4 demonstrated that it can be used by novices to address design problems in a manner consistent with quality professionals. Verification and validation was accomplished when the OQIE was used to analyze problems in the quality literature and its suggestions were comparable to those proposed by statistical experts. Evaluation, or user-friendliness, was demonstrated in a real-world setting when the OQIE was successfully used to analyze a young product.

5.3 Contributions

The major contribution of the proposed research lies in the formal blend of the Taguchi strategy with classical statistical experimental design tactics. As Hunter [1985, p. 219] observed, these concepts, "go hand in hand... [and] as students and practitioners our objectives must be to apply the best of both." Hunter's quote describes exactly what this system accomplishes.

A second contribution is that this prototype uses a variant approach in its experimental design module. The highlight of this continual quality improvement system is its design of experiments capability, and although other software packages on the market have a similar capability, they do not employ this approach to design. The designs proposed by the OQIE and the JMP design module are essentially identical, and the systems' response time is also the same. The process capability module of this prototype is no different than that available in other quality software packages, but the integration of these two modules provides a medium for continual off-line quality improvement that takes the best of two disparate approaches.

5.4 Managerial Implications

A manager implementing the OQIE system should be committed to kaizen, or a process of ongoing improvement. The search for perfection via incremental improvement requires dedication and perhaps some propensity for risk

taking since valuable productive time and raw materials might be sacrificed in order to conduct off-line experiments. The potential payback is enormous in improved product quality, productivity, or customer satisfaction. The OQIE facilitates such experimentation by providing a design suggestion given a list of operating factors and their nature.

An organization committed to continual improvement empowers its employees such that they feel free to offer suggestions regarding their process. The workers are eminently qualified to address their facet of the conversion process, but may not have a sufficient background in experimental design. Since statistical expertise is not common among line workers, or even in a quality control department in a small to medium-sized production facility, the OQIE fills the experimental planner niche. As a planner, the OQIE can assist with process improvement up to the point of experimentation.

After the experimental trials are laid out and observations are recorded, the data must be analyzed. It does not seem unreasonable to assume that if a firm is lacking in experimental setup expertise, then data analysis skills might also be lacking. If this is the case, then consulting help beyond the sophistication of the OQIE is required. On the other hand, if some rudimentary level of regression/experimental design data analysis competence is

available, the OQIE could be an invaluable aid if experimental parsimony is the key issue.

The OQIE may have some value as a training tool, due to the nature of its rule structure. The other systems discussed in Chapter 3 produce results that may be difficult to explain given the generative nature of their programming. The rules of the OQIE are written and may be viewed in such a manner as to make them more understandable to a less-informed user. From a risk-taking standpoint, the ability to view decision criteria may make the OQIE's suggestions easier to accept and implement.

5.5 Limitations and Key Assumptions

Perhaps the greatest limitation of the prototype may be the level of knowledge required to successfully operate the system or interpret its suggestions. This limitation is similar to that of O'Keefe's [1982] prototype that required near expert knowledge to operate. The inclusion of help screens aids in system operation but can in no way substitute for some grounding in experimental design and response surface methodology.

The field trial, while successfully implemented, was done so by an engineer that had received company training in experimental procedures. A true novice user was unavailable at the production facility due to the combination of the widespread training of production personnel and lack of authorization to conduct experiments and alter product

design and production techniques for those untrained personnel.

The engineer consulted help screens during the field validation to gain insights regarding some of the terminology used by the system's qualifiers. That these questions were adequately answered implies that at least some of the system help screens provide clear explanations of the information required. Further evaluation in manufacturing or laboratory settings is required to test the assumption that all help screens are equally clear for all varieties of users.

The number of noise variables and controllable variables accommodated by the advisor's designs is limited to eight. While this capacity handles many industrial experimentation situations, there are circumstances that would call for a greater number of variables, putting the situation beyond the capabilities of the current system. Conversations with those experienced in industrial experimentation settings leads me to believe that the majority of production inquiries are adequately addressed by an eight factor limit, but that assumption will not always hold.

Another limitation of the system is its inability to suggest designs for situations calling for anything but a pure linear or quadratic model. There is no provision for a mix of two- and three-level factors, nor is there a

provision for testing any factor with four or more levels. The central composite designs suggested by the system provide a facility to test factors at five levels, but the qualifier that leads the user to a central composite design must be told that the response is quadratic. The user is not informed that the system has any capability beyond two or three levels for each design or noise variable.

5.6 Future Research

Future research efforts may include the following.

(1) Expansion of the experimental design base to accommodate larger and more sophisticated arrays solves the limitation discussed in section 4 of this chapter. Such an enhancement to the system would permit a wider audience of users and may enable the concept to be tested in areas that would otherwise not be eligible for field studies.

(2) Determination of the degree of statistical sophistication required to effectively use the expert system would assist in an exploration of the system's utility as a tool for training manufacturing professionals.

(3) Another extension to the prototype would involve the inclusion of statistical software in the expert system. Doing so would create a turnkey process analysis system that would narrow the gap between experimental design and data analysis. The nature of experimental design is such that a complete investigation with the system would in most cases, require more than one session at the keyboard. A completely

self-contained package would not mitigate the multiple session requirement, but may prompt the user to follow an investigation through to completion. Inclusion of statistical results interpretation capabilities might also prompt increased use of the system.

(4) The system may also be used as a tool to assess different models of decision makers' confidence in information systems. The coding of the rules permits easy manipulation of the system's suggestions to provide intentional errors to undermine confidence in the output. Muir's [1987] model of trust in man-machine interaction has been tested in a real time control situation, it may be worthwhile to explore her model as it applies to a batch mode of interaction.

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APPENDIX A

PARTIAL CODE LISTING FOR THE OQIE

```
  RULE NUMBER: 1

IF:
     PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "VARIABLES"
and: [22] < 1.5

THEN:
     PROCESS IS OF LOW CAPABILITY - Confidence=9/10

NOTE:
  THE VARIABLES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS
SYSTEM IS THE TAGUCHI CAPABILITY INDEX, WHICH IS THE RATIO
OF THE DIFFERENCE BETWEEN THE UPPER AND LOWER SPECIFICATION
LIMITS TO SIX TIMES THE STANDARD ERROR ABOUT THE PROCESS
TARGET.  THIS MEASURE PLACES A PREMIUM ON MAINTAING
OPERATIONS ON TARGET, WITH A MINIMAL AMOUNT OF VARIATION.
THE CONCLUSION REACHED BY THE SYSTEM AS TO THE CAPABILITY OF
THE PROCESS IS A SUBJECTIVE ONE, AND IS BASED UPON
SUGGESTIONS SET FORTH IN THE REFERENCES TO THIS RULE.

REFERENCE:
  EVANS & LINDSAY, "THE MANAGEMENT & CONTROL OF QUALITY"
1993  PP. 446-449,  BOYLES, "JOURNAL OF QUALITY TECHNOLOGY"
V. 23, NO. 1, 1/91, PP. 17-26.

  RULE NUMBER: 2

IF:
     PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "VARIABLES"
and: 1.5 <= [22]
and: [22] < 2.0

THEN:
     PROCESS IS OF ADEQUATE CAPABILITY - Confidence=9/10

NOTE:
  THE VARIABLES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS
SYSTEM IS THE TAGUCHI CAPABILITY INDEX, WHICH IS THE RATIO
OF THE DIFFERENCE BETWEEN THE UPPER AND LOWER SPECIFICATION
LIMITS TO SIX TIMES THE STANDARD ERROR ABOUT THE PROCESS
TARGET.  THIS MEASURE PLACES A PREMIUM ON MAINTAING
OPERATIONS ON TARGET, WITH A MINIMAL AMOUNT OF VARIATION.
THE CONCLUSION REACHED BY THE SYSTEM AS TO THE CAPABILITY OF
THE PROCESS IS A SUBJECTIVE ONE, AND IS BASED UPON
SUGGESTIONS SET FORTH IN THE REFERENCES TO THIS RULE.
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REFERENCE:
EVANS & LINDSAY, "THE MANAGEMENT & CONTROL OF QUALITY" 1993 PP. 446-449, BOYLES, "JOURNAL OF QUALITY TECHNOLOGY" V. 23, NO. 1, 1/91, PP. 17-26.

RULE NUMBER: 3

IF:
PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "VARIABLES"
and: 2.0 <= [22]

THEN:
PROCESS IS OF HIGH CAPABILITY - Confidence=9/10

NOTE:
THE VARIABLES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS SYSTEM IS THE TAGUCHI CAPABILITY INDEX, WHICH IS THE RATIO OF THE DIFFERENCE BETWEEN THE UPPER AND LOWER SPECIFICATION LIMITS TO SIX TIMES THE STANDARD ERROR ABOUT THE PROCESS TARGET. THIS MEASURE PLACES A PREMIUM ON MAINTAING OPERATIONS ON TARGET, WITH A MINIMAL AMOUNT OF VARIATION. THE CONCLUSION REACHED BY THE SYSTEM AS TO THE CAPABILITY OF THE PROCESS IS A SUBJECTIVE ONE, AND IS BASED UPON SUGGESTIONS SET FORTH IN THE REFERENCES TO THIS RULE.

REFERENCE:
EVANS & LINDSAY, "THE MANAGEMENT & CONTROL OF QUALITY" 1993 PP. 446-449, BOYLES, "JOURNAL OF QUALITY TECHNOLOGY" V. 23, NO. 1, 1/91, PP. 17-26.

RULE NUMBER: 4

IF:
PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "ATTRIBUTES"
and: [LOW24] >= 0.10

THEN:
PROCESS IS OF LOW CAPABILITY - Confidence=9/10

NOTE:
THE ATTRIBUTES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS SYSTEM IS A FRACTION DEFECTIVE, WHICH IS OBTAINED BY DIVIDING THE NUMBER OF BAD ITEMS BY THE TOTAL NUMBER OF ITEMS INSPECTED. THE CONCLUSIONS REACHED REGARDING THE PROCESS CAPABILITY ARE WHOLLY SUBJECTIVE, AND SHOULD NOT BE USED AS AN ABSOLUTE MEASURE OF PROCESS WORTH. THE FRACTION DEFECTIVE DISPLAYED AT THE END OF A SESSION SHOULD BE USED AS THE BENCHMARK FOR ANY CURRENT OR FUTURE PROCESS IMPROVEMENT MEASURES.

REFERENCE:
  NO DESIGN FILE NECESSARY - CHECK INPUT DATA FILE AS REQUIRED

  RULE NUMBER: 5

IF:
     PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "ATTRIBUTES"
and: 0.10 > [LOW24]
and: [LOW24] >= 0.01

THEN:
     > PROCESS IS OF ADEQUATE CAPABILITY - Confidence=9/10

NOTE:
  THE ATTRIBUTES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS SYSTEM IS A FRACTION DEFECTIVE, WHICH IS OBTAINED BY DIVIDING THE NUMBER OF BAD ITEMS BY THE TOTAL NUMBER OF ITEMS INSPECTED. THE CONCLUSIONS REACHED REGARDING THE PROCESS CAPABILITY ARE WHOLLY SUBJECTIVE, AND SHOULD NOT BE USED AS AN ABSOLUTE MEASURE OF PROCESS WORTH. THE FRACTION DEFECTIVE DISPLAYED AT THE END OF A SESSION SHOULD BE USED AS THE BENCHMARK FOR ANY CURRENT OR FUTURE PROCESS IMPROVEMENT MEASURES.

REFERENCE:
  NO DESIGN FILE NECESSARY - CHECK INPUT DATA FILE AS REQUIRED

  RULE NUMBER: 6

IF:
     PROCEDURE DESIRED IS {PROCESS CAPABILITY STUDY}
and: [DUMMYA] = "ATTRIBUTES"
and: [LOW24] < 0.01

THEN:
     PROCESS IS OF HIGH CAPABILITY - Confidence=9/10

NOTE:
  THE ATTRIBUTES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS SYSTEM IS A FRACTION DEFECTIVE, WHICH IS OBTAINED BY DIVIDING THE NUMBER OF BAD ITEMS BY THE TOTAL NUMBER OF ITEMS INSPECTED. THE CONCLUSIONS REACHED REGARDING THE PROCESS CAPABILITY ARE WHOLLY SUBJECTIVE, AND SHOULD NOT BE USED AS AN ABSOLUTE MEASURE OF PROCESS WORTH. THE FRACTION DEFECTIVE DISPLAYED AT THE END OF A SESSION SHOULD BE USED AS THE BENCHMARK FOR ANY CURRENT OR FUTURE PROCESS IMPROVEMENT MEASURES.

```
REFERENCE:
  NO DESIGN FILE NECESSARY - CHECK INPUT DATA FILE AS
REQUIRED

  RULE NUMBER: 7

IF:
     [DESIGN] + [NOISE] > 8

THEN:
     THE COMBINED NUMBER OF DESIGN AND NOISE VARIABLES
     CANNOT EXCEED EIGHT.  THE SYSTEM HAS NO RECOMMENDATION
     SINCE YOU HAVE SUPPLIED IT WITH TOO MANY FACTORS TO
     CONSIDER.
and: STOP

  RULE NUMBER: 8

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [RUNS] = 0

THEN:
     STOP

  RULE NUMBER: 9

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 2

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECT OF ONE VARIABLE WITH A LINEAR RESPONSE

REFERENCE:
  NONE.DAT

  RULE NUMBER: 10

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {LINEAR}
and: 2 <= [RUNS]
and: [RUNS] < 4
```

```
THEN:
     2^1 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [NEXTBEST] IS GIVEN THE VALUE 4 - [RUNS]

NOTE:
  THIS DESIGN ALLOWS ONE MAIN EFFECT TO BE TESTED.  TWO RUNS
ARE REQUIRED TO TEST THE EFFECT OF A SINGLE VARIABLE BUT
LEAVE NO ROOM FOR ESTIMATION OF ERROR VARIANCE.  THREE RUNS
ALLOWS FOR SOME ESTIMATE OF ERROR VARIANCE BUT ONE LEVEL OF
THE FACTOR IS TESTED TWICE, WHILE THE OTHER LEVEL IS
OBSERVED ONLY ONCE.

REFERENCE:
  21.DAT

  RULE NUMBER: 11

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {LINEAR}
and: 4 <= [RUNS]

THEN:
     2^1 FACTORIAL W/REPLICATIONS - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  BY TESTING THE EFFECT OF ONE VARIABLE AT EACH OF TWO
LEVELS TWO OR MORE TIMES, AN ESTIMATE OF THE MAIN EFFECT OF
THAT VARIABLE AND THE EXPERIMENTAL ERROR CAN BE MADE.

REFERENCE:
  21.DAT

  RULE NUMBER: 12

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 3

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 3 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 3 - [RUNS]
```

```
NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF TWO VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 13

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {LINEAR}
and: [RUNS] = 3

THEN:
     2^2 SIMPLEX DESIGN - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [NEXTBEST] IS GIVEN THE VALUE 4 - [RUNS]

NOTE:
  SIMPLEX DESIGNS ARE A CLASS OF ORTHOGONAL DESIGNS
REQUIRING EXACTLY N=k+1 OBSERVATIONS, THAT IS, ONE MORE THAN
THE NUMBER OF VARIABLES IN THE RESPONSE MODEL.
GEOMETRICALLY, THE DESIGN POINTS REPRESENT THE VERTICES OF A
k-DIMENSIONAL REGULAR-SIDED FIGURE OR SIMPLEX.  THE DESIGN
FOR k=2 IS NOT UNIQUE ALTHOUGH ONLY ONE SET OF POINTS IS
GIVEN IN THE DESIGN FILE.  THIS DESIGN DOES NOT PERMIT
ESTIMATION OF ANY INTERACTION OR EXPERIMENTAL ERROR TERMS.

REFERENCE:
 22SIM.DAT

  RULE NUMBER: 14

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {LINEAR}
and: 4 <= [RUNS]
and: [RUNS] < 8

THEN:
     2^2 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]

NOTE:
  FOUR RUNS IS THE MINIMUM AMOUNT REQUIRED TO DEVELOP AN
ESTIMATE OF THE MAIN EFFECT OF EACH VARIABLE AS WELL AS THE
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INTERACTION BETWEEN THE TWO VARIABLES. NO ESTIMATE OF EXPERIMENTAL ERROR MAY BE MADE WITH ONLY FOUR RUNS. IF INTERACTION IS NOT CONSIDERED THEN AN ESTIMATE OF THE EXPERIMENTAL ERROR MAY BE MADE WITH ONLY FOUR RUNS. FIVE, SIX, OR SEVEN RUNS WILL PERMIT AN ESTIMATION OF EXPERIMENTAL ERROR WITH A FULL A,B, AND A*B MODEL.

REFERENCE:
22.DAT

RULE NUMBER: 15

IF:
PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]

THEN:
2^2 FACTORIAL W/REPLICATIONS - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
A FULL REPLICATION OF THE 2^2 FACTORIAL DESIGN ALLOWS FOR ESTIMATION OF BOTH MAIN EFFECTS, THEIR INTERACTION, AS WELL AS THE EXPERIMENTAL ERROR.

REFERENCE:
22.DAT

RULE NUMBER: 16

IF:
PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 4

THEN:
NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 4 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 4 - [RUNS]
and: STOP

NOTE:
YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY TEST THE EFFECTS OF THREE VARIABLES WITH LINEAR RESPONSES

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REFERENCE:
  NONE.DAT

  RULE NUMBER: 17

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: 4 <= [RUNS]
and: [RUNS] < 8
and: OF FACTORS [[UNO]], [[DOS]], AND [[TRES]], THE TWO WAY
     INTERACTION YOU WISH TO ESTIMATE IS: {[[UNO]] &
     [[DOS]]}

THEN:
     1/2 FRACTION 2^3 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 8 - [RUNS]

NOTE:
  THIS DESIGN IS CAPABLE OF ESTIMATING MAIN EFFECTS OF
FACTORS A, B, AND C.  THESE MAIN EFFECTS ARE ALIASED WITH
TWO-WAY INTERACTIONS, SO THEY ARE ALIASED AS FOLLOWS:  A=BC,
B=AC, AND C=AB.  IF FACTOR C IS TO BE IGNORED (AS A NOISE
VARIABLE) THEN THE DESIGN MAY BE CONSIDERED TO ESTIMATE THE
EFFECTS OF FACTORS A, B, AND THE AB INTERACTION.  ALIASING
MEANS THAT ANY EFFECT OBSERVED FOR FACTOR C MAY BE
ATTRIBUTABLE TO SOME COMBINATION OF FACTOR C AND THE AB
INTERACTION.  IF THE AB INTERACTION IS NEGLIGIBLE, THEN THE
EFFECT MAY BE ENTIRELY DUE TO FACTOR C.  IF FACTOR C IS
UNIMPORTANT, THEN THE EFFECT MAY BE ENTIRELY DUE TO THE AB
INTERACTION.  IF BOTH C AND AB ARE IMPORTANT THEN THE EFFECT
MAY BE HALF DUE TO FACTOR C AND HALF DUE TO THE AB
INTERACTION.  I STRONGLY RECOMMEND THAT YOU FIND ADDITIONAL
RESOURCES TO HIT THE FULL 2^3 FACTORIAL DESIGN.

REFERENCE:
  H23.DAT

  RULE NUMBER: 18

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: 4 <= [RUNS]
and: [RUNS] < 8
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and: OF FACTORS [[UNO]], [[DOS]], AND [[TRES]], THE TWO WAY
     INTERACTION YOU WISH TO ESTIMATE IS: {[[UNO]] &
     [[TRES]]}

THEN:
     1/2 FRACTION 2^3 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [TRES]
and: [FACTOR_C] IS GIVEN THE VALUE [DOS]
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 8 - [RUNS]

NOTE:
  THIS DESIGN IS CAPABLE OF ESTIMATING MAIN EFFECTS OF
FACTORS A, B, AND C.  THESE MAIN EFFECTS ARE ALIASED WITH
TWO-WAY INTERACTIONS, SO THEY ARE ALIASED AS FOLLOWS:  A=BC,
B=AC, AND C=AB.  IF FACTOR C IS TO BE IGNORED (AS A NOISE
VARIABLE) THEN THE DESIGN MAY BE CONSIDERED TO ESTIMATE THE
EFFECTS OF FACTORS A, B, AND THE AB INTERACTION.  ALIASING
MEANS THAT ANY EFFECT OBSERVED FOR FACTOR C MAY BE
ATTRIBUTABLE TO SOME COMBINATION OF FACTOR C AND THE AB
INTERACTION.  IF THE AB INTERACTION IS NEGLIGIBLE, THEN THE
EFFECT MAY BE ENTIRELY DUE TO FACTOR C.  IF FACTOR C IS
UNIMPORTANT, THEN THE EFFECT MAY BE ENTIRELY DUE TO THE AB
INTERACTION.  IF BOTH C AND AB ARE IMPORTANT THEN THE EFFECT
MAY BE HALF DUE TO FACTOR C AND HALF DUE TO THE AB
INTERACTION.  I STRONGLY RECOMMEND FINDING ADDITIONAL
RESOURCES SO THAT A FULL 2^8 FACTORIAL MAY BE RUN.

REFERENCE:
  H23.DAT

  RULE NUMBER: 19

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: 4 <= [RUNS]
and: [RUNS] < 8
and: OF FACTORS [[UNO]], [[DOS]], AND [[TRES]], THE TWO WAY
     INTERACTION YOU WISH TO ESTIMATE IS: {[[DOS]] &
     [[TRES]]}

THEN:
     1/2 FRACTION 2^3 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [DOS]
and: [FACTOR_B] IS GIVEN THE VALUE [TRES]
and: [FACTOR_C] IS GIVEN THE VALUE [UNO]
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 8 - [RUNS]
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NOTE:
  THIS DESIGN IS CAPABLE OF ESTIMATING MAIN EFFECTS OF
FACTORS A, B, AND C.  THESE MAIN EFFECTS ARE ALIASED WITH
TWO-WAY INTERACTIONS, SO THEY ARE ALIASED AS FOLLOWS:  A=BC,
B=AC, AND C=AB.  IF FACTOR C IS TO BE IGNORED (AS A NOISE
VARIABLE) THEN THE DESIGN MAY BE CONSIDERED TO ESTIMATE THE
EFFECTS OF FACTORS A, B, AND THE AB INTERACTION.  ALIASING
MEANS THAT ANY EFFECT OBSERVED FOR FACTOR C MAY BE
ATTRIBUTABLE TO SOME COMBINATION OF FACTOR C AND THE AB
INTERACTION.  IF THE AB INTERACTION IS NEGLIGIBLE, THEN THE
EFFECT MAY BE ENTIRELY DUE TO FACTOR C.  IF FACTOR C IS
UNIMPORTANT, THEN THE EFFECT MAY BE ENTIRELY DUE TO THE AB
INTERACTION.  IF BOTH C AND AB ARE IMPORTANT THEN THE EFFECT
MAY BE HALF DUE TO FACTOR C AND HALF DUE TO THE AB
INTERACTION.  I STRONGLY ADVISE FINDING ADDITIONAL RESOURCES
THAT PERMIT YOU A FULL 2^8 FACTORIAL EXPERIMENT.

REFERENCE:
  H23.DAT

  RULE NUMBER: 20

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]
and: [RUNS] < 16

THEN:
     2^3 FACTORIAL - Confidence=9/10
and: > 1/2 FRACTION 2^3 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  EIGHT RUNS ARE REQUIRED TO ESTIMATE THE MAIN EFFECTS AND
ALL TWO AND THREE-WAY INTERACTIONS OF THREE VARIABLES.  MORE
THAN EIGHT RUNS ALLOWS SOME ESTIMATION OF EXPERIMENTAL
ERROR.

REFERENCE:
  23.DAT
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  RULE NUMBER: 21

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]

THEN:
     2^3 FACTORIAL W/REPLICATIONS - Confidence=9/10
and: > 2^3 FACTORIAL - Confidence=5/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  A FULL REPLICATION OF THE 2^3 EXPERIMENT ALLOWS ONE TO
ESTIMATE ALL MAIN EFFECTS AND INTERACTIONS POSSIBLE WITH
THREE VARIABLES AS WELL AS THE EXPERIMENTAL ERROR.

REFERENCE:
  23.DAT

  RULE NUMBER: 22

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 5

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 5 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF FOUR VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 23

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 4
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and: THE RESPONSE IS {LINEAR}
and: 5 <= [RUNS]
and: [RUNS] < 8

THEN:
     2^4 SIMPLEX - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  THE SIMPLEX DESIGN REQUIRES ONLY N=k+1 OBSERVATIONS (IN
THIS CASE N=5) IN ORDER TO DEVELOP ESTIMATES OF EACH MAIN
EFFECT.  THERE IS NO ESTIMATE OF ANY INTERACTION EFFECTS OR
EXPERIMENTAL ERROR WITH THE MINIMUM NUMBER OF RUNS.  THIS
DESIGN MIGHT BE SUITABLE AS A SCREENING DEVICE IF YOU ARE
ABSOLUTELY CERTAIN THAT NONE OF THE VARIABLES HAVE STRONG
TWO-WAY OR THREE-WAY INTERACTIONS.

REFERENCE:
  24SIM.DAT

  RULE NUMBER: 24

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]
and: [RUNS] < 16

THEN:
     1/2 FRACTION 2^4 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  MAIN EFFECTS A, B, C, AND D CAN BE ESTIMATED.  THE
FOLLOWING TWO WAY INTERACTIONS ARE INDISTINGUISHABLE FROM
EACH OTHER (THEY ARE ALIASED) BUT CAN BE ESTIMATED:  AB=CD,
AC=BD, AD=BC.  USE A PRIORI KNOWLEDGE TO SETTLE ON A COMFORT
LEVEL WITH EACH OF THESE EFFECTS.  FOR EXAMPLE, IF
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YOU SUSPECT THAT THE CD INTERACTION EFFECT IS LARGE, YOU COULD RUN THE EXPERIMENT AND ATTRIBUTE THE ENTIRE SIGNIFICANCE OF THE ALIASED PAIR AB=CD TO THE CD EFFECT. WITH THIS DESIGN THERE IS NO WAY OF KNOWING IF THIS IS ABSOLUTELY TRUE, BUT IF THIS IS RUN AS A SCREENING EXPERIMENT AND BOTH FACTORS A AND B ARE FOUND TO BE INSIGNIFICANT, YOU MIGHT DROP THEM FROM THE NEXT TEST AND FULLY CHECK FACTORS C AND D AND THE CD INTERACTION WITH A FULL 2^2 FACTORIAL.

REFERENCE:
H24.DAT

RULE NUMBER: 25

IF:
PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]
and: [RUNS] < 32

THEN:
2^4 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 32 - [RUNS]

NOTE:
AT LEAST 16 RUNS ARE REQUIRED TO ESTIMATE ALL MAIN EFFECTS AND ALL POSSIBLE INTERACTIONS AMONG FOUR VARIABLES. WITH ONLY 16 RUNS THERE IS NO WAY TO ESTIMATE EXPERIMENTAL ERROR UNLESS HIGH ORDER INTERACTIONS SUCH AS THE FOUR-WAY (A*B*C*D) AND THE THREE WAY (A*B*C, A*B*D, A*C*D, ETC.) ARE POOLED TO FORM AN ERROR TERM. IT IS LIKELY THAT MOST OF THESE HIGH ORDER INTERACTIONS ARE NEGLIGIBLE AND UNINTERPRETABLE SO POOLING IS A VIABLE ALTERNATIVE TO REPLICATION OF THE 2^4 FACTORIAL. WITH 17 TO 31 RUNS IT IS POSSIBLE TO DEVELOP AN ESTIMATE OF EXPERIMENTAL ERROR WITHOUT POOLING.

REFERENCE:
24.DAT

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  RULE NUMBER: 26

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {LINEAR}
and: 32 <= [RUNS]

THEN:
     2^4 FACTORIAL W/REPLICATIONS - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THIS DESIGNS ALLOWS FOR ESTIMATION OF ALL MAIN EFFECTS AND
INTERACTIONS, AS WELL AS EXPERIMENTAL ERROR VARIANCE.  MANY
OF THE HIGHER ORDER INTERACTIONS WILL BE UNINTERPRETABLE
AND/OR NEGLIGIBLE SO YOU MAY WISH TO RUN AN UNREPLICATED 2^4
FACTORIAL, POOL THE INSIGNIFICANT HIGHER-ORDER INTERACTIONS
TO FORM AN ERROR TERM, AND THEN DROP THE INSIGNIFICANT
FACTORS FROM A FOLLOW-UP STUDY THAT USES THE LAST OF YOUR
RESOURCES.

REFERENCE:
  24.DAT

  RULE NUMBER: 27

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 8

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 16 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF FIVE VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT
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  RULE NUMBER: 28

IF:
     PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
and: [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]
and: [RUNS] < 16
and: OF FACTORS [[UNO]], [[DOS]], [[TRES]], [[QUATRO]], AND
     [[CINCO]], THE ONE YOU WISH TO BE ABLE TO ESTIMATE TWO
     INTERACTIONS WITH IS {[[UNO]]}
and: OF REMAINING FACTORS [[DOS]], [[TRES]], [[QUATRO]], AND
     [[CINCO]], THE TWO YOU WISH TO PAIR WITH [[UNO]] ARE
     {[[DOS]] & [[TRES]]}
and: OF THE FINAL TWO FACTORS [[QUATRO]] AND [[CINCO]], THE
     ONE THAT HAS THE LEAST SIGNIFICANT INTERACTIONS WITH
     [[DOS]] AND [[TRES]] IS {[[QUATRO]]}

THEN:
     1/4 FRACTION 2^5 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_C] IS GIVEN THE VALUE [DOS]
and: [FACTOR_D] IS GIVEN THE VALUE [TRES]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  MAIN EFFECTS FOR FACTORS A, B, C, D, AND E MAY BE
ESTIMATED.  TWO WAY INTERACTIONS THAT ARE ESTIMABLE BUT
EXIST IN ALIASED PAIRS ARE AS FOLLOWS:  AC=BD AND AD=BC.
THIS PROGRAM HAS ASSIGNED FACTORS A, B, C, AND D BASED UPON
YOUR ASSUMPTION THAT THE AC AND AD TWO-WAY INTERACTIONS ARE
FAR GREATER IN MAGNITUDE THAN THE BD AND BC TWO-WAY
INTERACTIONS.  IF THIS IS NOT THE CASE, THEN WHAT YOUR
ANALYSIS TELLS YOU IS THE AC EFFECT WILL ACTUALLY BE THE BD
EFFECT.  FROM AN INFORMATION STANDPOINT, YOU WOULD BE MUCH
BETTER OFF WITH THE NEXT LEVEL OF EXPERIMENT, THE
HALF-FRACTION 2^5 FACTORIAL.

REFERENCE:
  Q25.DAT

  RULE NUMBER: 88

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]
and: [RUNS] < 32
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
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THEN:
     1/2 FRACTION 2^5 FACTORIAL - Confidence=9/10
and: 1/4 FRACTION 2^5 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 32 - [RUNS]
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NOTE:
ALL MAIN EFFECTS AND ALL TWO WAY INTERACTIONS MAY BE ESTIMATED WITH THE HALF REPLICATE 2^5 DESIGN. HIGHER ORDER INTERACTIONS MAY NOT BE ESTIMATED SEPARATELY, BUT THEY ARE OFTEN NEGLIGIBLE AND UNINTERPRETABLE. THE DEFINING CONTRAST IS E=ABCD. THE 1/4 REPLICATE MAY BE USED TO CAPTURE MAIN EFFECTS, BUT THE TWO-WAY INTERACTIONS ARE ALIASED MAKING THIS A LESS DESIRABLE CHOICE.

REFERENCE:
H25.DAT & Q25.DAT

RULE NUMBER: 89

```
IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {LINEAR}
and: 32 <= [RUNS]
and: [RUNS] < 64
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/2 FRACTION 2^5 FACTORIAL - Confidence=9/10
and: 2^5 FACTORIAL - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 64 - [RUNS]
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NOTE:
ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS MAY BE ESTIMATED BY THE HALF REPLICATE. CHANCES ARE THAT THE THREE-WAY, FOUR-WAY, AND FIVE-WAY INTERACTIONS ARE NOT INTERPRETABLE (AND PERHAPS NEGLIGIBLE) SO THE HALF REPLICATE DESIGN USES FEWER TRIALS TO CAPTURE THE MOST CRUCIAL INFORMATION. ALL MAIN EFFECTS AND ALL INTERACTIONS MAY BE ESTIMATED BY THE FULL 2^5 DESIGN. HIGHER ORDER INTERACTIONS, SUCH AS THE FIVE-WAY AND THE FIVE FOUR-WAY INTERACTIONS, ARE OFTEN NEGLIGIBLE AND UNINTERPRETABLE. IF SO, THESE MAY BE POOLED TO FORM AN EXPERIMENTAL ERROR TERM.

YOU MAY WISH TO SCREEN ALL VARIABLES AND TWO-WAY INTERACTIONS WITH A HALF REPLICATE AND THEN FOLLOW UP WITH A CLOSER EXAMINATION OF THE MOST IMPORTANT MAIN EFFECTS AND INTERACTIONS USING THE LAST OF YOUR RESOURCES.

REFERENCE:
H25.DAT & 25.DAT

RULE NUMBER: 90

IF:
[DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {LINEAR}
and: [RUNS] >= 64
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
1/2 FRACTION 2^5 FACTORIAL - Confidence=9/10
and: 2^5 FACTORIAL - Confidence=8/10
and: 2^5 FACTORIAL W/REPLICATIONS - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
ALL MAIN EFFECTS AND INTERACTIONS MAY BE ESTIMATED WITH THE 1/2 REPLICATE 2^5 DESIGN. ALTHOUGH YOU HAVE INDICATED SUFFICIENT RESOURCES FOR THE FULL 2^5 AND FULL 2^5 W/REPLICATION DESIGNS, MANY OF YOUR DEGREES OF FREEDOM ARE SPENT ESTIMATING THREE, FOUR, AND FIVE-WAY INTERACTIONS THAT ARE USUALLY UNINTERPRETABLE AND NEGLIGIBLE. MANY OF THE HIGHER ORDER INTERACTIONS, I.E., THE FIVE, FOUR, AND THREE-WAY, MAY BE POOLED TO FORM AN EXPERIMENTAL ERROR TERM WHICH MITIGATES THE NEED FOR A TWO OR MORE REPLICATIONS OF THE FULL 2^5 FACTORIAL DESIGN. YOU MAY WISH TO RUN THE 1/2 REPLICATE 2^5 AS A SCREENING EXPERIMENT AND THEN TEST MORE THOROUGHLY ALL OF THE EFFECTS IT IDENTIFIES AS THE MOST IMPORTANT.

REFERENCE:
H25.DAT & 25.DAT

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  RULE NUMBER: 91

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 8
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: STOP
and: [NEXTBEST] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES3] IS GIVEN THE VALUE 8 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 32 - [RUNS]

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF SIX VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 92

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]
and: [RUNS] < 16
and: OF FACTORS [[UNO]], [[DOS]], [[TRES]], [[QUATRO]],
     [[CINCO]], AND [[SEIS]], THE TWO-WAY INTERACTION YOU
     WISH TO ESTIMATE IS {[[UNO]] & [[DOS]]}
 or: OF FACTORS [[UNO]], [[DOS]], [[TRES]], [[QUATRO]],
     [[CINCO]], AND [[SEIS]], THE TWO-WAY INTERACTION YOU
     WISH TO ESTIMATE IS {[[TRES]] & [[QUATRO]]}
 or: OF FACTORS [[UNO]], [[DOS]], [[TRES]], [[QUATRO]],
     [[CINCO]], AND [[SEIS]], THE TWO-WAY INTERACTION YOU
     WISH TO ESTIMATE IS {[[CINCO]] & [[SEIS]]}
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/8 FRACTION 2^6 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 16 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 32 - [RUNS]
```

NOTE:
  THE MAIN EFFECTS A, B, C, D, E, AND F CAN BE ESTIMATED. THE DEFINING CONTRASTS ARE D=AB, E=AC, AND F=BC. A SINGLE TWO-WAY INTERACTION CAN BE ESTIMATED BUT IS ALIASED IN THE FORM AB=CD=EF. IF YOU ARE INTERESTED IN ESTIMATING THE AB INTERACTION, YOU MUST DO SO WITH THE KNOWLEDGE THAT THE EFFECT YOU ARE CALLING "AB" IS IN FACT THE EFFECTS OF AB + CD + EF. IF THE EFFECTS OF CD AND EF ARE NEGLIGIBLE, THEN IT IS REASONABLY SAFE TO SAY THAT THE SINGLE TWO-WAY INTERACTION ESTIMATED IS AB. IF THE CD AND EF INTERACTIONS ARE SIZEABLE, THEN IT IS NOT APPROPRIATE TO ATTRIBUTE ALL OF THE EFFECT TO THE AB INTERACTION WITHOUT FURTHER TESTING (SUFFICIENT TO ALLOW SEPARATE ESTIMATION OF THE CD AND EF INTERACTIONS).

REFERENCE:
  E26.DAT

  RULE NUMBER: 97

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]
and: [RUNS] < 32
and: OF THE SIX FACTORS, THE ONE YOU WOULD LIKE TO ESTIMATE ALL 5 TWO-WAY INTERACTIONS WITH IS {[[UNO]]}
and: OF THE REMAINING 5 FACTORS, THE ONE YOU WOULD LIKE TO ESTIMATE 2 OTHER TWO-WAY INTERACTIONS WITH IS {[[DOS]]}
and: OF THE LAST FOUR FACTORS, THE TWO YOU'D LIKE TO COUPLE WITH [[DOS]] FOR TWO-WAY INTERACTIONS ARE {[[TRES]] & [[QUATRO]]}
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/4 FRACTION 2^6 FACTORIAL - Confidence=9/10
and: 1/8 FRACTION 2^6 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_C] IS GIVEN THE VALUE [DOS]
and: [FACTOR_D] IS GIVEN THE VALUE [TRES]
and: [FACTOR_F] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_B] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_E] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 32 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 32 - [RUNS]

NOTE:
  THE 1/4 FRACTION OF THE 2^6 FACTORIAL HAS AS DEFINING CONTRASTS E=ABC AND F=BCD. THIS ALLOWS THE ESTIMATION OF ALL MAIN EFFECTS AND 7 TWO-WAY INTERACTIONS (AMONG WHICH THERE IS CONSIDERABLE ALIASING). THE ALIASED TWO-WAY INTERACTIONS ARE AB=CE=DF, AC=BE, AD=BF, AE=BC, AF=BD,

CD=EF, AND CF=DE. SOME A PRIORI KNOWLEDGE MAY BE USED TO ASSIGN IDENTITIES TO THE MOST LIKELY CANDIDATES FOR INTERACTION. IT IS POSSIBLE TO ESTIMATE THE TWO-WAY INTERACTION OF ONE VARIABLE IN COMBINATION WITH ALL OTHER VARIABLES. THE EIGHTH FRACTION ALLOWS ESTIMATION OF THE MAIN EFFECTS ONE ALIASED TWO-WAY INTERACTION: AB=CD=EF.

REFERENCE:
Q26.DAT & E26.DAT

RULE NUMBER: 277

IF:
[DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: 32 <= [RUNS]
and: [RUNS] < 64
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
1/2 FRACTION 2^6 FACTORIAL - Confidence=9/10
and: 1/4 FRACTION 2^6 FACTORIAL - Confidence=7/10
and: 1/8 FRACTION 2^6 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 64 - [RUNS]

NOTE:
THE 1/2 FRACTION OF THE 2^6 FACTORIAL HAS AS A DEFINING CONTRAST F=ABCDE. ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS MAY BE ESTIMATED. THE 1/4 FRACTION OF THE 2^6 FACTORIAL HAS AS DEFINING CONTRASTS E=ABC AND F=BCD. THIS ALLOWS THE ESTIMATION OF ALL MAIN EFFECTS AND 7 TWO-WAY INTERACTIONS (AMONG WHICH THERE IS CONSIDERABLE ALIASING). THE ALIASED TWO-WAY INTERACTIONS ARE AB=CE=DF, AC=BE, AD=BF, AE=BC, AF=BD, CD=EF, AND CF=DE. SOME A PRIORI KNOWLEDGE MAY BE USED TO ASSIGN IDENTITIES TO THE MOST LIKELY CANDIDATES FOR INTERACTION. IT IS POSSIBLE TO ESTIMATE THE TWO-WAY INTERACTION OF ONE VARIABLE IN COMBINATION WITH ALL OTHER VARIABLES. THE EIGHTH FRACTION ALLOWS ESTIMATION OF THE MAIN EFFECTS ONE ALIASED TWO-WAY INTERACTION: AB=CD=EF. THE DEFINING CONTRASTS ARE D=AB, E=AC, AND F=BC.

REFERENCE:
H26.DAT & Q26.DAT & E26.DAT

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  RULE NUMBER: 278

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: 64 <= [RUNS]
and: [RUNS] < 128
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/2 FRACTION 2^6 FACTORIAL - Confidence=9/10
and: 2^6 FACTORIAL - Confidence=8/10
and: 1/4 FRACTION 2^6 FACTORIAL - Confidence=2/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 128 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 2^6 FACTORIAL HAS AS A DEFINING
CONTRAST F=ABCDE.  ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS
MAY BE ESTIMATED. A FULL 2^6 FACTORIAL ALLOWS ESTIMATION OF
ALL MAIN EFFECTS AND INTERACTIONS, BUT MANY OF THE HIGHER
ORDER INTERACTIONS ARE SMALL AND UNINTERPRETABLE.  THOSE
INTERACTIONS THAT ARE SMALL MAY BE POOLED TO FORM AN ERROR
ESTIMATE.  THE 1/4 FRACTION OF THE 2^6 FACTORIAL HAS AS
DEFINING CONTRASTS E=ABC AND F=BCD.  THIS ALLOWS THE
ESTIMATION OF ALL MAIN EFFECTS AND 7 TWO-WAY INTERACTIONS.
THE ALIASED TWO-WAY INTERACTIONS ARE  AB=CE=DF, AC=BE,
AD=BF, AE=BC, AF=BD, CD=EF, AND CF=DE.  SOME A PRIORI
KNOWLEDGE MAY BE USED TO ASSIGN IDENTITIES TO THE MOST
LIKELY CANDIDATES FOR INTERACTION.  IT IS POSSIBLE TO
ESTIMATE THE TWO-WAY INTERACTION OF ONE VARIABLE IN
COMBINATION WITH ALL OTHER VARIABLES.  YOU MAY WISH TO RUN
THE 1/2 FRACTION AS AN INITIAL SCREENING EXPERIMENT, DECIDE
ON THE MOST IMPORTANT FACTORS, AND THEN TEST THESE MORE
THOROUGHLY.

REFERENCE:
  H26.DAT & 26.DAT & Q26.DAT

  RULE NUMBER: 279

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
and: [RUNS] >= 128
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}
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```
THEN:
     1/2 FRACTION 2^6 FACTORIAL - Confidence=9/10
and: 2^6 FACTORIAL - Confidence=8/10
and: 2^6 FACTORIAL W/REPLICATIONS - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE 1/2 FRACTION OF THE 2^6 FACTORIAL HAS AS A DEFINING
CONTRAST F=ABCDE.  ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS
MAY BE ESTIMATED. A FULL 2^6 AND 2^6 FACTORIAL
W/REPLICATIONS ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND
INTERACTIONS, BUT MANY OF THE HIGHER ORDER INTERACTIONS ARE
NEGLIGIBLE AND UNINTERPRETABLE.  THOSE INTERACTIONS THAT ARE
NEGLIGIBLE CAN BE POOLED TO FORM AN ESTIMATE OF EXPERIMENTAL
ERROR.  PERHAPS THE MOST EFFICIENT METHOD OF TESTING WOULD
BE TO RUN THE 1/2 FRACTION AS A SCREENING EXPERIMENT AND
THEN TEST MORE THOROUGHLY THOSE FACTORS IDENTIFIED AS BEING
MOST IMPORTANT.

REFERENCE:
  H26.DAT & 26.DAT

  RULE NUMBER: 280

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 8
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF SEVEN VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT
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  RULE NUMBER: 281

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: 8 <= [RUNS]
and: [RUNS] < 16
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/16 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]

NOTE:
  THE 1/16 FRACTION OF THE 2^7 FACTORIAL DESIGN ALLOWS FOR
ESTIMATION OF ONLY MAIN EFFECTS.  THE DEFINING CONTRASTS ARE
D=AB, E=AC, F=BC, AND G=ABC.

REFERENCE:
  S27.DAT

  RULE NUMBER: 282

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]
and: [RUNS] < 32
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/8 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: 1/16 FRACTION 2^7 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 32 - [RUNS]
and: [RES4] IS GIVEN THE VALUE 32 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 64 - [RUNS]
```

NOTE:
  THE 1/8 FRACTION OF THE 2^7 FACTORIAL HAS E=ABC, F=BCD, AND G=ACD AS DEFINING CONTRASTS. THIS DESIGN ALLOWS FOR ESTIMATION OF ALL MAIN EFFECTS, BUT ALIASES THE TWO-WAY INTERACTIONS AS FOLLOWS: AE=BF=CG, AF=BE=DG, AG=CE=DF, BG=DE=CF, AB=CD=EF, AC=BD=EG, AD=BC=FG. THE 1/16 FRACTION OF THE 2^7 FACTORIAL DESIGN ALLOWS FOR ESTIMATION OF ONLY MAIN EFFECTS. THE DEFINING CONTRASTS ARE D=AB, E=AC, F=BC, AND G=ABC.

REFERENCE:
  E27.DAT & S27.DAT

  RULE NUMBER: 283

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: 32 <= [RUNS]
and: [RUNS] < 64
and: OF THE 21 POSSIBLE TWO-WAY INTERACTIONS, THE SINGLE FACTOR THAT IS INVOLVED IN 3 DIFFERENT TWO-WAY INTERACTIONS THAT DO NOT INTEREST YOU (OR ARE NOT SIGNIFICANT) IS {[[UNO]]}
and: OF THE REMAINING SIX VARIABLES, THE THREE THAT INTERACT WITH [[UNO]] TO CREATE UNINTERESTING TWO-WAY INTERACTIONS ARE {[[DOS]], [[TRES]], [[QUATRO]]}
and: PROCEDURE DESIRED IS {EXPERIMENTAL DESIGN SUGGESTION}

THEN:
     1/4 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: 1/8 FRACTION 2^7 FACTORIAL - Confidence=7/10
and: [FACTOR_D] IS GIVEN THE VALUE [UNO]
and: [FACTOR_E] IS GIVEN THE VALUE [DOS]
and: [FACTOR_F] IS GIVEN THE VALUE [TRES]
and: [FACTOR_G] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_A] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_B] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_C] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 64 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 64 - [RUNS]

NOTE:
  THE 1/4 FRACTION OF THE 2^7 FACTORIAL ALLOWS ESTIMATES OF ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS WITH THE EXCEPTION OF THE ALIASED PAIRS DE=FG, DG=EF, AND DF=EG. THE DEFINING CONTRASTS FOR THIS DESIGN ARE F=ABCD AND G=ABDE. THE 1/8 FRACTION OF THE 2^7 FACTORIAL HAS E=ABC, F=BCD, AND G=ACD AS DEFINING CONTRASTS. THIS DESIGN ALLOWS FOR ESTIMATION OF ALL MAIN EFFECTS, BUT ALIASES THE TWO-WAY INTERACTIONS AS FOLLOWS: AE=BF=CG, AF=BE=DG, AG=CE=DF, BG=DE=CF, AB=CD=EF, AC=BD=EG, AND AD=BC=FG

```
REFERENCE:
  Q27.DAT & E27.DAT

  RULE NUMBER: 423

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: 64 <= [RUNS]
and: [RUNS] < 128

THEN:
     1/2 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: 1/4 FRACTION 2^7 FACTORIAL - Confidence=7/10
and: 1/8 FRACTION 2^7 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 128 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 2^7 FACTORIAL HAS G=ABCDEF AS A
DEFINING CONTRAST.  THIS DESIGN ALLOWS ONE TO ESTIMATE ALL
MAIN, TWO-WAY, AND THREE-WAY EFFECTS.  NEGLIGIBLE THREE-WAY
INTERACTIONS MAY BE POOLED TO ESTIMATE EXPERIMENTAL ERROR
VARIANCE.  THE 1/4 FRACTION OF THE 2^7 FACTORIAL ALLOWS
ESTIMATES OF ALL MAIN EFFECTS AND ALL TWO WAY INTERACTIONS
WITH THE FOLLOWING EXCEPTIONS --  THE ALIASED PAIRS DE=FG,
DG=EF, AND DF=EG.  DEFINING CONTRASTS FOR THIS DESIGN ARE
F=ABCD AND G=ABDE. THE 1/8 FRACTION OF THE 2^7 FACTORIAL HAS
E=ABC, F=BCD, AND G=ACD AS DEFINING CONTRASTS.  THIS DESIGN
ALLOWS FOR ESTIMATION OF ALL MAIN EFFECTS, BUT ALIASES THE
TWO-WAY INTERACTIONS AS FOLLOWS: AE=BF=CG, AF=BE=DG,
AG=CE=DF, BG=DE=CF, AB=CD=EF, AC=BD=EG, AD=BC=FG.

REFERENCE:
  H27.DAT & Q27.DAT & E27.DAT

  RULE NUMBER: 424

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: 128 <= [RUNS]
and: [RUNS] < 256
```

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THEN:
     1/2 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: 2^7 FACTORIAL - Confidence=8/10
and: 1/4 FRACTION 2^7 FACTORIAL - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 256 - [RUNS]
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NOTE:
THE 1/2 FRACTION OF THE 2^7 FACTORIAL HAS G=ABCDEF AS A DEFINING CONTRAST AND ALLOWS ONE TO ESTIMATE ALL MAIN, TWO, AND THREE-WAY EFFECTS. INSIGNIFICANT THREE-WAY INTERACTIONS MAY BE POOLED IN ORDER TO ESTIMATE EXPERIMENTAL ERROR. THE FULL 2^7 FACTORIAL DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND INTERACTIONS. MUCH EXPERIMENTAL EFFORT IS WASTED OBTAINING ESTIMATES OF HIGHER ORDER INTERACTIONS, IE. 4, 5, 6, AND 7-WAY INTERACTIONS THAT ARE DIFFICULT TO INTERPRET AND OFTEN NEGLIGIBLE. THESE HIGHER ORDER INTERACTIONS MAY BE TREATED THE SAME AS THE 1/2 REPLICATE THREE-WAY INTERACTIONS THAT ARE NOT SIGNIFICANT. THE 1/4 FRACTION OF THE 2^7 FACTORIAL ALLOWS ESTIMATES OF ALL MAIN EFFECTS AND ALL TWO WAY INTERACTIONS WITH THE FOLLOWING EXCEPTIONS -- THE ALIASED PAIRS DE=FG, DG=EF, AND DF=EG. IT MAY BE WISE TO RUN THE 1/2 FRACTION AS A SCREENING EXPERIMENT, IDENTIFYING THE MOST IMPORTANT FACTORS, AND THEN CHECK THE MOST IMPORTANT FACTORS COMPLETELY WITH A FOLLOW-UP EXPERIMENT.

REFERENCE:
H27.DAT & 27.DAT & Q27.DAT

RULE NUMBER: 425

```
IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
and: [RUNS] >= 256

THEN:
     1/2 FRACTION 2^7 FACTORIAL - Confidence=9/10
and: 2^7 FACTORIAL - Confidence=8/10
and: 2^7 FACTORIAL W/REPLICATIONS - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
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and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE 1/2 FRACTION OF THE 2^7 FACTORIAL HAS G=ABCDEF AS A
DEFINING CONTRAST.  THIS DESIGN ALLOWS ONE TO ESTIMATE ALL
MAIN, TWO-WAY, AND THREE-WAY EFFECTS.  THE FULL 2^7
FACTORIAL AND THE REPLICATED 2^7 FACTORIAL DESIGNS ALLOW
ESTIMATION OF ALL MAIN EFFECTS AND INTERACTIONS.  MUCH
EXPERIMENTAL EFFORT IS WASTED OBTAINING ESTIMATES OF HIGHER
ORDER INTERACTIONS, IE. 4, 5, 6, AND 7-WAY INTERACTIONS THAT
ARE DIFFICULT TO INTERPRET AND OFTEN NEGLIGIBLE.  UNLESS THE
EXPERIMENTAL PROCESS IS TRIVIAL FOR YOU, IT WOULD BE
ADVISABLE TO RUN A 1/2 FRACTION AS A SCREENING EXPERIMENT
AND THEN CHECK MORE THOROUGHLY ALL FACTORS IDENTIFIED AS
BEING SIGNIFICANT.

REFERENCE:
  H27.DAT & 27.DAT

  RULE NUMBER: 426

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: [RUNS] < 16

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF EIGHT VARIABLES WITH LINEAR RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 427

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: 16 <= [RUNS]
and: [RUNS] < 32

THEN:
     1/16 FRACTION 2^8 FACTORIAL - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
```

and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]

NOTE:
THE 1/16 FRACTION OF THE 2^8 FACTORIAL HAS AS DEFINING CONTRASTS E=BCD, F=ACD, G=ABC, AND H=ABD. THE MAIN EFFECTS MAY BE ESTIMATED ALONG WITH THE FOLLOWING ALIASED TWO-WAY INTERACTIONS: AE=BF=CH=DG, AF=BE=CG=DH, AG=BH=CF=DE, AH=BG=CE=DF, AC=BD=EH=FG, AD=BC=EG=FH, AND AB=CD=EF=GH. IT IS POSSIBLE TO ESTIMATE THE TWO-WAY INTERACTION OF ONE FACTOR WITH EACH OTHER FACTOR.

REFERENCE:
S28.DAT

RULE NUMBER: 428

IF:
[DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: 32 <= [RUNS]
and: [RUNS] < 64
and: ONE OF THE FACTORS YOU WISH TO OBTAIN ALL TWO-WAY INTERACTIONS OF IS: {[[UNO]]}
and: OF THE REMAINING SEVEN FACTORS, TWO OTHERS THAT YOU WISH TO OBTAIN ALL TWO-WAY INTERACTIONS OF ARE: (IF YOU HAVEN'T ALREADY SELECTED [[UNO]], AND YOU WISH TO, TYPE CONTROL U TO GO BACK ONE SCREEN) {[[DOS]] & [[TRES]]}

THEN:
1/8 FRACTION 2^8 FACTORIAL - Confidence=9/10
and: 1/16 FRACTION 2^8 FACTORIAL - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_E] IS GIVEN THE VALUE [DOS]
and: [FACTOR_B] IS GIVEN THE VALUE [TRES]
and: THE REMAINING FACTORS CAN BE ASSIGNED TO ANY OF THE LETTERS C, D, F, G, AND H IN THE DESIGN FILE
and: [NEXTBEST] IS GIVEN THE VALUE 64 - [RUNS]
and: [RES5] IS GIVEN THE VALUE 64 - [RUNS]

NOTE:
THE 1/8 FRACTION OF THE 2^8 FACTORIAL DESIGN ALLOWS ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS OF FACTORS A AND E TO BE ESTIMATED. IN ADDITION, THE FOLLOWING TWO-WAY ALIASES CAN BE ESTIMATED: BC=DH, BF=DG, BG=DF, BH=CD, CG=FH, CF=GH, AND BD=CH=FG. THESE ALIASED INTERACTIONS PERMIT ESTIMATION OF ALL COMBINATIONS OF B,C,D,F,G, OR H WITH EACH OF THE OTHER FACTORS. THE 1/16 FRACTION OF THE 2^8 FACTORIAL

HAS AS DEFINING CONTRASTS E=BCD, F=ACD, G=ABC, AND H=ABD. THE MAIN EFFECTS MAY BE ESTIMATED ALONG WITH THE FOLLOWING ALIASED TWO-WAY INTERACTIONS: AE=BF=CH=DG, AF=BE=CG=DH, AG=BH=CF=DE, AH=BG=CE=DF, AC=BD=EH=FG, AD=BC=EG=FH, AND AB=CD=EF=GH. IT IS POSSIBLE TO ESTIMATE THE TWO-WAY INTERACTION OF ONE FACTOR WITH EACH OTHER FACTOR.

REFERENCE:
S28.DAT & E28.DAT

RULE NUMBER: 485

IF:
[DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: 64 <= [RUNS]
and: [RUNS] < 128

THEN:
1/4 FRACTION 2^8 FACTORIAL - Confidence=9/10
and: 1/8 FRACTION 2^8 FACTORIAL - Confidence=3/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: [NEXTBEST] IS GIVEN THE VALUE 128 - [RUNS]

NOTE:
THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD AND H=ABEF AS DEFINING CONTRASTS. THIS DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS. THE 1/8 FRACTION OF THE 2^8 FACTORIAL DESIGN ALLOWS ALL MAIN EFFECTS AND ALL TWO-WAY INTERACTIONS OF FACTORS A AND E TO BE ESTIMATED. IN ADDITION, THE FOLLOWING TWO-WAY ALIASES CAN BE ESTIMATED: BC=DH, BF=DG, BG=DF, BH=CD, CG=FH, CF=GH, AND BD=CH=FG. THESE ALIASED INTERACTIONS PERMIT ESTIMATION OF ALL COMBINATIONS OF B,C,D,F,G, OR H WITH EACH OF THE OTHER FACTORS.

REFERENCE:
Q28.DAT & E28.DAT

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  RULE NUMBER: 486

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: 128 <= [RUNS]
and: [RUNS] < 256

THEN:
     1/4 FRACTION 2^8 FACTORIAL - Confidence=9/10
and: 1/2 FRACTION 2^8 FACTORIAL - Confidence=8/10
and: 1/8 FRACTION 2^8 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: [NEXTBEST] IS GIVEN THE VALUE 256 - [RUNS]

NOTE:
   THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD
AND H=ABEF AS DEFINING CONTRASTS.  THIS DESIGN ALLOWS
ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS.
THE 1/2 FRACTION OF THE 2^8 DESIGN PERMITS ESTIMATION OF ALL
MAIN, TWO-WAY, AND THREE-WAY EFFECTS.  THE DEFINING CONTRAST
IS H=ABCDEFG.  BY POOLING INSIGNIFICANT THREE-WAY
INTERACTION TERMS, AN ESTIMATE OF EXPERIMENTAL ERROR
VARIANCE MAY BE DEVELOPED.  THE 1/8 FRACTION OF THE 2^8
FACTORIAL DESIGN ALLOWS ALL MAIN EFFECTS AND ALL TWO-WAY
INTERACTIONS OF FACTORS A AND E TO BE ESTIMATED.  IN
ADDITION, THE FOLLOWING TWO-WAY ALIASES CAN BE ESTIMATED:
BC=DH, BF=DG, BG=DF, BH=CD, CG=FH, CF=GH, AND BD=CH=FG.
THESE ALIASED INTERACTIONS PERMIT ESTIMATION OF ALL
COMBINATIONS OF B,C,D,F,G, OR H WITH EACH OF THE OTHER
FACTORS.

REFERENCE:
  Q28.DAT & H28.DAT & E28.DAT

  RULE NUMBER: 487

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: 256 <= [RUNS]
and: [RUNS] < 512

THEN:
     1/4 FRACTION 2^8 FACTORIAL - Confidence=9/10
```

and: 1/2 FRACTION 2^8 FACTORIAL - Confidence=8/10
and: 2^8 FACTORIAL - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: [NEXTBEST] IS GIVEN THE VALUE 512 - [RUNS]

NOTE:
THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD AND H=ABEF AS DEFINING CONTRASTS. THIS DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS. THE 1/2 FRACTION OF THE 2^8 DESIGN PERMITS ESTIMATION OF ALL MAIN, TWO-WAY, AND THREE-WAY EFFECTS. THE DEFINING CONTRAST IS H=ABCDEFG. THE FULL 2^8 FACTORIAL PERMITS ESTIMATION OF ALL MAIN EFFECTS AND ALL POSSIBLE INTERACTIONS, MOST OF WHICH ARE UNINTERPRETABLE AND/OR NEGLIGIBLE (4, 5, 6, 7, AND 8-WAY INTERACTIONS). POOLING INSIGNIFICANT HIGHER ORDER INTERACTION TERMS IN THE FULL 2^8 AND 1/2 FRACTION 2^8 WILL YIELD AN ESTIMATE OF EXPERIMENTAL ERROR. YOU MAY WISH TO RUN THE 1/4 OR 1/2 FRACTION AS A SCREENING EXPERIMENT GIVEN THE HUGE NUMBER OF TRIALS A FULL INVESTIGATION WOULD REQUIRE. ONCE THE MOST IMPORTANT FACTORS ARE IDENTIFIED, RUN A MORE THOROUGH CHECK ON ONLY THOSE FACTORS.

REFERENCE:
Q28.DAT & H28.DAT & 28.DAT

RULE NUMBER: 488

IF:
[DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
and: [RUNS] >= 512

THEN:
1/4 FRACTION 2^8 FACTORIAL - Confidence=9/10
and: 1/2 FRACTION 2^8 FACTORIAL - Confidence=8/10
and: 2^8 FACTORIAL - Confidence=1/10
and: 2^8 FACTORIAL W/REPLICATIONS - Confidence=1/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]

```
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
   THE 1/4 FRACTION OF THE 2^8 FACTORIAL DESIGN HAS G=ABCD
AND H=ABEF AS DEFINING CONTRASTS.  THIS DESIGN ALLOWS
ESTIMATION OF ALL MAIN EFFECTS AND TWO-WAY INTERACTIONS.
THE 1/2 FRACTION OF THE 2^8 DESIGN PERMITS ESTIMATION OF ALL
MAIN, TWO-WAY, AND THREE-WAY EFFECTS.  THE DEFINING CONTRAST
IS H=ABCDEFG.  THE FULL 2^8 FACTORIAL AND FULL 2^8
W/REPLICATIONS PERMIT ESTIMATION OF ALL MAIN EFFECTS AND ALL
POSSIBLE INTERACTIONS, MOST OF WHICH ARE UNINTERPRETABLE
AND/OR NEGLIGIBLE. POOLING INSIGNIFICANT HIGH ORDER
INTERACTIONS IN THE 1/2 AND FULL REPLICATE DESIGNS PERMITS
EXPERIMENTAL ERROR ESTIMATION.  IT WOULD BE WISE TO USE THE
1/4 OR 1/2 FRACTION DESIGN AS A SCREENING EXPERIMENT IN
ORDER TO DECIDE ON THE MOST IMPORTANT OF THE EIGHT FACTORS
AND THEN DO A MORE THOROUGH FOLLOW-UP ON THOSE IMPORTANT
FEW.

REFERENCE:
  Q28.DAT & H28.DAT & 28.DAT

  RULE NUMBER: 489

IF:
     [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 3

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 3 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT SPECIFIED SUFFICIENT RUNS TO COMPLETELY TEST
A SINGLE VARIABLE WITH A QUADRATIC RESPONSE

REFERENCE:
  NONE.DAT

  RULE NUMBER: 490

IF:
     [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {QUADRATIC}
and: 3 <= [RUNS]
and: [RUNS] < 6

THEN:
     3^1 FACTORIAL - Confidence=9/10
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```
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [NEXTBEST] IS GIVEN THE VALUE 6 - [RUNS]

NOTE:
  THE 3^1 FACTORIAL PERMITS ESTIMATION OF THE LINEAR AND
QUADRATIC EFFECTS OF ONE VARIABLE.

REFERENCE:
  31.DAT

  RULE NUMBER: 491

IF:
     [DESIGN] + [NOISE] = 1
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] >= 6

THEN:
     3^1 FACTORIAL W/REPLICATIONS - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE 3^1 FACTORIAL PERMITS ESTIMATION OF THE LINEAR AND
QUADRATIC EFFECTS OF ONE VARIABLE.  REPLICATION OF THIS
EXPERIMENT PROVIDES FOR ESTIMATION OF THE ERROR TERM.

REFERENCE:
  31.DAT

  RULE NUMBER: 492

IF:
     [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 6

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 6 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST 2 VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
  NONE.DAT
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RULE NUMBER: 493

IF:
[DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {QUADRATIC}
and: 6 <= [RUNS]
and: [RUNS] <= 8

THEN:
3^2 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [NEXTBEST] IS GIVEN THE VALUE 9 - [RUNS]

NOTE:
THE HARTLEY DESIGN IS USED WHEN SEQUENTIAL INVESTIGATION IS NOT DESIRED (OR POSSIBLE). A FRACTIONAL REPLICATE OF A 2^2 FACTORIAL CAN BE USED (WITH THE ADDITION OF STAR POINTS) TO ESTIMATE ALL MAIN EFFECTS, ALL TWO-WAY INTERACTIONS, AND ALL QUADRATIC TERMS. THE FRACTIONAL REPLICATE NEED NOT BE OF RESOLUTION V.

REFERENCE:
32H.DAT

RULE NUMBER: 494

IF:
[DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 9

THEN:
3^2 CENTRAL COMPOSITE - Confidence=9/10
and: 3^2 FACTORIAL - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [NEXTBEST] IS GIVEN THE VALUE 10 - [RUNS]

NOTE:
THE CENTRAL COMPOSITE DESIGN IS COMPOSED BY ROTATING A 2^2 FACTORIAL DESIGN 90 DEGREES AND ADDING 4 ADDITIONAL POINTS (CALLED STAR POINTS) THAT ARE LOCATED A DISTANCE OF THE FOURTH ROOT OF FOUR (1.4142) AWAY FROM THE CENTER POINT OF THE DESIGN. THIS DESIGN ASSUMES THAT YOU CAN SELECT 5 DIFFERENT LEVELS FOR EACH OF THE VARIABLES UNDER INVESTIGATION. REPLICATION OF THE CENTER POINT (OR OBSERVATIONS AT THE CURRENT SETTING) CAN PROVIDE FOR AN ERROR ESTIMATE. THE 3^2 FACTORIAL REQUIRES ONLY THREE LEVELS FOR EACH OF THE VARIABLES AND IS A REASONABLY EFFICIENT DESIGN. THE 3^2 CAN ESTIMATE MAIN EFFECTS, QUADRATIC

EFFECTS, AND TWO-WAY INTERACTIONS, AS WELL AS QUADRATIC INTERACTIONS (MOST OF WHICH WILL BE DIFFICULT TO INTERPRET).

REFERENCE:
  32CCD.DAT & 32.DAT

  RULE NUMBER: 495

IF:
     [DESIGN] + [NOISE] = 2
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] > 9

THEN:
     3^2 CENTRAL COMPOSITE W/CENTER POINT REPLICATED - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE CENTRAL COMPOSITE DESIGN IS COMPOSED BY ROTATING A 2^2 FACTORIAL DESIGN 90 DEGREES AND ADDING 4 ADDITIONAL POINTS (CALLED STAR POINTS) THAT ARE LOCATED A DISTANCE OF THE FOURTH ROOT OF FOUR (1.4142) AWAY FROM THE CENTER POINT OF THE DESIGN. THIS DESIGN ASSUMES THAT YOU CAN SELECT 5 DIFFERENT LEVELS FOR EACH OF THE VARIABLES UNDER INVESTIGATION. BY REPLICATING THE CENTER POINT OF THE DESIGN, EXPERIMENTAL ERROR MAY BE ESTIMATED.

REFERENCE:
  32CCD.DAT

  RULE NUMBER: 496

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 10

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 10 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY TEST THREE VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
  NONE.DAT

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  RULE NUMBER: 497

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: 10 <= [RUNS]
and: [RUNS] < 13

THEN:
     3^3 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 13 - [RUNS]

NOTE:
  THIS DESIGN IS A 1/2 FRACTION 2^3 DESIGN SUPPLEMENTED WITH
STAR POINTS.  DESIGN POINTS ARE EVENLY DISTRIBUTED AS THE
CENTERS OF THE FACES OF A CUBE, WITH FOUR OF THE CORNERS
TESTED AS WELL.  MAIN EFFECTS, QUADRATIC EFFECTS, AND
TWO-WAY INTERACTIONS MAY BE TESTED.

REFERENCE:
  33H.DAT

  RULE NUMBER: 498

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 13

THEN:
     3^3 BOX-BEHNKEN - Confidence=9/10
and: 3^3 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 14 - [RUNS]

NOTE:
  THE BOX BEHNKEN DESIGN USES A 2^3 FACTORIAL AT ITS BASE
AND TREATS THE "EXTRA" FACTOR AT ITS CENTER POINT.  EACH
COMBINATION OF THE TWO FACTORS IS TREATED AS A 2^2 FACTORIAL
WITH THE OTHER FACTOR HELD AT A MIDPOINT.  THE HARTLEY
DESIGN IS A 1/2 FRACTION 2^3 DESIGN SUPPLEMENTED WITH STAR
POINTS.  DESIGN POINTS ARE EVENLY DISTRIBUTED AS THE CENTERS
OF THE FACES OF A CUBE, WITH FOUR OF THE CORNERS TESTED AS
WELL.  MAIN EFFECTS, QUADRATIC EFFECTS, AND TWO-WAY
INTERACTIONS MAY BE TESTED.
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REFERENCE:
  33H.DAT & 33BB.DAT

  RULE NUMBER: 499

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 14

THEN:
     3^3 ICOSAHEDRON - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 15 - [RUNS]

NOTE:
  THE ICOSAHEDRON DESIGN CONFIGURATION IS ROTATABLE, BUT IS
NOT A CENTRAL COMPOSITE DESIGN.  A1 AND A2 (PARAMETERS IN
THE 33I.DAT FILE) SHOULD BE CHOSEN SUCH THAT A1/A2 = 1.617.

REFERENCE:
  33I.DAT

  RULE NUMBER: 500

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: 15 = [RUNS]

THEN:
     3^3 CENTRAL COMPOSITE - Confidence=9/10
and: > 3^3 ICOSAHEDRON - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]

NOTE:
  THE CENTRAL COMPOSITE DESIGN FOR THREE FACTORS IS A 2^3
FACTORIAL ROTATED 90 DEGREES WITH 6 STAR POINTS LOCATED A
DISTANCE OF THE FOURTH ROOT OF 8 (1.6818) AWAY FROM A CENTER
POINT.  THIS DESIGN ASSUMES YOU CAN SELECT 5 OPERATING
LEVELS OF THE THREE VARIABLES RATHER THAN THE MINIMUM NUMBER
(3) REQUIRED FOR A 3^3 FACTORIAL.  REPLICATION OF THE CENTER
POINT MAY PROVIDE AN EXPERIMENTAL ERROR ESTIMATE OR SAMPLING
FROM YOUR CURRENT OPERATING POINT MAY DO THE SAME.

REFERENCE:
  33CCD.DAT & 33I.DAT
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  RULE NUMBER: 501

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: 15 < [RUNS]
and: [RUNS] < 27

THEN:
     3^3 CENTRAL COMPOSITE DESIGN W/CENTER POINT REPLICATED
     -
       Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [NEXTBEST] IS GIVEN THE VALUE 27 - [RUNS]

NOTE:
  THE CENTRAL COMPOSITE DESIGN FOR THREE FACTORS IS A 2^3
FACTORIAL ROTATED 90 DEGREES WITH 6 STAR POINTS LOCATED A
DISTANCE OF THE FOURTH ROOT OF 8 (1.6818) AWAY FROM A CENTER
POINT.  THIS DESIGN ASSUMES YOU CAN SELECT 5 OPERATING
LEVELS OF THE THREE VARIABLES RATHER THAN THE MINIMUM NUMBER
(3) REQUIRED FOR A 3^3 FATORIAL.  BY REPLICATING
OBSERVATIONS OF THE CENTER POINT (A=0, B=0, C=0), AN
ESTIMATE OF EXPERIMENTAL ERROR MAY BE OBTAINED.

REFERENCE:
  33CCD.DAT

  RULE NUMBER: 502

IF:
     [DESIGN] + [NOISE] = 3
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] >= 27

THEN:
     3^3 CENTRAL COMPOSITE DESIGN W/CENTER POINT REPLICATED
     - Confidence=9/10
and: 3^3 FACTORIAL - Confidence=5/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE CENTRAL COMPOSITE DESIGN FOR THREE FACTORS IS A 2^3
FACTORIAL ROTATED 90 DEGREES WITH 6 STAR POINTS LOCATED A
DISTANCE OF THE FOURTH ROOT OF 8 (1.6818) AWAY FROM A CENTER
POINT.  THIS DESIGN ASSUMES YOU CAN SELECT 5 OPERATING
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LEVELS OF THE THREE VARIABLES RATHER THAN THE MINIMUM NUMBER (3) REQUIRED FOR A 3^3 FACTORIAL. BY REPLICATING OBSERVATIONS OF THE CENTER POINT (A=0, B=0, C=0), AN ESTIMATE OF MEAN SQUARED ERROR MAY BE OBTAINED. THE 3^3 FACTORIAL ALLOWS ESTIMATION OF ALL POSSIBLE MAIN EFFECTS AND INTERACTIONS, BUT MANY OF THE INTERACTIONS (QUADRATIC TWO AND THREE-WAY) ARE UNINTERPRETABLE AND OFTEN NEGLIGIBLE, RESULTING IN LITTLE PAYBACK FOR SOME OF THE EXPERIMENTAL TRIALS.

REFERENCE:
33CCD.DAT & 33.DAT

RULE NUMBER: 503

IF:
[DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 16

THEN:
NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 16 - [RUNS]
and: STOP

NOTE:
YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY TEST THE EFFECTS OF FOUR VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
NONE.DAT

RULE NUMBER: 504

IF:
[DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 16

THEN:
3^4 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 17 - [RUNS]

NOTE:
THIS DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS, TWO WAY INTERACTIONS, AND QUADRATIC TERMS. THE QUADRATIC INTERACTIONS ARE ALIASED, BUT THESE TERMS ARE USUALLY UNINTERPRETABLE AND NEGLIGIBLE.

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REFERENCE:
  34H.DAT

  RULE NUMBER: 505

IF:
     [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {QUADRATIC}
and: 17 = [RUNS]

THEN:
     1/2 FRACTION 3^4 CENTRAL COMPOSITE - Confidence=9/10
and: 3^4 HARTLEY - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 18 - [RUNS]

NOTE:
  THE HALF FRACTION CENTRAL COMPOSITE HAS  D=ABC AS A
DEFINING CONTRAST.  THE DESIGN IS A 2^4 FACTORIAL THAT HAS
BEEN ROTATED 90 DEGREES WITH 8 STAR POINTS ADDED AT A
DISTANCE OF THE FOURTH ROOT OF 8 (1.6818) AWAY FROM THE
DESIGN'S CENTER POINT.  THIS DESIGN REQUIRES TRIALS AT 5
LEVELS OF EACH OF THE VARIABLES.  THE HARTLEY DESIGN ALLOWS
ESTIMATION OF ALL MAIN EFFECTS, TWO WAY INTERACTIONS, AND
QUADRATIC TERMS.  THE QUADRATIC INTERACTIONS ARE ALIASED,
BUT THESE TERMS ARE USUALLY UNINTERPRETABLE AND NEGLIGIBLE.

REFERENCE:
  H34CCD.DAT & 34H.DAT

  RULE NUMBER: 506

IF:
     [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {QUADRATIC}
and: 17 < [RUNS]
and: [RUNS] <= 24

THEN:
     1/2 FRACTION 3^4 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: 3^4 HARTLEY - Confidence=2/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 25 - [RUNS]
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NOTE:
  THE HALF FRACTION CENTRAL COMPOSITE HAS  D=ABC AS A
DEFINING CONTRAST.  THE DESIGN IS A 2^4 FACTORIAL THAT HAS
BEEN ROTATED 90 DEGREES WITH 8 STAR POINTS ADDED AT A
DISTANCE OF THE FOURTH ROOT OF 8 (1.6818) AWAY FROM THE
DESIGN'S CENTER POINT.  THIS DESIGN REQUIRES TRIALS AT 5
LEVELS OF EACH OF THE VARIABLES.  EXPERIMENTAL ERROR MAY BE
ESTIMATED BY REPEATING TRIALS AT THE CENTER POINT OF THE
DESIGN.  THE HARTLEY DESIGN ALLOWS ESTIMATION OF ALL MAIN
EFFECTS, TWO WAY INTERACTIONS, AND QUADRATIC TERMS.  THE
QUADRATIC INTERACTIONS ARE ALIASED, BUT THESE TERMS ARE
USUALLY UNINTERPRETABLE AND NEGLIGIBLE.

REFERENCE:
  H34CCD.DAT & 34H.DAT

  RULE NUMBER: 507

IF:
     [DESIGN] + [NOISE] = 4
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 25

THEN:
     3^4 BOX BEHNKEN - Confidence=9/10
and: 3^4 CENTRAL COMPOSITE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [NEXTBEST] IS GIVEN THE VALUE 26 - [RUNS]

NOTE:
  THE CENTRAL COMPOSITE IS A 2^4 FACTORIAL THAT HAS BEEN
ROTATED 90 DEGREES WITH 8 STAR POINTS ADDED AT A DISTANCE OF
THE FOURTH ROOT OF 16 (2) AWAY FROM THE DESIGN'S CENTER
POINT.  THIS DESIGN REQUIRES TRIALS AT 5 LEVELS OF EACH OF
THE VARIABLES.  REPLICATION OF THE CENTER POINT PROVIDES AN
ESTIMATE OF EXPERIMENTAL ERROR.  THE BOX-BEHNKEN DESIGN
USES A 2^4 FACTORIAL AS A BASE, AND TREATS ALL "EXTRA"
FACTORS AT THEIR CENTER POINT.  EACH COMBINATION OF TWO
FACTORS IS RUN AS A 2^2 FACTORIAL WITH THE OTHER TWO FACTORS
HELD AT THEIR CENTER (ZERO) POINT.

REFERENCE:
  34CCD.DAT & 34BB.DAT

  RULE NUMBER: 508

IF:
     [DESIGN] + [NOISE] = 4
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and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] > 25

THEN:
     3^4 CENTRAL COMPOSITE W/CENTER POINT REPLICATED -
     Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE CENTRAL COMPOSITE IS A 2^4 FACTORIAL THAT HAS BEEN
ROTATED 90 DEGREES WITH 8 STAR POINTS ADDED AT A DISTANCE OF
THE FOURTH ROOT OF 16 (2) AWAY FROM THE DESIGN'S CENTER
POINT.  THIS DESIGN REQUIRES TRIALS AT 5 LEVELS OF EACH OF
THE VARIABLES.  REPLICATION OF THE CENTER POINT PERMITS
ESTIMATION OF EXPERIMENTAL ERROR.

REFERENCE:
  34CCD.DAT

  RULE NUMBER: 509

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 22

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 22 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF FIVE VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 510

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: 22 <= [RUNS]
and: [RUNS] <= 25
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THEN:
     3^5 WESTLAKE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 26 - [RUNS]

NOTE:
  THE WESTLAKE DESIGNS ARE BASED ON IRREGULAR FRACTIONS OF A
2^K FACTORIAL.  THERE ARE THREE DESIGNS CONTAINED IN THE
DATA FILE SHOWN IN THE REFERENCE SECTION, ALL OF WHICH ARE
BASED ON A 3/8 FRACTION OF A 2^5 FACTORIAL (PLUS 10 STAR
POINTS).

REFERENCE:
  35W.DAT

  RULE NUMBER: 511

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 26

THEN:
     3^5 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 27 - [RUNS]

NOTE:
  THE HARTLEY DESIGN ALLOWS ESTIMATION OF ALL MAIN EFFECTS,
QUADRATIC MAIN EFFECTS, AND TWO-WAY INTERACTIONS.  THE
DESIGN IS BASED UPON THE 1/2 REPLICATE OF A 2^5 FACTORIAL
DESIGN.

REFERENCE:
  35H.DAT

  RULE NUMBER: 512

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 27
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THEN:
     1/2 FRACTION 3^5 CENTRAL COMPOSITE - Confidence=9/10
and: 3^5 HARTLEY - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 28 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 3^5 FACTORIAL DESIGN PERMITS
ESTIMATION OF ALL MAIN EFFECTS, QUADRATIC TERMS AND TWO-WAY
INTERACTIONS.  THE DEFINING CONTRAST IS E=ABCD.  THE DESIGN
CONSISTS OF A 1/2 REPLICATE 2^5 FACTORIAL WITH 10 STAR
POINTS LOCATED A DISTANCE OF THE FOURTH ROOT OF 16 (2) AWAY
FROM THE CENTER POINT OF THE DESIGN.  THE HARTLEY DESIGN
IS ALSO BASED UPON THE 1/2 REPLICATE OF THE 2^5 FACTORIAL
DESIGN AND ALLOWS ALL MAIN, QUADRATIC MAIN, AND TWO-WAY
INTERACTIONS TO BE ESTIMATED.

REFERENCE:
  H35CCD.DAT & 35H.DAT

  RULE NUMBER: 513

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: 28 <= [RUNS]
and: [RUNS] <= 40

THEN:
     1/2 FRACTION 3^5 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 41 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 3^5 FACTORIAL DESIGN PERMITS
ESTIMATION OF ALL MAIN EFFECTS, QUADRATIC TERMS AND TWO-WAY
INTERACTIONS.  THE DEFINING CONTRAST IS E=ABCD.  THE DESIGN
CONSISTS OF A 1/2 REPLICATE 2^5 FACTORIAL WITH 10 STAR
POINTS LOCATED A DISTANCE OF THE FOURTH ROOT OF 16 (2) AWAY
FROM THE CENTER POINT OF THE DESIGN.  AN ESTIMATE OF
EXPERIMENTAL ERROR MAY BE COMPUTED BY REPLICATING THE CENTER
POINT.
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REFERENCE:
  H35CCD.DAT

  RULE NUMBER: 514

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: 41 <= [RUNS]
and: [RUNS] <= 42

THEN:
     1/2 FRACTION 3^5 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: 3^5 BOX BEHNKEN - Confidence=5/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 43 - [RUNS]

NOTE:
  THE BOX-BEHNKEN DESIGN IS COMPOSED OF ALL PAIRWISE
GROUPINGS OF THE FACTORS IN 2^2 FACTORIAL DESIGNS, WHILE THE
REMAINING 3 FACTORS ARE HELD AT THEIR CENTER POINT LEVELS.
THE 1/2 FRACTION OF THE 3^5 FACTORIAL DESIGN PERMITS
ESTIMATION OF ALL MAIN EFFECTS, QUADRATIC TERMS AND TWO-WAY
INTERACTIONS.  THE DEFINING CONTRAST IS E=ABCD.  THE
DESIGN CONSISTS OF A 1/2 REPLICATE 2^5 FACTORIAL WITH 10
STAR POINTS LOCATED A DISTANCE OF THE FOURTH ROOT OF 16 (2)
AWAY FROM THE CENTER POINT OF THE DESIGN.  THIS DESIGN
REQUIRES THAT ALL FACTORS BE RUN AT FIVE LEVELS.  AN
ESTIMATE OF EXPERIMENTAL ERROR MAY BE COMPUTED BY
REPLICATING THE CENTER POINT.

REFERENCE:
  35BB.DAT & H35CCD.DAT

  RULE NUMBER: 515

IF:
     [DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 43

THEN:
     3^5 CENTRAL COMPOSITE - Confidence=9/10
and: 3^5 BOX BEHNKEN - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
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and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [NEXTBEST] IS GIVEN THE VALUE 44 - [RUNS]

NOTE:
THE BOX-BEHNKEN DESIGN IS COMPOSED OF ALL PAIRWISE GROUPINGS OF THE FACTORS IN 2^2 FACTORIAL DESIGNS, WHILE THE REMAINING 3 FACTORS ARE HELD AT THEIR CENTER POINT LEVELS. THE 3^5 CENTRAL COMPOSITE DESIGN PERMITS ESTIMATION OF ALL MAIN EFFECTS, QUADRATIC TERMS AND TWO-WAY INTERACTIONS. THE DESIGN CONSISTS OF A FULL 2^5 FACTORIAL WITH 10 STAR POINTS LOCATED A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM THE CENTER POINT OF THE DESIGN. THIS DESIGN REQUIRES THAT ALL FACTORS BE RUN AT FIVE LEVELS.

REFERENCE:
35BB.DAT & 35CCD.DAT

RULE NUMBER: 516

IF:
[DESIGN] + [NOISE] = 5
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] > 43

THEN:
3^5 CENTRAL COMPOSITE W/CENTER POINT REPLICATED - Confidence=9/10
and: 3^5 BOX BEHNKEN - Confidence=7/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
THE BOX-BEHNKEN DESIGN IS COMPOSED OF ALL PAIRWISE GROUPINGS OF THE FACTORS IN 2^2 FACTORIAL DESIGNS, WHILE THE REMAINING 3 FACTORS ARE HELD AT THEIR CENTER POINT LEVELS. THE 3^5 CENTRAL COMPOSITE DESIGN PERMITS ESTIMATION OF ALL MAIN EFFECTS, QUADRATIC TERMS AND TWO-WAY INTERACTIONS. THE DESIGN CONSISTS OF A FULL 2^5 FACTORIAL WITH 10 STAR POINTS LOCATED A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM THE CENTER POINT OF THE DESIGN. THIS DESIGN REQUIRES THAT ALL FACTORS BE RUN AT FIVE LEVELS. REPLICATION OF THE CENTER POINT PERMITS ESTIMATION OF MEAN SQUARED ERROR.

REFERENCE:
35BB.DAT & 35CCD.DAT

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  RULE NUMBER: 517

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 28

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 28 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF SIX VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 518

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: 28 <= [RUNS]
and: [RUNS] < 45

THEN:
     3^6 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 45 - [RUNS]

NOTE:
  THE HARTLEY DESIGN IS BASED ON A 1/4 REPLICATE OF A 2^6
FACTORIAL. THE DEFINING CONTRASTS ARE C=AB AND F=DE.  ALL 15
TWO-WAY INTERACTIONS MAY BE ESTIMATED WITH THE EXCEPTION OF
THE FOLLOWING ALIAS PAIRS: A=BC, B=AC, C=AB, D=EF, E=DF, AND
F=DE.  GIVEN THE LACK OF INFORMATION REGARDING MAIN EFFECTS,
THIS DESIGN SHOULD BE USED ONLY IF YOU HAVE CONSIDERABLE
KNOWLEDGE BEFOREHAND REGARDING THE MAGNITUDE OF THE TWO-WAY
INTERACTIONS THAT ARE ALIASED WITH THE MAIN EFFECTS.

REFERENCE:
  36H.DAT
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  RULE NUMBER: 519

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 45

THEN:
     1/2 FRACTION 3^6 CENTRAL COMPOSITE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 46 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 3^6 CENTRAL COMPOSITE DESIGN HAS A
1/2 REPLICATE OF THE 2^6 FACTORIAL DESIGN AS ITS BASE.  THIS
DESIGN HAS BEEN ROTATED 90 DEGREES WITH 12 STAR POINTS ADDED
AT A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM
THE CENTER POINT.  ALL MAIN, QUADRATIC AND TWO-WAY
INTERACTION EFFECTS ARE ESTIMABLE.

REFERENCE:
  H36CCD.DAT

  RULE NUMBER: 520

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: 45 < [RUNS]
and: [RUNS] < 61

THEN:
     1/2 FRACTION 3^6 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 61 - [RUNS]

NOTE:
  THE 1/2 FRACTION OF THE 3^6 CENTRAL COMPOSITE DESIGN HAS A
1/2 REPLICATE OF THE 2^6 FACTORIAL DESIGN AS ITS BASE.  THIS
DESIGN HAS BEEN ROTATED 90 DEGREES WITH 12 STAR POINTS ADDED
AT A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM
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THE CENTER POINT. ALL MAIN, QUADRATIC AND TWO-WAY INTERACTION EFFECTS ARE ESTIMABLE. REPLICATION OF THE CENTER POINT PERMITS ESTIMATION OF THE ERROR VARIANCE.

REFERENCE:
H36CCD.DAT

RULE NUMBER: 521

IF:
[DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: 61 <= [RUNS]
and: [RUNS] < 77

THEN:
3^6 BOX BEHNKEN - Confidence=9/10
and: 1/2 FRACTION 3^6 CENTRAL COMPOSITE W/CENTER POINT REPLICATED - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 77 - [RUNS]

NOTE:
THE BOX-BEHNKEN DESIGN TAKES ALL COMBINATIONS OF TWO FACTORS AND TREATS THEM AS A SERIES OF 2^2 DESIGNS WHILE HOLDING THE OTHER FACTORS CONSTANT AT A CENTER POINT. THIS REQUIRES ONLY THREE LEVELS FOR EACH VARIABLE AS OPPOSED TO FIVE LEVELS FOR EACH VARIABLE FOR THE 1/2 FRACTION 3^6 CENTRAL COMPOSITE DESIGN. THE 1/2 FRACTION OF THE 3^6 CENTRAL COMPOSITE DESIGN HAS A 1/2 REPLICATE OF THE 2^6 FACTORIAL DESIGN AS ITS BASE. THIS DESIGN HAS BEEN ROTATED 90 DEGREES WITH 12 STAR POINTS ADDED AT A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM THE CENTER POINT. ALL MAIN, QUADRATIC AND TWO-WAY INTERACTION EFFECTS ARE ESTIMABLE. REPLICATION OF THE CENTER POINT PERMITS ESTIMATION OF THE ERROR VARIANCE.

REFERENCE:
36BB.DAT & H36CCD.DAT

RULE NUMBER: 522

IF:
[DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 77

```
THEN:
     1/2 FRACTION 3^6 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: 3^6 BOX BEHNKEN - Confidence=9/10
and: 3^6 CENTRAL COMPOSITE - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [NEXTBEST] IS GIVEN THE VALUE 78 - [RUNS]

NOTE:
  THE 3^6 CENTRAL COMPOSITE DESIGN HAS A 2^6 FACTORIAL AS A
BASE WITH 12 STAR POINTS ADDED AT A DISTANCE OF THE FOURTH
ROOT OF 64 (2.8284) AWAY FROM THE CENTER POINT.  THE DESIGN
ALLOWS ESTIMATES OF ALL POSSIBLE INTERACTIONS, WHICH MAY BE
MORE THAN ARE INTERPRETABLE.  THE BOX-BEHNKEN DESIGN TAKES
ALL COMBINATIONS OF TWO FACTORS AND TREATS THEM AS A SERIES
OF 2^2 DESIGNS WHILE HOLDING THE OTHER FACTORS CONSTANT AT A
CENTER POINT.  THIS REQUIRES ONLY THREE LEVELS FOR EACH
VARIABLE AS OPPOSED TO FIVE LEVELS FOR EACH VARIABLE FOR THE
1/2 FRACTION 3^6 CENTRAL COMPOSITE DESIGN.  THE 1/2 FRACTION
OF THE 3^6 CENTRAL COMPOSITE DESIGN HAS A 1/2 REPLICATE OF
THE 2^6 FACTORIAL DESIGN AS ITS BASE.  THIS DESIGN HAS BEEN
ROTATED 90 DEGREES WITH 12 STAR POINTS ADDED AT A DISTANCE
OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM THE CENTER
POINT.  ALL MAIN, QUADRATIC AND TWO-WAY INTERACTION EFFECTS
ARE ESTIMABLE.  REPLICATION OF THE CENTER POINT PERMITS
ESTIMATION OF THE ERROR VARIANCE.

REFERENCE:
  36CCD.DAT & 36BB.DAT & H36CCD.DAT

  RULE NUMBER: 523

IF:
     [DESIGN] + [NOISE] = 6
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] > 77

THEN:
     1/2 FRACTION 3^6 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: 3^6 BOX BEHNKEN - Confidence=9/10
and: 3^6 CENTRAL COMPOSITE W/CENTER POINT REPLICATED -
     Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
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and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
THE 3^6 CENTRAL COMPOSITE DESIGN HAS A 2^6 FACTORIAL AS A BASE WITH 12 STAR POINTS ADDED AT A DISTANCE OF THE FOURTH ROOT OF 64 (2.8284) AWAY FROM THE CENTER POINT. THE DESIGN ALLOWS ESTIMATES OF ALL POSSIBLE INTERACTIONS, WHICH MAY BE MORE THAN ARE INTERPRETABLE. THE BOX-BEHNKEN DESIGN TAKES ALL COMBINATIONS OF TWO FACTORS AND TREATS THEM AS A SERIES OF 2^2 DESIGNS WHILE HOLDING THE OTHER FACTORS CONSTANT AT A CENTER POINT. THIS REQUIRES ONLY THREE LEVELS FOR EACH VARIABLE AS OPPOSED TO FIVE LEVELS FOR THE 3^6 CENTRAL COMPOSITE DESIGNS. THE 1/2 FRACTION OF THE 3^6 CENTRAL COMPOSITE DESIGN HAS A 1/2 REPLICATE OF THE 2^6 FACTORIAL DESIGN AS ITS BASE. THIS DESIGN HAS BEEN ROTATED 90 DEGREES WITH 12 STAR POINTS ADDED AT A DISTANCE OF THE FOURTH ROOT OF 32 (2.3784) AWAY FROM THE CENTER POINT. ALL MAIN, QUADRATIC AND TWO-WAY INTERACTION EFFECTS ARE ESTIMABLE. REPLICATION OF THE CENTER POINTS IN BOTH CENTRAL COMPOSITE DESIGNS PERMITS ESTIMATION OF THE ERROR VARIANCE.

REFERENCE:
36CCD.DAT & 36BB.DAT & H36CCD.DAT

RULE NUMBER: 524

IF:
[DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 40

THEN:
NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 40 - [RUNS]
and: STOP

NOTE:
YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY TEST THE EFFECTS OF SEVEN VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
NONE.DAT

RULE NUMBER: 525

IF:
[DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {QUADRATIC}

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and: 40 <= [RUNS]
and: [RUNS] < 46

THEN:
     3^7 WESTLAKE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 46 - [RUNS]

NOTE:
  THE WESTLAKE DESIGN IS BASED ON A 13/64 FRACTION OF A 2^7
FACTORIAL. WESTLAKE'S PAPER IN BIOMETRICS 6/65 (PP. 324-336)
PRESENTS THE BASIS FOR THIS DESIGN.  THERE ARE ALIASING
PROBLEMS WITH THIS DESIGN SINCE THE FOLLOWING DEFINING
RELATIONS EXIST: BC=BD=BE=AF=BG=A, BC=BD=BE=AF=BG=B,
BC=BD=BE=AF=AG=A, AND BC=BD=BE=AF=AG=B.

REFERENCE:
  37W.DAT
  RULE NUMBER: 526

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {QUADRATIC}
and: 46 <= [RUNS]
and: [RUNS] < 85

THEN:
     3^7 HARTLEY - Confidence=9/10
and: 3^7 WESTLAKE - Confidence=8/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 85 - [RUNS]

NOTE:
  HARLTLEY'S DESIGN IS BASED UPON A QUARTER FRACTION OF A
2^7 FACTORIAL DESIGN.  THE DESIGN HAS BEEN SUPPLEMENTED WITH
STAR POINTS THAT PERMIT INVESTIGATION OF THE QUADRATIC
SURFACE.  WESTLAKE'S DESIGN IS BASED ON A 13/64 FRACTION OF
A 2^7 FACTORIAL.  WESTLAKE'S PAPER IN BIOMETRICS 6/65 (PP.
324-336) PRESENTS THE BASIS FOR THIS DESIGN.
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REFERENCE:
  37H.DAT & 37W.DAT

  RULE NUMBER: 527

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {QUADRATIC}
and: 85 = [RUNS]

THEN:
     3^7 BOX BEHNKEN - Confidence=9/10
and: 1/2 FRACTION 3^7 CENTRAL COMPOSITE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [NEXTBEST] IS GIVEN THE VALUE 86 - [RUNS]

NOTE:
  THE BOX-BEHNKEN DESIGN IS BASED ON PAIRWISE 2^2 FACTORIAL
DESIGNS FOR ALL POSSIBLE COMBINATIONS OF FACTORS.  THE OTHER
5 FACTORS ARE HELD AT THEIR CENTER POINT (0) WHILE THE
CURRENT TWO FACTORS ARE VARIED FROM -1 TO +1.  THE 1/2
FRACTION OF THE 3^7 CENTRAL COMPOSITE DESIGN IS BASED
ON A 1/2 REPLICATE OF A 2^7 DESIGN THAT HAS BEEN ROTATED 90
DEGREES WITH 14 STAR POINTS LOCATED A DISTANCE OF THE FOURTH
ROOT OF 64 (2.8284) AWAY FROM THE CENTER POINT OF THE
DESIGN.  THIS REQUIRES THAT ALL FACTORS BE TESTED AT 5
LEVELS BUT SUPPLIES INFORMATION ON ALL MAIN EFFECTS AND
TWO-WAY INTERACTIONS.  SOME HIGHER ORDER INTERACTIONS ARE
SACRIFICED, BUT THESE EFFECTS ARE USUALLY NEGLIGIBLE AND/OR
UNINTERPRETABLE.

REFERENCE:
  37BB.DAT & H37CCD.DAT

  RULE NUMBER: 528

IF:
     [DESIGN] + [NOISE] = 7
and: THE RESPONSE IS {QUADRATIC}
and: 85 < [RUNS]

THEN:
     1/2 FRACTION 3^7 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: 3^7 BOX BEHNKEN - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
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and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE BOX-BEHNKEN DESIGN IS BASED ON PAIRWISE 2^2 FACTORIAL
DESIGNS FOR ALL POSSIBLE COMBINATIONS OF FACTORS.  THE OTHER
5 FACTORS ARE HELD AT THEIR CENTER POINT (0) WHILE THE
CURRENT TWO FACTORS ARE VARIED FROM -1 TO +1.  THE 1/2
FRACTION OF THE 3^7 CENTRAL COMPOSITE DESIGN IS BASED
ON A 1/2 REPLICATE OF A 2^7 DESIGN THAT HAS BEEN ROTATED 90
DEGREES WITH 14 STAR POINTS LOCATED A DISTANCE OF THE FOURTH
ROOT OF 64 (2.8284) AWAY FROM THE CENTER POINT OF THE
DESIGN.  THIS REQUIRES THAT ALL FACTORS BE TESTED AT 5
LEVELS BUT SUPPLIES INFORMATION ON ALL MAIN EFFECTS AND
TWO-WAY INTERACTIONS.  SOME HIGHER ORDER INTERACTIONS ARE
SACRIFICED, BUT THESE EFFECTS ARE USUALLY NEGLIGIBLE AND/OR
UNINTERPRETABLE.  CENTER POINT REPLICATION PROVIDES AN
ESTIMATE OF EXPERIMENTAL ERROR VARIANCE.

REFERENCE:
  37BB.DAT & H37CCD.DAT

  RULE NUMBER: 529

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] < 48

THEN:
     NO EXPERIMENT POSSIBLE - Confidence=9/10
and: [NEXTBEST] IS GIVEN THE VALUE 48 - [RUNS]
and: STOP

NOTE:
  YOU HAVE NOT INDICATED SUFFICIENT RESOURCES TO COMPLETELY
TEST THE EFFECTS OF EIGHT VARIABLES WITH QUADRATIC RESPONSES

REFERENCE:
  NONE.DAT

  RULE NUMBER: 530

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {QUADRATIC}
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and: 48 <= [RUNS]
and: [RUNS] < 81

THEN:
     3^8 HARTLEY - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: [NEXTBEST] IS GIVEN THE VALUE 81 - [RUNS]

NOTE:
  THE HARTLEY DESIGN IS BASED UPON AN 1/8 FRACTION OF A 2^8
FACTORIAL DESIGN THAT HAS BEEN SUPPLEMENTED WITH 16
ADDITIONAL STAR POINTS THAT PERMIT ESTIMATION OF THE
QUADRATIC RESPONSE.

REFERENCE:
  38H.DAT

  RULE NUMBER: 531

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] = 81

THEN:
     1/4 FRACTION 3^8 CENTRAL COMPOSITE - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: [NEXTBEST] IS GIVEN THE VALUE 82 - [RUNS]

NOTE:
  THE 1/4 FRACTION OF THE 3^8 CENTRAL COMPOSITE DESIGN IS
COMPOSED OF A 1/4 FRACTION OF A 2^8 FACTORIAL ROTATED 90
DEGREES, WITH 16 STAR POINTS LOCATED A DISTANCE OF THE
FOURTH ROOT OF 64 AWAY FROM THE CENTER POINT.  THIS PERMITS
ESTIMATION OF ALL MAIN, QUADRATIC, AND TWO-WAY INTERACTIONS.
HIGHER ORDER INTERACTIONS ARE ALIASED, BUT ARE USUALLY
NEGLIGIBLE AND UNINTERPRETABLE.
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REFERENCE:
  Q38CCD.DAT

  RULE NUMBER: 532

IF:
     [DESIGN] + [NOISE] = 8
and: THE RESPONSE IS {QUADRATIC}
and: [RUNS] > 81

THEN:
     1/4 FRACTION 3^8 CENTRAL COMPOSITE W/CENTER POINT
     REPLICATED - Confidence=9/10
and: [FACTOR_A] IS GIVEN THE VALUE [UNO]
and: [FACTOR_B] IS GIVEN THE VALUE [DOS]
and: [FACTOR_C] IS GIVEN THE VALUE [TRES]
and: [FACTOR_D] IS GIVEN THE VALUE [QUATRO]
and: [FACTOR_E] IS GIVEN THE VALUE [CINCO]
and: [FACTOR_F] IS GIVEN THE VALUE [SEIS]
and: [FACTOR_G] IS GIVEN THE VALUE [SIETE]
and: [FACTOR_H] IS GIVEN THE VALUE [OCHO]
and: THE NUMBER OF TRIALS BUDGETED WITH THIS NUMBER OF
     VARIABLES PERMITS A THOROUGH INVESTIGATION

NOTE:
  THE 1/4 FRACTION OF THE 3^8 CENTRAL COMPOSITE DESIGN IS
COMPOSED OF A 1/4 FRACTION OF A 2^8 FACTORIAL ROTATED 90
DEGREES, WITH 16 STAR POINTS LOCATED A DISTANCE OF THE
FOURTH ROOT OF 64 AWAY FROM THE CENTER POINT.  THIS PERMITS
ESTIMATION OF ALL MAIN, QUADRATIC, AND TWO-WAY INTERACTIONS.
HIGHER ORDER INTERACTIONS ARE ALIASED BUT ARE FREQUENTLY
NEGLIGIBLE AND/OR UNINTERPRETABLE.  BY REPLICATING THE
CENTER POINT, AN ESTIMATE OF ERROR VARIANCE MAY BE OBTAINED.

REFERENCE:
  Q38CCD.DAT

  RULE NUMBER: 533

IF:
     [DESIGN] = 1
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
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  RULE NUMBER: 534

IF:
     [DESIGN] = 2
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]

  RULE NUMBER: 535

IF:
     [DESIGN] = 3
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]

  RULE NUMBER: 536

IF:
     [DESIGN] = 4
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D4] IS GIVEN THE VALUE [D4]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]
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and: [D4LOW] IS GIVEN THE VALUE [D4LOW]
and: [D4HIGH] IS GIVEN THE VALUE [D4HIGH]

  RULE NUMBER: 537

IF:
     [DESIGN] = 5 ´
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D4] IS GIVEN THE VALUE [D4]
and: [D5] IS GIVEN THE VALUE [D5]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]
and: [D4LOW] IS GIVEN THE VALUE [D4LOW]
and: [D4HIGH] IS GIVEN THE VALUE [D4HIGH]
and: [D5LOW] IS GIVEN THE VALUE [D5LOW]
and: [D5HIGH] IS GIVEN THE VALUE [D5HIGH]

  RULE NUMBER: 538

IF:
     [DESIGN] = 6 ˙
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D4] IS GIVEN THE VALUE [D4]
and: [D5] IS GIVEN THE VALUE [D5]
and: [D6] IS GIVEN THE VALUE [D6]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]
and: [D4LOW] IS GIVEN THE VALUE [D4LOW]
and: [D4HIGH] IS GIVEN THE VALUE [D4HIGH]
and: [D5LOW] IS GIVEN THE VALUE [D5LOW]
and: [D5HIGH] IS GIVEN THE VALUE [D5HIGH]
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and: [D6LOW] IS GIVEN THE VALUE [D6LOW]
and: [D6HIGH] IS GIVEN THE VALUE [D6HIGH]

  RULE NUMBER: 539

IF:
     [DESIGN] = 7
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D4] IS GIVEN THE VALUE [D4]
and: [D5] IS GIVEN THE VALUE [D5]
and: [D6] IS GIVEN THE VALUE [D6]
and: [D7] IS GIVEN THE VALUE [D7]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]
and: [D4LOW] IS GIVEN THE VALUE [D4LOW]
and: [D4HIGH] IS GIVEN THE VALUE [D4HIGH]
and: [D5LOW] IS GIVEN THE VALUE [D5LOW]
and: [D5HIGH] IS GIVEN THE VALUE [D5HIGH]
and: [D6LOW] IS GIVEN THE VALUE [D6LOW]
and: [D6HIGH] IS GIVEN THE VALUE [D6HIGH]
and: [D7LOW] IS GIVEN THE VALUE [D7LOW]
and: [D7HIGH] IS GIVEN THE VALUE [D7HIGH]

  RULE NUMBER: 540

IF:
     [DESIGN] = 8
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [D1] IS GIVEN THE VALUE [D1]
and: [D2] IS GIVEN THE VALUE [D2]
and: [D3] IS GIVEN THE VALUE [D3]
and: [D4] IS GIVEN THE VALUE [D4]
and: [D5] IS GIVEN THE VALUE [D5]
and: [D6] IS GIVEN THE VALUE [D6]
and: [D7] IS GIVEN THE VALUE [D7]
and: [D8] IS GIVEN THE VALUE [D8]
and: [D1LOW] IS GIVEN THE VALUE [D1LOW]
and: [D1HIGH] IS GIVEN THE VALUE [D1HIGH]
and: [D2LOW] IS GIVEN THE VALUE [D2LOW]
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and: [D2HIGH] IS GIVEN THE VALUE [D2HIGH]
and: [D3LOW] IS GIVEN THE VALUE [D3LOW]
and: [D3HIGH] IS GIVEN THE VALUE [D3HIGH]
and: [D4LOW] IS GIVEN THE VALUE [D4LOW]
and: [D4HIGH] IS GIVEN THE VALUE [D4HIGH]
and: [D5LOW] IS GIVEN THE VALUE [D5LOW]
and: [D5HIGH] IS GIVEN THE VALUE [D5HIGH]
and: [D6LOW] IS GIVEN THE VALUE [D6LOW]
and: [D6HIGH] IS GIVEN THE VALUE [D6HIGH]
and: [D7LOW] IS GIVEN THE VALUE [D7LOW]
and: [D7HIGH] IS GIVEN THE VALUE [D7HIGH]
and: [D8LOW] IS GIVEN THE VALUE [D8LOW]
and: [D8HIGH] IS GIVEN THE VALUE [D8HIGH]

  RULE NUMBER: 541

IF:
     [NOISE] = 1
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]

  RULE NUMBER: 542

IF:
     [NOISE] = 2
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]

  RULE NUMBER: 543

IF:
     [NOISE] = 3
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
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and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]

  RULE NUMBER: 544

IF:
     [NOISE] = 4    -
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
and: [N4] IS GIVEN THE VALUE [N4]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]
and: [N4LOW] IS GIVEN THE VALUE [N4LOW]
and: [N4HIGH] IS GIVEN THE VALUE [N4HIGH]

  RULE NUMBER: 545

IF:
     [NOISE] = 5    -
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
and: [N4] IS GIVEN THE VALUE [N4]
and: [N5] IS GIVEN THE VALUE [N5]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]
and: [N4LOW] IS GIVEN THE VALUE [N4LOW]
and: [N4HIGH] IS GIVEN THE VALUE [N4HIGH]
and: [N5LOW] IS GIVEN THE VALUE [N5LOW]
and: [N5HIGH] IS GIVEN THE VALUE [N5HIGH]
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  RULE NUMBER: 546

IF:
     [NOISE] = 6
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
and: [N4] IS GIVEN THE VALUE [N4]
and: [N5] IS GIVEN THE VALUE [N5]
and: [N6] IS GIVEN THE VALUE [N6]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]
and: [N4LOW] IS GIVEN THE VALUE [N4LOW]
and: [N4HIGH] IS GIVEN THE VALUE [N4HIGH]
and: [N5LOW] IS GIVEN THE VALUE [N5LOW]
and: [N5HIGH] IS GIVEN THE VALUE [N5HIGH]
and: [N6LOW] IS GIVEN THE VALUE [N6LOW]
and: [N6HIGH] IS GIVEN THE VALUE [N6HIGH]

  RULE NUMBER: 547

IF:
     [NOISE] = 7
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
and: [N4] IS GIVEN THE VALUE [N4]
and: [N5] IS GIVEN THE VALUE [N5]
and: [N6] IS GIVEN THE VALUE [N6]
and: [N7] IS GIVEN THE VALUE [N7]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]
and: [N4LOW] IS GIVEN THE VALUE [N4LOW]
and: [N4HIGH] IS GIVEN THE VALUE [N4HIGH]
and: [N5LOW] IS GIVEN THE VALUE [N5LOW]
and: [N5HIGH] IS GIVEN THE VALUE [N5HIGH]
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and: [N6LOW] IS GIVEN THE VALUE [N6LOW]
and: [N6HIGH] IS GIVEN THE VALUE [N6HIGH]
and: [N7LOW] IS GIVEN THE VALUE [N7LOW]
and: [N7HIGH] IS GIVEN THE VALUE [N7HIGH]

  RULE NUMBER: 548

IF:
     [NOISE] = 8
and: THE RESPONSE IS {LINEAR}
 or: THE RESPONSE IS {QUADRATIC}

THEN:
     [N1] IS GIVEN THE VALUE [N1]
and: [N2] IS GIVEN THE VALUE [N2]
and: [N3] IS GIVEN THE VALUE [N3]
and: [N4] IS GIVEN THE VALUE [N4]
and: [N5] IS GIVEN THE VALUE [N5]
and: [N6] IS GIVEN THE VALUE [N6]
and: [N7] IS GIVEN THE VALUE [N7]
and: [N8] IS GIVEN THE VALUE [N8]
and: [N1LOW] IS GIVEN THE VALUE [N1LOW]
and: [N1HIGH] IS GIVEN THE VALUE [N1HIGH]
and: [N2LOW] IS GIVEN THE VALUE [N2LOW]
and: [N2HIGH] IS GIVEN THE VALUE [N2HIGH]
and: [N3LOW] IS GIVEN THE VALUE [N3LOW]
and: [N3HIGH] IS GIVEN THE VALUE [N3HIGH]
and: [N4LOW] IS GIVEN THE VALUE [N4LOW]
and: [N4HIGH] IS GIVEN THE VALUE [N4HIGH]
and: [N5LOW] IS GIVEN THE VALUE [N5LOW]
and: [N5HIGH] IS GIVEN THE VALUE [N5HIGH]
and: [N6LOW] IS GIVEN THE VALUE [N6LOW]
and: [N6HIGH] IS GIVEN THE VALUE [N6HIGH]
and: [N7LOW] IS GIVEN THE VALUE [N7LOW]
and: [N7HIGH] IS GIVEN THE VALUE [N7HIGH]
and: [N8LOW] IS GIVEN THE VALUE [N8LOW]
and: [N8HIGH] IS GIVEN THE VALUE [N8HIGH]

  RULE NUMBER: 549

IF:
     [DESIGN] = 0
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [N1]

  RULE NUMBER: 550

IF:
     [DESIGN] = 0
and: [NOISE] = 2
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```
THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 551

IF:
     [DESIGN] = 0
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 552

IF:
     [DESIGN] = 0
and: [NOISE] = 4

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]
and: [QUATRO] IS GIVEN THE VALUE [N4]

  RULE NUMBER: 553

IF:
     [DESIGN] = 0
and: [NOISE] = 5

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]
and: [QUATRO] IS GIVEN THE VALUE [N4]
and: [CINCO] IS GIVEN THE VALUE [N5]

  RULE NUMBER: 554

IF:
     [DESIGN] = 0
and: [NOISE] = 6

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]
and: [QUATRO] IS GIVEN THE VALUE [N4]
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```
and: [CINCO] IS GIVEN THE VALUE [N5]
and: [SEIS] IS GIVEN THE VALUE [N6]

  RULE NUMBER: 555

IF:
     [DESIGN] = 0
and: [NOISE] = 7

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]
and: [QUATRO] IS GIVEN THE VALUE [N4]
and: [CINCO] IS GIVEN THE VALUE [N5]
and: [SEIS] IS GIVEN THE VALUE [N6]
and: [SIETE] IS GIVEN THE VALUE [N7]

  RULE NUMBER: 556

IF:
     [DESIGN] = 0
and: [NOISE] = 8

THEN:
     [UNO] IS GIVEN THE VALUE [N1]
and: [DOS] IS GIVEN THE VALUE [N2]
and: [TRES] IS GIVEN THE VALUE [N3]
and: [QUATRO] IS GIVEN THE VALUE [N4]
and: [CINCO] IS GIVEN THE VALUE [N5]
and: [SEIS] IS GIVEN THE VALUE [N6]
and: [SIETE] IS GIVEN THE VALUE [N7]
and: [OCHO] IS GIVEN THE VALUE [N8]

  RULE NUMBER: 557

IF:
     [DESIGN] = 1
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]

  RULE NUMBER: 558

IF:
     [DESIGN] = 1
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
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```
  RULE NUMBER: 559

IF:
     [DESIGN] = 1
and: [NOISE] = 2

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 560

IF:
     [DESIGN] = 1
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]
and: [QUATRO] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 561

IF:
     [DESIGN] = 1
and: [NOISE] = 4

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]
and: [QUATRO] IS GIVEN THE VALUE [N3]
and: [CINCO] IS GIVEN THE VALUE [N4]

  RULE NUMBER: 562

IF:
     [DESIGN] = 1
and: [NOISE] = 5

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]
and: [QUATRO] IS GIVEN THE VALUE [N3]
and: [CINCO] IS GIVEN THE VALUE [N4]
and: [SEIS] IS GIVEN THE VALUE [N5]
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  RULE NUMBER: 563

IF:
     [DESIGN] = 1
and: [NOISE] = 6

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]
and: [QUATRO] IS GIVEN THE VALUE [N3]
and: [CINCO] IS GIVEN THE VALUE [N4]
and: [SEIS] IS GIVEN THE VALUE [N5]
and: [SIETE] IS GIVEN THE VALUE [N6]

  RULE NUMBER: 564

IF:
     [DESIGN] = 1
and: [NOISE] = 7

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [N1]
and: [TRES] IS GIVEN THE VALUE [N2]
and: [QUATRO] IS GIVEN THE VALUE [N3]
and: [CINCO] IS GIVEN THE VALUE [N4]
and: [SEIS] IS GIVEN THE VALUE [N5]
and: [SIETE] IS GIVEN THE VALUE [N6]
and: [OCHO] IS GIVEN THE VALUE [N7]

  RULE NUMBER: 565

IF:
     [DESIGN] = 2
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]

  RULE NUMBER: 566

IF:
     [DESIGN] = 2
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
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  RULE NUMBER: 567

IF:
     [DESIGN] = 2
and: [NOISE] = 2

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
and: [QUATRO] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 568

IF:
     [DESIGN] = 2
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
and: [QUATRO] IS GIVEN THE VALUE [N2]
and: [CINCO] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 569

IF:
     [DESIGN] = 2
and: [NOISE] = 4

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
and: [QUATRO] IS GIVEN THE VALUE [N2]
and: [CINCO] IS GIVEN THE VALUE [N3]
and: [SEIS] IS GIVEN THE VALUE [N4]

  RULE NUMBER: 570

IF:
     [DESIGN] = 2
and: [NOISE] = 5

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
and: [QUATRO] IS GIVEN THE VALUE [N2]
and: [CINCO] IS GIVEN THE VALUE [N3]
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and: [SEIS] IS GIVEN THE VALUE [N4]
and: [SIETE] IS GIVEN THE VALUE [N5]

  RULE NUMBER: 571

IF:
     [DESIGN] = 2
and: [NOISE] = 6

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [N1]
and: [QUATRO] IS GIVEN THE VALUE [N2]
and: [CINCO] IS GIVEN THE VALUE [N3]
and: [SEIS] IS GIVEN THE VALUE [N4]
and: [SIETE] IS GIVEN THE VALUE [N5]
and: [OCHO] IS GIVEN THE VALUE [N6]

  RULE NUMBER: 572

IF:
     [DESIGN] = 3
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]

  RULE NUMBER: 573

IF:
     [DESIGN] = 3
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [N1]

  RULE NUMBER: 574

IF:
     [DESIGN] = 3
and: [NOISE] = 2

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
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```
and: [QUATRO] IS GIVEN THE VALUE [N1]
and: [CINCO] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 575

IF:
     [DESIGN] = 3
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [N1]
and: [CINCO] IS GIVEN THE VALUE [N2]
and: [SEIS] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 576

IF:
     [DESIGN] = 3
and: [NOISE] = 4

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [N1]
and: [CINCO] IS GIVEN THE VALUE [N2]
and: [SEIS] IS GIVEN THE VALUE [N3]
and: [SIETE] IS GIVEN THE VALUE [N4]

  RULE NUMBER: 577

IF:
     [DESIGN] = 3
and: [NOISE] = 5

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [N1]
and: [CINCO] IS GIVEN THE VALUE [N2]
and: [SEIS] IS GIVEN THE VALUE [N3]
and: [SIETE] IS GIVEN THE VALUE [N4]
and: [OCHO] IS GIVEN THE VALUE [N5]
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  RULE NUMBER: 578

IF:
     [DESIGN] = 4
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]

  RULE NUMBER: 579

IF:
     [DESIGN] = 4
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [N1]

  RULE NUMBER: 580

IF:
     [DESIGN] = 4
and: [NOISE] = 2

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [N1]
and: [SEIS] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 581

IF:
     [DESIGN] = 4
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [N1]
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and: [SEIS] IS GIVEN THE VALUE [N2]
and: [SIETE] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 582

IF:
     [DESIGN] = 4
and: [NOISE] = 4

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [N1]
and: [SEIS] IS GIVEN THE VALUE [N2]
and: [SIETE] IS GIVEN THE VALUE [N3]
and: [OCHO] IS GIVEN THE VALUE [N4]

  RULE NUMBER: 583

IF:
     [DESIGN] = 5
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]

  RULE NUMBER: 584

IF:
     [DESIGN] = 5
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [N1]

  RULE NUMBER: 585

IF:
     [DESIGN] = 5
and: [NOISE] = 2
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THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [N1]
and: [SIETE] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 586

IF:
     [DESIGN] = 5
and: [NOISE] = 3

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [N1]
and: [SIETE] IS GIVEN THE VALUE [N2]
and: [OCHO] IS GIVEN THE VALUE [N3]

  RULE NUMBER: 587

IF:
     [DESIGN] = 6
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [D6]

  RULE NUMBER: 588

IF:
     [DESIGN] = 6
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
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and: [SEIS] IS GIVEN THE VALUE [D6]
and: [SIETE] IS GIVEN THE VALUE [N1]

  RULE NUMBER: 589

IF:
     [DESIGN] = 6
and: [NOISE] = 2

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [D6]
and: [SIETE] IS GIVEN THE VALUE [N1]
and: [OCHO] IS GIVEN THE VALUE [N2]

  RULE NUMBER: 590

IF:
     [DESIGN] = 7
and: [NOISE] = 0

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [D6]
and: [SIETE] IS GIVEN THE VALUE [D7]

  RULE NUMBER: 591

IF:
     [DESIGN] = 7
and: [NOISE] = 1

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [D6]
and: [SIETE] IS GIVEN THE VALUE [D7]
and: [OCHO] IS GIVEN THE VALUE [N1]
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  RULE NUMBER: 592

IF:
     [DESIGN] = 8

THEN:
     [UNO] IS GIVEN THE VALUE [D1]
and: [DOS] IS GIVEN THE VALUE [D2]
and: [TRES] IS GIVEN THE VALUE [D3]
and: [QUATRO] IS GIVEN THE VALUE [D4]
and: [CINCO] IS GIVEN THE VALUE [D5]
and: [SEIS] IS GIVEN THE VALUE [D6]
and: [SIETE] IS GIVEN THE VALUE [D7]
and: [OCHO] IS GIVEN THE VALUE [D8]

  RULE NUMBER: 593

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 1

THEN:
     [D1MID] IS GIVEN THE VALUE [D1MID]

  RULE NUMBER: 594

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 2

THEN:
     [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]

  RULE NUMBER: 595

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 3

THEN:
     [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]

  RULE NUMBER: 596

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 4
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THEN:
      [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]
and: [D4MID] IS GIVEN THE VALUE [D4MID]

  RULE NUMBER: 597

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 5

THEN:
      [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]
and: [D4MID] IS GIVEN THE VALUE [D4MID]
and: [D5MID] IS GIVEN THE VALUE [D5MID]

  RULE NUMBER: 598

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 6

THEN:
      [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]
and: [D4MID] IS GIVEN THE VALUE [D4MID]
and: [D5MID] IS GIVEN THE VALUE [D5MID]
and: [D6MID] IS GIVEN THE VALUE [D6MID]

  RULE NUMBER: 599

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 7

THEN:
      [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]
and: [D4MID] IS GIVEN THE VALUE [D4MID]
and: [D5MID] IS GIVEN THE VALUE [D5MID]
and: [D6MID] IS GIVEN THE VALUE [D6MID]
and: [D7MID] IS GIVEN THE VALUE [D7MID]
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  RULE NUMBER: 600

IF:
     THE RESPONSE IS {QUADRATIC}
and: [DESIGN] = 8

THEN:
     [D1MID] IS GIVEN THE VALUE [D1MID]
and: [D2MID] IS GIVEN THE VALUE [D2MID]
and: [D3MID] IS GIVEN THE VALUE [D3MID]
and: [D4MID] IS GIVEN THE VALUE [D4MID]
and: [D5MID] IS GIVEN THE VALUE [D5MID]
and: [D6MID] IS GIVEN THE VALUE [D6MID]
and: [D7MID] IS GIVEN THE VALUE [D7MID]
and: [D8MID] IS GIVEN THE VALUE [D8MID]

  RULE NUMBER: 601

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 1

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]

  RULE NUMBER: 602

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 2

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]

  RULE NUMBER: 603

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 3

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]
and: [N3MID] IS GIVEN THE VALUE [N3MID]

  RULE NUMBER: 604

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 4
```

```
THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]
and: [N3MID] IS GIVEN THE VALUE [N3MID]
and: [N4MID] IS GIVEN THE VALUE [N4MID]

  RULE NUMBER: 605

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 5

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]
and: [N3MID] IS GIVEN THE VALUE [N3MID]
and: [N4MID] IS GIVEN THE VALUE [N4MID]
and: [N5MID] IS GIVEN THE VALUE [N5MID]

  RULE NUMBER: 606

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 6

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]
and: [N3MID] IS GIVEN THE VALUE [N3MID]
and: [N4MID] IS GIVEN THE VALUE [N4MID]
and: [N5MID] IS GIVEN THE VALUE [N5MID]
and: [N6MID] IS GIVEN THE VALUE [N6MID]

  RULE NUMBER: 607

IF:
     THE RESPONSE IS {QUADRATIC}
and: [NOISE] = 7

THEN:
     [N1MID] IS GIVEN THE VALUE [N1MID]
and: [N2MID] IS GIVEN THE VALUE [N2MID]
and: [N3MID] IS GIVEN THE VALUE [N3MID]
and: [N4MID] IS GIVEN THE VALUE [N4MID]
and: [N5MID] IS GIVEN THE VALUE [N5MID]
and: [N6MID] IS GIVEN THE VALUE [N6MID]
and: [N7MID] IS GIVEN THE VALUE [N7MID]
```

APPENDIX B

USER'S GUIDE TO THE OQIE

B.1 Introduction

The Expert Advisor for Off-Line Quality Improvement, hereafter referred to as the OQIE, is a software package designed to assist researchers in the selection of a parsimonious experiment that will yield insights to an existing product or process.

B.2 Hardware/Software Requirements

The OQIE runs on all IBM PC, XT, AT or compatible computers. It requires 640k RAM, DOS 2.0 or higher, and a hard disk or at least 720k floppy drive. It runs on any 80 column monitor, but a high resolution color monitor such as a VGA/EGA/SVGA permits inspection of color-coded rules, rule conditions, and help screens. For speed considerations, the system should be run from a hard drive as operation from a floppy drive is extremely time consuming.

The OQIE requires the expert system shell EXSYS PROFESSIONAL to operate. EXSYS PROFESSIONAL is a rule-based inference engine that accepts English-like or mathematical expressions as rules in order to derive conclusions based upon answers to qualifiers. The engine is capable of both forward and backward chaining.

B.3 Starting the OQIE

The OQIE is initiated by typing the command EXSYSP OQIE at the DOS prompt (C:\> EXSYSP OQIE). On typing this command, the screen shown in Figure B.1 is displayed. To exit the OQIE, type D for Done at the termination of a session, or type QUIT during a session. Typing QUIT during a session causes the OQIE to halt execution and prompt the user for a file name to store all information provided up to that point. Subsequent operations of the system may use these stored responses by answering yes to the question "Do you wish to used stored data?" and then providing the file name of interest.

B.4 EXSYS PROFESSIONAL Help Screens

Before execution of the rules, EXSYS PROFESSIONAL asks the operator if they wish instructions on running the program. A response in the affirmative yields the help screen shown in Figures B.2 and B.3. These screens feature hypertext, which permits deeper inquiry regarding specific user-selected concepts.

B.5 OQIE Help Screens

The OQIE has custom help screens for every qualifier and variable. Help is initiated by typing "?" in response to a question posed by the OQIE. All help screen text is contained in an ASCII file called ADVISOR.HLP. An example

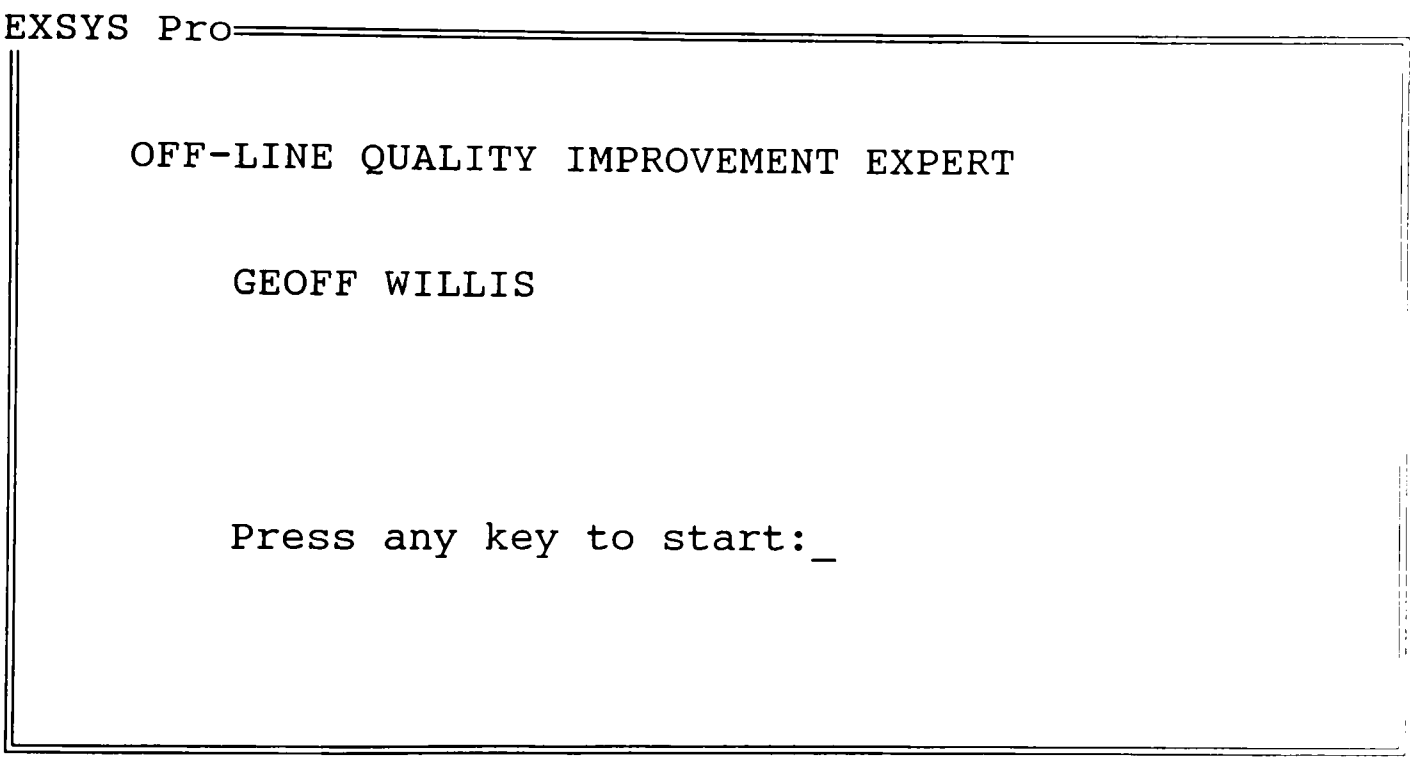

Figure B.1: Initial Expert Screen

EXSYS professional, a program for running expert system knowledge bases, will, in some ways, emulate the decision making process of a human expert.

The program will ask you a series of questions.
Often, the question will be asked of you by the displaying of a statement followed by a numbered list of alternatives which could all logically complete that statement.
You must select the number associated with the alternative which most accurately completes the statement for your particular situation. You may find that more than one of the alternatives you must choose from is an appropriate response to the question. In this case, you may select any and all of the relevant answers. They need only be separated by a space or a comma.
You may also be required to supply text or numeric data to the program. You will be prompted for the exact information needed.

Keyword Information-<F1> Return-<ESC> :
Press <ENTER> to continue:

Figure B.2 EXSYS EL Initial Help Screen

Any time you have doubts or questions, you need only type WHY and the computer will display the rule being tested.

If after viewing the relevant rule/rules you still require help, you can type in a ?. The author of the expert system may have included additional clarification, which will be displayed upon the typing of a ?.

At all times, the menu at the bottom of the screen will display the available options and the keystroke required to access each option.

When the expert system has arrived at its conclusions for your session, it will display these results in the final results screen.

Keyword Information-<F1> Prev. Screen-<Page UP> Return-<ESC> : Press <ENTER> to continue:

Figure B.3 EXSYS EL Second Help Screen

help screen for the qualifier, "The number of noise variables is" appears as Figure B.4.

Once the user has finished reviewing the help screen, control is returned to the OQIE and the OQIE once again asks the user for the information.

B.6 OQIE External Programs

The OQIE receives information from two programs that are external to the expert system shell. These programs are coded in Microsoft QuickBASIC [Microsoft 1990], which allows a program to be compiled rather than interpreted.

The first program, BUDGET.EXE, calculates the maximum number of experimental trials based upon a user-specified budget of time and money. The constraining number of trials is written to the file RETURN.DAT in the form "[RUNS] #" and is used to assign a value to the OQIE numeric variable [RUNS]. Along with the number of trials information, qualifier values that indicate the desire to perform an experimental design rather than a process capability study are written to the RETURN.DAT file.

The second program, CAPABLE.EXE, is used to perform a process capability study for either a variables measure of capability or an attributes measure of process capability. A variables process capability calculation is written to the file RETURN.DAT in the form "[22] #" and is used to assign a value to the OQIE numeric variable [22]. An attributes process capability calculation is also written to the file

NOISE VARIABLES REFER TO MANUFACTURING OR ENVIRONMENTAL VARIABILITY THAT REFLECT DIFFERENT OPERATING CIRCUMSTANCES FOR YOUR EQUIPMENT OR PRODUCT. FACTORS LIKE TEMPERATURE, PRESSURE, DUST, AND HUMIDITY THAT MIGHT AFFECT PRODUCT PERFORMANCE OF THE ITEM FALL INTO THIS CATEGORY.

AN EXAMPLE IS PROVIDED ON THE FOLLOWING SCREEN...

Figure B.4 OQIE Help Screen

RETURN.DAT in the form "[LOW24] #" and is used to assign a value to the OQIE numeric variable [LOW24]. In addition to the capability statistics, qualifier values that inhibit an experimental design suggestion are written to the RETURN.DAT file.

The OQIE reads the variable values from the RETURN.DAT file and then deletes that file at the end of a session. Each of the programs opens another file, called RETURN.DOT, during execution and writes the identical information that is written to the RETURN.DAT file. The RETURN.DOT file can be reviewed following execution of the OQIE to verify the information passed between the programs.

B.7 Experimental Design Feature Conclusions

Upon completion of a session with the OQIE, a list of information provided to the system, as well as the system's recommendations are displayed. For an experimental design recommendation, the OQIE lists between one and four possibilities and assigns each a level of confidence varying between one and nine, with nine being the highest level of confidence. If the OQIE has no recommended design, the message "No choice received an assignment greater than 1," will be displayed. The OQIE will also display the number of trials required to achieve the next best experimental procedure, as well as those required to achieve designs of resolution three, four, and five as applicable. If the indicated resources permit a thorough investigation of all

factors, the OQIE will state this. An example of the final conclusion screen from the OQIE is displayed in Figure B.5.

B.7.1 All Choices for System Recommendations

The user can identify all of designs that can be suggested by the OQIE and determine why some may not have been selected by entering the letter "A" at the conclusion screen. The OQIE will list all possible conclusions of the system, enabling the user to investigate a single conclusion by entering its number. The OQIE can then show the rules applied in deciding that choice to be inappropriate.

B.7.2 Greater Than Option for System Recommendations

The user may instead choose to view all conclusions reached by the system that were assigned a confidence level greater than a user-specified threshold value. This option is exercised by typing the letter "G" at the conclusion screen, followed by the specification of a numerical threshold. Since the OQIE uses a 0 to 10 confidence system, the threshold should lie within that range.

B.7.3 Print Option for System Recommendations

By pressing the letter "P", the user may print the results of a run. the user has the option of printing all of the data input to the program along with the conclusions. This option is of limited utility since the OQIE creates and

```
EXSYS EL
                                                    VALUE
 1 1/2 FRACTION 2^3 FACTORIAL                         9
 2 THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 2
 3 THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 1
 4 THE MAX NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 6
 5 FACTOR A OF THE DESIGN = Speed
 6 FACTOR B OF THE DESIGN = Rate
 7 FACTOR C OF THE DESIGN = Grinder
 8 THE LOW TEST SETTING OF Speed = 2300
 9 THE HIGH TEST SETTING OF Speed = 3500
10 THE LOW TEST SETTING OF Rate = 2
11 THE HIGH TEST SETTING OF Rate = 6
12 THE LOW TEST SETTING OF Grinder = A
13 THE HIGH TEST SETTING OF Grinder = B
14 THE NUMBER OF ADDITIONAL TRIALS REQUIRED TO ACHIEVE
   THE NEXT BEST DESIGN = 2
15 THE NUMBER OF ADDITIONAL TRIALS NEEDED TO PERMIT A
   RESOLUTION FIVE EXPERIMENT = 2

 All choices <A> only if value>1 <G>  Print <P>
 Change and Rerun <C>  Rules used <line #>  Quit/save <Q>
 Help<H>  Done<D>:
```

Figure B.5 Example of OQIE Conclusion Screen

saves the DESIGN.DAT file that can be printed later. If the change feature (discussed in section B.7.4) is used multiple times, the user might wish to print each run as it is completed and then, after rerunning the most promising scenario, print the DESIGN.DAT file that is created.

B.7.4 Change Option for System Recommendations

EXSYS PROFESSIONAL allows the user to perform if/then analysis on the conclusions offered by the expert system through the use of the change and rerun option, which is initiated by typing "C" at the conclusion screen, such as displayed in Figure B.5. An example of a change screen is provided as Figure B.6. The user has the option of storing the original information input to the system, storing the most recent information input to the system, or not storing any previously input information.

B.7.4.1 Line Number of Change Option. The OQIE will list all of the information provided by the user and ask the user which answer or answers he wishes to change. The user can indicate the desired changes by using arrow keys to highlight a line of information or by typing the line number of the information. Once the information has been selected, the user is prompted to provide a new value.

```
EXSYS EL═══════ ** CHANGE INPUT DATA ** ═══════════════════════
 1 THE RESPONSE IS LINEAR
 2 THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 2
 3 THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 1
 4 THE MAX NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 6
 5 FACTOR A OF THE DESIGN = Speed
 6 FACTOR B OF THE DESIGN = Rate
 7 FACTOR C OF THE DESIGN = Grinder
 8 THE LOW TEST SETTING OF Speed = 2300
 9 THE HIGH TEST SETTING OF Speed = 3500
10 THE LOW TEST SETTING OF Rate = 2
11 THE HIGH TEST SETTING OF Rate = 6
12 THE LOW TEST SETTING OF Grinder = A
13 THE HIGH TEST SETTING OF Grinder = B
```

Enter number of line to change <O> for original data
<R> to run the data <H> for help Memo <F10>

Figure B.6 Example of OQIE Change Screen

B.7.4.2 Original Data of Change Option. The user may elect to run the OQIE again using the original information. The OQIE stores only the information from the most recent run, so if the change option is selected multiple times, the "first-run" information cannot be retrieved using this option. This feature is most commonly used only if a mistake has been made in selecting the change option at the conclusion screen.

B.7.4.3 Running New Data From Change Option. Once all required changes have been selected, the system can be rerun by pressing the "R" key. The OQIE will then ask if the starting external program should be called again. If the number of trials should stay the same for the new set of information, then the starting program need not be recalled. If the user wishes to change the number of trials, then the starting program should be rerun with different values entered for the temporal and financial constraints. Selecting the change option and recalling the starting program is the quickest way to compare recommended designs for different levels of resources.

The OQIE will also ask the user if he wishes to store the most recent conclusions and information provided for a comparison. Once the user has changed some information, the OQIE will draw another conclusion, asking for additional information if needed. The new conclusions and information will then be displayed alongside the original conclusions

and information for comparison. This feature may be repeated as many times as the user wishes although only one set of answers may be stored at a time.

B.7.4.4 Help for the Change Option. Help for the Change option is identical to that available for the ultimate results screen. Help is summoned by pressing the "H" key and it consists of several screens of text, some of whose key words have additional help available in a hypertext format. Examples of the help screens appear as Figures B.7 through B.10.

B.7.4.5 Memo for the Change Option. The memo feature is activated by pressing the F10 function key. The memo feature writes comments to a file with an NBK (for notebook) extension. The menu that is brought up by selecting the memo option appears as Figure B.11. If the user wishes to add information to the notebook file, selecting option 1 will display a blank screen that will accept several lines of text input. If the user wishes to read the notebook, selecting 2 will display all contents of the OQIE notebook. An example of a notebook entry appears as Figure B.12.

B.7.5 Rules Used for System Recommendations

The OQIE allows the user to see the rules used in arriving at any conclusion or intermediate step in the session. By typing the letter "R" at the final screen, the

The computer has now created its list of choices, sorted with the most likely first. The number following the choice reflects the degree of confidence there is in that choice.

Only those choices with a value greater than a threshold are displayed. The program may tell you that all choices were eliminated. This is because they received a value less than the threshold value that was set by the system's author.

Return-<ESC> Continue-<ENTER>

Figure B.7 Initial Help Screen

To see all of the choices, even those with values less than the threshold, press <A> and the full list will be displayed. However, if a choice was not used in ANY rule that was true, it has NO value and will still not be displayed. To return to only those with values greater than the threshold press <G>. The program may also have displayed text notes or variables calculated by the program.

You may ask the computer how it arrived at a particular answer by entering the line number. The computer will show you all of the rules that were used to arrive at that conclusion.

Prev Scrn -<UP ARROW> Return-<ESC> Continue-<ENTER>

Figure B.8 Second Help Screen

You can examine the effect of changing some of your answers has on the final conclusions by selecting the change and rerun option. This option is selected by pressing <C>. You will be shown a list of all of the input you provided to the program. You may select an item by entering its number and you will be allowed to change its values. When the data is the way you wish it, press <R> to run the data. You may be asked additional questions if the new data necessitates additional information to reach conclusions. Once the program recalculates the data, it will display the old and new values for choices (unless that option was switched off).

To print the final list of choices, press <P>. You will have the option of also printing all of the input you gave the computer. If you have a report specification file for the report generator, you will have the option of using the report generator if it has not already been used.

Keyword Information-<F1> Prev Scrn-<UP ARROW>
Return-<ESC> Continue-<ENTER>

Figure B.9 Third Help Screen

To change the calculational method that is used to combine the values of choices, press <S>. ONLY the average mode can be used if negative values have been used.

If you want to store the data you have input so far and exit the program press <Q>. The program will ask you for the name of the file you want to store the data in. DO NOT use the name of any knowledge base. If there is already a file with the name you select, it will be erased. The QUIT option applies ONLY to the runtime program and not the editor.

When you are done press <D>.
You will be allowed to rerun the program.

Keyword Information-<F1> Prev Scrn-<UP ARROW>
Return-<ESC> Continue-<ENTER>

Figure B.10 Fourth Help Screen

```
                    NOTEBOOK

1 - Add data to notebook

2 - Read notebook

3 - DONE

Input number of selection:
```

Figure B.11 Example of the Memo Submenu

```
>>>>> Mon Jan 17 10:19:10 1994
this is a trial run

TO RETURN TO PROGRAM PRESS <SPACE>
```

Figure B.12 Example of a Notebook File

user is prompted to enter the line number of the information about which rule application is desired. All of the rules that were used in deriving that piece of information will be displayed in the order they were used. Single lines of applied rules may also be queried for their information source. The rules that have fired are color coded - yellow for true and red for false. Rules that the OQIE is unsure about are coded blue. Rules that did not fire may be tested by pressing the up and down arrow keys or typing the letter "J" (for jump) and entering a rule number.

B.7.6 Quit and Save for System Recommendations

The user can end a session with the OQIE by typing the letter "Q" at the recommendations screen. The OQIE can store all information provided it during a session by pressing the letter "Q" and assigning a file name to the information provided. Care must be taken to assign a file name that is unique to the current directory, since the system will overwrite any file with the same name.

If the user wishes to quit the current session without saving any information entered, the quit option should be selected and the <ENTER> key pressed when a file name prompt is issued.

B.7.7 Help Screens for System Recommendations

The help screens for the system recommendations may be initiated by pressing the letter "H". These screens are

identical to those available at the help submenu system of the change option, which are displayed as Figures B.7 through B.10.

B.7.8 Done Indication for System Recommendations

Once the user has finished a consultation with the OQIE, pressing the letter "D" will end the current session, wiping out all variable assignments and recommendations from active memory. The OQIE will then ask if the user wishes to begin another session, which may be initiated by typing "Y". The default answer to this question is no, which is achieved by typing <ENTER> or "N".

B.8 Design Files

The OQIE refers the user to an ASCII text file containing the factor settings for each experimental run. These files show the levels for all of the variables for each of the runs. The variable levels are expressed in a Yate's algorithm format with +1 representing the high setting of a factor, 0 representing the middle level (if any) of a factor, and -1 representing the low level of a factor. The central composite design files have five settings for each of the variables, three of which are +1, 0, and -1, with the other two depending upon the number of factors and runs in the experiment.

An example of a design file, for a half fraction of a five factor factorial linear model appears as Figure B.13.

Run	A	B	C	D	E=ABCD
1	-1	-1	-1	-1	+1
2	+1	-1	-1	-1	-1
3	-1	+1	-1	-1	-1
4	+1	+1	-1	-1	+1
5	-1	-1	+1	-1	-1
6	+1	-1	+1	-1	+1
7	-1	+1	+1	-1	+1
8	+1	+1	+1	-1	-1
9	-1	-1	-1	+1	-1
10	+1	-1	-1	+1	+1
11	-1	+1	-1	+1	+1
12	+1	+1	-1	+1	-1
13	-1	-1	+1	+1	+1
14	+1	-1	+1	+1	-1
15	-1	+1	+1	+1	-1
16	+1	+1	+1	+1	+1

The above information should be used a guideline for testing your product/process. Each row represents a single experimental trial in a series of 16. The order of the trials should be randomized, so do not run them in numerical sequence as trial #1, trial #2, trial #3, etc. Instead, select them completely at random by using a random number table or some other unsystematic method that insures the trials are conducted in no particular order.

Figure B.13 Design File for ½ Fraction 2^6 Factorial

B.9 Process Capability Feature Conclusions

Conclusions drawn by the OQIE regarding a process capability study are also written to the DESIGN.DAT file. The data input and calculations are performed by the external program CAPABLE.EXE, first mentioned in section B.6. The attributes process capability study uses a simple fraction defective measure. The number of defective units observed is divided by the total number of units inspected. The final screen of the OQIE for the same process capability study appears as Figure B.14.

B.10 System Output

The OQIE constructs an ASCII text file containing all information provided to the system by both the user and external programs, all variable assignments, all design recommendations, the names of the corresponding design files, and general information about the designs. This ASCII text file is called DESIGN.DAT and is written to the default directory at the time the system was run. The file is displayed immediately prior to the screens that contain all of the OQIE's conclusions.

There is considerable duplication between the two sets of screens, but since the screens containing the system conclusions vanish once a session is ended, the redundant display of the DESIGN.DAT file proves useful. Successive runs of the OQIE overwrite existing DESIGN.DAT files, so the

```
EXSYS EL
                                                    VALUE

1 PROCESS IS OF LOW CAPABILITY                        9
2 THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 0
3 THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 0
4 THE MAX NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 0
5 ATTRIBUTES PROCESS CAPABILITY (FRACTION DEFECTIVE)
 = .125

All choices <A> only if value>1 <G>  Print <P>
Change and Rerun <C>  Rules used <line #>  Quit/save <Q>
Help<H>  Done<D>:
```

Figure B.14 Example of OQIE Capability Study Conclusion Screen

user must rename or print out DESIGN.DAT files that merit further consideration.

B.10.1 DESIGN.DAT File for Design Recommendation

An example of a DESIGN.DAT file created for a three factor linear design in eight runs appears as Figure B.15. The DESIGN.DAT file begins with Section I, which is a list of the information provided by the user to the OQIE. The maximum number of experimental trials possible was derived from the external program BUDGET.EXE, but the number of design and noise variables along with their names and the nature of the response variable were all input by the user.

Section II of the DESIGN.DAT file shows the names assigned to all of the variables. If the number of experimental trials is inadequate for a full factorial, then the variable value assignments are made by the OQIE according to the user's *a priori* reasoning regarding important and/or significant interactions. If there are sufficient resources for a full factorial, then the system arbitrarily provides a designation for each design and noise variable. As shown in Figure B.15, there are adequate resources for a full 2^3 factorial, so the assignment of factor A to the design variable D1, factor B to the design variable D2, and factor C to the noise variable N1 amounts to little more than a tracking device once the experiment is run.

```
I. YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 8

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 2
THE FIRST DESIGN VARIABLE = D1
THE SECOND DESIGN VARIABLE = D2

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 1
THE FIRST NOISE VARIABLE = N1

THE RESPONSE IS LINEAR

II.  THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

FACTOR A OF THE DESIGN = D1
FACTOR B OF THE DESIGN = D2
FACTOR C OF THE DESIGN = N1

III. DESIGN RECOMMENDATIONS

A.   THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST SUITED FOR
     YOUR INDICATED SITUATION ARE LISTED BELOW:

2^3 FACTORIAL: Confidence=9/10
1/2 FRACTION 2^3 FACTORIAL: Confidence=1/10

B.   MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE.
     THE LIST BELOW SHOW THE NUMBER OF ADDITIONAL TRIALS
     REQUIRED IN ORDER TO EXTRACT MORE INFORMATION
     ABOUT THE SITUATION

THE NUMBER OF ADDITIONAL TRIALS REQUIRED TO ACHIEVE AN
IMPROVED DESIGN = 8

IV.  A DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

EIGHT RUNS ARE REQUIRED TO ESTIMATE THE MAIN EFFECTS AND ALL
TWO AND THREE-WAY INTERACTIONS OF THREE VARIABLES.  MORE THAN
EIGHT RUNS ALLOWS SOME EXPERIMENTAL ERROR ESTIMATION.

V.   THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN
     BE FOUND IN THE FILE(S) LISTED BELOW:

                23.DAT & H23.DAT
```

Figure B.15 Sample Output for DESIGN.DAT File

Section III of the DESIGN.DAT file is broken into two components. In part A, the OQIE lists one or more designs that are suitable for the situation at hand. If no experiment can be run, the system indicates that no experiment is possible given the number of runs allowed and the number of variables under investigation. If two or more different experimental designs are possible, this section will list each design along with the OQIE's confidence level for each one. In part B, the OQIE lists the number of runs required to achieve a more thorough experiment, if any exists, given the number of factors under investigation and the number of trials permitted. The number of added runs required to realize designs of resolution three, four, and five are shown as well as the number of added runs required for the next best design. In many cases, the design may already be a resolution three, so the only scenarios displayed are additional trials for resolution four and five designs, with the next best design coincident with the resolution four design.

A discussion of the strengths and weaknesses of the designs, as well as some information regarding the analysis of the experimental data appears as Section IV of the report. This information is drawn from the note portion of the rule that is ultimately judged by the OQIE to be true.

Section V of the DESIGN.DAT report displays the data files that contain the coding information for the designs

suggested by the OQIE. This information is extracted from the reference portion of the rule that best fits the situation.

B.10.2 DESIGN.DAT File for Process Capability Study

Figure B.16 is an example of the DESIGN.DAT file created by the attributes process capability study introduced in Section B.9. The format of a DESIGN.DAT file is structured to address the more complicated issue of experimental design, so there are several sections of the file that are not needed or used during a process capability report.

Sections I, II, IIIB, and V are not needed, but it is not possible to suppress their output. Consequently, they reflect the lack of experimental design requirements more than presenting information germane to a process capability study. Section IIIA indicates the conclusion reached by the OQIE regarding the goodness of the process. This judgement is discussed in section IV of the report, which points out that the process capability measure should be used as an internal benchmark, to be compared with subsequent capability studies on the same product/process.

I. YOU PROVIDED THE SYSTEM WITH THE FOLLOWING INFORMATION:

THE MAXIMUM NUMBER OF EXPERIMENTAL TRIALS POSSIBLE = 0

THE NUMBER OF DESIGN VARIABLES IN THE EXPERIMENT = 0

THE NUMBER OF NOISE VARIABLES IN THE EXPERIMENT = 0

THE RESPONSE IS LINEAR

II. THE VARIABLE VALUES HAVE BEEN ASSIGNED AS FOLLOWS

III. DESIGN RECOMMENDATIONS

A. THE DESIGN(S) THAT THE SYSTEM FEELS ARE BEST SUITED FOR YOUR INDICATED SITUATION ARE LISTED BELOW:

PROCESS IS OF LOW CAPABILITY: Confidence=9/10

B. MORE THOROUGH INVESTIGATIONS MAY BE POSSIBLE. THE LIST BELOW SHOWS THE NUMBER OF ADDITIONAL TRIALS REQUIRED IN ORDER TO EXTRACT MORE INFORMATION ABOUT THE SITUATION

IV. A BRIEF DISCUSSION OF THE RECOMMENDED DESIGN(S) FOLLOWS

THE ATTRIBUTES PROCESS CAPABILITY MEASURE EMPLOYED BY THIS SYSTEM IS A FRACTION DEFECTIVE, WHICH IS OBTAINED BY DIVIDING THE NUMBER OF BAD ITEMS BY THE TOTAL NUMBER OF ITEMS INSPECTED. THE CONCLUSIONS REACHED REGARDING THE PROCESS CAPABILITY ARE WHOLLY SUBJECTIVE, AND SHOULD NOT BE USED AS AN ABSOLUTE MEASURE OF PROCESS WORTH. THE FRACTION DEFECTIVE DISPLAYED AT THE END OF A SESSION SHOULD BE USED AS THE BENCHMARK FOR ANY CURRENT OR FUTURE PROCESS IMPROVEMENT MEASURES.

V. THE DATA FILES CONTAINING THE RECOMMENDED DESIGN(S) CAN BE FOUND IN THIS SUBDIRECTORY IN THE FILES LISTED BELOW:

PROCESS CAPABILITY STUDY - NO DESIGN FILES REQUIRED^G^C

Figure B.16 DESIGN.DAT File for Attributes Process Capability