A FORECASTING METHODOLOGY FOR MANAGERS
WITH CASE STUDY OF THE DESKTOP COMPUTER INDUSTRY

by

DAVID T. BEECHAM

Bachelor of Science in Electrical Engineering
University of Florida
1982

Submitted to the Sloan School of Management
in Partial Fulfillment of
the Requirements of the Degree of
Master of Science in the Management of Technology

at the

Massachusetts Institute of Technology
June 1993

© David T. Beecham (1993)
ALL RIGHTS RESERVED
The author hereby grants to MIT permission to reproduce and
to distribute publicly copies of this thesis document in
whole or in part.

Signature of Author ______________________________________________________________________

MIT Sloan School of Management
May 3, 1993

Certified by ____________________________________________

Ernst G. Frankel
Professor of Ocean Systems
Thesis Supervisor

Certified by ____________________________________________

James M. Utterback
Professor of Engineering
Thesis Reader

Accepted by ____________________________________________

Rochelle Weichman
Director, Management of Technology Program

ARCHIVES
MASSACHUSETTS INSTITUTE
OF TECHNOLOGY
JUN 18 1993
A FORECASTING METHODOLOGY FOR MANAGERS
WITH CASE STUDY OF THE DESKTOP COMPUTER INDUSTRY

by

DAVID T. BEECHAM

Submitted to the Alfred P. Sloan School of Management
and the School of Engineering
on May 3, 1993, in partial fulfillment
of the requirements for the Degree of
Master of Science in the Management of Technology

ABSTRACT

A problem faced by many business managers is how to allocate
their resources among different projects. A correct decision
can lead to prosperity and growth. An incorrect decision can
lead the firm into decline. Therefore, business managers
seek tools or methodologies to help them understand the
future and make strategic business decisions.

This thesis presents the hypothesis that forecasting methods
can be devised that will benefit the manager in decision
making. A forecasting methodology is developed which
provides information about a specific question or issue. The
output of the methodology is a set of critical factors and
potential future states. Quantitative analysis is used to
estimate which conditions of the critical factors and which
future states are most probable.

A case study of the desktop computer industry is included to
demonstrate the methodology. The forecasting methodology
identifies factors which will influence desktop computing. A
set of potential future states for the desktop computing
industry is also generated.

The manager will be able to make better decisions using the
knowledge gained during the forecasting process and the
output from the forecasting methodology.

Thesis Supervisor: Ernst G. Frankel
Title: Professor of Ocean Systems
ACKNOWLEDGMENTS

I would like to acknowledge my family for the sacrifices they made which enabled me to spend a year at MIT. During our year in Boston, Linda (my wife) went through two job changes and gave birth to our second son, Mark. To Linda, I owe a very special thank you.

My son Jimmy has endured the cold and decided that he does not like it. I thank him for understanding that daddy needed to be left alone to complete his MIT work.

I owe a great thanks to my sponsor, IBM. That includes Don Brown and Bill O'Brien. Without their support I would not have had the opportunity to come to MIT.

I have enjoyed each of the courses that I have taken at MIT. I want to thank the instructors, teaching assistants and administration office. Their combined efforts have provided me with a new set of ideas and outlook on life.

I want to thank Ernst Frankel, my thesis advisor. Ernst listened to me and helped me achieve my goals. He provided guidance in the process of constructing this thesis. Thank you Ernst.

Jim Utterback provided some suggestions and comments about my thesis which I found constructive and insightful.
# TABLE OF CONTENTS

## 1.0 ABSTRACT

## 2.0 ACKNOWLEDGMENTS

## 3.0 TABLE OF CONTENTS

## 4.0 INTRODUCTION

## 5.0 ENVIRONMENTAL MODEL

## 6.0 LOGICAL FORECASTING METHODOLOGY

   6.1 DATA TRENDS

   6.2 CAUSAL FACTORS

   6.3 ANALYSIS

   6.4 FORECAST AND ASSESSMENT

   6.5 TIME DEPENDENT AND FACTOR ANALYSIS

   6.6 FEEDBACK LOOP 1

   6.7 FEEDBACK LOOP 2

## 7.0 LOGICAL AND PHYSICAL METHODOLOGY RELATIONSHIP

## 8.0 FORECASTING METHODOLOGY

   8.1 MONITORING

   8.2 TREND ANALYSIS

   8.3 DELPHI STUDIES

   8.4 SCENARIOS

   8.5 CROSS IMPACT ANALYSIS

   8.6 MARKOV ANALYSIS

   8.7 METHODOLOGY REVIEW

## 9.0 CASE OUTLINE

   9.1 PREFACE

   9.2 CASE GOALS

   9.3 CASE INTRODUCTION

   9.4 SIMPLIFYING THE ENVIRONMENT

   9.5 USE OF FORECASTING METHODOLOGY

   9.6 KEY VARIABLES

## 10.0 CASE ANALYSIS

   10.1 MARKET DEFINITION

   10.2 USER DEFINITION

   10.3 MONITORING

   10.4 TREND ANALYSIS

   10.5 SCENARIO ANALYSIS

   10.6 CROSS IMPACT ANALYSIS

   10.7 MARKOV ANALYSIS

   10.8 METHODOLOGY REVIEW
4.0 INTRODUCTION

A problem faced by many business managers is how to allocate their resources among any number of research and development projects. An incorrect decision could put a large asset base at terrible risk. A correct decision can lead to growth and prosperity. This is especially true in technology related fields, such as the computer industry. Making strategic decisions forces business managers to try and understand a great many factors which can influence his firms competitive position.

In order to make decisions, managers need a model to simplify the environment and a forecasting tool to assist in predicting change.

The environmental model needs to simplify the decision making process by identifying factors which will have an affect on the firm or industry. I will propose and use a model of the environment that identifies a set of contributing factors and allows them to act through one of three variables: technology, the market or individuals.

The environmental model will be used to generate input to a forecasting methodology. The forecast will provide the
decision maker with a set of potential future events and their probabilities of occurrence over time.

The forecasting tool must be able to isolate affects of each of the variables and also account for the interaction among the variables. These requirements are balanced with needs of the user (manager) that the process be simple, understandable, accurate and cost effective.

This thesis presents the hypothesis that forecasting methods can be devised that will yield benefit to business managers. The strength of the proposed forecasting methodology is in its sequence, flow and combination of different forecasting tools. Output from each of the tools renders information, which when combined produce an output that yields significant insight about the future. The methodology also uses feedback loops to hone the forecast and make better predictions, which aid the decision maker.

The proposed methodology uses a model to simplify the environment and then takes the manager through a logical sequence of steps to develop a forecast. By using the forecasting methodology and his experience the manager will be able to make better decisions than if the methodology had not been employed.
The proposed forecasting process consists of five steps. The process allows managers to identify qualitative and quantitative contributing factors. These factors are then combined and a smaller set of critical driving factors are derived.

These critical factors are then used to create a set of scenarios that determine the range of potential future states or outcomes. The factors and states are then subjected to cross impact analysis to determine the interaction among them. A time dependent assessment is then performed to assess the impact of time on the individual states. The process uses feedback loops to more effectively interpret the output and identify more likely future events and states.

The final output is a set of scenarios which define the range of future outcomes. An associated set of contributing and critical factors along with their probabilities is also determined. Together these enable the decision maker to understand how technology, the market and individual factors combine to influence the future.

Success of the forecasting methodology can be judged by its ability to answer the business managers central question or concern. Another aspect is the usability of the output. Is
it in the appropriate form? Does it contain specific information that will help create strategic plans? The process must recognize and serve the needs of the user. The goal is to assist the manager in making decisions.

The thesis will present the environmental model and forecasting methodology. Next the model and methodology will be used in a case study of the computer industry.

5.0 ENVIRONMENTAL MODEL

The forecasting process employs a model to simplify the competitive environment. I will describe the environment, in which the firm operates, and its major forces. Next I will describe how the model tries to simplify the real environment.

The model was developed after careful study of the environment. The system to be modeled is open and is extremely complex. It is under constant change and is not assumed to be in equilibrium. The model will seek to simplify the interactions and focus only on the most critical aspects of the system.

At the heart of the environment is the firm. See figure 1. The firm is acted upon by a large number of independent, but
sometimes related forces. Exactly how the firm will be influenced is unknown. Each of the identified factors is individually complex: regulations are an excellent example. It is beyond the scope of this thesis to try and model the individual effects of each factor on the firm. I recognize the complexity of these factors and have classified them as acting through three variables: Technology, Individual or the Market.

![Diagram](image)

Figure 1. The environment is modeled as a system of forces that act upon the firm. Our focus places the firm at the center of the model.

Each variable is independent and represents a variety of forces. Some factors may exert a force through more than one
variable, but the model limits them to only one. Some examples are listed below.

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>MARKET</th>
<th>INDIVIDUAL</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demographic</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Economic</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Political</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Regulatory</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competition</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This matrix establishes a relationship between the larger environment in which the firm operates and the variables in the model. The purpose of the thesis is not to prove that this model is accurate, but rather to use it as a means to simplify the environment in which the firm operates.

The value of the three variables will be realized in the modeling stages of the forecasting process. Without this simplifying model the forecasting process would become unmanageable.

6.0 LOGICAL FORECASTING METHODOLOGY

As stated the goal of the forecasting methodology is to address the needs of the manager or user. Typically, a
central question or issue is identified and the model and methodology are used to provide answers or information in a usable form. The forecasting process is flexible enough so that it can be applied to different types of questions. Examples include designing company systems, competitive analysis, funding of research and development projects, investment analysis or evaluating existing strategic plans.

The methodology seeks to understand trends and causal relationships that exist between the contributing factors and the model variables. Qualitative and quantitative inputs are used to drive the model. The purpose is to balance the input and to recognize that some relationships, especially discontinuities, are not easily quantified. The methodology also tries to include the effects of interaction among the inputs (critical factors).

I will describe the methodology in two ways. First, I will describe the logical thought process upon which the physical model is based. See figure 2. Then I will describe the overall physical model, outlining its steps and basic operations.
6.1 DATA TRENDS

This stage is critical in identifying and (when possible), quantifying contributing factors. Contributing factors are those that affect the central question or issue. Special attention is applied to identify metrics that indicate the direction, speed and magnitude of future change. Point data can be used to mark milestones and track progress. Trends should indicate conditions like diminishing returns, exponential growth or saturation. With this type of
information, judgments can be made on the future significance of the specified factors.

6.2 CAUSAL FACTORS

In this stage qualitative factors and relationships are identified and are used to understand how quantitative data trends are linked to the central question. These relationships are important and are used to balance the quantitative input. Some relationships are difficult to quantify, especially secondary effects. Causal factors identify these types of relationships and allow them to be included in the analysis and assessment.

6.3 ANALYSIS

After identification of contributing factors and data collection, analysis is performed. Analysis attempts to link specific trends to the environmental model and understand their causal affects. In this stage the list of contributing factors is scrutinized and from it a list of critical factors and trends is developed. This list of critical factors is the input to the forecast and factor analysis steps. Judgment will often be required because of missing data or causal qualitative relationships. Judgment will be an important part of the forecast.
6.4 FORECAST & ASSESSMENT

In this step the critical factors are listed and estimates of their boundary conditions are made. Next, the critical factors are arrayed to create a matrix. This matrix defines a set of states which represent the intersection of these factors. The set of states combine the effects of each of the critical factors and define the range of potential futures. These states are then analyzed and their impact on the central question is assessed. In this analysis, a time frame is usually specified, for example three to five years.

6.5 TIME DEPENDENT AND FACTOR ANALYSIS

Time dependent analysis is performed on the set of states. Factor analysis determines the level of interdependence among the critical factors. These analysis reveal the probability of change, of the critical factors and states over time.

6.6 FEEDBACK LOOP 1/TIME DEPENDENT & FACTOR ANALYSIS TO FORECAST

If time dependent analysis reveals that a certain factor or state is time dependent, then this information can be used
to predict future outcomes. This then provides the forecaster with a better understanding for decision making. Factor analysis also determines probability levels for the critical factors. This information is then used to analyze the set of states.

6.7 FEEDBACK LOOP 2/FORECAST & ASSESSMENT TO ANALYSIS

At several points in the process it may become apparent that the model is neglecting a critical factor. Or a relationship has developed that was unforeseen. For example, the forecast may require a new metric to measure an emerging critical factor. These conditions would require further data collection and analysis. Therefore a feedback loop is necessary to allow the process to adjust input factors and causal relationships.

7.0 LOGICAL AND PHYSICAL MODEL RELATIONSHIP

The purpose of this section is to relate the logical thought process and the environmental model to the physical forecasting methodology. To prepare for the case study the reader must be familiar with the methodology, its steps, inputs and outputs. An understanding will be developed in this section and section 8.0.
The methodology uses the model to capture information from the environment that is related to the central question. It then filters and processes the information. The result is a set of outcomes, with probabilities, that bound the future state of the central question. See figure 3.
Figure 3. Information from the operating environment is filtered by the environmental model. Output from the environmental model is classified and used to drive the forecasting methodology.
Data Trends and Causal Factors collect information from the environment. The physical forecasting methodology uses two steps to accomplish this task: Monitoring and Trend Analysis. The purpose of these steps is to identify all contributing and critical factors.

An analysis of the trends identified in monitoring and trend analysis is conducted. The result is a set of critical factors which are used to derive the forecast.

In the forecast and assessment stage, a set of scenarios are developed. Using the critical factors identified in monitoring and trend analysis a scenario space is defined. These scenarios represent the forecast and are the main output of the forecasting methodology.

The set of scenarios may be analyzed at this point. However, more information about the scenarios is developed in the assessment and time dependent and factor analysis.

Time dependent and factor analysis consists of two steps: cross impact and Markov analysis. Time dependent analysis involves using Markov analysis to estimate change in the probabilities of the scenarios over time. The results of Markov analysis are used to understand the probability of occurrence of the scenarios. Markov results are run through
the feedback loop in the logical model, between the Forecast & Assessment and time dependent and factor analysis steps.

Cross impact analysis is used to determine the interdependence among the critical factors. Feedback from cross impact may change existing factor boundaries or identify new important factors for use in the scenario space. The effect of cross impact analysis on the scenario space is represented in the logical model by the feedback loop between the Forecast & Assessment and time dependent and factor analysis steps.

The output of the forecasting methodology is a set of critical factors and scenarios and their associated probabilities of occurrence.

The relationship among the environment, the environmental model and the forecasting methodology should be clear. Information from the environment is collected and simplified by the environmental model. Next the forecasting methodology uses the information to develop a set of scenarios which defines the range of outcomes associated with the central question.

The next section provides a more detailed review of the steps in the forecasting methodology. Each step is outlined
in detail to provide the reader with a better understanding before the case study.

8.0 FORECASTING METHODOLOGY

My hypothesis states that using the forecasting methodology will enable a manager to make better decisions. I have chosen to demonstrate the methodology using a forward looking test case, rather than test it with a historical test case. My hope is to clearly show the advantages of the methodology.

To receive full benefit from the methodology, each step must be followed. Combining the output from all the steps provides the manager with valuable insight in strategic decision making.

In this section I will describe each step in the forecasting methodology. See figure 4. The goal of the methodology is to provide information on a specific question or issue in a usable form. Each step in the methodology is necessary and plays a role in fulfilling the goal.
Figure 4. Physical Forecasting Methodology. Shows the flow, steps and feedback in the forecasting methodology.

8.1 MONITORING

Monitoring is a process of scanning a defined environment for new developments which could have an affect on a company's business. It may include qualitative and quantitative developments. For example, a supplier of RISC workstations might monitor the number of patents issued, cited or referenced that are associated with microprocessor
design or architecture. Or a firm might track research and development trends, contracts or funding by a competitor. Expert opinion may be used to understand causal relationships and technology development patterns.

Monitoring is an information gathering exercise and should be broad enough to scan distant but associated technical and marketing fields. It can serve as an early warning system to signal potentially significant new trends which could affect a firm's position. Once trends are detected they are quantified and monitored. Milestones may be established to track the progress of the trend and determine its rate of development.

Thus monitoring serves to identify as early as possible future developments. These developments are usually classified as to their potential significance to or upon the firm and monitored accordingly. The important trends are analyzed and milestones are determined to measure progress. Monitoring can be augmented with analysis of current trends to provide management with a complete environmental scan. The purpose of monitoring is to link technology, individual, and market factors to the competitive position of the firm. Monitoring can identify developing relationships that should be tracked using trend analysis.
Strengths of monitoring are evident: early warning, causal relationship identification, quantification and measurement of progress of new developments. Weaknesses include determining the appropriate environment to scan. This is particularly important because there are examples of technological development occurring outside the affected industry. Another weakness is trying to locate a metric to represent emerging developments. In addition, monitoring can lead to data overload (Porter, 1991).

Many trends develop slowly, often over a five to ten year period. Monitoring can be an effective tool in tracking these types of developments. However, discontinuities occur and are extremely difficult to identify through monitoring. Sudden popular movements, regulatory changes or natural disasters are examples.

8.2 TREND ANALYSIS

Trend Analysis uses mathematical techniques, such as regression analysis or other curve fitting techniques, to extend a data series into the future. Many types of data and metrics can be analyzed. For example, sales figures, R&D funding, number of competitors or market share.
Specific patterns of technology, market and product development and substitution have been characterized. Fisher-Pry's "S Curve" is a widely recognized technology substitution model. Dominant design, product and process innovation as defined by Utterback are other examples. However, the implicit assumptions of these models must be understood before their application.

Trend analysis is useful because it can help eliminate forecaster bias. It provides management with solid quantifiable data. It can help management understand how a technology is progressing and when it might reach a point of diminishing returns or commercial application. Trend analysis is also able to identify complementary and enabling technologies and track their progress.

Weaknesses of trend analysis include the assumption that the future will resemble the past. More significantly, one must be able to determine which trends to track, a situation that can lead to data overload. An incorrect decision could result in a firm missing an emerging technical, market or individual change. The purpose of trend analysis is to provide the firm with some measurement of how outside technology and market trends are developing and detect major pattern shifts. To do this requires that the firm correctly identify critical and related developments. The output of
trend analysis is used to develop potential future outcomes (Porter, 1991).

8.3 DELPHI STUDIES

Although not an explicit part of the methodology, Delphi studies can be used throughout the methodology. Delphi studies are a means of gathering group input without the side effects of group dynamics.

Delphi studies are used to collect opinions from a group of experts. These opinions can forecast uncertain events, identify critical factors or prioritize a list of factors.

Output from a Delphi study usually includes a median value, to the specified question, and some type of inter quartile measurement. The inter quartile measurement gives an indication of the relative level of consensus among the group of experts. The median score gives an indication of the magnitude or probability of a certain event.

For best results, a random sample of respondents is drawn from a larger group of experts. Each expert in the sample is then sent an initial questionnaire to complete. All responses are compiled anonymously. Successive questionnaires, that are the same as (or similar too) the
first are sent to the experts. They include the median response of the expert group and statements submitted or subscribed from individuals experts supporting outlying positions.

The number of questionnaires required depends on the how long it takes before the responses stabilize (remain unchanged). This iterative questioning, with feedback of the median responses, allows each respondent to individually reconsider their input. Each expert is able to read the groups median responses along with the written statements and then respond without any group dynamic side affects.

Care must be used when conducting a Delphi study. Selecting experts and choosing a random sample are very important. A large enough group must be selected to account for the minimum number of responses less any dropouts. Also, the questionnaires must be open and should not put limitations on the responses. Feedback must be unbiased (Rappa, 1993). If used carefully, Delphi studies can provide useful information.

Examples of where a Delphi study would prove useful in the methodology include: in monitoring to identify new emerging trends and in trend analysis to select and prioritize critical factors.
8.4 SCENARIOS

Scenario development is a process of developing potential future states using qualitative and quantitative factors. Scenarios may represent future states or snapshots, or a path by which to reach a desire state. The scenarios are usually constructed to address a specific concern or central question over a specified interval of time. Time intervals of two to ten years are typical.

There are two types of scenarios. First, extrapolative scenarios, focus on external forces and extend current trends into the future. The purpose is to project future developments that may enhance or jeopardize company goals.

The second, normative scenarios, depicts a desired future. This then allows management to outline key events or objectives that must be met in order to enhance the probability of achieving the desire future state (Porter, 1991).

Scenario development begins by considering as many qualitative and quantitative, technical, competitive, market, social and other factors as possible (monitoring and trend analysis). In order to be effective, scenarios must
directly involve executive management. The scenarios must also be directed at answering the central question(s) as outlined by the executives. Once all the factors have been considered and studied scenario development may proceed.

There are two different approaches to developing scenarios: plot writing and scenario space. Both methods rely on identification of critical factors and judgment of the forecasters.

There are two different methods to write plot based scenarios. The first usually identifies a base case scenario and then bounds it with optimistic and pessimistic scenarios. The idea is to create several different potential futures that can be contrasted and compared.

The second approach to writing plot based scenarios is to think creatively and imagine several different futures. Examples include devising a plot that includes a crisis or challenge to which the firm must respond. Another is to create a situation where the firm is in competition with another firm and will either win or lose the entire market. Scenarios may be based on disasters, such as a political change or technology break through. Other scenarios could be based on an evolutionary or revolutionary development trend (Schwartz, 1992). The purpose is to create different
plausible scenarios that can be contrasted and compared. Being creative allows the team to really think about the wide variance that exists among the potential future states.

The second approach to developing scenarios, is based on identifying critical driving factors and arraying them to create a scenario space (matrix). The critical factors could be derived from trend analysis or monitoring and may be either qualitative or quantitative. Each critical factor is defined and its boundary conditions estimated. Using the factors a square matrix is created that defines the scenario space. For example, if there are four critical factors (n=4) and each has two boundary conditions, then a 4x4 matrix or $2^n$ (16) scenarios will be created (Borough and Thomas, 1992).

Combining the boundary conditions of each of the critical factors creates unique potential future states. Once the states are identified they can be analyzed. The scenario space approach is not as creative as writing plot based scenarios. However, it offers a more disciplined process and a better opportunity for feedback and continuous improvement.

Once a group of scenarios has been developed, independent of the method used, they can be analyzed. Management can use
the future states to test their personal mental models of
the future. Depending on how the scenario output is
structured, they can be used to define the amount of
flexibility that must be designed into the companies
systems. The boundary conditions defined by the scenarios
can be used to evaluate a companies contingency and
strategic plans. Each scenario can be analyzed to determine
its potential affect on critical technology or market
characteristics which in turn affect the firm.

Scenarios provide other benefits. They can be used as a
communication vehicle among management and employees. They
also serve to identify the critical driving factors that
will influence a firms future competitive position. The
firms employees will become more aware of their environment
and have an increased ability to recognize significant
changes.

Scenarios may be evaluated by examining their plausibility,
consistency, validity and utility. For example, do the
scenarios address the central question or issue? Is the
range of outcomes plausible? Scenarios depend on the
experience of the manager, judgment of the forecasters and
the qualitative and quantitative factors identified in
monitoring and trend analysis. These earlier steps will have
a large impact on the value and quality of the scenarios.
Weaknesses of scenarios can be traced to the assumptions upon which they are based (critical factors). Also, they can be affected by forecaster bias. At times the scenarios may seem unconnected with reality. The purpose of scenarios is not to determine any particular future state. Rather, their purpose is to define the range and variability of the future so that a company may evaluate their plans and resources (Tenaglia and Noonan, 1992).

8.5 CROSS IMPACT ANALYSIS

Cross Impact analysis can be used to evaluate how an environment may change. Using the output from scenarios, monitoring or trend analysis, the interaction between factors and events can be modeled. Sensitivity analysis can also be performed. The evaluation is stochastic and contains uncertainty. The procedure is similar to that of creating a scenario space, except here we create an occurrence and non occurrence matrix with conditional probabilities.

Using specific critical factors or events that are believed to be interdependent, a square matrix is defined. For example, if there are four critical factors, then a 4x4 matrix is created. In this example the matrix would contain 16 conditional probabilities. Twelve of the conditional
probabilities would need to be estimated. The other four are assigned a value of one (in the occurrence matrix) or zero (in the non occurrence matrix). The form of a four event cross impact matrix is shown below.

<table>
<thead>
<tr>
<th>Probability of this event becomes</th>
<th>Given that this event has occurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event #</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>P(1</td>
</tr>
<tr>
<td>2</td>
<td>P(2</td>
</tr>
<tr>
<td>3</td>
<td>P(3</td>
</tr>
<tr>
<td>4</td>
<td>P(4</td>
</tr>
</tbody>
</table>

In this matrix the row events are referred to as event "i." The column events are called event "j." Elements P(1|2) (generically meaning P(i|j)), is read as the probability of event 1 given event 2. P(1|2) represents the probability of event 1 occurring given that event 2 has already occurred. If this was an occurrence matrix the four diagonal probabilities would all be set to one, i.e. P(4|4) is 1.

Listed below is an outline for cross impact analysis.
1. Events are defined. For example a factor may be set to one of its boundary conditions to represent an event.
2. Each event is arrayed symmetrically to create the occurrence matrix.
3. Initial marginal probabilities for each event are estimated individually. These probabilities are an estimate of event occurrence without influence from any other event.
4. An inhibiting or enhancing relationship is determined for matrix element (each event pair).
5. In the occurrence and non occurrence matrices, marginal probabilities are used to calculate the condition probability ranges.
6. Two conditional probability ranges for each event pair are calculated. The ranges are selected based on whether the conditional event is inhibited or enhanced. The forecaster does not have to assign a probability that is within the estimated range. The range calculations are shown below.

   A) If the occurrence of event \( j \) enhances (increases) the probability that event \( i \) will occur, then
   \[
   (8.1) \quad P(i)<P(i|j)<[P(i)/P(j)]
   \]

   B) If the occurrence of event \( j \) inhibits (decreases) the probability that event \( i \) will occur, then
   \[
   (8.2) \quad 1+\{[P(i)-1]/P(j)\}<P(i|j)<P(i)
   \]
C) Bayes rule establishes a relationship between the conditional probabilities above and below the diagonal in either matrix.

\( P(j|i) = \left[ \frac{P(i|j)}{P(i)} \right] P(j) \) \hspace{1cm} (8.3)

7. Using a similar approach a non occurrence matrix is constructed. A formula can be used to suggest conditional probabilities for the non occurrence matrix. Here, \( j' \), indicates that event \( j \) has not occurred.

\( P(i|j') = \left[ \frac{P(i) - P(j)P(i|j)}{1 - P(j)} \right] \) \hspace{1cm} (8.4)

8. Statistical consistency check of the matrix is made and marginal probabilities are adjusted as required.

9. Simulations are used to trigger the occurrence or non occurrence of one event. In the simulations the matrices are altered. The conditional probabilities replace the marginal probabilities as the events are selected. A Monte Carlo simulation may be used to determine the occurrence or non occurrence of the other events. The result is a set of outcomes which estimate the marginal probability of occurrence of each event based on the interaction (conditional probabilities) with the other events. See appendix 12.1, for further information.
Cross impact analysis can yield important information about the interaction between critical events or outcomes. It also requires very little input to yield usable results.

Its weaknesses include forecaster bias and the lack of a time dimension. Forecaster bias occurs because the marginal and conditional probabilities are estimated, not calculated.

Lack of a time dimension results in several assumptions. For example, no trends can be used and initial probabilities are assumed not to change. There is also no restriction on the order of event occurrence (Porter, 1991).

The purpose of cross impact analysis is to provide insight into the interdependence of the outcomes and factors. The output of cross impact can be used to interpret specific scenarios or to modify the scenario space.

8.7 MARKOV ANALYSIS

Markov analysis can be used to evaluate the change in probability and sequence of occurrence over time for an event or factor. Markov analysis allows the modeling of event to event movement or transition. In order to model change over time, events are arrayed to create a matrix. Resulting in a transitional probability matrix. For example,
if four events are used \((n=4)\), and each has two states, then a \(2^n \times 2^n\), or \(16 \times 16\) matrix is created. A total of \(16^2\), or 256 transitional probabilities would be required.

A two event Markov matrix \((n=2)\) yields a \(4 \times 4\) matrix, noted as \(p(t,1)\) is shown below. The two events combine to create four unique states. Since each event has two conditions (active and inactive), it can be represented by a binary number. A "1" indicates the event is active, a "0" indicates it is not active. Two binary bits are required to represent each state. Event 1 is represented by the first binary bit and event 2 by the second. For example, a 01, represents state number 2, where event 1 is inactive and event 2 is active. A two event matrix format is shown below.

<table>
<thead>
<tr>
<th>Markov Transition Matrix Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition from this state at time t</td>
</tr>
<tr>
<td>Binary State</td>
</tr>
<tr>
<td>State Number</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

The transitional probabilities, for each event pair, such as \(P(1:2)\), must be estimated. The probabilities have a value
between zero and one, inclusive. The transitional probability is dependent upon the current state. Thus, $P(1:2)$ represents the probability of transitioning to state 2, at time $t+1$, given that we are in state 1 at time $t$. Each row contains all possible transitions. Thus, the sum of the transitional probabilities in any row must equal 1.0.

There is a special state, named a "trapping state." A matrix may contain any number $(0, 1, 2, \ldots, n)$ of trapping states. The probability of remaining in the trapping state is 1. Conversely, the probability of transitioning to another state, from a trapping state, is zero.

A row vector, noted as $S_t$, is estimated. It contains the marginal probability of occurrence for each of the states in the current period ($t=0$).

Using matrix algebra, marginal probabilities for each event can be calculated across incremental steps in time. Markov analysis is useful because it reveals how probabilities of occurrence for the states change over time.

Calculation of marginal probabilities for future time periods is one of the most important outputs of Markov analysis. For example, a row vector containing the probabilities of occurrence of the states in period $t$, is
multiplied by the time $t$ transitional probability matrix. The result is a row vector representing the marginal probabilities of the states at time $t+1$. Notation for this operation is as follows.

1. Let $p(t,1) =$ the transitional matrix at time $t$. The 1 indicates that the matrix represents a 1 time period increment.
2. Let $s^t =$ the marginal probability row vector at time $t$.
3. Then the marginal probability row vector for time $t=t+1$

$$(s_{t+1} = s^t p(t,1))$$

In addition to calculating marginal probabilities, Markov analysis can also calculate cumulative transition probabilities. The cumulative probability, of a state, represents the probability of the state occurring over a specified number of time periods. The cumulative probabilities are obtained by multiplying transitional matrices together. See appendix 12.2 for more information.

$$p(t,n)= p(t,1)p(t+1,1)p(t+2,1)\ldots p(t+n-1,1)$$

Conversely, you can calculate the probability of no further changes or movement in the states. If desired, a calculation can be made to determine the first passage probability of a state in any given time period. These probability estimates
are useful because they indicate the time frame and sequence of state occurrence. This information can then be applied to either cross impact analysis or scenario development. For example if analysis reveals that the first passage probability of a new microprocessor architecture reaches a maximum value in three years, then this can be reflected in scenario development.

One weakness of Markov analysis is that it requires a large amount of data. Transitional matrices must be created for each time period to be analyzed. Forecaster bias is also a problem because the transitional probabilities are estimated, not calculated. However, some simplifying assumptions can be made, such as events occur only once and are not reversible, which greatly reduce the amount of data required. The purpose of Markov analysis is to provide some indication of the sequence of events, the probability of event occurrence over time and first passage estimates for an event (Porter, 1991).

8.8 METHODOLOGY REVIEW

The five steps in the methodology are each required to complete the forecast. Monitoring and trend analysis are necessary to gather information on which plausible and believable scenarios are constructed. Then cross impact and
Markov analysis, are used to evaluate the probabilities of the factors and scenarios. Thus the overall value and usefulness of the forecast depends on each step in the methodology performing its function. Deleting or reducing any step in the methodology reduces the quality of the output.

9.0 CASE OUTLINE

9.1 PREFACE

In order to show how the forecasting methodology might be used to aid in decision making, a case study will be performed. The case is used as a vehicle to demonstrate the mechanics of the methodology, its input requirements, output and potential use in decision making. The case studied involves a high degree of risk and uncertainty. The output of the case study is limited because of the uncertainty and the constraints under which I wrote this thesis. However, the output is representative of what can be accomplished using the forecasting methodology.

Judgment will be required to complete every step of the methodology and in interpreting the output. Because I made all of the judgments I am sure some readers will feel that the forecast is biased. However, I did not manipulate the
data and I avoided using my personal beliefs in the forecast.

The input requirements and mechanics will be written from the forecasters viewpoint. This will allow readers who intend to use the methodology or forecasting tools to understand the methodologies strengths and weaknesses. I assume that applications of the methodology in industry will benefit from increased resources and better and more thorough research. One example is in the use of Delphi studies. Industrial applications of the methodology would employ real expert opinion to determine critical factors. In this case I have combined the judgments of some fellow students and friends to produce a "self Delphi." I recognize the limitations that this puts on the output of the methodology.

As part of the conclusion, I will offer a decision makers viewpoint in analyzing the output of the methodology. This will help forecasters and decision makers understand how the output might be changed or structured to suit a specific need or user.

Another limitation on this analysis was my inability to involve or meet with the user of the forecast. Meeting with the user, while preparing the forecast, allows for an
exchange of information that will lead to a more believable and usable forecast. It is recommended that the user be involved in all stages of the forecast.

9.2 CASE GOALS

The goals of the forecast are listed below, in order of importance.

1. Provide information or an answer, in a language usable by the decision maker, to the central question or issue.
2. Provide an estimate of the range of potential future states of the central question or critical factors.
3. Provide an estimate of the correlation or interdependence among the critical factors, potential futures or events.
4. Provide some indication of how the probability of occurrence of the critical factors, potential futures or events may change over time.

9.3 CASE INTRODUCTION

The case provides information and a forecast around the central question, "What is the Future of the Desktop Computing Industry?" This analysis will set a time frame of 3 years into the future. So the question could also be stated as, "What Type of Desktop Computing Industry Will
Exist in 1996?" As will be seen in the case, may variations of this question are possible.

The case will identify contributing and critical factors surrounding desktop computing. It will provide some indication of the range of potential future events, factors and states. In the analysis, some of the trends and their effects will be clearly defined. Others will be less clear and will require the use of judgment and related experience.

9.4 SIMPLIFYING THE ENVIRONMENT

As outlined in Chapter 5, the environment must be simplified using a model. Through research that I have done, contributing factors have been identified which will be classified as acting through one of the three model variables: Market, Technology or the Individual. Identifying these variables as the main forces upon the firm will allow the quick identification of the most critical factors.

As we begin the forecast we have a broadly defined central question. In the analysis however, we will begin to narrow our focus and study only one or two aspects of the individual computing industry. This is an area where input from the user would be very helpful.
The methodology is open to input concerning emerging markets, such as Pen Computing or Personal Data Assistants. It can also include the convergence of industries, such as the phone, computer and fax. There is certainly opportunity to include changes in laws or regulations, such as taxes or FCC guidelines. These are some of the many factors which can and do influence the individual computing market.

9.5 USE OF THE METHODOLOGY

The methodology will be followed and explained. Output can be taken from several points within the methodology. It is my hypothesis that a combination of information, from all the steps, will provide the decision maker with a an information set that is greater than the sum of its parts. Therefore, I will stress the importance of utilizing the complete methodology.

9.6 KEY VARIABLES

As previously defined in my model of the environment, there are three independent variables. They are listed below with a brief description.

1. MARKET - includes supply and demand, price, economy, industry structure, R&D spending and other factors.
2. TECHNOLOGY - includes hardware and software, size, portability, applications, interoperability and other factors.
3. INDIVIDUAL - includes personal income and spending, user knowledge, user acceptance, current and latent user needs and other factors.

In Chapter 5, I outlined how the larger environment acted on the firm through these three variables. In this case the variables are used to classify the important factors and understand how they exert influence on the central question.

10.0 CASE ANALYSIS

10.1 MARKET DEFINITION

The central question uses the term "desktop computing." I will now define the market, related to this term, which will be analyzed.

We are interested in single user machines, costing less than $7,500. Our study is independent of hardware or software technology. In fact we expect to analyze how different technologies compete in this market. This analysis does not assume that the computer is connected to a LAN or other type of network. Additionally, this analysis is independent of
physical size, it includes laptops, deskside, desktop and portables computers that maybe used by an individual.

Here again, user input could be used to narrow the focus of the forecast. If the user has a specific interest in a technology or other computer attribute the forecast could emphasize it.

The case will focus on the battle between the makers of Personal Computers and Workstations. A similar focus will also be placed on the different software environments within these two platforms (DOS and UNIX). As PC's become more powerful and workstations decline in price, users are faced with new and complex purchasing decisions.

10.2 USER DEFINITION

This study focuses on business computer users. The individual, in our central question is understood to have a business computing need. The forecast recognizes current user needs and is open to the idea of latent and future needs. It does not assume a specific business user need.

10.3 MONITORING
To begin our analysis we start by monitoring the environment for emerging trends that could eventually affect the industry. Research and Delphi Studies are two methods to gather this type of information.

Monitoring differs from trend analysis because monitoring typically looks at factors and relationships that are not yet affecting the firm. We are interested in monitoring factors that help answer the central question. Therefore, it is useful to understand how the data gathered in monitoring will be used in developing scenarios, cross impact and Markov analysis. Each of the factors identified in monitoring or trend analysis will be classified as either contributing or critical. Critical factors will be used to drive the forecast.

Using the Market, Technology and Individual as categories, I have listed some of the trends that could be identified in monitoring. This list represents a first pass at identifying appropriate trends. Further study of each individual trend or relationship is required to determine if it needs to be monitored or studied in trend analysis.


<table>
<thead>
<tr>
<th>Market</th>
<th>Technology</th>
<th>Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convergence of Telecommunications</td>
<td>Optical and Molecular Processors</td>
<td>Number of Advanced Technical Degrees</td>
</tr>
<tr>
<td>and Computers</td>
<td>Portable Devices</td>
<td>Earned</td>
</tr>
<tr>
<td>R&amp;D Funding</td>
<td>Silicon Line Widths</td>
<td>Spending Levels</td>
</tr>
<tr>
<td>Market Saturation</td>
<td>Distributed Computing</td>
<td>Growing Leisure</td>
</tr>
<tr>
<td>Company Agreements</td>
<td>Massively Parallel Computing</td>
<td>Needs</td>
</tr>
<tr>
<td>New Market Demand (China)</td>
<td>Computer - Human Interface</td>
<td>Ability and willingness of individuals to use computers</td>
</tr>
</tbody>
</table>

In order to give the reader an understanding of what type of factors could be identified by monitoring, I will describe a few of the items listed above.

Ability and Willingness of Individuals to Use Computers:
One might believe that there is a causal relationship between the willingness and ability of individuals to operate and accept computers and the ultimate market demand for computers. If a relationship can be established that connects some attribute or individual characteristic to the ability or willingness to use computers, then this attribute may be tracked as a proxy to latent market demand.
Monitoring can be used to identify a long term relationship between market demand and computer users. The problem is how to identify, quantify and track this qualitative relationship.
One attribute of individuals that might influence their ability to use computers is their computer knowledge or training. One might then decide to study school age children to determine their computer knowledge. The forecaster may hypothesize that students will have different levels of ability and willingness to use computers that is dependent upon their computer knowledge. How can computer knowledge of the students be measured?

Statistics are available on the computer knowledge of school age children. Studies conducted by the National Assessment of Education, have measured the computer competence of third, seventh and eleventh graders. Highlights of the study are listed below (Martinez, 1988).

1. Most Students like using computers and want greater access to them.
2. Males, in general, demonstrate a slightly higher level of computer competence than females.
3. Students in general had trouble answering questions on the assessment, especially questions about computer applications and programming.
4. The experiences of having used a computer, of studying computers in school, and of having access to a computer at home are positively related to computer competence.
This type of information can be used to develop an understanding of the next generation of computer users. It indicates that computers are generally accepted, but that the students have difficulty with applications and programming. This suggests that making computers easier to use will boost their acceptance among future users. Alternatively, educational programs aimed at removing the difficulty that students have may increase their computer knowledge.

The emergence of technology can be studied in the monitoring phase. An effort is made to identify and track factors that could affect technology. One factor that could be identified to influence the growth in computer technology, is the number of advanced technical collegiate degrees earned. The premise of this relationship is that technical advances are typically made by technical entrepreneurs working in their related fields. Thus the trend in the number of scientific or computer science degrees could be used as a leading indicator of future technical growth. See figures 5 and 6, which show the year to year trend in the number of Bachelor, Masters and Doctorate degree earned in technical areas (U.S. Bureau of the Census, 1991).
Figure 5. Number of Engineering and technology degrees earned in the United States, over a 28 year period.

Figure 6. Number of Computer Science degrees earned in the United States, over a 28 year period.
The data indicate a downward trend in the number of engineering and technology degrees and in the number of Computer and Information Science degrees earned. This clearly shows that the supply of engineers and programmers, with Bachelor degrees, is declining. The data also show that the number of Masters and Doctorate degrees are constant or increasing slightly. In order to assess the impact of these trends it is necessary to fully understand the demand for these skills relative to the decreasing supply. We are trying to link quantitative data to the central question.

Unfortunately, I was not able to identify a good metric to gauge the demand for these skills. However, it appears that the demand for these skills is decreasing as evidenced by the recent layoffs and downsizing by Defense and Computer industry companies (IBM, DEC, WANG). Therefore, the impact of the decline in the number of Bachelor degrees earned may not have a large impact on the growth in computer technology.

Monitoring can also be used to study market changes and allow a firm to position itself for pending change. There is a continuing trend of companies entering into agreements with other companies: alliances, joint ventures and mergers are examples. Two recent agreements include the joint
venture between IBM, Apple and Motorola to design, build and sell a RISC based microprocessor. This alliance represents an agreement between former competitors and is typical of other agreements.

Another agreement has, Hewlett-Packard, Novell, IBM, Sun and Santa Cruz Operation agreeing to build a common UNIX software interface. The software interface will allow applications to be executed on different platforms (hardware and software), but still have the same user interface. Sun, Hewlett Packard and IBM are three of the top four worldwide suppliers of workstations.

Another example is DEC's recent announcement that its new ALPHA processor products will support Microsoft's NT. This has created two distinct camps which both hope to "set the standard."

These alliances are meant to facilitate the push of RISC workstations into the desktop computing market. Software has been a barrier to entry of RISC workstations, into the commercial market. Specifically, the lack of applications and "usable" operating systems. Agreement on a standard interface will help speed the development of software applications for the RISC based computers. This should
reduce the barrier to entry that workstation face in the commercial desktop market.

These cooperative agreements allow alliances to build on the strengths of each of the participants. The microprocessor agreement can be seen as a challenge to the near monopoly held by Intel. The software agreement can be seen as a challenge to the near monopoly in software held by Microsoft.

The trend to recognize is when one firm has a dominant position in a market, their smaller competitors will tend to ally themselves to gain strength and challenge the larger competitors market share. The competitive challenge seems to be based on the attitude, "get the leader." Another analogy is the use of "wolf pack tactics" to attack the leader. This opens up a new era in defender and attacker strategies and tactics.

These agreements will change the competitive structure of the desktop computing industry. A firm is no longer sure of its competitors or allies. Some of the agreements may also confuse customers. Customers are no longer sure of their suppliers.
Another area that has a definite causal affect on market and technology growth is Research and Development (R&D) funding. There are two sources of R&D funding in the United States: private industry and the government. Funding in the US is equally divided between these two sources. However in Japan private industry contributes about 80% and in Germany about 70% of total R&D funds (Agence France Presse, 1993).

R&D funding by the United States government is under revision and will most likely decrease as the government struggles to balance its budget. As government funding decreases, private industry will need to increase funding to maintain current R&D levels. See figure 7, for historical Federal R&D spending levels in technical areas (U.S. Bureau of the Census, 1991).
Figure 7. Federal Research and Development funding in the United States, in constant 1982 dollars. Two categories of funding, Engineering, and Math and Computer Science.

R&D alliances can be seen as a response to the change in industry profits, cost of technology development and technology risks. For example the cost to develop and implement a higher density Dynamic Random Access Memory (DRAM) is so large that a single firm is no longer capable of accomplishing this task without assistance. IBM, Siemans and Toshiba have agreed to share technology and cost in the development of the next generation of DRAM's.

As profits are reduced, firms have looked to outside sources for basic research and have focused their internal R&D efforts toward products. There is a growing tendency for
firms to jointly fund university and other external basic research activities. This represents a major shift in R&D practice which will have an affect on the market. Sharing basic research will allow more companies to exploit breakthroughs and could result in new technologies reaching the market faster.

In the computer industry hardware and software companies both fund R&D. However the current hardware price war has eroded the profit of many of the large hardware suppliers: IBM, DEC and Compaq are examples. This has reduced their ability to fund R&D. Meanwhile some of the software companies continue to make large profits which enable them to continuing funding R&D.

What long term affect will decreased hardware and increased software R&D spending (relatively speaking) have on the computer industry? Monitoring can help answer this question. Specific metrics can be developed to track R&D. For example, the number of patent applications and patent awards. Consortium funding, here Semitech is an example. One might expect that the rate of improvement in hardware advance will slow (in spite of Semitech) while the rate of advances in software will increase, in the long term. This relationship is very judgmental. An analysis of the metrics would reveal the true R&D spending levels and its potential affect.
To monitor technology, a firm could scan the environment for new and related areas of research or product development. One emerging new technology and product set is that based on Massively Parallel Processing (MPP). MPP is usually considered a technology that is applied to large super computers. However, in the process of monitoring the environment, the potential affect of MPP on desktop computing must be considered. It is true that MPP is a small, but growing niche market. Sales in 1990 were about $110 million and are estimated to grow to about $750 million in 1995 (Data Analysis Group, 1992). The technology is progressing at a rate determined by software and software tool development. What might happen if a break through in MPP software is achieved? Could this technology be applied to desktop computers? Can multiple inexpensive processors out price perform a more expensive single processor in a desktop package?

Monitoring could identify MPP as a critical technology. A company would then want to establish milestones and therefore be able to track MPP's progress. For example, setting a milestone of sales of $1.5 billion. This could represent the threshold at which major software application suppliers would be compelled to port their products to an MPP platform. A similar milestone could be determined for
software tool or operating system development. The goal would be to detect the pending development of a sufficient base for applying MPP to the desktop computer market.

These examples show that monitoring is used to scan the environment and detect factors that have the potential to affect a firm's future products or technologies. Some of the relationships are qualitative and require judgment and experience. More effort may be required to demonstrate causality.

Monitoring can reduce uncertainty and at the same time create uncertainty. Agreements between competitors to develop products or share R&D will certainly affect the market. Will the affect be positive for the firms? Will consumers benefit? Monitoring does not answer these questions. These questions are better answered in scenario or cross impact analysis.

10.4 TREND ANALYSIS

Trend analysis provides a method to study individual qualitative and quantitative trends and events that affect the desktop computer market. These trends and events can be identified by monitoring (as explained above) or through analysis of current environment trends. Trend analysis is
typically used to track known factors or relationships.
Quantitative data trends are extended into the future. Thus, trend analysis is more quantitative than monitoring.

The approach here is to identify as many factors as possible that affect the desktop computing market. Then using a judgmental technique (Delphi) identify four or five critical factors that will most likely influence the course of individual or desktop computing. These factors are then studied further in scenario, cross impact and Markov analysis. Given my time and resource constraints, I developed an abbreviated list of factors from which four will be identified as critical.

One method to identify and prioritize developing trends, that can affect the desktop market, is to use a Delphi study. In the Delphi study, a group of recognized experts will be identified and then asked a series of questions. The experts could identify the different trends that might have a potential impact on the desktop market. The Delphi study would allow the experts to prioritize the trends.

A self Delphi study was done to identify current trends that have an affect on the desktop market. The current trends are listed below using the three variables (Market, Technology,
and Individual) to classify the trends. The list is not exhaustive.

<table>
<thead>
<tr>
<th>Market</th>
<th>Technology</th>
<th>Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Supply and Demand</td>
<td>* Interoperability</td>
<td>* Spending/Income</td>
</tr>
<tr>
<td>* Open Systems</td>
<td>* Software Technology</td>
<td>* Home Use</td>
</tr>
<tr>
<td>* Hardware Price</td>
<td>* Computer</td>
<td>* Computer</td>
</tr>
<tr>
<td>Trends</td>
<td>Architecture</td>
<td>Literacy</td>
</tr>
<tr>
<td>* Industry</td>
<td>* Client/Server</td>
<td>* Latent Needs</td>
</tr>
<tr>
<td>Cooperation</td>
<td>Networks</td>
<td>* Leisure</td>
</tr>
<tr>
<td>* Industry Profits</td>
<td>* Size/Portability</td>
<td></td>
</tr>
<tr>
<td>* Computer Sales</td>
<td>* RISC Performance</td>
<td></td>
</tr>
<tr>
<td>* Standardization</td>
<td>* Operating Systems</td>
<td></td>
</tr>
<tr>
<td>* Economy</td>
<td>* Application</td>
<td></td>
</tr>
<tr>
<td>* Computer Services</td>
<td>Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Multi Media</td>
<td></td>
</tr>
</tbody>
</table>

There are many other factors and trends which can be identified that will impact the desktop computer industry. The purpose here was to develop a list of factors that are recognizable and important. Analyzing these factors will demonstrate the methodology. The result will be the identification of critical factors. What is important is to understand how these factors may be identified, analyzed and then used in the methodology.

The next step in trend analysis is to analyze all the factors and then selected four or five to be used to develop our scenario space. Therefore, as we proceed with trend
analysis we are thinking about the development of a scenario space.

To understand market trends, we can analyze sales trends in the desktop market. There are two competing hardware technologies in the desktop market: Complex Instruction Set Computing (CISC) and Reduced Instruction Set Computing (RISC). CISC is the dominant technology and is in a defenders role. RISC is an emerging technology and is attacking CISC in the desktop market. The desktop computing market has been and will continue to be affected by the competition between these two technologies.

In this analysis, CISC machines are based on Intel processors (80XXX) and are generally IBM or EISA compatible. There are many suppliers of these machines; Compaq, IBM, Dell, etc. RISC machines in this market are generally low end workstations supplied by Sun Microsystems, Hewlett Packard, Digital Equipment, or IBM.

Using the Fisher-Pry "S Curve" function, I have plotted the sales of personal computers (CISC machines) and workstations (RISC machines). See figures 8 and 9 (Predicasts' BASEBOOK, 1992). Although actual PC sales flattened out in 1989, S curves analysis estimates that sales of personal computers will continue to grow at a rapid pace. I was not able to get
Personal Computer Units Shipped

Figure 8

Units Shipped (Millions)

Year

Actual

Projection
Workstation Units Shipped

Figure 9

Units Shipped x1000

Year

--- Actual
--- Projection
sales figures for 1991 or 1992, but I expect that sales have increased significantly. However, the S Curve function has a basic assumption which must be examined.

S Curves assume that the a new technology is emerging in an established mature market. The S Curve shows how the new technology grows and becomes a complete substitute for the existing technology. Let \( f \) be the fraction of the market obtained by the new technology. The form of the Fisher-Pry equation and its parameters are shown below (Porter, 1991).

\[
(10.1) \quad f = \frac{1}{[1 + ce(-bt)]} \quad \text{or} \quad z = \ln[(1-f)/f] = \ln(c) - bt
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PC S Curve</th>
<th>WS S Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L )</td>
<td>( 15000 \times 10^6 ) Units</td>
<td>( 1200 \times 10^3 ) Units</td>
</tr>
<tr>
<td>( c )</td>
<td>( 2.3297 \times 10^{259} )</td>
<td>( 2.2058 \times 10^{299} )</td>
</tr>
<tr>
<td>( b )</td>
<td>0.3007</td>
<td>0.34546</td>
</tr>
</tbody>
</table>

Alternatively, \( f = Y/L \), where \( L \) is the upper bound of growth and \( Y \) is the total market; \( b \) and \( c \) are curve fitting parameters which must be determined analytically.

Growth of the new technology (PC's) is dependent upon the fraction of the market penetrated \( (f) \) and the fraction that remains to be penetrated \( (1-f) \). In the case of personal computers, decentralized computing is a growing substitute for centralized computing. Therefore, the attached S Curve estimates how PC sales would grow without competition or
other external influences. Unfortunately this is not a likely scenario because RISC technology is challenging PC's.

Figure 9, shows how workstations sales would grow as a complete substitute for the existing technology. We are using these S Curves to try and understand how PC's and workstations will "battle" each other in the desktop computing market. S Curves are a weak indicator of how two competing technologies will gain market share. Both S Curves suggest significant growth, which is not likely to happen. What the curves provide is an indication of the magnitude of growth of distributed computing. Should one technology eliminate the other, tremendous growth will result.

One result of the competition between these two technologies has been a continuing decrease in hardware prices. As PC's and workstations compete for market share, each will continue to improve its price performance.

As RISC technology attacks CISC, several defensive strategies are possible. CISC can try and improve its performance and defend its market share. Or the CISC suppliers can adopt RISC technology. This is in fact what has happened. The new Intel 80586, is a RISC based CISC processor. This signals that RISC has become the new dominant technology. The impact on the industry, of this
change by Intel, is uncertain. It does signal that the price and performance battle among microprocessor suppliers will continue. It will also decrease the performance advantage the suppliers of RISC microprocessors (DEC, MIPS, IBM, HP) have over Intel.

As RISC workstation suppliers have developed and released low priced products, PC producers have responded with aggressive price cuts. Figure 10 shows the cost of PC computing over time (Manasian, 1993). Now that Intel has incorporated RISC technology into their processors, price competition will intensify. We are likely to see a shift (increasingly negative) in the slope of the price performance curve.

Cost of PC MIPS

![Graph showing the cost of PC MIPS from 1987 to 1993](image)

Figure 10. PC performance is measured in Millions of Instructions per Second (MIPS) per dollar. The price of a PC MIP is declining by over 30% per year.
As mentioned earlier, we are searching for trends upon which we can build a scenario space. We must find a way to include the contributing factors into the scenario space.

Because of the difficulty in interpreting the S Curves, I have chosen not to use them directly in the scenario analysis. However, the competition between these two technologies will drive price competition. Therefore, hardware price trend will be a critical factor in the future of desktop computing. It will be included as one of the critical factors in developing the scenario space.

Another important market factor is the level of profits within the computer industry. See figure 11 (Manasian, 1993). These profits are an aggregation of computer companies.
Figure 11. Profits as a percentage of sales for 1992 computer companies. Declining profits are a result of the continued hardware price war.

The trend in profits is clear. However, the level of profits in 1990 and 1991, may have been affected by one time losses. For example, IBM, DEC and Wang took large write-offs during those years. Those write-offs were not due to operating results, but were attributed to restructuring activity.

The write-offs tend to demonstrate that there is a dichotomy between the hardware and software suppliers. The hardware price war, combined with the high cost of advancing technology, has significantly reduced profits of hardware suppliers. At the same time several software companies are
recording excellent profits; Microsoft and Novell are examples. This uneven distribution of profits will have an eventual affect on the level of Research and Development (R&D) spending by computer firms.

The link between R&D spending and profits is not exact. Revenue for the software suppliers grew at 22% in 1991. Software firms have been slowly decreasing their R&D spending as a percentage of revenue. Below is a table that shows the percentage and current R&D dollar spending by software companies (Hodges and Melewski, 1992).

<table>
<thead>
<tr>
<th>Year</th>
<th>Revenue $ billion</th>
<th>Percentage of R&amp;D to Sales</th>
<th>R&amp;D Spending $ billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td></td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>$ 11.3</td>
<td>18%</td>
<td>$ 2.03</td>
</tr>
<tr>
<td>1991</td>
<td>$ 13.9</td>
<td>17%</td>
<td>$ 2.36</td>
</tr>
</tbody>
</table>

The level of profits in the industry will eventually affect the rate of entry of new competitors into the industry. This will in turn affect the rate of new product introduction. It is not clear how the hardware suppliers will fund their future R&D, in light of their decreasing profits. The affect of decreased R&D spending will not be felt for several years. Despite this uncertainty, the profit level of the industry is a critical factor and will be included in the scenario space.
Evaluating the factors related to the individual focuses on user acceptance. User acceptance of new technology can be linked qualitatively to several factors. Including, user income, latent needs, computer competence and knowledge. The growth of the computer industry has been based on its ability to convince individuals and businesses to spend money on new hardware and software. How long can the computer industry continue to gain a growing share of business and personal income? See figure 12, which shows that spending on computer hardware, software and service per capita has flattened out and is trending down (Manasian, 1993). This downward trend can be attributed to several factors.
Figure 12. Total spending on hardware and software products per white collar worker. Spending in all geographic regions has converged.

First, the cost per person, of a desktop computer is decreasing. Second, parts of the market are becoming saturated. Many schools and businesses have purchased and installed computers, thus reducing demand. Markets that were once growth opportunities are now classified as replacement driven.

These two factors are somewhat offsetting. The market is saturated, but the price of a computer is falling. Combining these two factors results in a qualitative factor that I term "user acceptance." Growth in the desktop market will be
driven by the rate of new product introductions and the level of user acceptance of new and existing products.

User acceptance is a qualitative factor. It combines business income and spending, new product introductions, price performance, latent needs and other factors. User acceptance is a macro level factor that will be included in the scenario space. Its purpose is to represent the rate at which new desktop computer products are accepted (purchased) by users.

In the technology area there are several factors that will have a large impact on the desktop computer market. We have already discussed computer architecture, in the battle between CISC and RISC technologies. Another emerging technology trend is the use of client/server networking. This is a complementary technology that is aiding the move away from centralized computing toward distributed computing. Processor architecture and client/server technologies will have a large impact on the desktop computing market, but are not critical factors. They both provide support for improving price performance which has had a tremendous impact on the desktop computing market.

Operating system development, marketing and market share have impacted the desktop computing market. There are
several current competing operating systems: MS-DOS, Windows, O/S 2, Apple's System 7, Uniware and several UNIX variants. Others are planned for release in the future: NT, Taligent and PowerOpen are examples.

The same situation exists in the networking environment. There are several competing networking schemes: Banyan, Microsoft and Novell are examples. This competition extends into the application arena also: word processors, spreadsheets, etc. The point is that a user is forced to make a purchase decision that is complicated by the lack of transferability of software.

Because of the incompatibility of software, on several levels, system performance is limited. Users are forced to simultaneously consider hardware and software in their purchase decisions. Once a platform is selected, switching costs increase because the user is unable to easily transfer their skills, hardware and software to another system.

What is desirable from a users standpoint is a high level of interoperability. Interoperability can exist at several levels.

1. APPLICATIONS - ability to execute an application on different software and hardware platforms. An example is the
difference between MAC and DOS applications. One version of WordPerfect should be executable on either platform.

2. LAN COMMUNICATIONS - there are three main competing LAN products. Although a standard might solve the problem, the user should be able to inter-operate across these different systems.

3. USER INTERFACES - different user interfaces exist for the same application when executed on different platforms. Application operation on UNIX variants is an excellent example.

4. OPERATING SYSTEMS - there is tremendous differentiation between competing operating systems. Standard emulation modes or interfaces, while slow, could allow users to access data and programs independent of the operating system.

Thus the four factors that we will use to create our scenario space is interoperability. It represents the level of independence among the application, operating system, LAN and hardware platform. This is a qualitative factor for which I could not develop a good metric. However, a high level of interoperability at any or all levels, would bring about significant change to the desktop industry: users, hardware and software suppliers. Interoperability can enlarge the market for a product and is desirable by the supplier and customer. It will lower the switching costs for
users. Further, interoperability will separate hardware and software purchase decisions.

At this point we have identified four different factors to use in the development of our scenario space. Two are quantitative: hardware price trends and industry profits. Two are more qualitative: user acceptance and interoperability.

Before we move forward in the methodology we need to pause and review what we have accomplished. We monitored our environment for emerging trends and relationships which could have a future affect on the desktop computing market. We developed a list of items and then discussed some qualitative relationships that linked the factors to the demand for desktop computers. The line between these factors and the market was sometimes weak and required the use of judgment.

Trend analysis offered us the opportunity to explore some current trends and to discuss the market and its major competitors. Conducting a Delphi study is recommended, but was not done because of time and resource constraints. Our process in trend analysis was similar to monitoring, but relied on relationships that are better defined and measurable.
Trend analysis started with a list of current trends and events. We then analyzed some of the trends and using qualitative judgment and quantitative analysis identified four critical factors. These critical factors will now be used to create a scenario space. The scenario space will define the range of future states of desktop computing. The interpretation of the different futures will be enhanced by the data that was gathered and analyzed in monitoring and trend analysis.

10.5 SCENARIO ANALYSIS

Constructing the scenario space is not difficult once the critical factors have been determined. We will create scenarios which are potential futures of the desktop computing market. They are unique combinations of different states of the four critical factors. Our scenario space will cover a three year time period.

Each of the scenarios will be examined and given an appropriate name. We are not trying to pick one of the scenarios as most likely. Instead we are developing a set to determine the range of future outcomes in the desktop computing market. It is possible that some of the scenarios created will be improbable or simply not feasible.
The scenario space resembles a binary table. Zeros and ones can be used to represent the state of the critical factors in each of the scenarios. In this case we have defined four critical factors \( n=4 \). Therefore our scenario space will include \( 2^n \) or 16 individual and unique scenarios. To create the 16 scenarios each critical factor will assume one of two possible states in each scenario. The critical factors and their two states are listed below.

1. HARDWARE PRICE TRENDS - this factor is the result of continued competition in the desktop computing market. Its two states represent the following.

   A.) Flat trend (LOW) - price performance is stable, premium pricing exists, while discounting may exist steep discounts are not common.

   B.) Steeply decreasing trend (HIGH) - price performance is increasing at about 30% per year, premium prices are rare, steep discounts are common.

2. INDUSTRY PROFITS - this factor represents the combined profits of hardware and software suppliers. Its two states represent the following.

   A.) Low Profitability - industry profit levels are below the return of the S&P 500 and can be negative. The market outperforms the industry.
B.) High Profitability - industry profit levels are above the S&P 500.

3. USER ACCEPTANCE - this factor represents the overall market demand for new and existing products. It represents total spending levels in the desktop business computing market. Its two states represent the following.

A.) Low Acceptance - users are not inclined to spend money for new and improved products. Deep price cuts and performance enhancements do not greatly increase sales.

B.) High Acceptance - users accept new products. Users pay a premium for new and improved products. Deep price cuts are not necessary to increase sales.

4. INTEROPERABILITY - this factor represents the general ability to compute, independent of the application, operating system, hardware, LAN and user interface. Its two states represent the following.

A.) Low Interoperability - very little ability to run the same application on different platforms. Large hardware and software product differences exist, no single standard is set or agreed upon.

B.) High Interoperability - high ability to run the same application on different platforms. Seamless computing within the hardware, LAN, operating system and application. Standards set and followed. High industry cooperation.
Developing the scenario space requires that we draw a matrix and assign the states of the factors. Each scenario is then given a name and analyzed. In the matrix a "1" represents the state of the critical factor, a " " blank space indicates that the state is not active. Some abbreviations are used: HW is hardware, SW is software, Mkt is market, Ind is industry.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Hardware Price Trend</th>
<th>Industry Profits</th>
<th>User Acceptance</th>
<th>Interoperability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flat</td>
<td>Steep</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1 Mkt Stagnation</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2 HW Prices Stable</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3 Niche Markets</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4 SW Delight</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5 Market Pull</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6 Unstable Profits</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7 Rich Niches</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8 Ind Cooperation</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9 HW Death</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10 Mkt Shakeout</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11 Cheap Hardware</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12 Shoppers Delight</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13 SW Profits</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14 Technology Push</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15 Industry Thrives</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>16 Ind &amp; User Gain</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

One must first realize the wide variance between scenarios number 1 and 16. The range of outcomes stretch from stagnation to industry and users gain. This wide range of
outcomes demonstrates the variability of potential futures states. The scenario space forces the decision maker to consider this variability in his plans.

In order to fully analyze the scenario space, each scenario must be reviewed to ensure that it is plausible and believable. Those scenarios that do not meet this criteria are discarded. Those that do meet the criteria are reviewed so the manager can understand what must occur in order to bring the potential scenario to fruition. We will analyze a few of the more interesting scenarios to provide the reader with an understand of how to interpret the scenario space.

In reviewing the scenario space I identified four scenarios that are not very plausible. These scenarios could be discarded from further analysis. They are listed below with a short reason for their lack of plausibility.

1. Scenario 3: Niche Mkts. High user acceptance without interoperability or increasing hardware price performance is improbable.
2. Scenario 5: Market Pull. High industry profits without user acceptance and interoperability is unlikely.
3. Scenario 13: SW Profits. Increasing hardware price performance trend (price war), low interoperability and low
user acceptance are unlikely to generate high industry profits.

4. Scenario 14: Technology Push. High industry profits, high interoperability and increasing price performance without user acceptance is an unlikely scenario.

Assigning names to the scenarios allows the user to provoke an image in the reader's mind. For example, the last scenario is named, "Industry and Users Gain." Under what conditions could this occur? The matrix provides the answer.

In the last scenario, the following conditions exist:
1. Hardware price performance trend is steeply increasing, (this means that the cost of a PC MIP is decreasing).
2. Industry profits are high.
3. User acceptance is high.
4. Interoperability is high.

These conditions combine and allow the desktop computing industry to grow. Increasing hardware price performance, high user acceptance, high industry profits and high interoperability represent near utopia. If a manager decided that he wanted to enhance the probability of this outcome, then he would need to understand what factors support the required states of the four critical factors. Then try and
manage his resources to obtain the desired states of the critical factors.

The first scenario named, "Market Stagnation," has the opposite effect of the last scenario. In it the following conditions exist.
1. Hardware price performance trend is flat.
2. Industry profits are low.
3. User acceptance is low.
4. Interoperability is low.

These conditions could be brought about by a decrease in hardware R&D spending. Which could result in slower technology improvements and fewer new products. Fewer new products leads to stabilizing prices and an end to the hardware price war. However, user acceptance is low, possibly due to the economy, higher prices and low interoperability. This causes profits in the industries to decline. In this scenario there would probably be some niche suppliers due to the lack of interoperability and price stability. Again, the manager would need to consider the factors that would support the critical factors necessary to produce or avoid this scenario.

A manager could use these scenarios to evaluate the affect on his firm. This would require the manager to link the
firms critical variables to each scenarios. What values might the firms variable take? How large is the variance? Which variables are most sensitive? Answers to these questions can provide insight and result in a more robust strategic plan.

A scenario that I believe describes today's desktop market is "Cheap Hardware." It is characterized by the following conditions.
1. Hardware price performance trend is steeply increasing, (continuing price war).
2. Industry profits are low.
3. User acceptance is high.
4. Interoperability is low.

If you agree that this describes today's market, then the question to ask is, where will the industry go next? What is the most likely next state to be entered? This type of question can be answered using Markov analysis.

However, by reviewing the scenario space, it is worrisome to realize that "Hardware Death," differs from "Cheap Hardware," by only the state of user acceptance. If user acceptance changes from high to low, and the other factors do not change, then the industry could enter the "Hardware Death" scenario. Markov analysis will provide some insight
into the probability of transition from "Cheap Hardware" to any of the other scenarios.

As we have seen there are several ways to view the scenario space. A manager can identify a scenario that is favorable and then try and influence the critical factors to achieve the desired outcome. In another use we have identified a scenario that describes today's market. Using it as a base we can analyze what other states are likely to be achieved next.

A third use of the scenario space is to construct or evaluate a strategic plan. The ability to do this could be a user requirement. This type of analysis allows the firms strategic plan to be tested by a number of diverse yet potential future states. The company will be able to assess the strategic plans flexibility and ability to maintain company performance in different scenarios. This analysis is useful because it can expose flaws or invalid assumptions that are included in the firms strategic plan.

In this example we have constructed a scenario space to address the central question, "What is the future of desktop computing industry?" The reader should realize that a different scenario space could easily be constructed to answer other questions. For example, we could analyze the
potential future competitive positions of the current market share leaders; Intel, Microsoft, Apple, or others. This could provide a mechanism for understanding what events or trends would support the rise or fall of a competitor.

The scenario space is the central component in the forecasting methodology. Scenarios provide a systematic method of analyzing the future. A decision maker can use the scenario space to aid in strategic and tactical planning and goal setting. Scenarios are also an excellent communication vehicle.

I have shown that there are several approaches to analyzing the scenario space. They are summarized below.

1. Discard scenarios that are not plausible.
2. Select desired or undesired scenarios and manage resources to enhance or inhibit scenario probability.
3. Select a scenario that describes today's environment. Evaluate it and consider which scenarios are likely successors.
4. Evaluate strategic plan in each of the scenarios.

Cross impact and Markov analysis helps the decision maker understand each of the above approaches.
10.6 CROSS IMPACT ANALYSIS

Cross Impact Analysis can help the manager understand which of the scenarios are more or less probable by analyzing the critical factors. Cross impact analysis provides a method to understand how the critical factors influence each other. The forecasting methodology has a feedback loop between cross impact and scenario analysis. This feedback loop is used to analyze how the interdependence of the critical factors affects the scenario space. Cross impact analysis therefore helps the manager interpret the scenario space and understand the interrelationships among the critical factors.

In order to maintain continuity in the methodology, cross impact analysis will be based on the same four critical factors used in scenario analysis. This is not a requirement. More factors could be added or the factors could be replaced.

I used a computer program to facilitate cross impact analysis (Porter, 1991). The program calculates the conditional probabilities ranges and runs simulations to determine a new set of marginal probabilities. The program requires the following input.
1. List of events.

2. Initial independent probability of occurrence of each event, known as the marginal probability.

3. Indication of whether an event inhibits or enhances the probability of occurrence of the other events.

4. Estimation of the conditional probabilities for the occurrence and non occurrence matrices

The output of cross impact analysis is a revised set of independent probabilities of occurrence for each event. The events and their estimated initial marginal probabilities of occurrence are listed below.

<table>
<thead>
<tr>
<th>Event</th>
<th>Marginal Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing HW Price Trend</td>
<td>0.65</td>
</tr>
<tr>
<td>High Industry Profits</td>
<td>0.30</td>
</tr>
<tr>
<td>High User Acceptance</td>
<td>0.55</td>
</tr>
<tr>
<td>High Level of Interoperability</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Next we must determine the relationship between the independent events. The relationship must be classified as either inhibiting or enhancing. This decision will guide the assignment of conditional probabilities in the occurrence and non occurrence matrices. This classification is usually based on judgment.
To create the matrix below, you must ask yourself a question such as the following, "Is the probability of High Industry Profits inhibited or enhanced, given that high user acceptance has already occurred?" In this case the answer is obviously enhanced. This entry is made in row one, column three. Other relationships are not so apparent and could require discussion, Delphi studies or research. The completed matrix is shown below.

<table>
<thead>
<tr>
<th>Events</th>
<th>High Profit</th>
<th>High Interop</th>
<th>High Acceptance</th>
<th>High Price Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Profit</td>
<td>na</td>
<td>Inhibit</td>
<td>Enhance</td>
<td>Inhibit</td>
</tr>
<tr>
<td>High Interop</td>
<td>Inhibit</td>
<td>na</td>
<td>Enhance</td>
<td>Enhance</td>
</tr>
<tr>
<td>High Acceptance</td>
<td>Inhibit</td>
<td>Enhance</td>
<td>na</td>
<td>Enhance</td>
</tr>
<tr>
<td>High Price Trend</td>
<td>Inhibit</td>
<td>Enhance</td>
<td>Enhance</td>
<td>na</td>
</tr>
</tbody>
</table>

The occurrence and non occurrence matrices may be constructed based on the above relationships. The conditional probabilities are estimated based on the marginal probabilities, laws of probability and a range of statistically acceptable conditional probabilities.

There are two ranges of statistically acceptable conditional probabilities: inhibiting and enhancing. In estimating P(i|j), the following guidelines are used (Porter, 1991).

1. If the occurrence of event j enhances (increases) the probability that event i will occur, then
\[(8.1) \quad P(i) < P(i|j) < [P(i)/P(j)] \]

2. If the occurrence of event j inhibits (decreases) the probability that event i will occur, then
\[(8.2) \quad 1 + \{[P(i)-1]/P(j)\} < P(i|j) < P(i) \]

It is not required that the assigned conditional probability fall within the designated range. The ranges are guidelines that are based on conditional probability and statistics. They are not meant to override forecaster knowledge or judgment.

Below are the conditional occurrence and non occurrence matrices. The entries indicate the probability of the row event (event i) occurring given that column event (event j) has already occurred. For example, the conditional probability that high industry profits will occur given that high user acceptance has already occurred is 0.60.

<table>
<thead>
<tr>
<th>Events</th>
<th>High Profit</th>
<th>High Interop</th>
<th>High Acceptance</th>
<th>High Price Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Profit</td>
<td>1.0</td>
<td>0.10</td>
<td>0.54</td>
<td>0.10</td>
</tr>
<tr>
<td>High Interop</td>
<td>0.40</td>
<td>1.0</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>High Acceptance</td>
<td>0.25</td>
<td>0.77</td>
<td>1.0</td>
<td>0.80</td>
</tr>
<tr>
<td>High Price Trend</td>
<td>0.15</td>
<td>0.84</td>
<td>0.83</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Using the above events, marginal probabilities and matrices, 20,000 simulations were run on the computer. The result of the simulations is a revised set of initial (marginal) probabilities for the four critical events. They are shown below.

This analysis indicates that the probability of high industry profits has the potential to increase based on the other critical events. At the same time there is a decrease in the probability of increasing hardware price performance trend. This interaction is consistent with our earlier classification that high industry profits is inhibited by increasing price performance trend. Let's try and interpret this data and apply it to the scenario space.
The results indicate that the probability of high user acceptance is independent of the other factors, which is surprising. Also, the probability of high interoperability is decreased by the other critical factors. The main interdependence, which cross impact has identified, is between increasing profits and decreasing price performance. Cross impact indicates that scenarios with these states are more likely.

If a manager were to try and manage the critical factors the results of cross impact would be helpful. Restoring industry profits requires an end to the price war, that's obvious. But maintaining user acceptance is not related to the other factors. This indicates that more research in monitoring and trend analysis is required to determine a link to user acceptance.

Let us reflect back on what we have accomplished thus far with the methodology. We started our forecast to explore the central question, "What is the future of the desktop computing industry?" Our methodology has provided us with an opportunity to scan the environment for emerging trends and relationships. In the monitoring stage, we identified and reviewed several items in detail. Next, in trend analysis, we identified a list of current trends that affected the desktop computer market. From this list we defined a set of
four critical factors that were then used to create a scenario space.

The scenario space has given us an idea of the range of potential future outcomes of the desktop computer industry. We identified some desirable states and one that seemed to describe today's environment. We then used cross impact analysis to understand the interaction and interdependencies among the four critical factors. Analysis of the critical factors has given us some indication of which factor states and therefore which scenarios are more or less probable.

10.7 MARKOV ANALYSIS

In the last stage of the methodology, we will use Markov analysis to estimate probabilities of occurrence and transition among the different scenarios. The results will be used to interpret the scenario space to hone the forecast.

Markov analysis uses a transition matrix to answer questions about probabilities of events (scenarios) over time. This can be extremely useful information. However, there is a price to pay. Markov analysis requires a tremendous amount of data. A matrix for four events (n=4) requires $2^{2n}$, or 256 entries. A 16x16 matrix must be developed, based mainly on
judgment. In addition, marginal probabilities must be estimated for all 16 events (scenarios).

The required input for Markov analysis is listed below. The current period will be noted as t=0.

1. Probabilities of occurrence estimates for all 16 events, \( \Theta_{t=0} : S^0 \).
2. Transitional probabilities, 16x16 matrix, \( \Theta_{t=0} : p(0,1) \).

Output from Markov analysis will include:

1. Probabilities of occurrence estimates for all 16 events (scenarios) for time \( t=1, t=2 \) and \( t=3 \): \( S^t \).
2. Selected transition probability calculations.

To begin constructing the transitional matrix we first examine the individual states to ensure that we fully understand each one. Transitional probabilities are assigned to represent the probability of moving from state \( i \) to any state \( j \) in a specified number of time periods.

The transitional probabilities may take any value from zero to one, inclusive. A thorough understanding of each state and its underlying factors is required to make accurate estimates of the transition probabilities. Markov analysis
has no memory and no restrictions. Transition from one state to any of the other 15 states or non transition (staying in the same state), is allowed.

In this case I used a spreadsheet to develop the transitional matrix and to perform the matrix manipulations. Input, including the transitional matrix \( p(0,1) \) for \( t=0 \), is shown in figures 13A & 13B. The scenario numbers and names are consistent with the scenario space. Below the matrix is a row vector \( s^0 \) that shows the estimated marginal probabilities for each scenario for time \( t=0 \). The probabilities were based on information gathered in monitoring, trend analysis and today's industry environment.

I assigned the transitional probabilities by analyzing the conditions of the factors in each of the individual scenarios. I used the following guidelines in estimating the transitional probabilities.

1. The more factors that changed, the lower the transition probability. For example moving between states 1 (0000) and 2 (0001) causes only one factor to change states. While moving from state 1 to state 8 (0111) causes three factors to change.

2. Some factor changes can be associated as being probable or improbable. For example moving from state 3 (0010) to
state 7 (0110) is probable because high user acceptance could likely generate high industry profits. Conversely, moving from state 4 (0011) to state 3 (0010) would require a loss of interoperability, which is improbable.

3. States with high user acceptance and high industry profits tend to be self sustaining.

4. The conditional probabilities of each row must sum to 1.

5. In assigning the initial probabilities for each scenario, I assumed that scenario 11, described today's environment. Therefore it has a probability of one in $S^0$.

I made the simplifying assumption that the transition matrix did not change with $t$; i.e., $p(t,1)=p(t+1,1)=p(t+2,1)$. This assumption will facilitate the calculation of successive row vectors and transition matrices.

The results from Markov analysis are shown in figures 14A & 14B and 14C. The row vectors ($S_t$), which represent the scenario probabilities, were calculated using equation 8.5. These vectors represent the probabilities of each state in different time periods (Porter, 1991).

\begin{equation}
S_{t+1} = S_t p(t,1) \\
S_1 = S_0 p(0,1)
\end{equation}

In Markov analysis we performed two different analysis: probability of occurrence and transitional. Occurrence
Markov Analysis

Event Definition
1 High Hardware Price Perf
2 High Industry Profits
3 High User Acceptance
4 High Interoperability

State Definition
1 = HIGH
0 = LOW

EVENT STATES

<table>
<thead>
<tr>
<th>STATE #</th>
<th>PRICE</th>
<th>PROFITS</th>
<th>ACCEPT</th>
<th>INTEROP</th>
<th>SCENARIO NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 Mkt Stagnation</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 HW Prices Stale</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0 Niche Mkts</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1 SW Delight</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0 Mkt Pull</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1 Ind Cooperation</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0 Rich Niche</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1 Stable Profits</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 HW Death</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 Mkt Shakeout</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0 Cheap HW</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1 Shoppers Delight</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0 SW Profits</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1 Technology Push</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0 Industry Thrives</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1 Ind &amp; User Gain</td>
</tr>
</tbody>
</table>

IN THE ANALYSIS WE ASSUME THAT THE TRANSITION MATRIX P(t,n) IS CONSTANT
THIS MEANS, P(0,1) = P(1,1) = P(2,1)

THEREFORE
P(0,2) = P(0,1)P(0,1)
P(0,3) = P(0,1)P(0,1)P(0,1)

THEN THE EVENT PROBABILITY VECTORS S(t) CAN BE CALCULATED

S(1) = P(0,1)S(0)
S(2) = P(0,2)S(1)
S(3) = P(0,3)S(2)

FIGURE 13A. EVENT DEFINITION AND FORMULAS
**MARKOV ANALYSIS INPUT**

**ROW VECTOR, S(0)**

**TRANSITION MATRIX, P(0,1)**

<table>
<thead>
<tr>
<th>STATE</th>
<th>Market</th>
<th>HW Prices</th>
<th>Niche</th>
<th>Software</th>
<th>Delight</th>
<th>Pull</th>
<th>Stable</th>
<th>Profts</th>
<th>Rich</th>
<th>Ind Co-</th>
<th>Hardware</th>
<th>Death</th>
<th>Shakeout</th>
<th>Hardware</th>
<th>Cheap</th>
<th>Shoppers</th>
<th>Software</th>
<th>Techny</th>
<th>Industry</th>
<th>Ind &amp; User</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.06</td>
<td>0.04</td>
<td>0.12</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>0.18</td>
<td>0.05</td>
<td>0.14</td>
<td>0.03</td>
<td>0.09</td>
<td>0.02</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.22</td>
<td>0.07</td>
<td>0.07</td>
<td>0.32</td>
<td>0.02</td>
<td>0.08</td>
<td>0.04</td>
<td>0.04</td>
<td>0.11</td>
<td>0.04</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
<td>0</td>
<td>0.05</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>0.06</td>
<td>0.17</td>
<td>0.05</td>
<td>0.12</td>
<td>0.02</td>
<td>0.03</td>
<td>0.05</td>
<td>0.11</td>
<td>0.06</td>
<td>0.12</td>
<td>0.15</td>
<td>0.1</td>
<td>0.09</td>
<td>0.06</td>
<td>0.09</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.08</td>
<td>0.1</td>
<td>0.09</td>
<td>0.09</td>
<td>0.25</td>
<td>0.12</td>
<td>0.1</td>
<td>0.04</td>
<td>0.04</td>
<td>0.14</td>
<td>0.09</td>
<td>0.04</td>
<td>0.11</td>
<td>0.05</td>
<td>0</td>
<td>0.02</td>
<td>0.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
<td>0.03</td>
<td>0.02</td>
<td>0.04</td>
<td>0.12</td>
<td>0.05</td>
<td>0.11</td>
<td>0.06</td>
<td>0.1</td>
<td>0.02</td>
<td>0.06</td>
<td>0.04</td>
<td>0.1</td>
<td>0.03</td>
<td>0</td>
<td>0.06</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
<td>0.09</td>
<td>0.1</td>
<td>0.1</td>
<td>0.25</td>
<td>0.12</td>
<td>0.1</td>
<td>0.04</td>
<td>0.1</td>
<td>0.15</td>
<td>0.11</td>
<td>0</td>
<td>0.04</td>
<td>0.03</td>
<td>0</td>
<td>0.03</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.08</td>
<td>0.04</td>
<td>0.01</td>
<td>0.06</td>
<td>0.12</td>
<td>0.04</td>
<td>0.14</td>
<td>0.09</td>
<td>0.04</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>0.04</td>
<td>0.03</td>
<td>0</td>
<td>0.06</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.0</td>
<td>0.03</td>
<td>0.23</td>
<td>0</td>
<td>0.58</td>
<td>0.01</td>
<td>0.14</td>
<td>0.08</td>
<td>0.06</td>
<td>0.15</td>
<td>0.11</td>
<td>0</td>
<td>0.04</td>
<td>0.03</td>
<td>0</td>
<td>0.03</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.14</td>
<td>0.03</td>
<td>0.02</td>
<td>0.23</td>
<td>0</td>
<td>0.58</td>
<td>0.01</td>
<td>0.14</td>
<td>0.08</td>
<td>0.06</td>
<td>0.12</td>
<td>0</td>
<td>0.12</td>
<td>0.04</td>
<td>0</td>
<td>0.04</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.07</td>
<td>0.09</td>
<td>0.06</td>
<td>0.12</td>
<td>0.37</td>
<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>0</td>
<td>0.04</td>
<td>0.04</td>
<td>0</td>
<td>0.06</td>
<td>0.12</td>
<td>0</td>
<td>0.04</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.04</td>
<td>0.0</td>
<td>0.2</td>
<td>0.08</td>
<td>0.06</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
<td>0.26</td>
<td>0</td>
<td>0.11</td>
<td>0.03</td>
<td>0</td>
<td>0.19</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.0</td>
<td>0.17</td>
<td>0.1</td>
<td>0.23</td>
<td>0</td>
<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>0</td>
<td>0.04</td>
<td>0.04</td>
<td>0</td>
<td>0.06</td>
<td>0.12</td>
<td>0</td>
<td>0.04</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.04</td>
<td>0.0</td>
<td>0.2</td>
<td>0.08</td>
<td>0.06</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.03</td>
<td>0.26</td>
<td>0</td>
<td>0.11</td>
<td>0.03</td>
<td>0</td>
<td>0.19</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.0</td>
<td>0.22</td>
<td>0.14</td>
<td>0.04</td>
<td>0.05</td>
<td>0.15</td>
<td>0.02</td>
<td>0.23</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0</td>
<td>0.05</td>
<td>0.05</td>
<td>0</td>
<td>0.05</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EVENT PROBABILITY VECTOR**

| S(0) | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   |

**FIGURE 13B. TRANSITION MATRIX P(0,1) AND EVENT PROBABILITY VECTOR S(0)**
analysis looked at the marginal probability of occurrence of the 16 scenarios ($S^t$), independent of the current state, for any time period $t$. Transitional analysis provides data on the sequence of states and when any state $i$ may transition to any state $j$, at time $t$.

I calculated $S^t$, for $t=1, 2, 3$, to evaluate the probabilities of the scenarios over a three year time period. It turns out that the matrix does converge (to Industry Cooperation). The most likely scenarios and their probabilities through time are listed below.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Number</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$t=1$</td>
</tr>
<tr>
<td>Industry Cooperation</td>
<td>8</td>
<td>4.0%</td>
</tr>
<tr>
<td>Industry &amp; User Gain</td>
<td>16</td>
<td>11.2%</td>
</tr>
<tr>
<td>Shoppers Delight</td>
<td>12</td>
<td>10.0%</td>
</tr>
<tr>
<td>Software Delight</td>
<td>4</td>
<td>6.0%</td>
</tr>
</tbody>
</table>

These results indicate that the industry has an increasing probability of achieving Industry Cooperation. This state is represented by high profits, high user acceptance, high interoperability and flat hardware price performance trend. The results indicate that this is a stable industry state because its cumulative probability continues to increase.

We are now in a position to estimate what events are likely to follow today's environment (Cheap Hardware). Using the
MARKOV ANALYSIS
INPUT PROBABILITY VECTOR S(0)
OUTPUT PROBABILITY VECTORS S(1), S(2), S(3), S(4)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S(0)</td>
<td>0</td>
<td>0</td>
<td>0.09</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
<td>0.12</td>
<td>0.04</td>
<td>0.07</td>
<td>0</td>
<td>0</td>
<td>0.11</td>
<td>0</td>
<td>0.06</td>
<td>0.12</td>
</tr>
<tr>
<td>S(1)</td>
<td>0.07</td>
<td>0</td>
<td>0.09</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
<td>0.12</td>
<td>0.04</td>
<td>0.07</td>
<td>0</td>
<td>0</td>
<td>0.11</td>
<td>0</td>
<td>0.06</td>
<td>0.12</td>
</tr>
<tr>
<td>S(2)</td>
<td>0.0403</td>
<td>0.0106</td>
<td>0.0285</td>
<td>0.0509</td>
<td>0.0315</td>
<td>0.0224</td>
<td>0.0806</td>
<td>0.2051</td>
<td>0.0326</td>
<td>0.0477</td>
<td>0.0686</td>
<td>0.1174</td>
<td>0.0162</td>
<td>0.0379</td>
<td>0.0675</td>
</tr>
<tr>
<td>S(3)</td>
<td>0.0249</td>
<td>0.0141</td>
<td>0.0166</td>
<td>0.0481</td>
<td>0.0220</td>
<td>0.0342</td>
<td>0.0471</td>
<td>0.2933</td>
<td>0.0268</td>
<td>0.0443</td>
<td>0.0407</td>
<td>0.1399</td>
<td>0.0114</td>
<td>0.0410</td>
<td>0.0434</td>
</tr>
<tr>
<td>S(4)</td>
<td>0.0162</td>
<td>0.0130</td>
<td>0.0100</td>
<td>0.0503</td>
<td>0.0155</td>
<td>0.0344</td>
<td>0.0287</td>
<td>0.3502</td>
<td>0.0189</td>
<td>0.0452</td>
<td>0.0261</td>
<td>0.1482</td>
<td>0.0072</td>
<td>0.0419</td>
<td>0.0290</td>
</tr>
</tbody>
</table>

FIGURE 14A: STATE PROBABILITY VECTORS, S(1)
STATE 11, IS THE ASSUMED INITIAL STATE
### MARKOV ANALYSIS OUTPUT

#### TRANSITIONAL MATRIX P(0.2)

<table>
<thead>
<tr>
<th>STATE</th>
<th>Market</th>
<th>HW Prices</th>
<th>Niche</th>
<th>Software</th>
<th>Delight</th>
<th>Market</th>
<th>Stable</th>
<th>Profits</th>
<th>Rich</th>
<th>Ind Co-op</th>
<th>Death</th>
<th>Hardware</th>
<th>Shakeout</th>
<th>Hardware</th>
<th>Cheap</th>
<th>Shoppers</th>
<th>Software</th>
<th>Techiny</th>
<th>Industry</th>
<th>Ind &amp; User</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>1</td>
<td>0.0622</td>
<td>0.0232</td>
<td>0.0298</td>
<td>0.0614</td>
<td>0.076</td>
<td>0.0414</td>
<td>0.0622</td>
<td>0.1044</td>
<td>0.059</td>
<td>0.0679</td>
<td>0.0865</td>
<td>0.1063</td>
<td>0.0171</td>
<td>0.0537</td>
<td>0.0603</td>
<td>0.0986</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0.0489</td>
<td>0</td>
<td>0.078</td>
<td>0</td>
<td>0.0839</td>
<td>0</td>
<td>0.3018</td>
<td>0.0013</td>
<td>0.0811</td>
<td>0</td>
<td>0.2107</td>
<td>0</td>
<td>0.0477</td>
<td>0.0069</td>
<td>0.1403</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.0445</td>
<td>0.0259</td>
<td>0.0327</td>
<td>0.056</td>
<td>0.0378</td>
<td>0.0457</td>
<td>0.0778</td>
<td>0.1598</td>
<td>0.049</td>
<td>0.0523</td>
<td>0.0717</td>
<td>0.1151</td>
<td>0.0229</td>
<td>0.0428</td>
<td>0.0682</td>
<td>0.0972</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
<td>0.0236</td>
<td>0</td>
<td>0.0777</td>
<td>0</td>
<td>0.0521</td>
<td>0</td>
<td>0.3807</td>
<td>0.0032</td>
<td>0.0727</td>
<td>0</td>
<td>0.1694</td>
<td>0</td>
<td>0.0475</td>
<td>0.0081</td>
<td>0.165</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.046</td>
<td>0.0244</td>
<td>0.0258</td>
<td>0.0457</td>
<td>0.0549</td>
<td>0.0547</td>
<td>0.0552</td>
<td>0.1381</td>
<td>0.0564</td>
<td>0.072</td>
<td>0.0698</td>
<td>0.1131</td>
<td>0.021</td>
<td>0.0551</td>
<td>0.0712</td>
<td>0.0966</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0</td>
<td>0.0252</td>
<td>0</td>
<td>0.0604</td>
<td>0</td>
<td>0.0633</td>
<td>0.0198</td>
<td>0.3289</td>
<td>0.0025</td>
<td>0.0773</td>
<td>0.0045</td>
<td>0.1699</td>
<td>0.0018</td>
<td>0.0527</td>
<td>0.0297</td>
<td>0.164</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.0478</td>
<td>0.0088</td>
<td>0.0338</td>
<td>0.0439</td>
<td>0.0493</td>
<td>0.0409</td>
<td>0.022</td>
<td>0.1882</td>
<td>0.0516</td>
<td>0.0306</td>
<td>0.0785</td>
<td>0.1052</td>
<td>0.0234</td>
<td>0.0343</td>
<td>0.0798</td>
<td>0.1177</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.0014</td>
<td>0.0045</td>
<td>0</td>
<td>0.0467</td>
<td>0.0023</td>
<td>0.0214</td>
<td>0</td>
<td>0.4986</td>
<td>0.0063</td>
<td>0.0271</td>
<td>0.002</td>
<td>0.1603</td>
<td>0</td>
<td>0.0341</td>
<td>0.0022</td>
<td>0.1931</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.0524</td>
<td>0.0321</td>
<td>0.0394</td>
<td>0.0556</td>
<td>0.0401</td>
<td>0.0612</td>
<td>0.049</td>
<td>0.1149</td>
<td>0.067</td>
<td>0.0579</td>
<td>0.0766</td>
<td>0.1229</td>
<td>0.0272</td>
<td>0.0366</td>
<td>0.0652</td>
<td>0.1019</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>0.0222</td>
<td>0</td>
<td>0.1009</td>
<td>0</td>
<td>0.0482</td>
<td>0</td>
<td>0.3387</td>
<td>0.0014</td>
<td>0.0851</td>
<td>0</td>
<td>0.1628</td>
<td>0</td>
<td>0.0523</td>
<td>0.0153</td>
<td>0.1731</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0.0403</td>
<td>0.0106</td>
<td>0.0285</td>
<td>0.0509</td>
<td>0.0315</td>
<td>0.0224</td>
<td>0.0806</td>
<td>0.2051</td>
<td>0.0326</td>
<td>0.0477</td>
<td>0.0686</td>
<td>0.1174</td>
<td>0.0162</td>
<td>0.0379</td>
<td>0.0675</td>
<td>0.1422</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>0</td>
<td>0.018</td>
<td>0</td>
<td>0.0459</td>
<td>0</td>
<td>0.0379</td>
<td>0</td>
<td>0.4494</td>
<td>0.0037</td>
<td>0.0369</td>
<td>0</td>
<td>0.1784</td>
<td>0</td>
<td>0.0421</td>
<td>0.0187</td>
<td>0.1877</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.0592</td>
<td>0.0168</td>
<td>0.0096</td>
<td>0.0196</td>
<td>0.0748</td>
<td>0.0812</td>
<td>0.0146</td>
<td>0.1508</td>
<td>0.0466</td>
<td>0.1142</td>
<td>0.0684</td>
<td>0.0804</td>
<td>0.0173</td>
<td>0.0807</td>
<td>0.0594</td>
<td>0.1324</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0</td>
<td>0.0298</td>
<td>0</td>
<td>0.0297</td>
<td>0</td>
<td>0.0904</td>
<td>0</td>
<td>0.3028</td>
<td>0.001</td>
<td>0.0853</td>
<td>0</td>
<td>0.1896</td>
<td>0</td>
<td>0.0772</td>
<td>0.0153</td>
<td>0.1789</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.0219</td>
<td>0.004</td>
<td>0.0133</td>
<td>0.0301</td>
<td>0.0172</td>
<td>0.0134</td>
<td>0.101</td>
<td>0.2791</td>
<td>0.0177</td>
<td>0.025</td>
<td>0.0478</td>
<td>0.1441</td>
<td>0.014</td>
<td>0.0257</td>
<td>0.0831</td>
<td>0.1596</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0458</td>
<td>0</td>
<td>0.0185</td>
<td>0.434</td>
<td>0.0005</td>
<td>0.0285</td>
<td>0.1555</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>0.2135</td>
<td>0.005</td>
<td>0.2135</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 14B. TRANSITION MATRIX P(0.2)**
### MARKOV ANALYSIS OUTPUT
TRANSITIONAL MATRIX P(0,3)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0343</td>
<td>0.0214</td>
<td>0.0210</td>
<td>0.0534</td>
<td>0.0326</td>
<td>0.0479</td>
<td>0.0470</td>
<td>0.2184</td>
<td>0.0667</td>
<td>0.0616</td>
<td>0.0526</td>
<td>0.1303</td>
<td>0.0153</td>
<td>0.0460</td>
<td>0.0503</td>
<td>0.1313</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0002</td>
<td>0.0202</td>
<td>0.0000</td>
<td>0.0692</td>
<td>0.0003</td>
<td>0.0468</td>
<td>0.0014</td>
<td>0.3925</td>
<td>0.0031</td>
<td>0.0626</td>
<td>0.0006</td>
<td>0.1709</td>
<td>0.0001</td>
<td>0.0472</td>
<td>0.0091</td>
<td>0.1765</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0297</td>
<td>0.0176</td>
<td>0.0176</td>
<td>0.0541</td>
<td>0.0280</td>
<td>0.0404</td>
<td>0.0483</td>
<td>0.2552</td>
<td>0.0302</td>
<td>0.0556</td>
<td>0.0456</td>
<td>0.1351</td>
<td>0.0124</td>
<td>0.0444</td>
<td>0.0475</td>
<td>0.1992</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0004</td>
<td>0.0168</td>
<td>0.0000</td>
<td>0.0567</td>
<td>0.0077</td>
<td>0.0419</td>
<td>0.0018</td>
<td>0.4290</td>
<td>0.0040</td>
<td>0.0501</td>
<td>0.0010</td>
<td>0.1710</td>
<td>0.0002</td>
<td>0.0439</td>
<td>0.0067</td>
<td>0.1817</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0289</td>
<td>0.0197</td>
<td>0.0167</td>
<td>0.0522</td>
<td>0.0294</td>
<td>0.0466</td>
<td>0.0439</td>
<td>0.2424</td>
<td>0.0308</td>
<td>0.0614</td>
<td>0.0450</td>
<td>0.1366</td>
<td>0.0125</td>
<td>0.0470</td>
<td>0.0479</td>
<td>0.1391</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0023</td>
<td>0.0154</td>
<td>0.0012</td>
<td>0.0555</td>
<td>0.0211</td>
<td>0.0426</td>
<td>0.0111</td>
<td>0.3970</td>
<td>0.0049</td>
<td>0.0525</td>
<td>0.0053</td>
<td>0.1683</td>
<td>0.0014</td>
<td>0.0450</td>
<td>0.0153</td>
<td>0.1791</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.0315</td>
<td>0.0129</td>
<td>0.0194</td>
<td>0.0467</td>
<td>0.0302</td>
<td>0.0317</td>
<td>0.0554</td>
<td>0.2662</td>
<td>0.0328</td>
<td>0.0446</td>
<td>0.0506</td>
<td>0.1294</td>
<td>0.0138</td>
<td>0.0404</td>
<td>0.0514</td>
<td>0.1429</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.0013</td>
<td>0.0078</td>
<td>0.0004</td>
<td>0.0478</td>
<td>0.0017</td>
<td>0.0274</td>
<td>0.0009</td>
<td>0.4737</td>
<td>0.0059</td>
<td>0.0333</td>
<td>0.0020</td>
<td>0.1631</td>
<td>0.0003</td>
<td>0.0382</td>
<td>0.0032</td>
<td>0.1929</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.0308</td>
<td>0.0200</td>
<td>0.0183</td>
<td>0.0586</td>
<td>0.0323</td>
<td>0.0420</td>
<td>0.0440</td>
<td>0.2360</td>
<td>0.0327</td>
<td>0.0611</td>
<td>0.0476</td>
<td>0.1347</td>
<td>0.0124</td>
<td>0.0467</td>
<td>0.0475</td>
<td>0.1951</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.0002</td>
<td>0.0197</td>
<td>0.0000</td>
<td>0.0555</td>
<td>0.0003</td>
<td>0.0456</td>
<td>0.0034</td>
<td>0.4097</td>
<td>0.0035</td>
<td>0.0524</td>
<td>0.0010</td>
<td>0.1744</td>
<td>0.0003</td>
<td>0.0452</td>
<td>0.0079</td>
<td>0.1799</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.0249</td>
<td>0.0141</td>
<td>0.0166</td>
<td>0.0481</td>
<td>0.0220</td>
<td>0.0342</td>
<td>0.0471</td>
<td>0.2933</td>
<td>0.0268</td>
<td>0.0443</td>
<td>0.0407</td>
<td>0.1399</td>
<td>0.0114</td>
<td>0.0410</td>
<td>0.0343</td>
<td>0.1523</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.0005</td>
<td>0.0099</td>
<td>0.0000</td>
<td>0.0534</td>
<td>0.0009</td>
<td>0.0316</td>
<td>0.0000</td>
<td>0.4564</td>
<td>0.0047</td>
<td>0.0413</td>
<td>0.0007</td>
<td>0.1639</td>
<td>0.0000</td>
<td>0.0414</td>
<td>0.0036</td>
<td>0.1918</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.0248</td>
<td>0.0229</td>
<td>0.0152</td>
<td>0.0445</td>
<td>0.0252</td>
<td>0.0596</td>
<td>0.0272</td>
<td>0.2524</td>
<td>0.0309</td>
<td>0.0659</td>
<td>0.0368</td>
<td>0.1456</td>
<td>0.0115</td>
<td>0.0543</td>
<td>0.0390</td>
<td>0.1443</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.0001</td>
<td>0.0160</td>
<td>0.0000</td>
<td>0.0578</td>
<td>0.0002</td>
<td>0.0475</td>
<td>0.0034</td>
<td>0.3930</td>
<td>0.0031</td>
<td>0.0607</td>
<td>0.0010</td>
<td>0.1673</td>
<td>0.0003</td>
<td>0.0515</td>
<td>0.0117</td>
<td>0.1864</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.0188</td>
<td>0.0079</td>
<td>0.0121</td>
<td>0.0443</td>
<td>0.0163</td>
<td>0.0241</td>
<td>0.0483</td>
<td>0.3437</td>
<td>0.0202</td>
<td>0.0342</td>
<td>0.0333</td>
<td>0.1428</td>
<td>0.0095</td>
<td>0.0361</td>
<td>0.0418</td>
<td>0.1665</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.0007</td>
<td>0.0073</td>
<td>0.0000</td>
<td>0.0453</td>
<td>0.0012</td>
<td>0.0274</td>
<td>0.0000</td>
<td>0.4778</td>
<td>0.0052</td>
<td>0.0323</td>
<td>0.0010</td>
<td>0.1642</td>
<td>0.0000</td>
<td>0.0393</td>
<td>0.0019</td>
<td>0.1964</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 14C. TRANSITION MATRIX P(0,3)**
p(t,n) matrices, we can calculate the cumulative probability of transitioning to any state from today's state.

I calculated p(0,n), for n=1,2,3 to evaluate the cumulative transitional probabilities. Using these matrices we can determine the cumulative probabilities and the likely first passage time for the most likely scenario. The equations used to calculate the transition matrices are shown below. In addition, the difference between cumulative probabilities, defined as f(i:j), is the incremental change in probability over time, shown in equation 10.1 (Porter, 1991).

\[ p(t,n) = p(t,1)p(t+1,1)p(t+2,1)\ldots p(t+n-1,1) \]
\[ p(0,2) = p(0,1)p(1,1) \]
\[ p(0,3) = p(0,1)p(1,1)p(2,1) \]

\[ f(i:j) = P(i:j)^{t+1} - P(i:j)^t \]

<table>
<thead>
<tr>
<th>Transition in Time period</th>
<th>Cumulative Probability</th>
<th>Incremental Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=1</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>t=2</td>
<td>20.5%</td>
<td>16.5%</td>
</tr>
<tr>
<td>t=3</td>
<td>29.3%</td>
<td>8.8%</td>
</tr>
<tr>
<td>t=4</td>
<td>35.0%</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

**Probability of Transition Analysis**
Given that today's environment is represented by the "Cheap Hardware," scenario (number 11), then we can evaluate the probabilities associated with the transition to the "Industry Cooperation," scenario (number 8). The table shows how the cumulative probability of transition from scenario 11 to 8 increases. The probability of reaching scenario 8 by the third period is 29.3%. In addition the largest increment in probability (16.5%) occurs between periods 1 and 2. This represents the first passage time of P(11:8).

Markov analysis indicates that the individual computing industry is heading toward a period of industry cooperation. This will require a change in three of the four factors: industry profits, interoperability and hardware price trend. The scenarios and their factors are shown below.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Price Trend</th>
<th>Industry Profit</th>
<th>User Acpt</th>
<th>Interop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap Hardware</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Industry Cooperation</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>

Transitional analysis gives the same result as probability of occurrence analysis, which is not always true. This matching result is due to two conditions.

1. We assumed that the transitional probability matrix did not change with time.
2. The initial probability matrix set the probability of "Cheap Hardware" to one, and all others to zero.

Combining transitional and probability of occurrence analysis could lead to the following interpretation. Today's industry is described by the scenario named "Cheap Hardware." However, the industry has a 29% probability of transitioning to a state of cooperation, in the next three years. The transition will be brought on by an increase in interoperability which should increase user acceptance. Then, possibly due to increased user acceptance and lower R&D spending, the hardware price performance trend will begin to flatten out. This will signal the beginning of the end of the hardware price war. A period of industry cooperation and high profits will follow. This period will be stable because industry profits and user acceptance are both high.

This interpretation is based on the output of Markov analysis. The results of Markov analysis indicate that many other sequences are also possible. Another item to note is the fact that this result was dependent upon the initial starting point. The state probability vector, \( S^0 \), can be changed and multiplied by the transition matrix to generate another set of row vectors.
Markov analysis has provide a better indication of which scenarios are more and less probable. This information can be used by the decision maker. The results might be interpreted to mean that the industry is going to continue to be characterized by increasing hardware price performance trends and low profits. However, this is expected to change in the next two years.

Combining the output of cross impact and Markov analysis results in a generally consistent prediction in the short term. Both analysis indicate that moving toward a scenario, such as "industry cooperation," is probable. Cross impact suggests that profits and price trend are interdependent and moving toward a state of high profits and flat price performance trend. Markov analysis indicates that moving to such as scenario has a high probability.

Cross impact assumed that user acceptance was high and indicated that it was independent of the other factors. Markov analysis indicates that it will remain high.

Long term analysis should be based on the scenario space and Markov analysis. Cross impact analysis does not contain a time element, which renders its output questionable in the long run. The long term forecast is for industry cooperation.
How the scenarios affect an individual firm will vary and require study, interpretation and judgment. The decision maker must now use his judgment and experience to interpret the results of the forecast. The results clearly show that short term plans for large expenditures or expansion should be reviewed carefully. A manager might decide to follow the developing trend of sharing R&D expenditures to minimize cost and risk. And to form alliances where necessary to challenge the market leader. The manager should seek to position his firm to benefit in the pending period of industry cooperation.

10.8 METHODOLOGY REVIEW

Monitoring and trend analysis have provided a wealth of information about the desktop computer industry. The knowledge gained has provide the forecaster with a solid foundation for scenario, cross impact and Markov analysis.

Scenario analysis has created a set of potential future outcomes, which should spark thoughts and images in the mind of the manager. Are the scenarios feasible? Which are desirable? What factors can inhibit or enhance each scenario? These clearly demonstrate the wide range of variance among the set of feasible future states.
Markov and cross impact analysis have provided a great deal of insight into which scenarios are more likely. The output of these two steps provides a clear reason why the all the methodology steps must be followed. Furthermore, these analysis techniques are repeatable and therefore maybe improved. Repetitive use of the methodology and the tools will bring an increased understanding of their usefulness.

11.0 CONCLUSION

My hypothesis stated that forecasting methods can be devised that will yield benefit to business managers. Specifically, when the proposed methodology is used, the manager will be in a better position to make judgments about the future. Further, with this knowledge the manager will be prepared to make informed strategic decisions.

The case study has been used to demonstrate (not prove) the hypothesis. The reader should understand the benefits that result from the use of the forecasting methodology.

In the methodology, monitoring and trend analysis provided a mechanism to develop knowledge about the environment. This was accomplished by identifying relationships and collecting and analyzing data. Creating a scenario space, based on a
set of critical factors, is a disciplined and repeatable process to generate potential plausible futures. The scenarios set can create ideas, generate consensus and provide a vehicle for communicating company goals and strategies.

Cross impact and Markov analysis then allowed the scenario set to be studied. Cross impact analysis gives the decision maker more information about the critical factors. It revealed relationships that can be used to enhance or inhibit the probability of a particular scenario. Markov analysis focused directly on the scenario set. It provided the manager with an indication of which scenarios are more or less probable.

The benefit of the forecasting methodology can be summarized into five points.
1. Trend analysis and monitoring give the manager a set of related qualitative and quantitative factors. These factors are the building blocks for all the analysis in the forecasting methodology and are the basis for decision making.
2. The scenario space yields a set of outcomes which provide the manager with an indication of the variability among potential future states. The manager should realize that single point forecasts do not take into consideration any of
this variability. The scenario space can create new ideas about situations which were previously unknown and untested.

3. Cross impact analysis provided a keen insight into how the critical factors influence each other. Should a critical event occur, the manager will understand the affect on the other critical factors. This insight can result in an increased ability to react to change.

4. Markov analysis provided the manager with a tool to understand which scenarios are most probable. In addition, the manager has an indication of the potential sequence of events. This knowledge can be used to map out a long term strategy which can include managing the critical factors.

5. The combination of the above four items yields the most significant benefit. The manager started by collecting information from the environment. At the end of the forecasting process he has gained knowledge of current and future trends, the inter-relationship among the trends, how critical factors may be combined to form future states, and which future states are most probable. This combination of information, insight and understanding should enable better decision making.

11.1 SELF REFLECTION

I found monitoring and trend analysis difficult. They require a great deal of expertise and judgment. You can find
many quantitative and qualitative factors, but their relationships and interpretations can be unclear.

During the case analysis I particularly enjoyed analyzing the scenario space. It provided me with an understanding of how certain scenarios are related: Hardware Death and Cheap Hardware differ by on the level of user acceptance.

I was also surprised by the output from cross impact analysis. I did not expect user acceptance to be unrelated to the other critical factors. Also, I was happy that Markov analysis had a convergent solution.

The strength of the forecasting methodology is based on its logical and physical structure, which creates its information flow and processing ability. The methodology provides continuity between the steps and uses feedback to hone the scenario set. It is a definable, repeatable process.

11.3 METHODOLOGY EVALUATION

In the introduction I stated that the output from the methodology could be evaluated by the following criteria.

1. Answer the managers question or concern.
2. Output in a usable form.
3. Contain information to create a strategic plan.
4. Process be simple, understandable, accurate and cost effective.

Specific user requirements can easily be accommodated. In fact I recommend that the user be involved in each step of the forecast to ensure that their requirements are met. The methodology can focus on one specific issue if desired by the user.

The methodology generates output from each step which can be delivered in any desired format. No special requirements are imposed on the format of the data. Thus, the output can be changed to fit the users specifications.

The scenario set, and its evaluation have a variety of uses. For example, it can be used to create a strategic plan, communicate company goals and increase awareness. Cross impact and Markov analysis provide information which can be useful in developing a strategic plan.

The forth criteria can only be answered by the reader. It requires a cost-benefit analysis. I acknowledge that this methodology is long and is best applied to questions or issues that represent significant risk to a firm.
Combining all the information generated in using the methodology provides the manager with a better foundation upon which to make judgments and strategic decisions. The methodology is repeatable and can therefore be improved to provide more accurate and usable output. It can be used to answer very specific questions or issues. The usefulness of the methodology is gained by following the process, which provides learning and knowledge. Interpreting its output, provides insight and provokes thought and discussion. This combination of benefits, provided by the forecasting methodology, is of great value to the manager. I offer these results in support the stated hypothesis.

12.0 APPENDIX

12.1 CROSS IMPACT ANALYSIS AND SIMULATION

I want to demonstrate how simulation is used to determine the revised initial probabilities (Porter, 1991).

SIMULATION TO DETERMINE CROSS IMPACTED PROBABILITIES

1. Establish a rule that links the selection of the four critical events and a random number between 0 and 1. For example, a random number between 0 and 0.24 will cause event number 1 to be selected.

2. Establish a rule between a random number (0 to 1) and the occurrence or non occurrence of an event. For example, if the random number is less than the initial or conditional
probability of occurrence then the event is assumed to occur.

3. Using rule number 1, select an event.

4. Using rule number 2, determine its occurrence or non occurrence.

5. Replace the marginal probabilities of the three remaining (impacted) events with the appropriate (occurrence or non occurrence) conditional probabilities.

6. Using rule number 2, determine the occurrence or non occurrence of the three impacted events.

7. Repeat this process many times: 20,000 in our case study.

8. Determine the revised (impacted) probabilities of occurrence based on the frequency of occurrence found in steps 1 through 6.

FOR EXAMPLE, ASSUME HIGH INDUSTRY PROFITS HAS OCCURRED (BY USING RULES #1 & 2), THEN THE FOLLOWING RELATIONSHIPS EXIST

<table>
<thead>
<tr>
<th>Events</th>
<th>Marginal Probability</th>
<th>Conditional Probability</th>
<th>Random Number</th>
<th>Occur Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Profit</td>
<td>0.30</td>
<td>1.0</td>
<td>X</td>
<td>na</td>
</tr>
<tr>
<td>High Interop</td>
<td>0.70</td>
<td>0.40</td>
<td>0.22</td>
<td>YES</td>
</tr>
<tr>
<td>High Acceptance</td>
<td>0.55</td>
<td>0.25</td>
<td>0.35</td>
<td>NO</td>
</tr>
<tr>
<td>High Price Trend</td>
<td>0.65</td>
<td>0.15</td>
<td>0.55</td>
<td>NO</td>
</tr>
</tbody>
</table>

The random numbers are compared to the conditional probabilities of the impacted events: high interoperability, high user acceptance and high price performance trend. Only
high interoperability has a conditional probability which meets rule number 2 (0.40 > 0.22). Therefore, it is assumed to have occurred.

In this simulation cycle only one of the three impacted events occurred. This process must be repeated to obtain a statistically valid frequency of occurrence for all the events.

12.2 MARKOV ANALYSIS

12.2.1 STOCHASTIC PROCESSES (Frankel, 1988, p88)

If a random variable and its associated probability distribution function are dependent on time (time varying), they are said to characterize a random or stochastic process. Stochastic processes can be discrete or continuous in time or in the parameter of the variable. This provides the following relationship (E is epsilon, u is tau).

\[(12.1) \quad w(x,t)dxdt = P[x<E<x+dx, t<u<t+dt]\]

which is the probability that our parameter assumes a value between x and x+dx when time is between t and t+dt.

12.2.2 Discrete Markov Chain (Frankel, 1988, p97-99)
In a situation where there are many variables \((x_1, x_2, \ldots, x_n)\), then the following conditions exist and can be proven using Markov properties and Bayes Theorem.

\[
(12.2) \quad P[X(t_n) = x_n | X(t_{n-1}) = x_{n-1}] = P[X(t_{n-1}) = x_{n-1} | X(t_{n-2}) = x_{n-2}] \times P[X(t_{n-2}) = x_{n-2}, \ldots, X(t_0) = (t_0)]
\]

In other words this means that the joint probability density of the stochastic variable \(x\) when it assumes a value of \(x_0\) at \(t_0\), \(x_1\) at \(t_1\), \ldots, \(x_n\) at \(t_n\) is equal to the product of probability that the variable takes on the value \(x_0\) at \(t_0\) times the probability it takes on the value of \(x_1\) at \(t_1\) given that it took on the value of \(x_0\) at \(t_0\) \ldots \times \) times the probability it takes on the value \(x_n\) at \(t_n\) given that it took on the values of \(x_{n-1}\) at \(t_{n-1}\). If it happens that the Markov chain is also homogeneous and that the separation between times \(t_0, t_1, \ldots t_n\), is one unit (or step) so that

\[t_n - t_{n-1} = t_{n-1} - t_{n-2} = \ldots = t_n - t_0 = 1\]

then, using \(f(x)\) to represent the joint probability distribution function, the above expression may be further simplified to:

\[f(x_n, x_{n-1}, \ldots, x_0; t_n, t_{n-1}, \ldots, t_0) = P_{n-1, n}(t_{n-1}, t_n)\]

117
\[ p_{n-2,n-1}(t_{n-2}, t_{n-1}) \cdots p_{0,1}(t_0) \]

- \[ p_{n-1,n}(1) p_{n-2,n-1}(1) \cdots p_{0,1}(1)p_{0}(t_0) \]

where \( p_{ij}(t_i, t_j) \) is the probability that the variable \( x \) is equal to \( x_i \) at \( t_i \) given it was equal to \( x_j \) at \( t_j \). Therefore, in a stationary Markov Chain (\( E=\epsilon \text{psilon} \)):

\[ p[E=x_i, t_i/E = x_{i-1}, t_{i-1}] \]

depends only on \( (t_i - t_{i-1}) \) and is independent of the actual value of \( t_i \). In this case it can be shown that the

\[ \lim (\text{as } t_n \text{ approaches infinity}) \ P[E=x_n, t_n/E=x_{n-1}, t_{n-1}] \]

exists, which implies that a stationary Markov process (or chain) guarantees that a steady-state solution exists. Similarly, if the transition probability of going from state \( i \) to a state \( j \) in \( n \) steps is represented by \( P_{ij}(n) \) then

\[ \text{Summation (of } j=0 \text{ to } m) \ P_{ij}(n)=1 \]

since the process can be in only one of the \( (m+1) \) steps after any number of steps. It should be noted that \( P_{ij}(n) \) may be also represented in a more expanded form:
\[ P_{ij}(n) = \text{Summation (of } k=0 \text{ to } m) \ P_{ik}(r) \cdot P_{kj}(n-r) \]

for any \( r < n \)

This equation resembles equation 8.6.

\[
* \quad P_{ik}(0) = \begin{cases} 
1 & \text{if } i=j \\ 
0 & \text{if } i \neq j 
\end{cases} \quad (e=\sigma)
\]
13.0 REFERENCES


