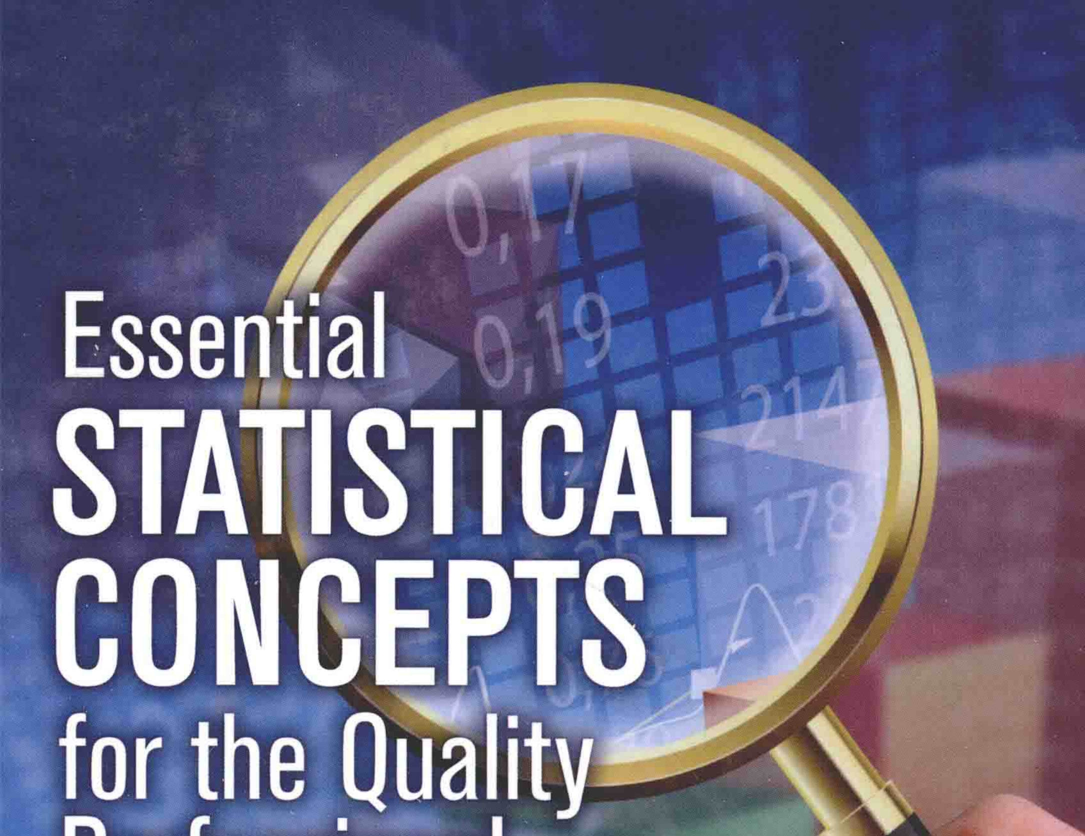

# Essential STATISTICAL CONCEPTS for the Quality Professional

D.H. Stamatis

CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742



Printed and bound in Great Britain by TJ International Ltd, Padstow, Cornwall
Version Date: 20120210

International Standard Book Number: 978-1-4398-9457-6 (Hardback)



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# Essential STATISTICAL CONCEPTS for the Quality Professional

*To my grandchildren:*

*Jamey, Stacey, Caitlyn, and Dean*

# Preface

Many books and articles have been written on how to identify the root cause of a problem. However, the essence of any root cause analysis in our modern quality thinking is to go beyond the actual problem. This means that not only do we have to fix the problem at hand but that we also have to identify why the failure occurred and what was the opportunity to apply the appropriate knowledge so that avoidance of the problem would be the case.

This approach is somewhat new and unique; however, there are tools and methodologies that can help one evaluate the system for prevention. These tools and methodologies focus on structured, repeatable processes that can be instrumental in finding real, fixable causes of human errors and equipment failures that lead to most quality issues. Traditional approaches to this are the Failure Mode and Effect Analysis (FMEA), Advanced Product Quality Planning (APQP), and others.

As good and effective as these methodologies are, we as quality professionals need to go beyond these. For example,

1. Use as much evidence of the failure (problem) to understand what happened before trying to decide why it happened.
2. Always look to identify multiple opportunities to stop the problem (multiple causal factors).
3. When possible, have built-in expert systems that can be used by problem solvers to find the root causes of each of the causal factors.
4. Encourage problem solvers to look beyond the immediate causes and find correctable systemic issues.
5. Encourage problem solvers to find effective actions to prevent the problem's recurrence when all the root and generic causes have been identified. (There is a risk here because of possible interpolation; however, it is worthwhile.)

One will notice (Table P.1) that all these are based on four things: (1) strategy; (2) governance; (3) integrated business processes; and (4) methods with appropriate data. In this book, we focus on the methods, especially statistical ways of solving issues and problems.

However, before we begin our discussion, we must understand some very important reasons why we pursue problem solving and why we use statistics. Generally speaking, when someone asks the question "why problem solving?" it is not unusual to have a response like

- We do not need a problem-solving approach because we have our own approach to solving problems.
- We really do not have any idea about problem solving. This may come in different flavors such as
  - We do not need to get data; we have a feeling of what the problem is.
  - We have a set way of doing this and it is a repeatable process.
  - The process is very complicated and we cannot define it—so we have to use trial and error.
  - We have tried a systematic approach before but it does not work for us.
  - We are doing our best—there is nothing else that can be done.

Obviously, this kind of thinking is flawed. All problems must be approached in a systematic way to make sure that the appropriate problem is investigated and resolved in the most efficient way. Here, we must also recognize that there may be many ways to solve a particular problem, but there is only one approach that will work all the time. That approach is statistical thinking and the use of statistics as much as possible.

**TABLE P.1**

The Four Basic Items for Viewing the New Approach to Solving Root Causes

| | | |
|---|---|---|
| **Strategy** | | |
| Vision, value, and culture | | |
| **Management** | | |
| Executive ownership, decision making, accountability, and appropriate compensation | | |
| **Integrated Business Processes** | | |
| Automated, closed loop, customer relationship management and business intelligence integration, life-cycle management, and communication | | |
| **Method** | **Reporting** | **Research** |
| Data collection, contact management, sampling method, and survey questions | Selection of methodology for data analysis, benchmarking, micro and macro improvements, and dissemination practices | Business impact: financial, operational, constituency links, and use of customer information |
| **Micro Approach** | **Macro Approach** | |
| Identify and resolve special causes | Identify and resolve common causes | |
| Focus on changing individual-specific issues | Focus on solving systematic concerns | |
| Make specific improvements that affect the customer | Make the effort to improve the entire organization | |
| Focus on short-term solutions | Find long-term solutions | |

To illustrate this approach, let me use an analogy using the justice system as it is supposed to work:

- A crime is committed—a rule or a specification has been broken.
- Investigation of the crime and the crime scene is initiated—check out the problem, determine what is appropriate and applicable, and gather clues that will help in prosecution.
- Issue a warrant for the criminal(s) after you have identified the significant few, which you believe affect the output. To do this, a clear definition of the crime must be stated, otherwise the case may be questionable at best.
- Build the case. Use appropriate clues and circumstances to evaluate cause and effect. Statistically speaking you may use design of experiments (DOE), *t*-tests, *F*-tests, chi-square, analysis of variance (ANOVA), and anything else that you deem necessary and appropriate.
- Present the case and state the facts—statistical analysis.
- Present the closing arguments—practical significance.
- Lessons learned—what did you learn and what do you still need to know?

This analogy is, of course, fundamental in understanding that problem solving and the use of statistics are inherently build into the continual improvement attitude of any quality professional in any environment.

In the language of quality, this is, in fact, the classic approach of the traditional **P**lan, **D**o, **C**heck/**S**tudy, **A**ct (PDC/SA) with an additional component which is the **I**ngrain (some call it **I**nfusion and some call it **I**nstitutionalization) of the gain into the organization. This approach is summarized in Table P.2.

Specifically, this book will cover the following:

**Introduction**: *Some Issues and Concerns about Using Statistics.* An overview of some pitfalls that should be considered when undertaking an experiment for improvement.

**Chapter 1**: *What Is Statistics*? explains what statistics is and how it is used in improvement endeavors.

**Chapter 2**: *Data* explains the lifeblood of all experiments. It identifies data and how they are used in an experimentation process.

**Chapter 3**: *Summarizing Data* emphasizes the need for summarizing data and some techniques to facilitate a decision based on sound interpretation of data.

**TABLE P.2**

A Summary of the PDC/SA Approach

| | | |
|---|---|---|
| **Plan** | Identify the problem<br>Identify the tools useful for identifying potential causes | Define the problem in practical terms. Usually, the problems are due to centering or spread<br>Use graphs to illustrate the problem. Remember that a picture is worth 1000 words. Also, do not underestimate the value of observing the process yourself |
| **Do** | Gather evidence (data) to narrow down the number of causes | Use historical and applicable data; use comparative and associative tests such as graphs; *t*-tests; correlation, and regression. Above all, do not underestimate your own experience or of those involved with the process—including operators |
| **Check/ Study** | Check: Verify problem and appropriate tools<br>Study: Use appropriate tools to confirm causation | Use graphs when appropriate and applicable<br>Use screen designs then follow up with fractional and full factorial analysis depending on time, cost, and significance of interactions. Do not be intimidated by central composite designs and surface methodology. Use them; they can help you optimize your results. Whenever possible, use cube plots, main effects plots, interaction plots, and Pareto diagram to see the effects of key factors |
| **Act** | Make the necessary changes | Document what you have done. This may be in a written form or via illustrations; implement necessary training; implement better controls; define the settings of your process control based on the analysis. Above all, make sure that you develop a new maintenance schedule for the new system |
| **Ingrain** | Demonstrate "ongoing" improvement changes | Use control charts, graphs, and capability analysis to demonstrate the "effective change" that has taken place. Once the sustainability is demonstrated, the new process should only be checked periodically or after a new change in the process |

*Special note:* For those who use the Six Sigma methodology, the PDCA model is also applicable. Thus: Plan in Quality equates to Define in Six Sigma; Do equates to Six Sigma's Measure phase; Check equates to Analyze; and Act equates to Improve and Control.

**Chapter 4**: *Tests and Confidence Intervals for Means* introduces the reader to some common tests and confidence intervals for means.

**Chapter 5**: *Tests and Confidence Intervals for Standard Deviations* introduces the reader to some common tests and confidence intervals for the standard deviation.

**Chapter 6**: *Tests of Distributions and Means* introduces the reader to distributions and tests for normality and means.

**Chapter 7**: *Understanding and Planning the Experiment and Analysis of Variance* focuses on specific plans for any experiment for improvement and introduces the reader to ANOVA.

**Chapter 8**: *Fitting Functions* expands the notion of experimentation by dealing with mathematical models such as regression to optimize improvement and understand the relationship among several factors.

**Chapter 9**: *Typical Sampling Techniques* emphasizes the need for sampling and introduces some specific techniques in order to make sure that accuracy and precision of the data are appropriate and applicable for the study at hand.

**Chapter 10**: *Understanding Computer Programs for Design and Estimating Design Power* gives an anthology of designs for ANOVA and estimating power with each approach.

**Appendix A**: *Minitab Computer Usage* explains the most intricate part of the software (the work screen) with specific examples and graphics. It also addresses some of the actual screens for basic statistics and MSA analysis.

**Appendix B**: *Formulae Based on Statistical Categories* provides selected formulas for several categories; for example, parameter, regression, ANOVA, and others.

**Appendix C**: *General Statistical Formulae* provides many common and powerful formulas that may be used in the course of implementing statistics in an improvement environment.

**Appendix D**: *Hypothesis Testing Roadmap* provides a cursory roadmap for selecting specific statistical tests depending on the sample.

**Appendix E**: *Test Indicators* provides indicators for selecting appropriate basic statistic tests, statistical process control charts, and multivariate tests.

**Appendix F**: *Hypothesis Testing—Selected Explanations and Examples* provides the reader with selected additional background information on hypothesis testing along with examples.

**Appendix G**: *When to Use Quality Tools—A Selected List* provides a selected list of tools and their application.

**Glossary** provides a lexicon of statistical terms and concepts that the modern quality professional should be aware of and use in his or her application of statistics, by no means is it an exhaustive list.

**Selected Bibliography** provides readers with some additional current sources for pursuing their own research on the specific tests and methodologies covered in this book.

# *Acknowledgments*

Being in the field of quality for over 30 years, I have come to realize that most people like quality, and they want quality. However, when a professional practitioner tries to explain quality quantitatively, he or she generally falls short of convincing the other person who may be a supervisor, management, customer, supplier, or whoever of how he or she has arrived at the specific decision and how sure that decision makes him or her feel.

Over the years, this was very difficult indeed; however, with the introduction of computers and their accessibility on the work floor and office, the issue of what is common and easy and understandable, as well as applicable, has become a concern for many. The concern is that they have an answer but they are not sure what it means.

To identify all situations and all applications is not possible. That is why I have written this book to help professionals in the application of statistics for improvement no matter what the situation. I had much help in formalizing what is indeed very important and useful for a professional using statistics for improvement. Obviously, I have not covered all issues and all tests available, but with the help of many I believe that what is covered in this book will indeed be very helpful.

As I said, many individuals have helped in crystallizing some of these issues, and I want to thank them for sharing their thoughts. I cannot thank everyone but rest assured that I appreciate all their inputs.

High on the list is Dr. M. Lindsay who introduced me to DOE in manufacturing. Also Dr. J. Framenco who gave me the first opportunity to run DOE in both classical and Taguchi methods at Ford Motor Company.

Dr. J. Kapur and Dr. R. Roy helped in applying DOE in many situations within the automotive industry.

Dr. L. Williams early on was patient enough to answer all my questions about SAS and the specific applications that it offered.

The late Dr. H. Bajaria for his thoughtful comments and interaction. His discussion points are still memorable due to the vivid analogies he used. His contribution to statistical problem-solving discussions as well as the long discussions about the benefits of classical DOE and Taguchi were very helpful.

Dr. R. Munro asked thoughtful and always provocative questions about applicability and appropriateness as well as helping in the selection process of the flow of the book.

Dr. S. Stamatis, my son, who even though had his hands full finishing his own dissertation, was always available to help with computer work but also—and more importantly—to debate and discuss the content of the book.

He always wanted a little more theory, while I was more concerned about the practical side of the content. Thanks, son. I wish you the best in Iowa.

C. Wong, a long-time friend, kept pushing me to write this book. His enthusiasm and belief in me are greatly appreciated.

I also want to thank K. Wong for the long hours of typing previous drafts, especially the statistical formulas. Thank you very much. You were a tremendous help in bringing this work to the finish line.

I also want to thank Minitab, Inc. for giving me permission to use the screens of Minitab® Statistical Software.

A special thanks to Random House, Inc., for allowing me to reproduce a portion of the *Iacocca: An Autobiography* by Lee Iacocca pages 50–52.

I want to thank the producers of this book for making it not only pleasant to the eye but also for improving the graphics and layout of the text to make for better flow and easier understanding.

Finally, I thank my wife Carla for always encouraging me and supporting me in everything I do. Of course, I cannot overlook her general comments and editing throughout the writing of this work. Thanks, Carla J.

# *Introduction*

## Some Issues and Concerns about Using Statistics

There is a great misconception about quality practitioners and the use of statistics in general. There is a prevalent idea that the higher the level of statistical analysis performed on a process, given a set of data, the more positive the results and understanding. That is not always the case. To avoid erroneous results, the following must be addressed at the start of any statistical analysis.

1. **Avoid Falling Victims to the "Law of the Instrument":** The Law of the Instrument states: "Give a small boy a hammer and everything he encounters needs pounding." Some experimenters seem to "suffer" from familiarity of a specialized forecasting technique and seem to use it on every occasion. However, there is no such thing as the ideal method. The "right" statistical technique depends on a number of conditions:
   - Is the purpose of the study clear and practical?
   - What is the accuracy required? Is the acceptable range of the statistical analysis appropriate? What is the level of risk?
   - What about the personnel doing the study—are they available? Do they have the appropriate background? What is their level of expertise and how much time do they have to spend on the study?
   - What is the working budget? Is it flexible? For example: Can you hire outside experts and/or consultants?
   - What kind of data is available?
   - What are management's inclinations? Do they want a highly scientific study or a quick answer?
2. **Use Multimethods:** Gunther (2010) made a study of lucky people. He reported his findings in the *Luck Factor*. One of his findings was that lucky people seemed to base their actions on forecasts derived from both hard and soft data (Corollary 2 of "The Hunching Skill"—Collect "soft" facts along with the "hard"). In statistical analysis, it's a good idea to follow Gunther's Corollary 2. Use a collage of techniques, some quantitative and some qualitative. This approach helps

the study to stand the test of common sense. Too often experimenters get so enamored with a technique, they accept the results without question. This danger is perhaps especially prevalent when using "esoteric" quantitative techniques. (In manufacturing this is very dangerous when one evaluates the process controls for the failures. We do have a tendency to repeat past controls even though they may have worked marginally or not at all, just because they have become comfortable. To avoid this, *one of the techniques you should always use—even though you may not incorporate its results in your findings—is a trend line.*)

3. **Be wary of Transition Periods:** There are certain stages of the product/service life-cycle curve when statistical analysis is most difficult. Transition periods are those periods where the product/service is changing from one stage to another (i.e., from introduction to growth) or when it is undergoing rapid growth or decline or when structural changes are taking place. If you use statistical techniques during these periods, make sure that you adjust the coefficients/formulas with qualitative judgments.
4. **Search for Causal Relationships:** There is the story about an Indian lying down with his ear pressed to the ground. A cowboy rode up, saw the Indian and asked, "What is it?" The Indian replied, "Half hour from here. Wagon. Four wheels. Pulled by two horses. One beige. One roan. Driven by white man in black suit. Black hat. Woman riding next." The cowboy cut him off. "Why that's tremendous. To be able to hear all that." The Indian replied, "Not hear—see. Wagon run over me one half hour ago!"

   Sometimes things aren't what they seem. Make sure you understand the correct causal relationships; if you haven't done so, put together a demand formula (transformation function) (multiple regression) for your specific product or process (sometimes even for the industry). You may not have all the data necessary to "run" the formulas, but the mere attempt of formulation will help you better understand the causal relationships within your company or even your industry.
5. **Consider Potential Competitive Actions:** The classic battle situation between a mongoose and a cobra describes this notion. The two are almost equally matched: the mongoose with its lightning speed and the cobra with its deadly, swift strike. Yet the mongoose almost invariably wins because of its "competitive strategy."

   The two meet—the mongoose feigns an attack. The cobra strikes, fully extending itself. And thus begins the dance of death. But the mongoose, perhaps smarter, has a strategy. After each successive feign attack, the mongoose shortens its distance. The cobra, however, continues to fully extend itself trying to bite the mongoose.

Soon, however, the mongoose's feigned attack is nothing more than a movement of the head; the cobra's strike, however, leaves the cobra fully extended. While the cobra is thus extended and its mobility greatly reduced, the mongoose attacks, crushing the cobra's head with its jaws.

Too many experimenters just do not take into account potential competitive actions. Such forecasts usually are based on the assumption that competitors will be benign—they will continue to do the same thing that they have been doing in the past; for example, when you do benchmarking make sure you take this competitive action into account.

6. **Get Management Involvement:** Management must believe in the statistical analysis if it is to be used. They must be convinced of the "data-driven" solutions. All statistical analyses will always be questionable because of the different motives of management personnel.

   The statistical analysis will be especially suspect if it is not "surprise free," that is, if it differs from what management expects to happen—"conventional wisdom." Therefore, believability will be highly questionable if the analysis differs from the past trend or the firm is operating in a constant change environment where structural stability is under stress. Thus, the less the analysis is surprise free, the greater the need for involvement. Two techniques to get management involved are

   - Have management involved at the outset
   - Communicate as often as possible via formal and informal means

7. **Avoid the Dowser-Rod Syndrome:** Some people claim that people who "witch" for water are using the dowser rod as an excuse for drilling a well in a location where they would like the well to be. In statistical analysis, make sure that you do not arrive at a specific analytical tool that will give you an excuse for pursuing a course of action you would like to follow. Make sure that the statistic is more than a methodological excuse. Avoid wishful thinking coloring your analysis.

8. **Be Careful of Intuition:** Be careful of intuition, especially in areas about which you know little. Occasionally, you may run into a person who has a sixth sense—able to predict what is going to happen. But you find these people only *rarely*. The last person I heard of who could do this was, unfortunately, crucified over 2000 years ago. More common is the type of situation where a person knows an industry so thoroughly that he develops what he thinks is an intuitive sense. But what he does is subconsciously draw trend lines and adjust them for seasonal and competitive behavior, and the like. Many times he

is quite accurate. But then, the so-called intuitive forecasting can get one into trouble especially where a person believes he has a sixth sense, but actually has been good at forecasting because of his intimate knowledge of a particular type of business. When a person believes that he has a sixth sense and starts shooting from the hip, trouble may ensue.

9. **Seek Out—But Scrutinize—Secondary Data:** Much has been written about existing data. Unfortunately, it's hard to find. Although there are a number of sources, here are some of the major ones you shouldn't overlook:

    - Your industry association
    - Libraries
    - Syndicated data sources, such as Mead Data Control. (Spend noon hours talking with representatives.)

    Make sure, however, that you check the authenticity of the secondary data. First, what is the timeliness of the data? Then, what was the character of the authors/agency who wrote the article/conducted the research? Did they have a vested interest in the point of view that they were trying to make?

    Then, if the data was based on a survey, examine these three levels:

    - Level 1. Was it the right universe?
    - Level 2. Was the sample representative of that universe?
    - Level 3. What about the survey instrument and execution itself? Did they seem appropriate? Or were they likely to create bias?

10. **Watch Out for Target Fixation:** One of the dangers of low-level fighter strafing is that pilots tend to become so involved in destroying a truck, tank, etc. that they lose their sense of closure. "That truck, I've hit it a number of times. Why doesn't it blow up?" Just a few more cannon bursts and I'll have him ... And so on. But unfortunately, the pilot gets so wrapped up that he gets too close to the ground. Sometimes you'll get so involved in trying to find a certain bit of information on a particular customer and or product or service that you'll spend a disproportionate amount of time in the search.

    Avoid target fixation by planning and budgeting the statistical analysis process. This is just common, managerial sense. But a short review won't hurt. Understand (or determine):

    - The accuracy required. What is the magnitude of the decision resting on this forecast? What is the acceptable range of the forecast accuracy in terms of dollars and/or units?
    - When must the forecast be completed?

- What kind of budget do you have to work with in terms of personnel time and money?

Then lay out the steps that you will have to complete in order to finish the forecast. Why not use an arrow diagram to help organize your thinking? On each activity specify the time and resources required. This will help you avoid spending excessive time on noncritical areas.

If you're having someone else do the forecast, make sure that the person knows, in specific terms, what you want accomplished (see above). Avoid such loose terms as "determine potential." Rather, let that person know the accuracy required, how the tasks fits into the forecasting process, and what actions will be taken as a result of the forecast. It might not be a bad idea to also have the person lay out the planned procedure on an arrow diagram.

11. **Don't Wait for All the Facts:** Here's an excerpt from Lee Iacocca's book, *Iacocca*, New York: Bantam Books, 1984, pp. 50–52. Although he's referring specifically to decision making, the general principle applies to "putting the forecast to bed."

> If I had to sum up in one word the qualities that make a good manager, I'd say that it all comes down to decisiveness. You can use the fanciest computers in the world and you can gather all the charts and numbers, but in the end you have to bring all your information together, set up a timetable, and act.
>
> And I don't mean act rashly. In the press, I'm sometimes described as a flamboyant leader and a hip shooter, a kind of fly by the seat of the pants operator. I may occasionally give that impression, but if that image were really true, I could never have been successful in this business.
>
> Actually, my management style has always been pretty conservative. Whenever I've taken risks, it's been after satisfying myself that the research and the market studies supported my instincts. I may act on my intuition—but only if my hunches are supported by the facts.
>
> Too many managers let themselves get weighted down in their decision making, especially those with too much education. I once said to Philip Caldwell, who became the top man at Ford after I left: "The trouble with you, Phil, is that you went to Harvard, where they taught you not to take any action until you've got all the facts. You've got ninety-five percent of them, but it's going to take you another six months to get that last five percent. And by the time you do, your facts will be out of date because the market has moved on you. That's what life is all about—timing."
>
> A good business leader can't operate that way. It's perfectly natural to want all the facts and to hold out for the research that guarantees a particular program will work. After all, if you're about to spend $300