3

SUCCESSFUL PLANT PROBLEM SOLVING

3.1 INTRODUCTION

Before beginning a discussion on how one conducts successful engineering problem solving, perhaps a definition of the activity is appropriate. Engineering problem solving is defined as the application of *engineering principles* to allow *discovery*, *definition*, and *solution* of plant operating problems in an expedient and complete fashion. The *discovery* and *definition* phases of problem solving are often ignored or considered obvious or unimportant. However, these phases prevent small problems from growing into large problems and allow the problem-solving phases to be done in an expedient fashion. Finding the problem involves sorting through the mass of laboratory and process data to uncover deviations that may only be a slight departure from normal, but which have the potential to grow into large deviations. Defining the problem involves developing a quantitative description of the problem specifications.

Successful engineering problem solving will always involve the following:

- A *daily* monitoring system.
- A *disciplined* (not intuitive), *learned* (not inherited) engineering problem-solving approach.
- The ability to distinguish between problems requiring technical problem solving and those only requiring an expedient answer. The ability to determine how detailed a technical analysis should be is also required to

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efficiently solve plant process problems. This is later referred to as *optimum technical depth*.

3.2 FINDING PROBLEMS WITH A DAILY MONITORING SYSTEM

In order to successfully find and define problems, the problem solver must obtain and maintain a historical database. The database can be maintained by using several different sources. The *managerial objective* will also be important. The managerial objective is defined as the goal that management has defined for the particular process. This goal will vary depending on the age of the process, staffing of the location and the value added by the process to name a few. Table 3-1 shows a grid of both managerial objectives and sources of data.

As an example for the use of this table, assume that a well established process is producing a commodity chemical. As a general rule, a low value is added to commodity chemicals. That is, the difference between the product revenue and the cost of production is very small. Management might elect to staff this operation so that the organization could only respond to established significant problems. Thus the managerial objectives might be characterized as Minimizing Routine Work and Maximizing Variable Retention. In this case, the number of process variables to be retained would be maximized. As shown in Table 3-1, Computer Data Storage would be the desired source of data to fit this objective. If a problem developed, the problem solver could then go back and use the stored data to attempt to resolve the problem. He might find this difficult due to the vast amount of data that must be analyzed. In addition, the data sources

Table 3-1 Sources of historical data

	Managerial Objective				
	Minimize	Maximize Finding	Maximize Trend	Maximize Variable Retention	
Source	Routine Work	Hidden Problems	Spotting	Volume	Key[a]
Computer data storage	X			X	
Computer or hand graphs			X		X
Delta data graphs[b]		X	X		X
Communication with hourly workers		X			
Visual observation of field equipment		X			

[a] The concept of "key variable retention" involves retaining the graphs or delta data graphs of only the key variables, whereas "volume retention" involves a data source that relies on maintaining values of every variable.

[b] "Delta data graphs" are the difference between actual values and a theoretical or established value. An example of such a plot is shown in Fig. 3-1.

entitled Communication with Hourly Workers and Visual Observation of Field Equipment would likely not be available since people's memory might have faded and changes might have occurred in the field equipment.

On the other hand, if the process being considered is an unproven process and/or is a high value added process, management might elect the objective of Maximize Finding of Hidden Problems. In this case, the problem solver would use Delta Data Plots, Communications with Hourly Workers and Visual Observations of Field Equipment as his data sources. It is likely that the main source of historical data would be the trend graphs or delta data graphs. Of course, in this case, the computer would still be used to store all process variable data. However, it would not be the primary source of data for the problem solver. While this objective allows for finding problems quickly, it likely will require more technical and/or operations staffing.

In the two cases cited above there are implicit assumptions. In the case where the managerial objective is Minimizing Routine Work and Maximizing Variable Retention, the implicit assumption is that essentially all process problems that occur can be readily solved without a detailed problem analysis. In the case where the managerial objective is to Maximize Finding of Hidden Problems, the implied assumption is that essentially all problems will require a detailed problem analysis.

If graphs are to be used in any of the cases shown in Table 3-1, they should be drawn, reviewed, and monitored on a daily basis. To monitor the process by preparing these graphs only once a week defeats the purpose of finding problems or spotting trends.

This daily monitoring system should be designed to allow the problem solver to monitor process variables by incorporating several variables into process models that summarize the operation of each section of the process. An example of this is shown in Figure 3-1. In this figure, reaction kinetics are

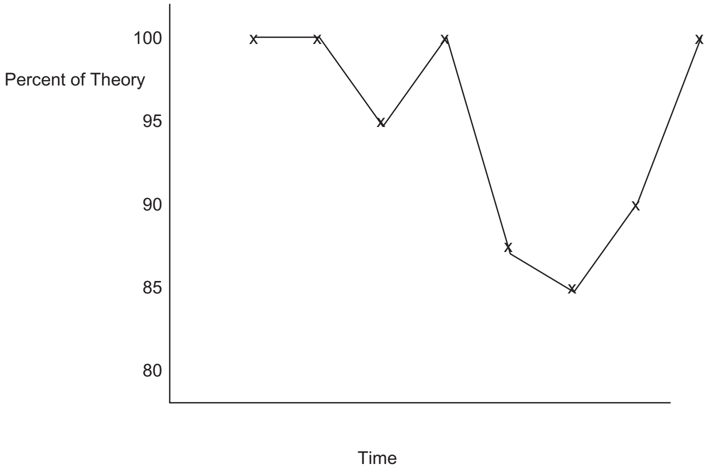

Figure 3-1 Essential variable (reactor kinetics) percent of theory vs. time.

expressed as a percentage of theoretical. Significant deviations from 100% are indicative of process impurities, catalyst contamination, or inaccurate process measurements. Thus with only a glance at the figure, it is possible to assess the status of the reactor section of the process.

Even a cursory look at Figure 3-1 will raise the question of when the problem solver declares that a problem has occurred. Is it the first drop in kinetics or the second? For each variable that is graphed, there should be a designated point at which, if the actual value exceeds or doesn't meet a certain limit, will indicate to the problem solver that a problem is likely occurring. This will be discussed later and is referred to as the concept of a "trigger point."

One source of historical data requiring elaboration is discussions with operating, mechanical, and laboratory hourly personnel. Even if the problem solver is an operator, it is likely that the observations of other operators, mechanics, or laboratory technicians will be of value. Their observations may be highly qualitative but at the same time very meaningful. For example, discussions with laboratory personnel revealed that a standard Millipore filter test used to determine the level of solids contamination in a hydrocarbon resulted in "fusing" (melting together of the two parts) of the Millipore filter container. This plastic container was known to be inert to the hydrocarbon and fusing had never been encountered before. Based on the laboratory technician's comment that the container was fusing, an investigation was initiated. This investigation showed that the hydrocarbon was contaminated with methanol. The plastic used in the Millipore apparatus was soluble in methanol. Small amounts of methanol would cause reduction of the melting point of the plastic and the fusing of the two parts of the container. The realization that the hydrocarbon was contaminated with methanol provided a strong clue for developing a hypothesis for determining the source of the known hydrocarbon contamination.

In this day and age, with multiple means of "nonpersonal" data acquisition techniques, the communications flow must be cultivated and nourished primarily by the problem solver. When it comes to cultivating communications, the best mode is face to face dialog. Telephone interactions also provide an acceptable means of communications. Written communications, including e-mail or text messaging, tend to be quick and efficient, but can often lead to misunderstandings and inaccuracies.

The observation of field equipment is accomplished by walking through the process plant and both looking at and listening to the equipment to detect any differences since the last walk through. For example, a loud noise that appears to be emanating from a process vessel might be indicative of the condensation of vapor inside of the drum. A problem solver on a walk-through may observe a new sample connection which, on closer examination, may appear to be installed in such a fashion that it will not give a representative sample. These observations by themselves may not be problems, but they are sources of data that can be considered when other problems are detected. The problem solver should make notes on anything that seems different. These notes will provide data with a time stamp that can be used for future references.

It is inadequate to only record data and collect observations. The examination of the data can best be made with "trigger points." "Trigger points" are limiting values of either laboratory analyses, instrument readings, or computed variables. If the variable being monitored is outside of these limits, the successful problem solver will declare that a problem exists and begin to solve the problem. It should be emphasized that the successful problem solver will find and define the problem well before it becomes a major problem. Finding and defining the problem are the first steps toward problem resolution. Resources may not be available to resolve the problem completely; however, management will recognize that a problem has been uncovered. The "trigger point" approach is similar to that used by the medical profession. Medical and laboratory tests such as blood pressure, cholesterol level, and hemoglobin levels are used to spot minor problems before they become major problems.

Trigger points, whether used in the medical field or in a process plant, are based on statistics. This book does not cover statistics in detail. However, to introduce the concept of trigger points, it is necessary to explain two statistical functions. For the purpose of this book, the two important statistical functions are as follows:

- *Average*: This is determined by adding up the values of a variable and dividing by the total number of values. It represents a middle value of the variable. The average can also be calculated using a spreadsheet.
- *Standard Deviation, or Sigma* (σ): This is determined by a more complicated function than the average. Fortunately, this function is also available in any spreadsheet. The spreadsheet calculates the σ using all of the values that were used for the average. It represents the range of the values. The greater the σ, the wider the range of data. This is illustrated in Figure 3-2.

As shown in Figure 3-2, two sets of data may have the same average, but widely different distributions. Figure 3-2a has a very broad distribution and thus a large σ. On the other hand, Figure 3-2b has a very narrow distribution and thus a small σ. In a process plant, this is manifested in a process with a narrow distribution by a trigger point that is close to the target operating condition.

The standard deviation is often expressed as a multiple of the calculated value such as 1, 2, or 3 σ. Standard deviation is abbreviated as σ. The higher the multiple, the more data is included in the range, as shown in Table 3-2. Thus the width of the data range is a function of both the numerical value of σ and the number of standard deviations. For example, if the average value of a pressure in a process is 100 psig and the 1 σ of the measured values is 5 psig, it can be concluded that 68% of the measured values will fall into a range of 95 psig to 105 psig. However, if the problem solver wants to determine the

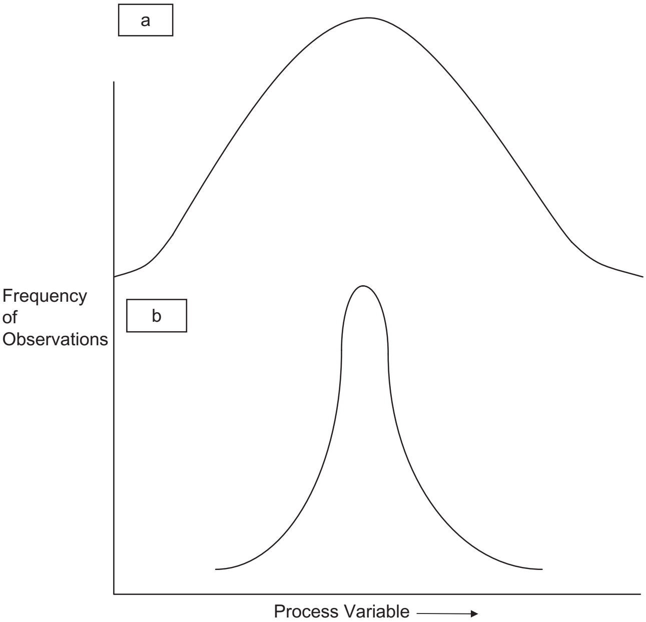

Figure 3-2 Affect of σ. (a) Large σ; (b) small σ.

Table 3-2 Percentage of values in the range

Width of Range	% of Values in Range
±1σ	68
±2σ	95
±3σ	99+

range of pressures that will include 95% of the data (2σ), he would multiply the σ (5 psi) by 2. The pressure range will be 95 ± 2σ or 95 ± 10. Thus if 95% of the data is included, the pressure range will be 90 to 110 psig.

It is clear from Table 3-2 that the multiple of σ is important in determining the percentage of the values that falls within any range. A trigger point that is based on 3σ will include essentially all of the data and cause problems to be ignored. However, if a value falls outside of this range, the problem solver can be 99+% confident that a problem is occurring. Conversely, a trigger point based on 1σ means that there is only a 68% chance that a problem is really occurring. Thus with a trigger point set at ±1σ, 32% of the announcements that a problem exists will be false alarms. As discussed later, it may be completely acceptable to have a relatively high frequency of false alarms in order to find problems at an early point.

One of the most important factors to recognize when setting trigger points is that there is a difference between using statistics to control a process and using statistics to find problems. Control statistics require that the process be greater than 3σ from target before changes are made. This implies that there is a greater than 99% confidence level that there has been a real change in the process as opposed to process variability. The successful problem solver cannot wait until he is greater than 99% confident that there is a process problem. For example, very few car owners wait until they are greater than 99% confident that they have an automobile problem before they begin a problem-solving activity.

Trigger points can be set for the following different types of variables:

- *Theoretical/Laboratory/Pilot Plant Demonstrated*: Each of these variables would have a "lumped parameter constant" (to be discussed later) that can be calculated from plant data. These constants can then be compared to similar constants demonstrated in the laboratory or pilot plant or that can be developed from theory. Examples of these are reaction rate constants (demonstrated in the laboratory or pilot plant) or fractionation tower tray efficiencies (demonstrated by theoretical calculations).
- *Plant Demonstrated*: These include variables that are equipment-related, such as production, purity, slurry concentration, or additive controllability. They can only be demonstrated in a commercial size plant where full-scale equipment is utilized.
- *Vendor Demonstrated or Guaranteed*: These will be almost exclusively equipment items. These variables will include items such as highly specialized valves, volatile removal equipment, or heat exchange equipment.

Statistical techniques can be utilized to set trigger points. For example, in a process demonstrated to have a catalyst efficiency of 5000 with a 1σ of 200, a low trigger point of 4900 would be ludicrous. Conversely, a trigger point of 4400 would cause many problems to be ignored. Obviously, determining a meaningful standard deviation is mandatory if the trigger point approach is to be utilized.

It is likely that in an industrial process, the standard deviations of essential variables are not well known. Rather than doing elaborate laboratory statistical studies, a more expedient approach involves developing approximate standard deviations and allowing the daily process monitoring to help determine the real commercial standard deviation. This approximate standard deviation can be determined by examining at least 20 values of a variable obtained while the plant under consideration is operating at steady state and calculating σ from the equation below:

$$\sigma = (V_{\max} - V_{\min})/6 \tag{3-1}$$

where

$V_{\max}$ = maximum value of the variable in the data set
$V_{\min}$ = minimum value of the variable in the data set

The σ can also be calculated more exactly using the algorithms available in spreadsheets.

In a new process, there is great value in setting the standard deviation and/or standard deviation multiple on the low side and attempting to explain as many deviations as possible. The tightening of the standard deviation for a new process will cause the maximum number of problems to be uncovered while management's attention is focused on getting the new process operational and adequate resources are available to solve problems. The opposite approach, that is, having a large standard deviation and/or multiple, will result in an apparent good startup followed by a multitude of problems 6 to 12 months later. These problems that occur in 6 to 12 months were actually present during the startup as small problems that went undetected due to the large standard deviation and/or multiple being utilized.

While problem solvers generally think in terms of negative deviations (failure to achieve a target), positive deviations must also be considered. For example, a critical heat exchanger that had a known heat transfer coefficient of 120 ± 10 BTU/hr-ft^2-F suddenly began operating with a coefficient of 150. An investigation is warranted to determine what had happened to cause an apparent new base line. This investigation of positive deviation will often lead to new or improved operating procedures.

While the actual setting of trigger points depends on the process as well as the individual company, Table 3-3 shows some suggested trigger points. It should be recognized that each of these is based on a statistical approach once a standard deviation has been developed or approximated.

Table 3-3 Suggested trigger points

Magnitude of Variable on Profits	Trigger Point	Probability of Type 1 Error (%)[a]
Very significant (or new process)[b]	1σ	32
Moderate	2σ	5
Insignificant	3σ	<1

[a] A Type 1 Error is the probability that a problem would be declared when no problem really existed. For example, if the trigger point criterion is set at 1σ, there is a 32% probability that a declared problem is really just a normal fluctuation in the process. However, there is a 68% probability that a real problem exists.

[b] Items that could cause a very serious upset (e.g., plant shutdown) should be evaluated using a one sided test against a criterion of being 60% or less sure that you are right. Thus, a trigger point of only 0.3σ could be important.

In summary, the key concepts in the use and the definition of trigger points are as follows:

- They should be based on statistics and theoretical values when possible.
- The criterion for declaring that a problem exists is different from the criterion for taking control action.
- The criterion for declaring that a problem exists will be a function of severity of the problem. In addition, the point on the learning curve for specific processes should be considered.
- Positive deviations must always be considered.

Another concern involved with the operation of a full-scale commercial unit is that some problems can be caused by transient process upsets. An adequate explanation of these upsets will usually require extrapolation to steady state condition. For example, an impurity is present for only 30 min in the feed to a reactor with a residence time of 3 hr, and causes the conversion to drop 2%. Determination of the seriousness of this feed impurity will require extrapolation to steady state conditions. The approach to developing a simplified dynamic model is discussed in Chapter 10.

While the daily monitoring system has been discussed primarily in process engineering terms, it can also be used for following mechanical equipment. One of the essential areas that can be monitored is "mean time between failures." This is the time that a piece of equipment is in service before it fails. Well-kept records will allow operators to determine whether there is any change in the failure history of a piece of mechanical equipment. In many process plants there is a strong relationship between the process and the mechanical equipment, so the problem solver should be careful that he does not exclude events that are occurring in the plant because they are not strictly in his area of training or specialization. For example, a decrease in mean time between failures of a mechanical seal may be related to the presence of very small particles in the seal flush fluid. The presence of these particles may be related to some change in process conditions.

The implementation of an effective daily monitoring program can be established using the information discussed above along with the following guidelines.

1. Pick 6 to 10 essential variables and graph then (by computer or hand) on a continuous daily basis using delta graphs and theoretically determined target values. Combine as many variables as is justified based on theory into single graphs. For example, the graph shown in Figure 3-1 combines such variables as catalyst efficiency, reactor residence time, production rate, reactor temperature, and reactor pressure into one graph.
2. Establish positive and negative trigger points for each variable. Compare the actual value to the trigger points on a daily basis.

3. On a daily basis, either obtain comments from others or observe the process and follow up on any unusual comments or observations.
4. Visually observe all equipment in the field at least weekly.
5. Store the essential variable plots so that this information can be easily accessed.

3.3 SOLVING PROBLEMS WITH A DISCIPLINED AND LEARNED PROBLEM-SOLVING APPROACH

A disciplined and learned problem-solving approach is a technique that allows one to determine if the problem really occurred, specify the problem in quantitative terms, and resolve the problem accurately and quickly. The approach discussed here differs significantly from techniques discussed in traditional problem-solving courses. The approach discussed in this book emphasizes using techniques that will verify whether the problem really occurred. Many problems presented either are not real problems or are radically different from the way they were first described.

In addition, this book emphasizes the need to use engineering principles when formulating a hypothesis to explain the problem. In the void problem described earlier, the relationship between voids and production rate is an idea or vision. A scientifically correct hypothesis would be developed by exploring the following logic path along with appropriate calculations. This logic path is as follows:

1. Voids are caused by immiscible volatiles.
2. These volatiles are present due to either or a combination of excessive immiscible volatiles in the feed or from a steam leak, poor mass transfer, and/or lack of residence time in the dryer.
3. At this point additional data could be collected and hypotheses could be developed that explain the data and observations associated with the voids on this specific grade.

The approach in this book also emphasizes that any hypothesis must be confirmed with a plant test, through calculations, or by making “directionally correct changes.” A successful plant test is one that conclusively proves or disproves the hypothesis. The concept of confirming a hypothesis by making directionally correct changes will be discussed later. The approach in this book emphasizes that a problem solution must not create new problems.

The *Disciplined, Learned Problem-Solving Approach* consists of the following five steps:

Step 1: Verify that the problem actually occurred. Communications in an operating environment are almost always second- or third-hand

and are often highly garbled. The problem solver must have a means to reduce the confusion at this point.

Step 2: Write out an accurate statement of what problem you are trying to solve.

Answers to the following questions may be helpful:

- What happened?
- When did it happen?
- Where did it happen?
- What was the magnitude of the problem?
- What else happened at the same time or shortly before?
- What actions are you planning?

Step 3: Develop a theoretically sound working hypothesis that explains as many specifications of the problem as possible.

Step 4: Provide a mechanism to test the hypothesis.

Step 5: Recommend remedial action to eliminate the problem without creating another problem.

The problem verification phase may be the most overlooked part of this five-step procedure. The problem often arrives at the problem solver so jumbled that the best approach is to go directly to the "horse's mouth." For example, by talking to the operator who is having an equipment-related problem or to the laboratory technician who got a strange result, the problem solver can find out exactly what was observed. He will often find that the real problem is considerably different than what was described in an e-mail that he received. Problem verification may also take the form of data verification. While this is the subject of a later discussion, it should be noted here that application of engineering principles can often eliminate a problem by determining whether the alleged problem was caused only by a defective instrument. For example, an engineer sent to investigate the poor operation of a 40 psig steam desuperheater found that the measured steam temperature was below the temperature of 40 psig saturated steam and yet water did not appear to be present in the steam. Specifically, the measured temperature of the 40 psig steam was 280°F. The boiling point of water at 40 psig is about 286°F. Since this is a theoretically impossible situation, he began to investigate the accuracy of the instrumentation. He determined that the steam temperature instrument had been incorrectly calibrated.

The person directly involved with the problem can usually be helpful in the problem specification phase (step 2). However, his knowledge base may not allow him to formulate technically sound hypotheses, although he would normally do so. At this point, it is important to focus on the activities of step 2 (writing an accurate specification of the problem). While this description does not have to be a formal document, shortcuts or even shorthand meant to facilitate a quick answer will be counterproductive. The problem statement

Table 3-4 Problem specification example

SHORT TITLE OF PROBLEM____________________

DESCRIPTION OF EVENT (make sure that step 2 is utilized to provide a complete problem description)____________________

____

____

____

____

____

____

HOW THE PROBLEM WAS DISCOVERED (was it by data plotting, operator discussion, etc.)____________________

____

____

PRELIMINARY PROBLEM ASSESSMENT
COST OF PROBLEM (HIGH, MODERATE, LOW)____________________
IS IT AN OPERATING OR TECHNICAL PROBLEM____________________
IS THERE AN OBVIOUS IMMEDIATE FIX____________________
IF YES, WHAT IS PROBABILITY OF SUCCESS____________________
IF NO, WHAT AMOUNT OF EFFORT IS INVOLVED
IN PROVIDING A FIX?____________________
ARE YOU ACTIVELY WORKING ON THIS PROBLEM____________________

should be as short as possible while still including pertinent data. There is great value in writing out the problem specification using a structured approach. The structured approach provides a means to uncover gaps in the data. In addition, the writing process forces one to clarify data and thought processes.

Table 3-4 shows an example of a problem statement format that could be used. The key part of this format is the problem statement (i.e., the description of the event). The other parts of this format may or may not be of value depending on the organization needs.

The purpose of this format is to provide a simplified communication tool between the problem solver and different managerial layers, and to provide a format to allow the problem solver to both state the problem in problem-solving terms and assess the severity and solution difficulty of the problem.

While this form is only presented to serve as an example, there are two important concepts involved in using this or similar forms. The form should be kept as simple as possible. In addition, the tendency of management to review and edit all documents must be avoided. It should be remembered that this form is only a device to advise management of the status of problem-solving activity in the problem solver's realm of responsibility. The involvement of bureaucracy or any type of editing will be counterproductive and will often reduce the desire of the problem solver to use this technique.

The development of a theoretically sound hypothesis (step 3) to explain the problem is an essential concept in allowing industrial problems to be eliminated. A cause-effect relationship does little good unless the cause can be eliminated or understood. For example, in the void problem discussed earlier, reduction of the production rate only masks the problem rather than eliminating the problem. An example of a theoretically sound hypothesis for this problem is as follows:

> There is a condensate leak causing water to flow from the steam side of the indirect dryer to the polymer side. This water is trapped in the pores of the polymer flakes. It is not removed when it is heated in the extruder because the extruder does not have a vent. As the particle is cooled, the water condenses, forming a second phase in the polymer particle. This second phase is what causes the discontinuity in appearance.

This hypothesis must be tested against plant data, but it could explain both the appearance of voids and the sensitivity to rate. As the production rates and heat input requirements are increased, the steam pressure on the dryer would have to increase in order to provide the temperature-driving force necessary to provide more heat input. This increase in steam pressure would create more leakage potential.

Chapter 6 provides more information on how hypotheses can be formulated. The development of theoretically correct hypotheses will involve the application of engineering principles. Some of these applications are described in the following paragraphs.

Unit operations and/or equipment design calculations can be used to formulate hypotheses associated with pump or compressor motor overloading. For example, changes in the pump or compressor horsepower requirements that occur as the composition changes might be used to determine why a motor overloads. Another example is that the calculation of the amount of condensate produced from a steam turbine might be used to show that a steam trap was being overloaded, resulting in the poor performance of a heat exchanger.

Unsteady state accumulation calculations that allow analysis of a process in a dynamic mode could be used to determine how fast propane builds up in a polypropylene process. These calculations could also be used to determine how many displacements of a system are required to achieve a given degree of cleanliness during a transition or startup operation.

Mass and energy balances could be used to analyze steady state or dynamic operations. Examples of the use of these balances for dynamic operations are:

- How hot would the wall of a reactor become if heat transfer failed?
- How long could a process operate without cooling water?

The development of a theoretically correct working hypothesis is mandatory to reduce the unlimited number of hypotheses to the few that make sense. Problem solving that is not based on theoretically sound hypotheses will degenerate into unstructured brainstorming. Unstructured brainstorming quickly becomes a contest to determine who can generate the greatest number of hypotheses (sound or unsound).

As the next step (step 4) is addressed, the definition of a successful plant test must be considered. A successful hypothesis test is often thought of as one that proves the hypothesis is correct. However, disproving a proposed hypothesis is as valuable as proving one. Therefore, the definition of a successful hypothesis test is a test that either proves or disproves the proposed hypothesis conclusively. A failed hypothesis test is simply one that is inconclusive. Whether the test proves or disproves the hypothesis, the results of the test must be documented. Even for a test that disproves the hypothesis, documentation is important. This will avoid any chance of repeating the test later. This subject is covered in greater detail in Chapter 12.

The mechanism to test the hypothesis can consist of a plant test of new operating conditions, an increase in data collection frequency and/or new data, a series of calculations, or a temporary mechanical fix.

Regardless of which mechanism is selected to test the hypothesis, a great deal of salesmanship will be required to obtain the necessary cooperation from all parties that are involved. The first meeting in which the hypothesis test is proposed may be the problem solver's first encounter with the individual who originally uncovered the problem. Regardless of whether this is true or not, the carefully prepared problem statement and a statement of the theoretically correct working hypothesis will be very beneficial at this point. These two documents, along with the proposed hypothesis test, will provide an outline of the following:

- What problem are you trying to solve?
- What is the working hypothesis?
- How do you plan to prove the hypothesis?

The mode to a successful hypothesis test often lies in the hands of the hourly personnel. If the hypothesis is to be demonstrated by a plant test or by any technique that involves the hourly work force, the need to communicate the goals of the test must not be overlooked. This will also be an opportunity to explain the theoretically correct working hypothesis. This pretest communication is an excellent opportunity to teach and train as well as to obtain support for the test. A test that fails because, allegedly, "The operator did not want it to succeed," usually indicates that there was inadequate communication with the operator. The successful problem solver will always be backed by the hourly work force, who also want the test to be successful. Post-test communication is also of value. Such items as the test results, the conclusions, and future plans will help ensure future positive results.

While a plant test is a typical approach to testing a hypothesis, increased data collection can also be used as a test mode. While this appears to be an obvious statement, the existence of highly specialized techniques for obtaining additional data should be considered. Examples are as follows:

- Temperature measurements using infrared detectors can be used to either supplement and/or confirm existing instrumentation.
- High-speed data acquisition devices can often be of benefit in determining the exact sequence of events.
- A specialty designed venturi flow meter can be used to detect the presence of two-way flow in a pipe.
- X-ray pictures of equipment can be used to confirm the presence of a plugged downcomer or a damaged fractionation tray.
- Qualitative laboratory tests can be used to confirm the presence of an element that could only be present if an O-ring were failing.

The important considerations are to use all the resources available and to think outside the box to allow the proposed hypothesis to be conclusively tested.

While it is similar to a plant test, a temporary mechanical fix can be used to provide a test of a hypothesis. This approach provides a circuitous route to proving or disproving a hypothesis. In cases where a plant test is undesirable or would require an excessive amount of time, a temporary mechanical fix may allow confirmation of the hypothesis. The problem solver will use logic prior to the mechanical fix to specify what criteria would be required to demonstrate that the hypothesis was correct. The logic might be stated as "If the hypothesis is true and the proposed mechanical fix is made, the following will be observed ________." If the anticipated results are obtained, the hypothesis is confirmed with some degree of certainty. However, there is always the possibility that the hypothesis was wrong and the mechanical fix, while providing the anticipated results, did so because of a different hypothesis than the one proposed. A specific example of this approach is discussed in Chapter 4.

Once a proposed hypothesis has been demonstrated to be true, the problem must now be eradicated (step 5). The three keys to step 5 (recommend remedial action to eliminate the problem without creating another problem) are as follows:

1. In order to avoid creating another problem with the solution to the initial problem, a thorough potential problem analysis should be conducted. A potential problem analysis is a technique for visualizing what problems may occur if the recommended solution is implemented. Once a potential problem is discovered, consideration can be given to eliminating or ameliorating the problem via preventative or contingency actions. This analysis should also include safety aspects.

2. Make sure that the problem solution is the simplest one that will work. Keeping things simple is even more important in problem solving than in plant design. Make sure that, in attempting to provide a perfect solution, the solution's complexity does not create a trap.
3. Make allowances for follow-up. New operating or maintenance techniques will require a great deal of nagging, hand holding, and coddling to keep them from being forgotten or ignored.

3.4 DETERMINING THE OPTIMUM TECHNICAL DEPTH

Any discussion of optimum technical depth is meant to apply to those process problems that require serious engineering considerations. There are many process plant problems that are best solved by intuitive judgment and experience-based know-how as discussed in Chapter 1. Some of these manifest themselves in emergency and startup situations. In those situations, there is no question of optimum technical depth. Things must be done quickly with little time for introspective analysis. The concept of technical depth does not mean calculations or analyses performed by a graduate engineer, but rather calculations or analyses performed by an operator or process specialist with some training in technical calculations.

For those problems that require a more in depth analysis, there will always be a question of the required technical depth. For the purpose of this discussion, *optimum technical depth* can be defined as "the ability to compromise between expediency and thoroughness in order to solve a process problem in a minimum amount of time." This definition is shown schematically in Figure 3-3.

This is an exceptionally difficult area to quantify. It will vary greatly from company to company. Even in the same company different divisions appear to have different standards. A few definitions are required before proceeding further:

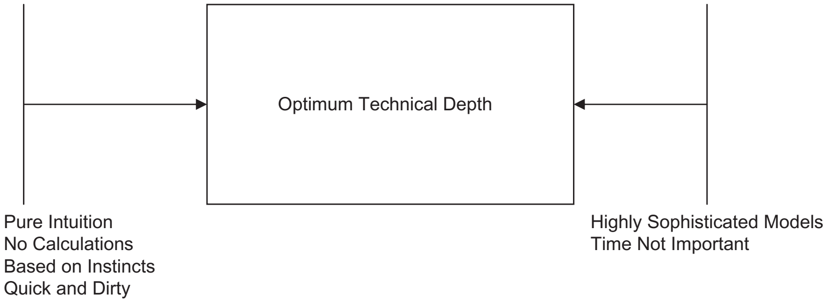

Figure 3-3 Optimum technical depth schematic.

Confidence level is defined as the probability that the recommended problem solution will completely eliminate the problem without creating another problem. There are two different confidence levels to be considered. One is the required confidence level as suggested by management. The other is the probable confidence level as assessed by the problem solver. In order to avoid misunderstandings, the probable confidence level should be greater than the required confidence level.

Project execution time is the amount of time required from the time that the problem solver begins to work on the problem until the problem is solved. This involves time for data collection, data analysis, and implementation of operating changes or installation of mechanical equipment. Obviously this can be as short as a few days to as long as several months.

In spite of the difficulty in quantifying optimum technical depth, the problem solver should give consideration to this variable prior to initiating problem-solving efforts. Some suggested guidelines that may help in quantifying the optimum technical depth are provided in the following paragraphs.

The probable confidence level that the problem solution is correct is directly proportional to the technical depth involved in the problem-solving activity. For example, a pressure drop calculation that assumes the length of the line is about 200 ft is much less accurate than a calculation based on line measurement and a count of the number of fittings.

The required confidence level in an industrial environment is much lower than that in an academic or research environment. Courtrooms are filled with examples of alleged inadequate required confidence levels within the pharmaceutical and medical research fields. In an industrial environment where product liability is not an issue, the daily cost of the process problem often dictates the need for a lower required confidence level. The exception to this is where safety or product liability is involved. In these cases, there is a need to have a high degree of confidence that the urgency to solve a process problem does not create a product liability or safety-related problem.

The required confidence level is directly proportional to the cost and/or the execution time of the solution. Often, the solution to a process problem involves the engineering and construction of additional facilities. This can require a period of 12 to 48 months, depending on the complexity of the design. These facilities can often be very costly. If the chosen problem solution will require additional facilities, the problem solver should have a great deal of confidence that the revisions will result in a true problem solution. On the other hand, there are problem solutions that require minimal cost and can be installed quickly. These will require a lower degree of confidence prior to installation.

The required confidence level is also directly proportional to the cost of the problem, that is, the required confidence levels for solutions to costly problems are higher than those for less costly problems. In an industrial environment, costly problems also get the greatest visibility. That is, they get more management attention and, as such, require a higher degree of confidence in the problem solution. The less costly problems that require a long execution time or involve a large expense for equipment also require a high confidence level in the chosen solution. The less costly problems that can be solved by a quick, low-cost fix do not require as high a confidence level.

Unfortunately, the very expensive problems often require a detailed technical analysis. Since they are expensive, they place a great deal of pressure on the problem solver to develop a quick fix. Rather than doing the required technical analysis, the problem solver often submits to the temptation to "try something." He then finds himself spending some of his limited amount of time implementing the "something" multiple times rather than doing a detailed technical analysis.

Another aspect of assessing the optimum technical depth involves estimating the project execution time. For typical engineering projects, most industrial companies have well-established project execution times. However, for problem solving, these engineering and construction guidelines will likely not be applicable. The problem solver is the best equipped person to make an estimate of the work that needs to be done and the amount of time and resources that will be required. Once the number of man-days for completion of the project is known, the manning can be estimated. As a general rule, if the estimated project execution time exceeds 3 months, it will be desirable to increase the manning so that the execution time can be reduced to 3 months or less.

There is always a minimum degree of confidence that is acceptable regardless of the cost of the problem, the cost of project execution, or the length of project execution. It would seem that one should be at least 70% confident of the problem solution before it is proposed.

These concepts are illustrated in Figure 3-4. In this figure, the required and probable confidence levels are shown on the *y*-axis. The *x*-axis is the

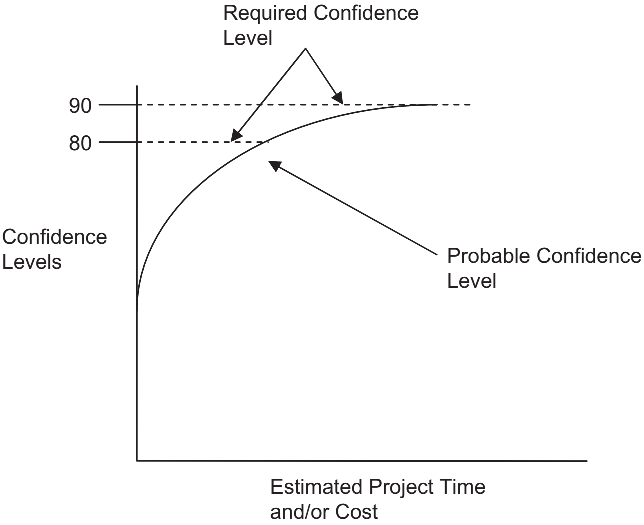

Figure 3-4 Estimated project time and/or cost.

project execution time and/or project cost. Thus as the project execution time and/or the project cost increase, the probability of success also increases. Two levels of required confidence are shown (80 and 90%). The required confidence level is set by discussions at the start of the project. It should be recognized that these discussions may start off with generalized statements such as "Just get it right," or "Do something quick." These can be translated into required confidence levels that provide some idea of what degree of certainty is required before a recommendation is presented. Obviously these are very subjective evaluations. However, the time that it takes to carry them out will eliminate future disappointment when recommendations are presented. This effort will also allow the problem solver to indicate to management whether the project can be accomplished with the required confidence level within the time and cost constraints that have been determined.

As indicated earlier, the goal of any problem-solving exercise is to obtain a true solution to the process problem in the minimum amount of time. It may be possible to do this by either:

- A detailed analysis that leads to one unique solution with a high probable confidence level that exceeds the required confidence level.
- A multitude of attempts to solve the problem. Each of these attempts will likely have a probable confidence level less than the required confidence level. However, because each of these attempts is done sequentially, the problem will eventually be solved. It should be noted that this concept still requires technical analysis to confirm that each attempt to solve the problem is a theoretically correct hypothesis. The technical analysis is not a detailed analysis and, therefore, each attempted solution has a low probable confidence level.

It is possible that the problem solver will have to consider both of these execution approaches. Management may indicate that the required resources are not available or that the required execution time is too long for the alternative with a high probable confidence level (detailed analysis). In this situation, the problem solver can help make an execution plan decision by providing management with his best assessment of the alternative execution strategy. One way of doing this is illustrated in Figure 3-5. The hypothetical example shown in this figure presents two approaches to solving the same problem. In this example, there is one unique solution to the problem. In one approach, this solution can be reached with a 90% probable confidence level with detailed study. The *x*-axis is the cost and/or the length of time required to reach this solution. The *y*-axis represents the probable and required confidence levels. In the first approach (detailed study), the required confidence level is reached by a single path. The more detailed the study is, the higher is the probability of success. In the alternative approach that uses multiple attempts to solve the problem, the required confidence level is reached, but only after several failed attempts.

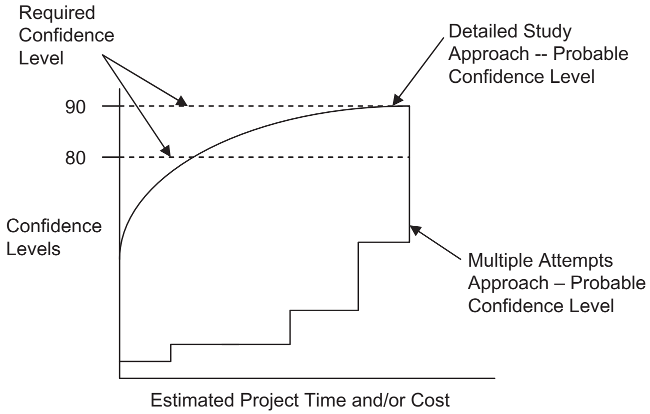

Figure 3-5 Detailed study approach compared with multiple attempts approach.

In this example, the times/costs have been adjusted so that the 90% confidence level is reached after the same expenditure of cost and/or time for both approaches. This is not the normal chain of events. Normally, the detailed study will allow you to reach the required confidence level in less time and at a lower cost. Figure 3-5 also shows what happens in the hypothetical example if the required confidence level is reduced to 80%. In this case, the detailed analysis will allow you to reach this level faster and/or at a lower cost. This is more typical of industrial problem solving. Although this is a highly theoretical example, it is given to illustrate the thought processes that should be followed in assessing the best approach to reach a final, successful problem solution in a minimum amount of time and/or cost.

Once the solution path can be agreed upon, it can be used to steward the progress of the project using the confidence level versus time/cost type of relationship that was developed to determine the project execution approach. In Figure 3-5, if the detailed study route was chosen as the project execution strategy, the problem solver should feel about 85% confident in the approach when the project is about 50% complete. This is true whether the project is building a mathematical model or installation of new equipment. Progress reports would consist of status of the project as well as an indication of probability of success. This accountability will allow for any necessary midcourse corrections.

In the second approach of multiple attempts, the relationship can also be used to steward progress. Management reports in this case will likely consist of reports of failed attempts and number of trials remaining. This reporting of multiple failed trials often leads to loss of management confidence in the problem working process.

While it may seem that the above considerations are not worth the effort required, it should be recognized that whether this type of thinking is quantified or not, it happens when any problem-solving exercise is being considered.

Proof that such thinking is present is found in statements such as, "We have to try something quickly," "That approach is nice, but it takes too long," or, "Let's just put in a treatment bed." When faced with these criticisms, the wise problem solver will attempt to define a cost/timing and confidence level analysis of the various approaches. The above technique is one approach to try to quantify this analysis.

The approach described here can be criticized as attempting to quantify items that are so subjective that they cannot be quantified. However, it should be recognized that whether these items are quantified or not they are always present in the minds of management and the problem solver. Through attempts to quantify such areas as required confidence level, probable confidence level, and execution times, better decisions on approaches and resource allocation will result.

3.5 USING THE DIRECTIONALLY CORRECT HYPOTHESIS APPROACH

There are times when the problem solver will be faced with a hypothesis that appears to be correct, but because of lack of calculation techniques or lack of technology correlations, the hypothesis cannot be proven with calculations. If the problem solver truly has a "directionally correct hypothesis" in mind, this knowledge may by itself lead to an effective problem solution. This approach differs from the trial and error approach where calculations can be made but are not because of the time or cost involved. This directionally correct hypothesis approach assumes that if one can make a small and low cost (in either time or money) change to an independent variable, the impact of this change will by itself either prove or disprove the working hypothesis. The change must be small enough so that no other parts of the process are impacted, but large enough to be confident that the impact (if any) on the dependent variable is statistically significant. As a general rule, the problem solver should have at least a 75% confidence level that the independent variable will affect the dependent variable. The sources of these directionally correct hypotheses are likely to be experience-based. The problem solver is likely to have experience with a similar process or similar piece of equipment. In his experience, a problem was solved by a change in an independent variable. He thinks that a similar change will solve the current problem. The hypothesis could be tested by making small and low-cost changes in the process. Since this small change would be expected to make only a small change in the dependent variable, it would be necessary for the process to continue operating in the new mode until enough data accumulated to statistically prove or disprove the theory. It should be noted that this method still requires technical analysis and a theoretically correct hypothesis.

An example of a situation in which this approach can be used is that of an engineer whose previous experience indicates that there should be a direct correlation between a quality attribute of a product and a plant operating variable. His experience is based on a similar but not identical process. However, in the existing process there is a large amount of scatter in the correlation of the product attribute and the plant operating variable such that he has only a 60 to 70% confidence level that there is any correlation at all. Increasing the plant operating variable is the directionally correct approach to increase the product attribute. As a test, the plant operating variable can be increased a small amount to determine if there is any change in the product attribute. Over an extended period of time, sufficient data will be collected to show whether or not there is a statistically significant difference in the quality attribute.

A similar approach to this is the need for an efficient means to test hypotheses that have been developed by the detailed analysis methods discussed earlier. It will often be desirable to test hypotheses in a low-cost fashion with minimal disruptions to plant operations. In a case study to be discussed later, two alternative approaches were available to test a hypothesis. One of the approaches would require 215 days at reduced operating conditions to provide a 90% confidence level that the hypothesis was correct. The alternative approach required no reduction in operating conditions, could be implemented immediately and was very inexpensive. Thus it met the criteria of being low cost and having minimal impact on the process. It still required 215 days to provide a 90% confidence level that the hypothesis was correct. However, during these 215 days, no reduction in operating conditions was required.

3.6 WHEN TO ASK FOR HELP

Regardless of whether one is a doctor, mechanic, or operator, there will be a time when he must evaluate his situation and his capability and knowledge and request higher level resources. This can even happen in the world of athletics. In the 1972 Super Bowl game, the Miami Dolphins' field goal kicker Garo Yepremian picked up a blocked field goal try and attempted to throw a pass. Even though he was a highly respected kicker, the pass was poorly thrown and was intercepted by the Washington Redskins' Mike Bass and returned for Washington's only touchdown of the game. If the kicker had analyzed the situation and accepted the reality that he was a kicker, not a passer, he would have simply fallen on the ball to recover it for the Dolphins. The score of the game would have been 14 to 0.

In the world of business, the problem solver may often find it necessary to request assistance from someone more knowledgeable than he is. For the process operator or specialist, this may mean requesting help from the process engineer. This request should not be considered an admission of failure, but should be considered to be good judgment on the part of the problem solver. Some guidelines for knowing when to ask for help are given in the following paragraphs.

Perhaps the most obvious time to ask for an expert's help is when a problem is being experienced with a process operation that is not covered in sufficient detail in this book. For example, this book does not specifically cover liquid-liquid extraction. The principles of this unit operation are similar to those described in Chapter 8. However, it is likely that a process operator may not be able to extrapolate information from this chapter to allow application to liquid-liquid extraction. Another area that is not covered in detail in this book is scaleup from laboratory or pilot plant data. Scaleup often creates a set of unique problems. Problems in areas such as lack of geometric similarity or mixing energy per unit volume may or may not result in scaleup problems. Both of these are examples of problems where the operator or specialist will find it of value to seek help from a process engineer.

Additional help from a process engineer might be necessary if the techniques given in this book have not resulted in a solution to a problem that has become chronic. The failure of the techniques given might be due to an improper application of either the techniques or the calculation procedures. Often, a quick review from a process engineer will allow discovery of one of the following:

- There is an error in the calculation procedure. This might be an error in the input data, such as heat content, or an error in the actual numerical manipulation.
- The calculation procedure, while being done correctly, does not apply to the specific situation. The calculation procedures in the book have limitations that are enumerated. However, at times these procedures may have been used without careful considerations of their limits.
- There is an error in the development of the problem statement, or the working hypothesis is theoretically impossible. In the previously discussed steam desuperheater problem, the original problem statement was that the desuperheater was not working because the steam was cooled too much. This was theoretically impossible since the temperature was below the boiling point of water at the measured pressure and no water was present.
- There are very subtle chemical or physical forces occurring that require the combined skills and experience of operators, chemists and various engineering disciplines to fully understand the problem. The green elastomers problem given later in Chapter 4 is an example of this.
- An adequate plant test has not been formulated. Remembering that a successful plant test is one that proves or disproves the hypothesis, the process engineer may be able to suggest an improved plant test.

The key thing to remember when additional resources are necessary is that asking for additional help is not an admission of failure, but a sign of mature judgment—don't try to be a passer if you are a kicker.