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Improving Problem Solving

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Improving Problem Solving

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ABSTRACT

We will consider some popular methods applied in the context of problem solving along with the supporting thought process commonly observed in practice. This will lead us to propose some principles that should help avoidance of frequent pitfalls. Clearly problem solving per se is no substitute for fundamental improvement or innovation since it merely represents a return to status quo - where one had otherwise planned to be. We shall thus close considering the relationship between problem solving and system improvement.

Keywords: Control Chart, Defect Analysis, Descriptive Statistics, Failure Analysis, Induction, Pareto, Problem Identification, Problem Resolution, Problem Solving, Statistical Control, Systems.

Improving Problem Solving

Ian Bradbury[1] & Gipsie Ranney[2]

We will consider some popular methods applied in the context of problem solving along with the supporting thought process commonly observed in practice. This will lead us to propose some principles that should help avoidance of frequent pitfalls. Clearly problem solving per se is no substitute for fundamental improvement or innovation since it merely represents a return to status quo - where one had otherwise planned to be. We shall thus close considering the relationship between problem solving and system improvement.

Introduction

We shall start by a consideration of some of the pitfalls that may befall us in the practice of solving problems. A common theme here is how the inferences we draw about the potential causes of the problem(s) at hand are related to how we observe. What we intend to show is that many intuitive approaches to observation have built in to them the likelihood that we may draw erroneous conclusions or miss important patterns. Based upon this we will propose some guidelines for the study of problems aimed at avoiding such pitfalls in practice. We will also consider levels of solution to a problem, their economics and sustainability. This leads to examination of solving problems at a higher level, for which some of the same principles will be seen to apply.

Some Pitfalls in Problem Solving

Study of only the defectives

In Deming (1982) the story of defective nuclear reactor tubes is told:

The vice president of a huge concern told me that he has a strict schedule of inspection of final product. To my question about how they use the data came the answer: "The data are in the computer. The computer provides a record and description of every defect found. Our engineers never stop *till they find the cause of every defect."*

Deming discusses many of the difficulties that arise when attention is focused exclusively on defects. However, this would appear to be an approach not uncommonly taken; we have a problem with defects, hence we should scrutinize with extreme care each and every defective item we can get our hands on. It is certainly commonplace for manufacturers to request that all defective product be returned - perhaps as a part of the warranty agreement - so that they might learn how to improve. It is also not uncommon for manufacturers and providers of service alike to carefully analyze customer complaints with the intent of taking actions that will improve customer satisfaction. Such an approach seems intuitively reasonable.

To consider some possible pitfalls in such an approach we would like to offer two illustrations.

The first is taken from a presentation made by Hogg (1990) and has to do with the Challenger O-ring failure data. Apparently, prior to the launch of Challenger on January 28, 1986 there had been concern that there might be a relationship between temperature and the occurrence of distressed rings. As a result, data from previous launches were collated and a plot similar to figure 1 drawn up:

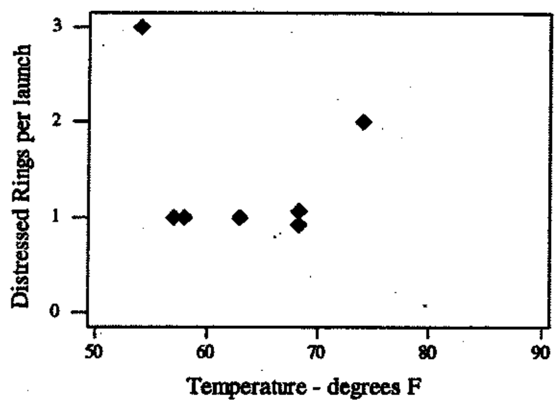

Figure 1. *Challenger O-ring failure data*

From this plot of O-ring failures it is not particularly apparent that a relationship between temperature and occurrence of distressed rings exists, at least over the range of temperatures observed. In examination of this graph with various groups of engineers and managers, lively discussion has occurred with people arguing opposite relationships, according to whether the flight with 2 ring failures or the flight with 3 ring failures is discarded as an 'outlier'. When these groups are then asked what their choice would have been if they had been responsible for deciding whether or not to launch Challenger on January 28, 1986, when it was 34°F at Cape Canaveral, debate has typically continued along similar lines. If one then shows to such a group figure 2, asking them whether their decision would be the same, most respond that they would have decided not to launch. Examination of all relevant data, rather than

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restricting analysis to cases involving defects alone presents a different picture. Understanding that it was the former scenario under which the fateful decision to launch was made understandably leaves many with a sense of shock.

Another example of looking at failed parts comes from Tveite (1990). A manufacturer of fuel injectors had been having a problem with mild leakage. When the fuel injector should have been closed, small amounts of fuel were seeping past the fuel injector's sealing surface into the engine's inlet manifold. This often shows up first as a lack of smoothness of the engine at idle or reduced ease of starting.

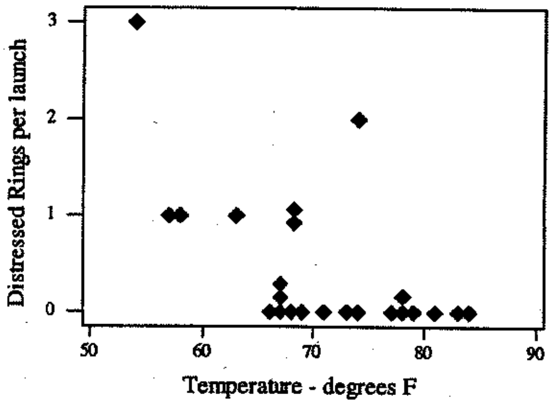

Figure 2. Challenger O-Ring Data

Under the warranty agreement fuel injectors that were replaced at car dealerships for being leaky were returned to the manufacturer for problem solving analysis. Tear down of the fuel injectors and careful examination under the microscope revealed a relationship like that depicted in figure 3.

Most of the problem fuel injectors were found to contain contamination of various kinds. Contamination is a logical cause for leaks since material that becomes stuck in the seal area can provide a potential leak path. A number of actions had thus been initiated to reduce the level of contamination. Possible actions that were being considered included redesign of the injector and fuel line filters, additional washing, flushing and inspection operations in the manufacturing process, increased air filtration and so on.

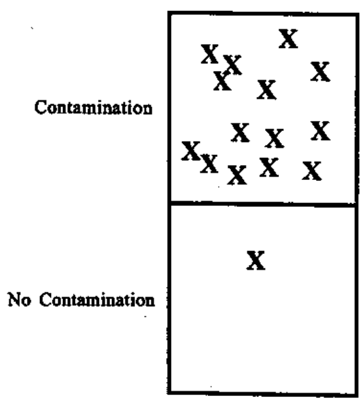

Figure 3. Analysis of fuel injector failures

The people working on the problem were asked whether they had examined any fuel injectors which were not leaky. They had not, but decided to do so. Figure 4 was the result of the combined analysis.

It thus became apparent that the contamination that they had been observing was present, independent of the occurrence of leakage. If "non-defective" injectors had not been examined, substantial time and capital could have been expended on reduction of the presence of contamination of the type observed without benefit to the problem at hand.

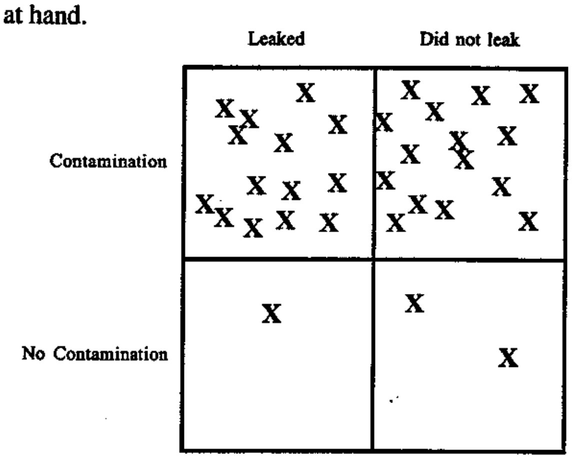

Figure 4. Analysis of fuel injectors

The two examples above seek to illustrate a principle of problem solving. If one only considers the "problem" category of results from a system, one may either miss an important causal relationship (as in the Challenger case) or erroneously infer presence of a causal relationship. To avoid these pitfalls,

- It is advisable to consider all events or outcomes - whether problem or non-problem - for distinguishing features. This might be more simply stated as "do not just study the defects."

The same process that delivered the defects delivered outcomes or results that were not defective. Study of the defects alone presumes that the defects are necessarily produced by a special cause. Such a presumption may frequently be invalid.

Unwarranted generalizations

The preceding examples actually illustrate logical traps we set for ourselves in processing information and forming theories about cause and effect. The following examples are further illustrations of use of faulty logic.

It is easy to make faulty generalizations by selectively ignoring some observations and paying attention to others. Indeed, in a small company, two employees asked a manager to think about hiring an additional employee to carry out one of their activities. They said "we spend all our time on this activity. We need to hire someone to do it, so we can do our other work." The manager and the employees were all aware of some degree of exaggeration in the statement, but the manager did not want to discount the concerns the employees were raising. She devised a plan for a study. The purpose of the study was to get some objective data on how much time was actually being spent on the activity. She gained agreement from the employees to conduct the study.

The manager purchased two watches that could be set to alarm at intervals of 60 minutes. Using a table of random digits, she identified two random start points for each day - one for each of the employees. Each random start point was a time during the first hour of the work day. Each morning she would set the two watches to alarm at the random start time and would give them to the two employees. Each watch would alarm at the start time and then again every 60 minutes thereafter throughout the day. Each time the watch would alarm, the employee was to record on a log the date, time and what they were doing when the watch alarmed. Five activity categories had been identified - A, B, C, D and E - so the employee classified their activity at the time of the alarm into one of these five categories. Category A was the activity in question. The study was conducted over a period of twenty working days, resulting in 320 observations - eight observations per day for the two employees over the twenty days.

When the data were tabulated, fewer than 15% of the observations were category A (47 of the 320), indicating that the statement "we spend all of our time on this activity" was more than a slight exaggeration to make a point. Their generalization that Activity A was the primary cause of difficulties in getting their work done was not supported by objective data about how they were spending their time. However, there were patterns in the data that provided some further clues about how the employees might have been led to focus on Activity A. Time spent on activity A, as reflected in the data, was concentrated on particular days. During those days, the two employees spent a lot of time engaged in a particularly onerous part of activity A - answering telephone calls from expediters in customer plants and dealing with their complaints. Apparently, the discomfort associated with these phone calls had influenced the employees' assessment of the situation.

After the data were gathered and discussed, the manager and the two employees began work to redesign their work processes to make them more efficient and effective. The employees and the manager were not in a position to address directly the sources of their problems with activity A, since they did not control the shipping of product to customers nor the company's relationship with the customer company. Concerns about those issues were taken to the company's executive committee.

Obviously, the two employees were not really claiming that every minute at work was spent on activity A, but statements that include the words "all" or "never" are enticing generalizations that govern thought and action when there are no objective data to force a more balanced view. Such generalizations can lead to proposed solutions that focus on only a small part of the collection of factors that may contribute to a problem.

Another example illustrates a different kind of generalization. In a manufacturing plant, castings are produced by pouring molten metal through a system of gates into a mold. The amount and distribution of porosity present in the castings are often a focus of concern.

The following describes a previously traditional practice in the plant. Whenever "too much" porosity began to appear in the castings, the gating system was changed, although no clear definition of what constituted "too much" porosity existed. When changes were made to the gating system, an apparent decrease in the level of porosity would lead to the conclusion that the problem had been solved. There are theoretical reasons to believe that gating structure can have an important effect on porosity. However, the practice had not been to use ongoing data to see the effects of gating changes or other changes on the output. No objective data on porosity were regularly collected and analyzed.

Posing a question led to different thinking about the problem of porosity. The question was whether castings that did not have "too much" porosity were made during the time when "too much" porosity was occurring. Engineers changed the gating system design whenever "too much" porosity appeared in the castings, and yet the same gating system design in use when castings with "too much" porosity were produced was also in use when castings without "too much" porosity were produced. A factor that is always present and invariant in its action is not likely to be the sole cause of both "problem" results and "non-problem" results. There are at least two possibilities for what might be occurring: (1) gating design is not a cause of "too much" porosity and some other factor or factors are producing the problem or (2) some other factor (or combination of factors) that fluctuates over time combines with gating structure in some way to produce the problem. In this particular case, it turned out that gating system design was not a primary cause of porosity, acting either alone or in concert with other factors. Certain physical properties of the metal that fluctuated over time were identified as the primary factors creating "too much" porosity.

Over time, engineers in the plant had operated with the theory that the gating structure was the most effective way for dealing with porosity problems. Whenever the problem appeared, their generalization that gating structure was the best solution was employed. No objective data were used to assess whether the problem of "too much" porosity was chronic or occurred sporadically. If the problem was sporadic, it would be difficult to believe that a cause that was common to all outcomes over a period of time (gating structure) could act by itself to create the problem. If the problem was chronic, gating structure could be considered as a potential cause acting in combination (interacting) with some other cause or causes to produce excessive porosity. Considerable money and effort may have been invested over a period of years applying the same solution to "solve" problems that may have been created by factors that were never examined.

Of course, one is nearly always in the position of forming theories and making judgments on the basis of limited data. Cochran (1977) provides a view of the extent of our difficulty in seeking to learn from observations:

Our knowledge, our attitudes, and our actions are based to a very large extent on samples. This is equally true in everyday life and in scientific research. A person's opinion of an institution that conducts thousands of transactions every day is often determined by the one or two encounters he has had with the institution in the course of several years. Travelers who spend 10 days in a foreign country and then proceed to write a book telling the inhabitants how to revive their industries, reform their political system, balance their budget, and improve the food in their hotels are a familiar figure of fun. But in a real sense they differ from the political scientist who devotes 20 years to living and studying in the country only in that they base their conclusions on a much smaller sample of experience and are less likely to be aware of the extent of their ignorance. In science and human affairs alike we lack the resources to study more than a fragment of the phenomena that might advance our knowledge.

To guard against the kinds of generalizations illustrated in the earlier examples, we would suggest the following as aids to problem-solving:

- Assess with objective data whether there is support for use of words such as "always" or "never."
- When an assertion is made about causes of a problem, state carefully the variety of conditions in which it is believed the problem occurs and ensure that data are available for those conditions <u>and</u> for conditions in which it is believed the problem does not occur. Filling in the cells of some simple tables can help to clarify thinking:

When

Problem	
Present	Absent

In the table above, conditions and times when the problem is present and when it is absent are described.

Where

Problem	
Present	Absent

In the table above, locations where the problem occurs and locations where it does not occur are described.

	Problem	
Potential Cause	Present	Absent
Present		
Absent		

In the table above, a potential cause is taken to be of a binary nature; that is, it either is present at the time when an observation is made or it is not. Attempts should be made to obtain observations in every cell of the table. In the fuel injector example, failure to obtain observations in the right column of the table above contributed to the error of logic described.

- If the magnitude of the problem fluctuates,
  1. Construct a time ordered plot of frequency of occurrence
  2. Collect data on potential causes to observe possible matches of patterns in characteristics of potential causes with patterns of occurrence of the problem.
- If the problem never occurred before a particular time and it has always occurred since that time, match descriptive information about potential causes to the timing of onset of the problem.

- Make an attempt to name several potential causes of a problem, rather than just one. Without enlarging the list of possible causes, solutions tend to be restricted to habitual ones that may have no benefit and may tend to be based on myths that have grown up over time, often with no rational basis.

Failure to take variation into account

The existence of variation renders interpretation of observations more difficult. On the other hand, study of variation provides a means to guard against the kinds of faulty logic discussed above.

Consider the problem of "too much" porosity in castings. Suppose there were a consistent method used to determine when castings contain "too much" porosity[3]. Suppose roughly the same number of castings were produced over a series of time periods and the proportion of castings produced with "too much" porosity showed the pattern of variation illustrated in figure 5. Times when gating system changes were made are marked on the horizontal time scale.

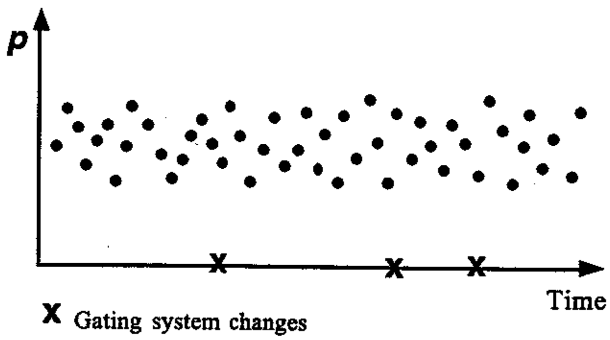

Figure 5. Stable Variation in a Series of Results

Taking the variation shown in figure 5 into account, it is difficult to conclude that past gating system changes have produced any sustained effect on the occurrence of "too much" porosity. The stable variation in figure 5 indicates that the problem of porosity is chronic and is produced by a collection of factors that are always acting on the results. (We have not shown statistical limits on the graphs shown in figures 5, 6 or 7. Our purpose for these figures is to characterize the behavior of streams of results that exhibit different kinds of variation. In a practical situation, the judgment of whether variation is stable or not is made on the basis of a control chart with statistical limits.) In a case such as this, the way to produce sustained improvement is to conduct a series of planned studies and experiments to understand the factors that affect porosity and to conduct tests of changes that could lower the level of porosity in production output. The structure of the gating system would be one of several possible causes of porosity that would be under study.

A different kind of circumstance in the case of casting porosity is illustrated in figure 6. The last point in the series may indicate that a change has occurred in the conditions of production. Placing statistical control limits on the chart confirms that this point is a signal of the action of a special cause. If the same gating system in use when

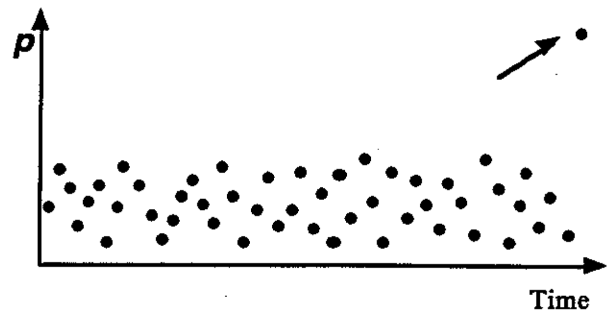

Figure 6. Signal of the Action of a Special Cause

these results were produced had been in use for the previous time periods reflected on the chart, it is again difficult to imagine that gating system structure could be the sole cause of the worsening of results reflected in the last point.

In a case such as that shown in figure 6, the appropriate action is not to make changes in factors that have been acting in the same way throughout the time when variation showed stability, but rather to try to identify changes in materials and conditions that may have coincided with the change in results. The thinking appropriate to the accumulated history shown in figure 6 is that there is a special cause acting to produce the wild point and that identification of that cause should be pursued as a course of action, rather than to "tinker" with normal operating conditions to seek improvement.

Figure 7 shows a circumstance in which a change in the gating system reasonably could be believed to have an effect on the generation of porosity, given that other conditions remained roughly the same over the time period de-

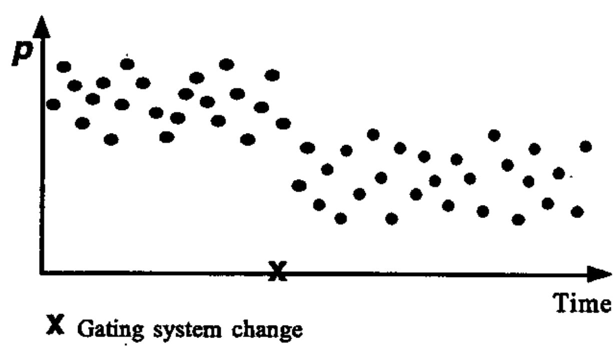

Figure 7. Shift in Results

[3] *We note here that the location of porosity may have more to do with how "too much porosity" is defined than the actual amount.*

picted. The proportion of castings with "too much" porosity produced after the gating system change shows a sustained reduction in level from what is seen to have been occurring prior to the change.

Study of variation with a methodology that enables us to link results to their causes in a logical way can help to guard against faulty logic in problem solving. The theory and methods of statistical control originated by Walter Shewhart provide a means to study variation for the purpose of improving problem solving. When results show stable variation over time (figure 5), actions to adjust process factors in reaction to a single up or down fluctuation in results are likely to accomplish nothing but an increase in variation in the future. (This kind of behavior is described by Deming (1994) as "tampering.") When a single result provides evidence (via a point outside statistical control limits) of the existence of a special cause (figure 6), the appropriate action is to search for unusual conditions that may have existed during the time when the result was produced. When a change is followed by a sustained alteration in the series of results that follows the change, in comparison to those produced prior to the change (figure 7), one has some confirmation that the causes addressed in the change were acting as believed. In all of these situations, maintaining a record of variation in results provides a means to consider possible causes from a more solid logical basis than would be possible otherwise. A further suggestion for the improvement of problem-solving is:

- Determine important measures of performance of a process or system and maintain a running graphical record of variation in those measures. A simple run chart represents an improvement over no record or a record in tabular form.

Adopting this practice will provide some insurance against inappropriate theories about cause and effect.

Over-reliance on Pareto in problem solving

Suppose we have problems that may be categorized A, B, ..., K with a rate of occurrence observed for each category.

Ishikawa (1976) provides information on how to construct Pareto charts. A Pareto chart for rates may be formed by first ordering the categories by their rates of occurrence, then drawing a bar chart of category or problem by the rate at which it occurs. Pareto charts are similarly formed for counts, costs, or any other metric by which prioritization is believed to be helpful.

Doing this often results in the "typical Pareto pattern" observed in figure 8. It is frequently suggested that such a graph may provide the sole basis for deciding where one should focus one's initial efforts at improvement. This

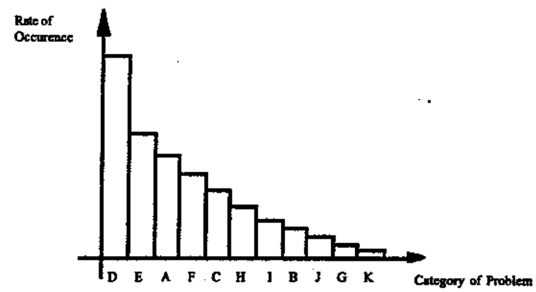

Figure 8. *"Typical Pareto Pattern"*

seems obvious since, after all, is not the category associated with the highest bar (i.e., the highest cost, rate, count, etc.) the obvious place to start?

The following example is paraphrased from a popular problem solving seminar where it is provided as illustrating "appropriate application of the Pareto principle":

A manufacturing plant manager looks at a Pareto chart of problems by business unit manager to see who had the most problems yesterday, last week, last month, etc. This business unit manager is rewarded with the highest attention of the plant manager. The business unit manager then looks at a Pareto chart of lines for the line with the most problems, and then she uses a Pareto chart to decide upon the operation within that line with the most problems. It is suggested that such an operation would be a good place to start one's problem solving efforts.

A similar thought process is sometimes followed for deciding which of the product defects should be the initial or primary focus of analysis in efforts to improve product quality, reliability or warranty costs.

In attempting to solve problems we have the opportunity to make one of two mistakes in our interpretation of the variation we observe and the actions we take as a consequence (Deming, 1982):

Mistake 1: *Approach a problem as if it is due to a special cause, when in fact the cause belongs to the system (common causes), and*

Mistake 2: *Approach a problem as if it is due to the system (common causes) when in fact the cause is special.*

Implicit to the uses of Pareto charts described above is the view that all differences in results are indicative of differences in their causes. This is the case since such differences are being viewed as requiring differential explanation or differential action. One problem with this approach to thinking about variation is that, even though one will achieve a perfect record regarding making mistake 2, one will maximize the frequency with which mistake 1 is made.

The following paragraph from Deming (1982) discusses the need for rules as regards these two types of mistake:

Shewhart (about 1925) recognized the fact that good management consists of making one mistake now and then, and the other one now and then. What was needed, he saw, were rules that can be put into practice by which to try to achieve minimum net economic loss from both mistakes. To this end, he contrived the 3-sigma control limits. They provide, under a wide range of unknowable circumstances, future and past, a rational and economic guide to minimum economic loss from both mistakes.

Figures 9-11 are c-charts of the number of customer complaints received about 3 services that are provided by a company, labeled A, B and C. They are provided to help illustrate why the distinction described is necessary and useful. The horizontal lines labeled UCL and LCL are the 3-sigma control limits referred to in the previous paragraph.

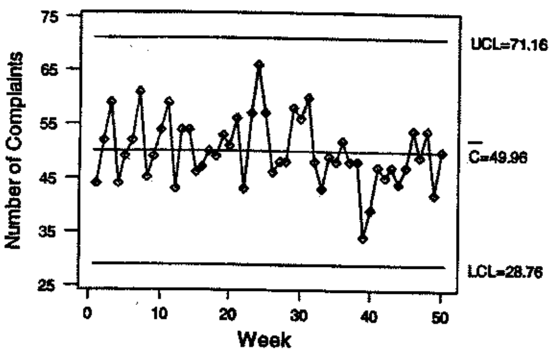

Figure 9. c-Chart for Class A

The c-chart for Class A exhibits a state of statistical control, indicating that there appears to be a common-cause system for counts of complaints. In other words the causes of complaints would appear to be consistent over time. In this case improvement activities would most appropriately be directed at the fundamental design of the service and the process of delivery.

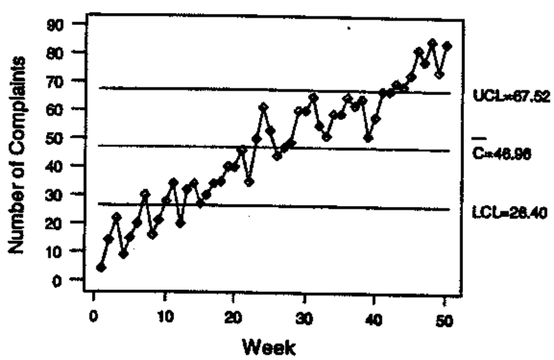

Figure 10. c-Chart for Class B

The variation shown in the c-chart for Class B does not exhibit a state of statistical control, but rather an underlying upward trend in the count of complaints over time. In this case improvement activities would best be directed initially at trying to understand the special cause of degradation over time. A thorough understanding of the way in which the data were collected would be necessary, since such patterns can result purely from the method of gathering data. Other examples of special cause rationale for this type of data might be degradation in the quality of service due to expansion of the customer base faster than the organization can support the growth (training, infrastructure, etc.) or customer expectations increasing over time more quickly than the improvement of service quality.

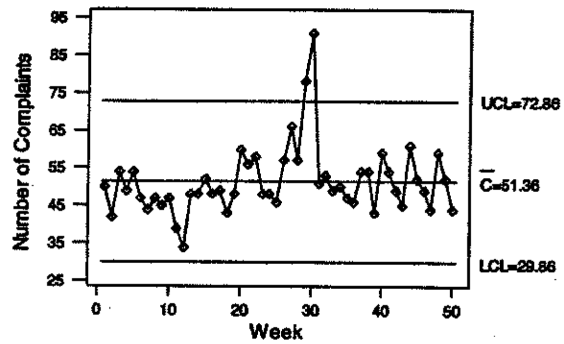

Figure 11. c-Chart for Class C

The c-chart for Class C does not exhibit a state of statistical control, with a special cause of variation being indicated around the 30th and 31st data values. In this case it would make sense to initiate one's improvement effort with looking to see what was different during that particular point in time.

The four Pareto charts in figures 12-15 were generated from the same data, at time points 5, 7, 30 and 50 respectively. These charts clearly demonstrate that the class one would choose as the first priority for improvement would depend upon which point in time the Pareto chart was made.

The charts also demonstrate that no matter which class was selected, data from a single time point provides no clues as to the nature of causes.

From the Pareto charts alone one would certainly *not be able to make the proper judgment* about which problem to work on, and which methods to apply to the problem or which questions to ask to identify causes.

It is critical to note here that improvement for these three cases is rooted in addressing fundamentally different questions about causes of problems.

Another complicating issue in the use of Pareto charts alone for prioritization is interdependence in systems. For instance, in manufacturing, problems observed in a machining operation may have contributions from variation in cast locators, variation in material properties, measurement processes, lack of operational definitions and so on, which

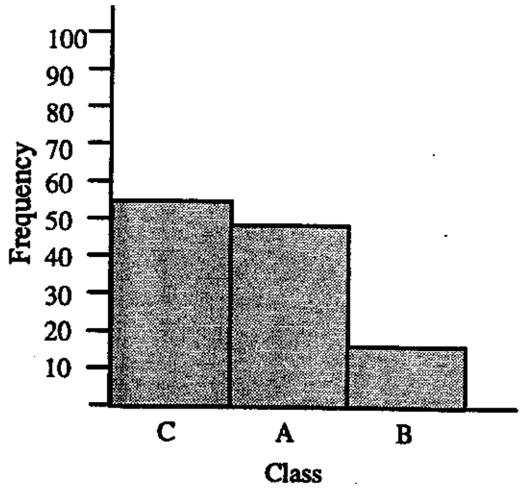

Figure 12. Pareto Chart for Time Point 5

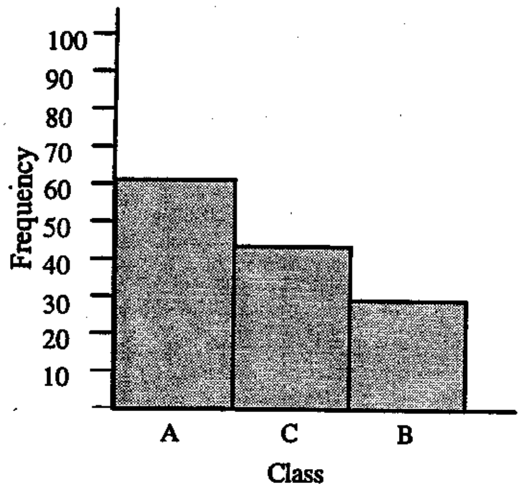

Figure 13. Pareto Chart for Time Point 7

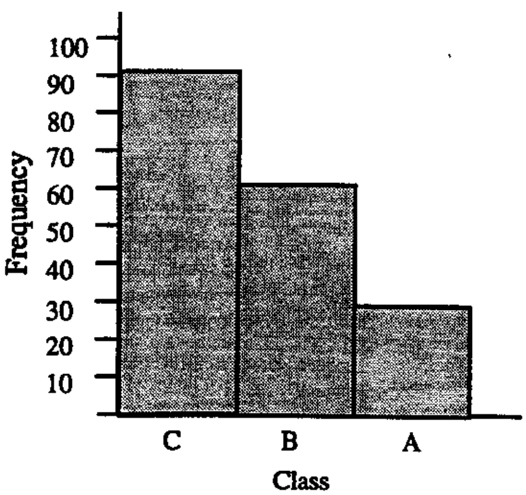

Figure 14. Pareto Chart for Time Point 30

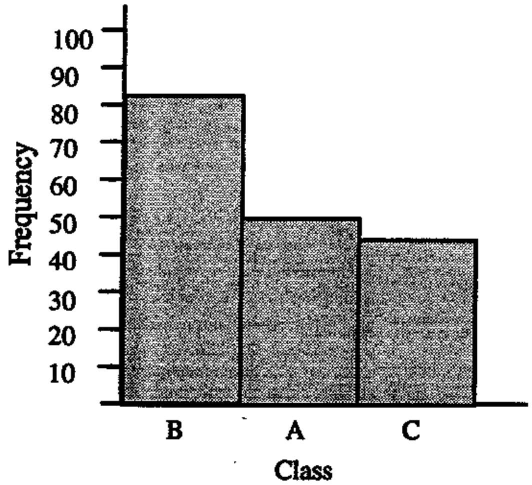

Figure 15. Pareto Chart for Time Point 50

originate elsewhere in the system. In field repairs of a product, certain items may exhibit high rates of replacement due in part to diagnostic processes that are not sufficiently complete (by design or practice), methods of remuneration for dealers, effectiveness of the capture of a customer's description of their problem and so on. Process flow diagrams may be used to describe the way in which work is done in practice. This is a useful way of uncovering system interdependencies and flaws, and thus leverage points for improvement. A cause and effect diagram is also a helpful tool for organizing theories of cause and effect for test and guidance of leveraged action.

Implicit in the use of any Pareto chart is the chosen classification of results. This strongly affects the usefulness of the chart, as displayed in the following example. An automotive assembly plant manager made the statement "Data analysis doesn't help us - all our problems are onesies and twosies." To support his contention he presented a Pareto chart of problem parts, classified by part number. Indeed there was no clear pattern evident from having organized and reported the data this way. Through conversation about potential causes of problems, it was decided that reclassifying the problem parts by type of problem might be useful. For the history available, the distribution of problems by type was:

Type of problem	**Rate**
Damage in assembly	~15%
Misassembly - wrong part, missing part etc.	~35%
Manufacturing defect - in plant	~20%
Defective parts from suppliers	~30%

It had also been previously stated that "If only our suppliers would ship us good parts, we'd be OK." We can see that the theory articulated in this statement is not born out by the data, when the data are organized in such a way that the theory may be tested. Improvement of the situation here will likely require actions in different parts of the production system, such as product design, process design, material handling and supplier quality. To avoid the pitfalls displayed above, and to seek clues as to the nature of cause, such data should also be viewed over time.

The principles illustrated in the preceding are:

- Pareto charts do not take into account the nature of variation in results
- Pareto charts rely on frequency of occurrence for prioritization. This is often not the same prioritization as results from:
  - substantive knowledge of relative leverage
  - knowledge of relative value from the viewpoint of customers, or
  - consideration of difficulty of fixing the problem
- A single method of classifying results is implicit in any single Pareto chart

To aid in avoiding the pitfalls identified in use of Pareto charts, we recommend:

- Use of control charts to view variation in data over time that would otherwise be viewed via Pareto chart.
- Use of process flow diagrams to describe the way in which work is done in practice.
- Use of cause and effect diagrams to document theories about cause and effect.
- Classification of results in such a manner that theories about cause and effect can be tested.

Misuse of descriptive tools

Tools to summarize the information in a collection of data are created with the assumption that users know how to use them appropriately. The unsophisticated user can be easily misled when they rely on the tool or method to supply the *thinking* required for appropriate use.

An illustration of misuse of descriptive tools comes from a large hotel chain. A regional executive sent out a memo to hotel managers with several bar graphs attached. Figure 16 shows a bar graph summarizing a month's recorded accidents in the region's hotels by seniority in months of the people having the accidents[4].

[4] *The bar graphs presented in this section and the next are also subject to the pitfalls associated with not examining variation over time.*

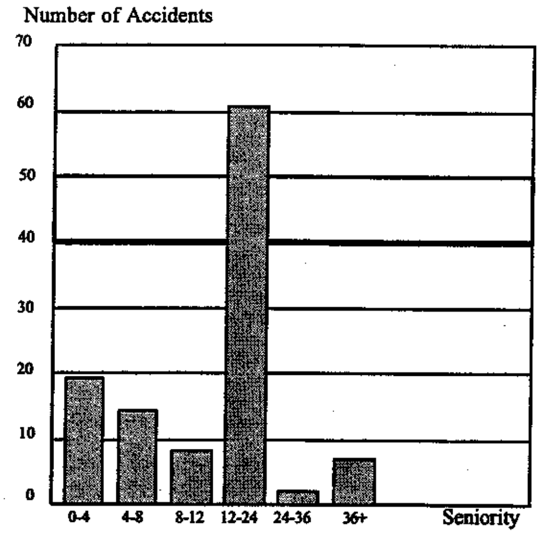

***Figure 16.** Number of Accidents by Seniority of Employee*

The executive's memo contained the following statements: "...We need to continue to focus on reducing accidents... Our associates who have been here 12 to 24 months are having too many accidents. Just because people have been trained does not mean they stay that way..." The executive's statement can be directly associated with the bar graph in figure 16. The seniority category with the highest bar is 12 to 24 months.

A cursory examination of the seniority categories shown on the graph leads to a different interpretation of the information. The seniority categories correspond to different periods of time: the first three categories are four months in length, the next two are twelve months in length and the last is open-ended. If one were to divide the 12-24 month category into three four-month intervals, as was done for seniorities of one year or less, one might see no support for the executive's statement. Good practice in construction of bar graphs when the criterion for classification of measurements into categories is on a continuous scale is to divide the range over which measurements occur into equal length intervals. This practice helps to guard against the possibility of distortion and faulty reasoning.

There is another opportunity for faulty thinking built into the data summarized in figure 16. Suppose we assumed that accidents occurred "randomly" at a fixed rate per hour of exposure to accidents that was the same, regardless of seniority. Suppose that the number of labor hours by seniority for the month in question had a relative frequency distribution described by the bar graph in figure 17. (No actual information was available to produce figure 17; it is simply a hypothetical distribution created to illustrate the possible effect of an underlying factor on the picture shown in figure 16.)

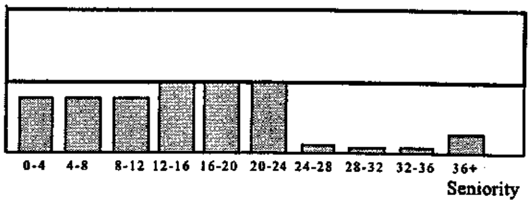

Figure 17. Relative Frequency Distribution of Labor Hours by Months of Seniority (Hypothetical)

Given these assumptions, suppose a bar graph was produced for the average number of accidents that would be recorded in each of the seniority categories shown in figure 16. There would be variation in the actual number of accidents recorded in a given month, if accidents occurred "at random" at some constant rate, but we have ignored that variation in the production of the bar graph for average number of accidents shown in figure 18.

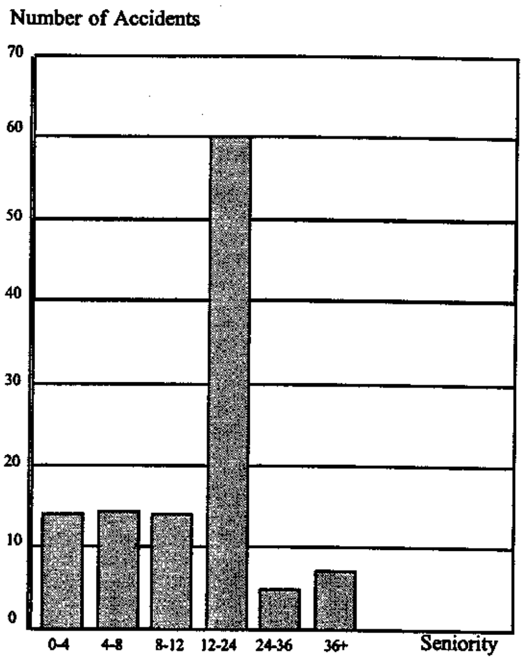

Figure 18. Average Number of Accidents by Seniority in Months[5]

Figure 18 is very similar to figure 16. The appearance of figure 16 and the apparently overwhelming number of accidents in the fourth seniority category in figure 16 could be the result of distribution of number of labor hours worked over the seniority categories, accentuated by the use of unequal width categories. The appearance of figure 16 may have nothing whatsoever to do with a different propensity to have accidents among employees who have been on the job between one and two years. Interpretation of the information in any graphical summary of data, such as a bar graph or a histogram, should include thought about all the potential factors or causes that might produce the picture being interpreted. We have illustrated only one of a great variety of opportunities to misuse simple descriptive tools. Huff (1954) contains illustrations of other pitfalls associated with their use. Another helpful source in regard to interpreting data and avoiding traps related to graphical deception is Wheeler (1994).

Focus on only one process element in thinking about causes

The tendency to focus on only one process factor when thinking about causes appears to be common and to be linked to lack of a process view of work. A process is a transformation of inputs into outcomes through the interactions over time of many factors, including people and machines, but not confined to either. In addition, a process and its outcomes are affected by factors that exist in the environment within which the process exists. The view that the outcomes of a process are produced purely by the people or by the machines ignores the effects of one on the other and the effects of other factors that may act on results.

When improvement in some type of outcome is desired, a focus on only one factor or cause that may affect the outcome can lead to comments such as "we can't do anything to improve this unless we buy a new machine," or "re-instruct the operator about the importance of his job," or "retrain the employees." In some cases, these suggestions may be entirely rational suggestions for improvement. But, too often, they are the first and only suggestion and are the result of limited thinking about potential avenues for improvement. No machine operates in a vacuum, absent of maintenance and operating practices, nor are the results of the machine's operation unaffected by the material input or the environmental conditions in which the machine operates. No operator or service worker is unaffected by the input, supervision and information he receives, the equipment he works with, and the conditions in which he works. Failure to recognize the existence of many process factors that may possibly affect the outcome can be a significant barrier to improvement.

In the previous section, we described a hotel executive's memo concerning accidents and the interpretation of a histogram attached to the memo. Several other histograms were also attached to the memo. Figure 19 shows number of accidents summarized by location in the hotel and figure 20 shows the summary by type of injury.

The executive's comments in the memo illustrate an apparent focus only on the contributions of people to the occurrence of accidents. "...We need to continue to focus

[5] *Using hypothetical distribution of labor hours, exposure to accidents shown in figure 17 and assuming same rate of occurrence for all seniority categories.*

on reducing accidents... Our associates who have been here 12 to 24 months are having too many accidents. Just because people have been trained doesn't mean they stay that way...". One could imagine a thought process that goes something like: "people have accidents because they aren't being careful. Since accidents are most frequent among people with 12 to 24 months' seniority, it is apparent that people grow careless after a while and they need to be reminded (retrained)." Such a thought process ignores the fact that work is conducted in a physical environment with tools that may contribute to conditions in which accidents will be had. That is, the conditions for accidents may be designed into the work processes the people use, as well as into the people.

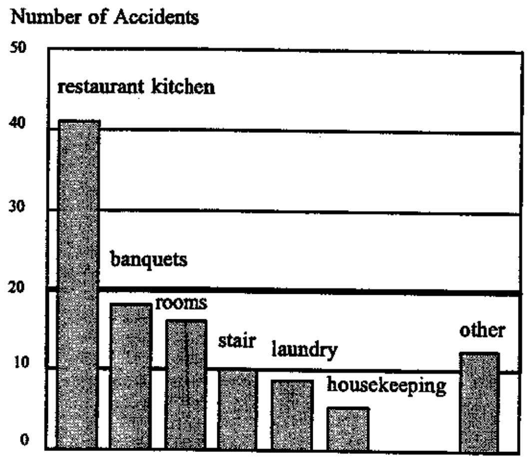

Figure 19. Number of Accidents by Location in Hotel

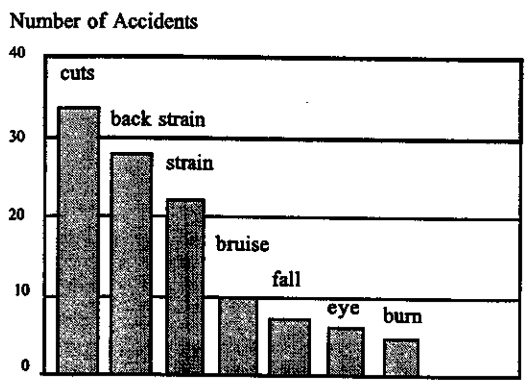

Figure 20. Number of Accidents by Type of Injury

A cursory examination of figures 19 and 20 raises questions about whether workers in the kitchen and banquet areas have the greatest exposure to the conditions for cuts, burns, and eye injuries and whether back and other kinds of strains tend to occur when people are required to lift or move heavy objects.

Many other questions that could reveal opportunities to reduce the rate of occurrence of accidents could be developed by noting the existence of other factors besides people that potentially contribute to the occurrence of accidents in the workplace. As long as the focus remains on the people to whom the accidents are happening, improvement opportunities are restricted to exhortations about being careful and training about how to cope with existing conditions. Conditions that contribute to accidents will not be designed out of the environment and the equipment people must use.

A similar example, again dealing with accidents and with a single-factor focus, came from the safety department of a small company that produces molded parts[6]. Molding process operators load blanks into mold cavities, load the mold into a press and unload the molded parts. The molding process is carried out at extremely high temperatures. The safety director was concerned about the rate of occurrence of accidents in production and had constructed a control chart of accidents per thousand labor hours. Variation in accidents per thousand labor hours month to month showed a state of statistical control. Until he discussed the situation with a statistician, the safety director had the erroneous view that since the variation was stable, nothing could be done to reduce the occurrence of accidents. He did not realize that the existence of stable variation would alter the kind of thinking and action required to bring about improvement, in contrast to what might be undertaken if there were indications of the existence of special causes, but the opportunity to reduce the rate of occurrence still existed. In the case of stable variation, improvement would have to come from action on factors always present in the process.

When asked about causes of accidents, the safety director responded that people do not pay attention to what they are doing and they have accidents. A conversation ensued about accidents on streets and highways. The safety director agreed that accident rates were probably quite different for different streets, intersections and segments of highway. He also agreed that highway design, traffic density and weather conditions might combine to contribute to the differences. This led to a discussion of other possible contributors to accidents besides the operators' degree of attention. The safety director commented that it might pay to ask an engineer to analyze the process with a focus on how the process design might be improved. Engineers made some fairly simple and inexpensive changes to the equipment and mold designs to reduce the likelihood of burns when operators unloaded parts from hot molds. Subsequently, there was a noticeable reduction in the rate of occurrence of burns. Had the safety director continued to focus on only one process factor affecting occurrence of accidents (the people), this opportunity for sustainable improvement would have been missed.

[6] *For a complete discussion of this example, see Bounds et al (1994)*

To aid in avoiding focus on a single process factor when thinking about possible causes of problems and opportunities for improvement, good practice would include asking the following questions:

- Have we jumped too quickly to an explanation in terms of a single causal factor?
- Have we constructed a list, possibly in the form of a cause and effect diagram, of the many factors that may affect the outcome we are trying to improve or the problem we are trying to solve?
- Have we made plans to test our theories and assumptions under a variety of conditions?

Allowing temporary measures to become permanent

When a problem escalates into a perceived crisis, the desire to make the problem go away can overwhelm better judgment about what might be an effective solution. A temporary "solution" is put into place and appears to work. Attention is directed toward the next crisis and the temporary "solution" is left in place permanently[7].

Temporary "solutions" often consist of instituting inspection or requirements for authorization to proceed at the point in production where the problem becomes visible, and building in "buffers" of time or material and rework loops to ensure that production can continue in spite of the problem. None of these practices can be viewed as real solutions to problems. *They simply disguise the problem so that it is no longer visible.* They enable a return to status quo, but at the expense of increased cost and complexity.

Typical types of "solutions" put into place at the point where the problem becomes visible are pictured in figure 21. These kinds of "solutions" can be viewed economically as buying a kind of insurance policy to avoid the costs incurred by failure further downstream. The cost of the policy includes the costs of inspection, rework, maintaining "buffer stocks" of time and material, as well as the less visible costs associated with managing a more complex system. When these kinds of temporary solutions are allowed to become permanent, we are implicitly assuming that (1) the problem will persist at the same level in the future, (2) the cost of insurance is less than the downstream failure costs, and (3) the cost of this insurance is less than the cost of addressing the source of the problem less the benefits to be derived by doing so. There may be situations in which these implicit assumptions are justified. However, there are many situations in which they are not. When they are not, the alternative approach is to eliminate the temporary "solution" as soon as a real solution at the source of the problem is developed. Allowing temporary solutions to become permanent is a way to guarantee the cost and complexity associated with the temporary solution.

[7] *In some companies, this kind of behavior is encouraged by "problem resolution" procedures that require a solution to a problem be put in place within a certain time period after the problem is reported.*

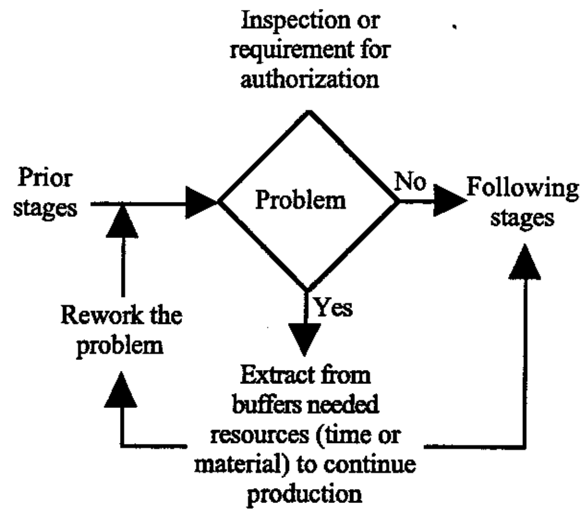

Figure 21. Inspection, Buffers and Rework

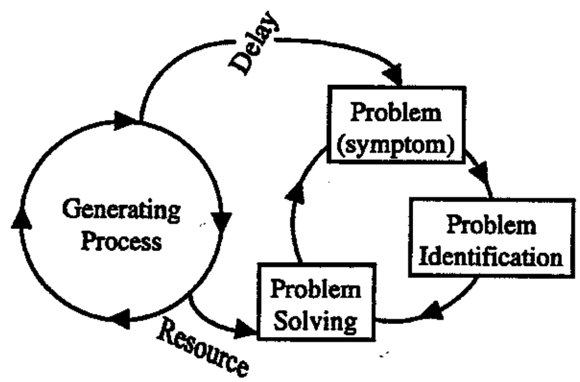

Figure 22. Application of the Shifting the Burden system archetype.

In the stream of activities that compose a process of designing and producing a product or service, the types of "solutions" described above can be viewed as shown in figure 22. The kinds of temporary "solutions" described above are not effective improvements. Effective improvement is directed at process re-design at the source of the problem - often far upstream from where a problem becomes visible. This is the distinction that needs to be kept in mind when problem-solving is initiated and when sustained improvement of organizational performance is desired.

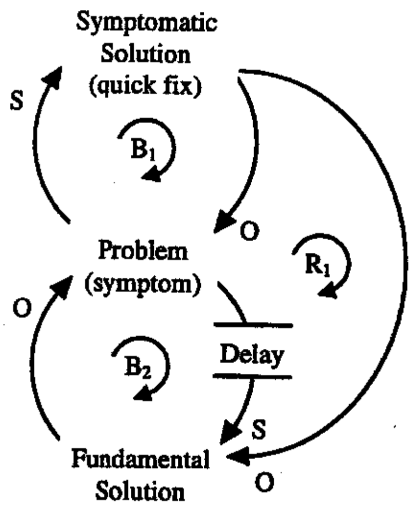

Figure 23. Shifting the Burden system archetype.

From problem solving to system improvement

Figure 22 is an example of the more general *shifting the burden* system archetype of Senge (1990) displayed in figure 23.

The archetypes introduced in Senge (1990) are a language for talking about the dynamic structures which may repeatedly be seen in our actions. In the *shifting the burden* archetype two solutions are displayed to a given problem. The upper loop, B_1, represents the 'quick fix' approach to solving the problem, which may be thought of as taking the kind of action that makes the symptom go away. At a personal level, an example of this would be taking a pain killer to address the problem (symptom) of pain. The lower loop, B_2, represents taking action on the fundamental cause of the problem we are observing. This contains a delay since the diagnosis of the fundamental cause of a problem required for a fundamental solution is typically more difficult than just treating the symptom. The loop on the right, R_1, represents a disturbing aspect of this archetype - that just taking the quick fix approach often results in more problems in the long run. This occurs for a variety of reasons. One is that energy being expended on the symptomatic solution is not being expended on the fundamental solution - this is shown in figure 22 as resources being drawn away from working on the generating process to work on solving problems downstream. It is also the case that the quick fix loop may be addictive in a manner which ends up making the fundamental cause even worse. For example, if a person has a stress problem with fundamental causes in their psychology, methods of work and misalignment of their capability with their workload, they might turn to drinking as a method to quickly relieve the stress. As the person drinks more, their physical health declines, resulting in an even worse disparity between their capability and workload. The resultant worsening of stress drives them to drink even more heavily, and the person is caught in a vicious addictive cycle.

This cycle of addiction is paralleled in business. We pull people away from working on the development of future products to solve the problems with the products of today. In doing so, we compromise the development of future products, increasing the likelihood of the future products having problems. Since we saw that pulling people away from future programs in the past resulted in problems being solved, it is addictively tempting to react to the present problems in the same manner.

Earlier we described the typical symptomatic solutions of instituting inspection or requirements for authorization to proceed at the point in the process where the problem becomes visible, and building in "buffers" of time or material and rework loops to ensure that work can continue in spite of the problem. If these types of solution are the end of the problem solving process, increased cost and complexity are built in. Viewing the organization as a system, such solutions represent improvement on the dimensions the problem is observed (defects, errors, complaints) by taking actions that result in a worsening of the dimensions corresponding to productivity.

Principles which one may derive from the *shifting the burden* archetype are:

- Discipline is required to ensure that there is continued investment in working on the fundamental solution - this may require one to experience some short-term symptomatic discomfort and cost.
- The approach taken in the symptomatic solution of a problem should be such that one learns about the deeper fundamental causes. Action on the fundamental causes will eventually reduce the level of problems generated and thus the need for symptomatic solutions.

In the case of problem solving, this means:

- Resources should be invested in improvement of the generating processes at a level that will reduce the need for solving similar problems in the future.
- Problem solving efforts should go deep enough into the understanding of causes that they generate knowledge useful for improvement of the generating processes.

Some companies that appreciate this last point spend time following the introduction of new product tracing back the deeper systemic causes of the problems experienced. This may be viewed as a feedback system for the product planning and development processes, workload assignment method and so on. This is a desirable step forward for a company trying to learn for improvement at a system level. However, a caution must be sounded about such efforts that has as its logical basis in the thinking explored in the first section - study of only the defectives. The same inferential traps that applied to only looking at the defectives for solution of a particular problem also apply to system improvement. For example, the product planning and development processes which delivered the 'problems' observed during introduction of a new product were the same processes that delivered 'non-problems.' To avoid the types of faulty conclusions described in the first section:

- It is advisable to examine all events or outcomes - whether problem or non-problem - in thinking about their deeper systemic causes.

Conclusions

Albert Einstein once said "Our theories determine what we measure." In this statement Einstein was reflecting the position of the pragmatist school of philosophy[8] - that we do not view reality objectively, but rather through the lens of theories we implicitly or explicitly hold in our minds. In this paper we have sought to elaborate on implicit theories regarding the nature of causes imbedded in many common approaches to problem solving. Specific recommendations at the end of each section were aimed at the inferential difficulties that arise from the common inadequacy of these theories.

The pragmatist view is also reflected in the overarching framework of thought that we would recommend - that of making change in a manner that builds knowledge for improvement. This is best represented by the PDSA cycle described by Deming (1982). In this cycle, we start by making explicit our improvement theory - an expression of the current state of knowledge. From this theory, actions should be deduced which we predict will result in improvement. After the actions have been taken, the results are compared with what was predicted from the improvement theory. If results are not as predicted, we have cause for revision of the theory or, at least, the bounds of its applicability. A new starting point is thus provided for taking action aimed at further improvement. If results are as predicted, our belief in the usefulness of the improvement theory is increased. Continued use of the PDSA cycle may further test the bounds of the improvement theory's usefulness. Such a learningful framework for action is the root of improved knowledge that provides the basis for improved quality *and* productivity. This interplay of theory and experience is also represented in the introduction to Box, Hunter and Hunter (1978) as inductive and deductive interplay in iterative learning.

[8] *See for instance, Lewis (1929)*

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