QUALITY IMPROVEMENT: IN FRONT OF LIVE PROBLEMS

Dr. H. J. Bajaria
Multiface, Inc.
Garden City, Michigan 48135

R. P. Copp
Holley Automotive Division
Warren, Michigan 48090

ABSTRACT

During the 1980's, approaches to quality improvement have generated numerous philosophical discussions, changes in business systems, computerization, and automation. Many companies have expended much of their improvement budgets without gaining a proportional return on their investment at the bottom line. The paper presents a results oriented improvement strategy taking place "in front of live problems" which focuses on the execution of defining and solving problems. Driven by results instead of techniques, the approach synthesizes the best of all ideas offered by training, teamwork, problem solving, and statistical approaches. The basic premise of the approach can be summed up in one major principle, "The cost of finding a solution must be as close to zero as possible."

INTRODUCTION

PROBLEMS THAT NEED DEFINITIONS AS WELL AS SOLUTIONS. With changing market conditions, quality continues to receive increasing emphasis as a major element of business strategy. Management has responded with a willingness to look at quality improvement as a science, attracting many professionals to this growing field. However, a high level of activity does not automatically guarantee success. Successful quality improvement requires a multi-phase strategic attack to search out hidden opportunities. The opportunities lie in providing clear definitions of previously unrecognized critical problems as the first step in reaching solutions.

Because problems are typically most visible during manufacture, a large proportion of improvement efforts have been directed there, although it does not necessarily follow that the problems originate there. Opportunities for improvement lie in all stages of the product cycle and in the administrative, operations support, and service functions of a business.

Hidden problems that need to be attacked fall into two broad categories that affect a company's competitiveness. First, how products and services are perceived by customers defines the **quality** issues. Second, given that we are satisfying the customer, whether we do things faster and more efficiently than our competition defines the **productivity** issues. The two issues are connected in that productivity improvements naturally result as a by product of properly executed quality improvement activities.

Some examples of quality issues are: (1) the amount of waste during a process set up, (2) the amount of unreported scrap, and (3) the amount of rework that is included within standard time and not easily detectable. After several years of focusing on quality improvement, most of the remaining quality issues are hiding within comfortable, traditional industry indexes or budgets. If an attempt is made to seek an improvement, it often meets great resistance from the status quo. The challenge of uncovering hidden problems is exacerbated by the difficulty of finding an honest database from which to work. Most databases in industry were created to support administrative functions rather than to support ongoing problem solving efforts. Thus, they have little problem solving value, so problem solvers must gather data to uncover and define problems. Many problem solving efforts fail early on because they are perceived as a big data collection project instead of a habitual periodic examination seeking continuous improvement opportunities.

Some examples of productivity issues are: (1) the time it takes to create a product design, (2) the time required to deliver a product after the order is placed, (3) the amount of time it takes to respond to a particular inquiry, (3) the time to set up a process, and (4) the amount of downtime for machinery. Industries generally establish norms or standards for productivity instead of viewing them as improvement opportunities.

If concern for quality and productivity is extended into the administrative and service areas, the concept of improvement is less prevalent than it is in the manufacturing or design activities of a company. A disproportionately large amount of resources are committed to nonvalue-added daily chores rather than value-added continuous improvement activities driven by analysis of the database created from daily chores.

The severity of the problem created by missed opportunities to improve quality and productivity in the hidden areas is now recognized by management and the work force, but only in light of the current quality and productivity achievements of the competition. The recognition did not arise from an ingrained philosophy of continuous improvement, but out of necessity as market share was lost.

Recognition of competitive deficiencies by top management has been accompanied by additional factors favoring fruitful attacks on continuous improvement tasks. The favorable factors are: (1) the willingness of top management to spend time and financial resources to do justice to the issue of continuous quality and productivity improvement, (2) the contributions of many professionals and consultants who were previously under utilized, (3) the availability of personal computers and problem solving software, (4) increasing awareness on the part of employees to pay attention to quality as a job security element, and (5) the willingness of employees to participate in the teamwork required to solve complex problems.

The favorable factors listed above will only generate improved competitiveness if the focus is shifted from the present practice of emphasizing improvement approaches and techniques to emphasizing improvement opportunities and results. As opportunities emerge, the particular improvement task will dictate the most appropriate approach.

APPROPRIATENESS OF RECENT IMPROVEMENT APPROACHES. A search of recent improvement approaches includes :(1) statistical process control (SPC), (2) design of experiments (DOE), (3) the Taguchi approach to quality engineering and design of experiments, (4) Just-In-Time (JIT) systems, (5) automation, (6) Quality Function Deployment (QFD), (7) company wide quality control (CWQC), and others. The merit of each of these approaches to quality and productivity improvement cannot be argued. However, the manner in which each of these approaches is applied will definitely influence their impact on the bottom line.

Two common pitfalls must be noted. First, many of these approaches are implemented or instituted on a broad scale rather than seen as something to apply selectively and appropriately. Second, the implementation frequently follows a path dominated by education and training rather than a path of execution "in front of live problems." The education and training path is expensive and delays realizing a benefit on the bottom line. The training often contains content that is irrelevant to the trainees. Personnel armed with the new approach become rebels in search of a cause. They may choose an improvement opportunity for which their new tool is not truly appropriate. Once underway the implementation itself may be jeopardized when the newly trained team hits sticky or difficult points in execution, having only their hypothetical classroom background to rely on. Conversely, following the execution path will provide education and training even as a problem is solved and the bottom line is favorably affected.

In addition to the general pitfalls listed above, each of these valid improvement approaches is subject to specific misapplication.

Statistical Process Control (SPC) is an approach which is widely acclaimed as a quality and productivity improvement tool. However, the manner in which it is applied leaves doubt whether it will ever achieve its full potential. Naive SPC advocates assume that the form of instability which is evident on an SPC chart is easily and immediately understandable, and therefore immediately correctable. Plentiful evidence exists to prove that neither understandability nor how to correct are obvious. In fact, about 8 out of 10 applications of SPC require further investigations and problem solving efforts to understand and correct what the SPC charts reveal. Given that this is the case, one must question the appropriateness of the massive investment in gages, electronic data collection devices, and computers to support the implementation of SPC. Since in about 8 out of 10 applications corrective action is not obvious, the real time signal provided by electronic gages is of no practical use. Proper use of SPC to investigate problems and confirm that they have been solved may lead to the need to have real time signals. Would it not be more appropriate to solve some "live problems" and let the gains made from the solutions pay for the investment (if justified) rather than be faced by the surprise that further investigations are necessary?

Design of experiments (DOE) is an excellent problem solving tool in determining which variables and their combinations influence process output. It offers the discipline to handle a large number of variables. Most companies attempting to realize improvements through use of the DOE approach have chosen a training path. The training emphasizes the mathematical efficiency of designed experiments and offers virtually no hints toward executing experiments in the live environment. Absent from the training message is the fact that the mathematically shortest possible path cannot necessarily be executed in the live environment. In other words, the assumption is made that to accommodate the efficient mathematical path the necessary funding will be available to counteract the slowdown in production efficiency and/or the use of production equipment for experimental purposes, since the improvements made will ultimately result in savings that will more than pay for the cost of executing the designed experiment. More often than not, such is not the case. Even if that were so, why spend money needlessly, if a zero cost approach is possible? Actually, to maintain the balance between business realities and the DOE discipline, a path must be sought to apply the discipline with an investigation cost that approaches zero. The example at the end of this section will illustrate a case in which the cost of investigation was very high, despite the small sample size yielded by the mathematical efficiency of the DOE discipline. An execution path can be followed in which the

variation already present in the product or process can be observed and recorded **as it occurs** without disrupting the yield or efficiency, maintaining the delicate balance between business realities and the DOE discipline.

A second difficulty in DOE training is the strong assumption that all the necessary preceding steps to execution of the experiment have taken place, including proper problem definition, creating a comprehensive list of variables, and paring that list down to a manageable size. Personal participation by the authors in many live problem solving situations suggest otherwise. In far too many cases, problem definition is very poor and the lists of variables selected for study are highly confounded or incomplete. Considerable skill is required to define a problem and determine what variables should be studied. If those preceding steps are not properly executed a great deal of unnecessary expense will be encountered and the odds of the experiment leading to a permanent problem solution are greatly diminished.

The major cause of poor problem definition comes not from how the problem is defined, but from how it is perceived. Problems are defined by emphasizing the visible aspects of the problem, while neglecting the four necessary elements in proper problem definition. Those four elements, which will be covered in more detail later, are: (a) strategically selecting where to begin the investigation, (b) determining how the process output will be measured, (c) quantifying the problem magnitude, and (d) creating a "statistical" definition of the problem.

Creating a **complete** list of suspect variables is rarely done at the outset of an investigation. Important variables may be left off the list. Confusion about what actually is a variable leads to variables and "subvariables" being on the same list. Thus, the variables get confounded and undermine the validity of the experimental results. Additionally, process flow diagrams and cause and effect diagrams are not effectively utilized to compartmentalize the problem and thereby control the length of the variable list.

Making a list of variables is a difficult task and is complicated by lack of clarity in problem definition. Failure to satisfy those two fundamental criteria in DOE application will result in a failed or inconclusive experiment. Therefore, training of DOE is more meaningful "in front of live problems" where the science of problem definition and listing variables is perceived by students as an absolutely necessary prerequisite for a successful experiment. Only by facing the problem definition and variable listing tasks in front of a live problem will the student truly appreciate the skill required to accomplish them. The message will not come through in the classroom dazzle of mathematics with slick computer examples.

<u>The Taguchi approach</u> to experimental design is a part of Dr. Taguchi's broad contributions to the quality discipline. His system of experimental design is used by many as a problem solving tool, and as such is a specific subset of the DOE discipline. It has its foundation in mathematically efficient fewer trials in highly fractionalized experiments. The merits of such efficiency can, once again, come under scrutiny in the live problem solving environment. Work similar to the Taguchi approach has been visible in the literature by Plackett-Burman specifically and fractional factorial experiments generally. These types of experiments have produced some successful results in the product and process development stage, but are ill suited to application as a problem solving tool in the ongoing production environment. The lack of popularity of fractional factorials is due to the high degree of difficulty in conducting the experiments. Unfortunately, that difficulty is not outweighed by their mathematical efficiency, except in limited, specific situations. Those companies making a massive training investment in the Taguchi approach may not need to question the mathematical validity of the approach, but <u>should</u> examine the question of the appropriateness of the approach from a business strategy perspective. Business strategy would demand a clear and successful demonstration that the investment required to conduct the experiment is far exceeded by the benefits. Further, the benefits must continuously pay for further investment. The Taguchi approach, much the same as the fractional factorial approach, will have to stand that scrutiny before it can be widely accepted as a vital element in quality and productivity improvement.

The <u>Just-In-Time</u> (JIT) system is an excellent concept in material flow management providing control by downstream demand rather than upstream forecasting. JIT success is dependent upon predictability of all the process elements that are involved in meeting the downstream demand on time. Some of the process elements are (a) predictability of set up time and the amount of scrap generated during set up, (b) predictability of quality of process output and the amount of defectives generated during the process run, and (c) predictability of machine downtime. It appears that these process elements are major problems in many companies. If companies can successfully work on these problems and create a predictable environment, then JIT will be the end result of such work. JIT is not something that somebody works on, it is the end result of solving inherent problems successfully.

Present material flow systems in existence are not necessarily due to a lack of awareness of JIT, but are largely due to either the inability or unwillingness to solve problems.

Automation definitely occupies a strategic place in creating a higher order of consistency than human hands, human attention to details, human judgement, and human knowledge can provide. In hardware form, automation takes the form of robotics when it replaces human hands, process control instrumentation when it replaces human attention to details and human judgement, and Artificial Intelligence when it replaces human knowledge. Since many forms of automation exist, they must be strategically balanced with respect to each product or service application. For example, most any manufacturing process quality and productivity can be improved with the introduction of automation. However, an optimum return on investment can come from balancing robotics, instrumentation controls, and artificial intelligence. Many companies have invested heavily in robotics with no strategic balance criteria. Once again, problem solutions shown to lead to quality and productivity improvements should dictate the degree to which automation is necessary. Automation should not occur for automation's sake.

Quality Function Deployment (QFD) is another good idea for quality and productivity improvement, which is known to U.S. companies as project management. Successfully managed projects will find nothing overly startling about QFD. Its major contribution to the project management discipline is that it offers some unique ideas about making the translation from customer wants to product or service features, organizing and integrating information, and setting priorities for those working on a project. But U.S. companies have recognized the various aspects of project management for a long time as indicated by the functions of the various groups involved in product planning and development. Marketing learns the needs and expectations of the consumer, marketing and design translates those needs and expectations into a design, design and manufacturing reviews the designs so they are producible, manufacturing then engineers the process to product the product. The catch comes in that inherent problems are encountered throughout the product development cycle. QFD, like any other effective project management system, may highlight potential problems early in the cycle, but ultimately it is the **solution** of the live problems that will determine the success of a product or service. Classroom QFD discussion can hardly compete with what live problems solutions can achieve.

Company Wide Quality Control (CWQC) suggests that all department functions and personnel must think of continuous improvement as part of their job description. To accomplish this one must formulate an improvement index for any set of activities and follow it systematically to motivate improvement actions by personnel, functions, or departments. CWQC programs fail to reach full potential due to the difficulty in formulating the improvement indexes and due to lack of practice in front of live problems. CWQC lectures are interesting with their concepts. However, execution of CWQC leaves much to be desired.

The purpose in the critiques of the improvement approaches above is not to argue against the merits of any particular philosophy or approach. The critiques flow from a sense of obligation from the viewpoint of problem solving to warn against a manner of implementation and application which is unfruitful or even wasteful. The true merit of any approach is measured not on its theoretical or philosophical merit, but on its true effect on the bottom line. One might counter that we need problem **prevention**, not problem **solving**. However, the reality is that in all functions and at all stages of providing a product or service, problems are encountered. Those problems are the improvement opportunities.

When management focuses on a specific improvement **opportunity**, as opposed to trying to "implement" a new improvement **philosophy**, the execution trail will result in the appropriate application of an improvement science to solve that specific problem, resulting in quick positive impact on the bottom line. It is the execution approach that leads to breakthroughs. One example serves well to illustrate the major points of the above introduction.

A U.S. manufacturer faced a problem with an assembly. Only 20% of the assemblies functioned properly and passed a 100% inspection gate without any repair. Eventually all the product was shipped, although after several attempts at repair. Initially, the management of the plant did not even perceive a problem, since all the product was shipped. No scrap cost was seen. However, one assembly reached a customer in a nonfunctional condition and the management's attention was turned to the problem.

Some quality practitioners at the plant had recently been trained in the use of designed experiments. They set up a mathematically efficient orthogonal array requiring 8 trials to evaluate 7 dimensions on the two critical parts in the assembly. To have the experimental hardware made was to take 3 weeks and cost about $40,000 dollars. The search for a job shop to make up the needed hardware led finally to a British shop!

Meanwhile, another problem solver got involved who was concerned with not only mathematical efficiency, but also the cost of investigation. Driven by the problem at hand rather than a particular method or philosophy, this new problem solver gathered together several functional and nonfunctional assemblies, took them apart and measured the very same dimensions that were to be part of the designed experiment. Using multiple regression analysis, it was determined which of the dimensions had to be controlled most closely and new targets were found for each dimension. Component parts were then found in the existing stock which had those approximate target values. Assemblies were made that all functioned properly, confirming the new targets. The blueprints were changed to reflect the new targets and the problem was solved. All this activity occurred at virtually no hardware cost and in a very short span of time, while waiting for the special experimental hardware to arrive from England.

AN IMPROVEMENT APPROACH THAT SYNTHESIZES THE BEST

HOW THE SYNTHESIS OCCURS. Team effort, as opposed to individual effort, constitutes a universal and necessary part of any problem solving effort. Thus, forming the right team is the first step toward synthesizing the best quality improvement approaches. Member selection requires special consideration, since ultimate success depends upon the team members knowledge of the problem at hand. A facilitator proficient in the problem solving skills is also essential. The synthesis of process knowledge and problem solving skills will refine the existing knowledge and move it to a new level. In a manufacturing process problem, the team may consist of a production operator, quality inspector, foreman, process engineer, metallurgist/chemist, design engineer, a downstream user of the process output and a facilitator. In an administrative problem teams may be smaller with at least two members related to a functional area, a downstream user of the administrative services, and a facilitator.

The team's training needs are defined based upon what problem has been selected and the members' current skill levels. Training needs assessment should occur after the facilitator has explained to the team the problem solving approach and how the statistical approach differs from the conventional approach. The team facilitator himself is a student, since he is learning about the specific details of the process and its related problem. Team training should cover the basic facets of problem solving steps with an emphasis on methods applicable to the problem at hand. The training should not become bogged down and turn into a general problem solving course. The team members are likely to be overwhelmed with the presentation of methods and mathematical details that are irrelevant to their problem. On the other hand, the team will show great interest in methods applicable to their specific problem.

As the team enters the problem solving activity they will begin to share important information about the problem with one another. Mutual respect will develop among the team members for each member's individual skill and knowledge. The need for a team approach to problem solving will become evident to the team.

FINDING PROBLEMS IN THE STATUS QUO. Most professionals today are well compensated and view themselves as quite self sufficient. Problem solving suggestions coming from disciplines other than their own can be threatening. Unfortunately, the majority of problems that can bring significant productivity gains have their origin in the "cracks" between departments. "Hidden" problems are sensed within a company and as they surface, finger pointing frequently occurs instead of recognizing the opportunity for improvement. Top management participation is necessary to make the "cracks" visible and bring the necessary team members together. The improvement science can then deal with the problems objectively without getting involved in finger pointing and "turf" issues. Left on their own without top management participation and the presence of a facilitator, separate departments will fail to recognize the "cracks," let alone form the teams that will seek solutions.

Another area in which problems hide is in comfortable business indexes. For example, the large amount of scrap generated during a set-up could be buried in indirect costs and not easily revealed for meaningful analysis. Also, budgeted scrap allowances are unapproachable for reduction, since only that scrap resulting in a budget variance is reported. Whether it is budgeted or not, scrap represents a real dollar loss to a business. Where loss occurs, opportunity exits. Numerous similar opportunities exist where problems have been hiding for years. It requires genuine commitment and problem solving skill to uncover one of these inherent productivity problems.

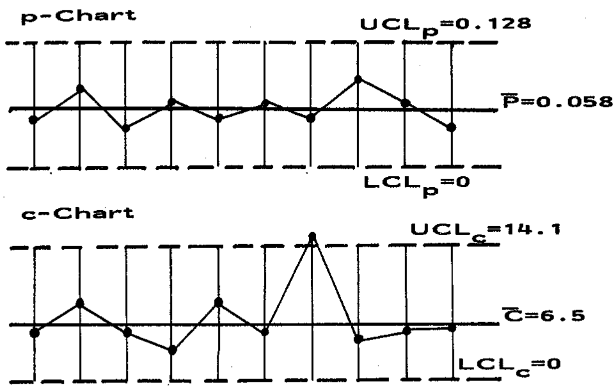
MAKING PROBLEMS APPROACHABLE THROUGH PROBLEM DEFINITION. The essential initial step of solving any problem is getting a clear definition of the problem. Defining problems requires a considerable amount of skill; inadequate problem definition is a common cause of failing to solve problems. To successfully define a problem, four essential steps should be followed. They are: (1) the problem must be picked strategically, (2) there must be consensus regarding how the output will be measured, (3) the magnitude of the problem must be estimated, and (4) the problem must be described statistically.

Apart from the four steps above, a common pitfall at the problem definition stage is the confusion between the problem itself and the suspected causes of the problem. For example, many problem solvers say that they have a material problem, a tooling problem, or a temperature profile problem. Those things are actually highly suspected causes of the problem, not the well-established causes or root cause, nor are they the problem itself. Examples of problems include "fails the leak test," "won't assemble," and "surface imperfections." When one declares that a suspected cause of a problem is the problem, the problem solving effort heads off in the wrong direction. Even if the problem solver successfully eliminates the cause, it does not necessarily follow that the problem itself will go away. The focus must be on the problem.

STRATEGICALLY SELECTING THE PROBLEM. The strategic selection of the problem begins with the idea that system instabilities must be corrected before system improvement can progress. That is, infrequent and unpredictable incidents must be addressed before addressing the frequent, chronic incidents. The strategies for solving problems of instability differ substantially from the strategies for solving frequent, chronic problems occurring in a stable process. The most effective means to begin solving problems of instability is to employ a p-chart, c-chart, and Pareto chart combination. An example is pictured in Figure 1.

The p-chart measures what proportion of the process output is affected by the problem and is a direct indicator of the business loss. The c-chart measures the number of occurrences of the failure within a given unit of output. It will indicate more scientifically the degree of difficulty in generating the output. The Pareto chart indicates where the majority of difficulties lie with respect to the problem.

A successful strategic selection of the problem begins with instabilities revealed by the p-chart and/or the c-chart. If the problem solver finds instabilities, he should examine the Pareto chart to reveal which category of output causes the instability. For instance, an assembly passing through a 100% inspection gate may fail for numerous reasons. The categories of failure should be listed on the bottom of the p-chart and c-chart. The first categories to attack are those that cause the instabilities, even if they do not cause the majority of the total failures. That cause of instability then becomes the problem to be solved. If the problem solver does not find any instabilities on the charts, he should examine the Pareto chart to reveal which category is the major or primary contributor to the failures. That category of frequent and stable failures becomes the problem to be solved.



Proportion Defectives	05	08	04	06	05	06	05	09	06	04	Total Defects
Number of Defects	6	8	5	3	8	5	15	4	5	6	65
Item1	/	///	/	/	///	//	////	//	/	///	21
Item2		/		/		/	/		//	/	7
Item3	//	//	/						/		6
Item4		/			/		/			/	4
Item5	//						/////				7
Item6		/		/		/	/				4
Item7	/		/		//		/		/	/	7
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Pareto Chart

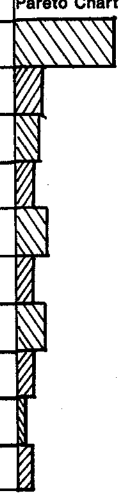

Figure 1 - p-Chart, c-Chart and Pareto Chart

MEASUREMENT OF THE PROBLEM. In some cases, measurement of process output presents a genuine difficulty in problem solving. However, in many instances the difficulty of measurement becomes an easy excuse not to proceed with problem solving until a better measurement scheme can be found. Finding a better scheme is usually not necessary to begin the problem solving process, since, in general, if a measurement scheme can allow a company to conduct its business, that scheme will be able to facilitate problem solving. The following principles aid in solving problems with existing measurement schemes in which one of three objections occur. The objections are: (1) the measuring instruments are imprecise, (2) the characteristic is an object of disagreement as to what constitutes a failure, and (3) the assessment is too subjective.

For the imprecise instrument, the average of several readings will provide a more precise estimate of the truth than a single reading. If an estimate of the measurement precision is available or studied, then one can easily compute the number of readings needed for the desired precision with which the average of the readings agrees with the true value.

Disagreements as to what constitutes a failure are likely to arise when more than one inspector is used in the problem solving scheme. The disagreements can degenerate into arguments that stop progress towards solving the problem at hand. Limiting the assessment to a single inspector will avoid arguments and in most cases allow the problem solving effort to proceed successfully.

Subjective assessments can also be resolved by allowing a single inspector to rate the output. A second way to resolve the problem is to use two inspectors and use the median of their ratings.

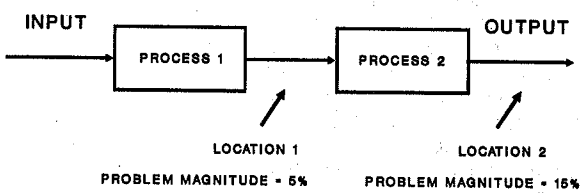

Figure 2 -Choosing Location in Problem Solving

ESTIMATING THE MAGNITUDE OF THE PROBLEM. It is important to know the magnitude of a problem, since problems of relatively small magnitude require special consideration for three reasons. (1) The authors' experience has shown that smaller magnitude often indicates that the problem is caused by higher order interactions of the suspect causes and process variables. Therefore, any investigation should not make assumptions that favor dropping those interactions. Conversely, a larger magnitude indicates that is is likely that the problem is caused by the influence of one or two dominant variables acting independently, and the investigation will take a different tact. (2) Improvement may be impractical to detect in the problem solving process when the problem is of smaller magnitude. An alternative strategy is to select variable levels that generate defectives during the investigation. The solution is to move in the opposite direction from those combinations which are found to contribute to the problem. Conversely, improvements are obvious in situations where the magnitude of the problem is large, so they can be measured directly. (3) Smaller magnitude problems sometimes indicate that the problem may not be solvable by exploiting the flexibility in the process variables. Some hardware expense may be involved in creating new variable options or new technology may be necessary. Conversely, problems of large magnitude often indicate mismanagement of the existing process, so that problem solutions can be implemented by changing how the process is managed or controlled, not by making expensive hardware changes.

STATISTICAL DESCRIPTION OF THE PROBLEM. Besides having a visible evidence of the problem, a statistical definition is necessary, as it will narrow down the list of variables with which the problem solver must work.

Once the strategic selection of the problem is made one should determine the source of the largest contribution to the problem variation. For instance, **where** to attack the problem is an important issue. In Figure 2, the process capability at locations 1 and 2 can help determine the largest contributor to the problem.

Once the location of the problem is chosen, the further breakdown of the product output may help focus on the problem. Use of statistical process control charts is useful in that regard.

Average and range charts can break down a problem into four categories, namely (1) off-target problem, (2) target instability, (3) range instability, and (4) process incapability. The p-chart can separate a problem into two categories, (1) instability and (2) incapability. The runs chart, or X-chart, can break down a problem into three categories, namely (1) off target problem, (2) general instability, and (3) incapability.

In instances where a "WHAM!" process (many characteristics are created simultaneously) is involved, it may be necessary to define a problem in terms of more than one characteristic simultaneously. For instance, if two characteristics are involved, it is helpful to know which of the following conditions is the problem: (1) low-low condition, (2) low-high condition, (3) high-low condition, or (4) high-high condition.

Many problems involve "envelope" type characteristics, in which the problem can develop due to one or more of several independent physical conditions. For instance, a shaft may not fit a hole due to its (1) size, (2) out of round condition, (3) excessive taper, (4) straightness, or (5) some combinations of those characteristics. Therefore, it is important to know which of the conditions or their combinations is presenting the fit problem. Figure 3 illustrates the cross section of a shaft. Figure 3b shows a plot where the out of round condition is contributing more variation than piece to piece size variation. Figure 3c shows a plot in which the piece to piece size variation is contributing more variation than the out of round condition.

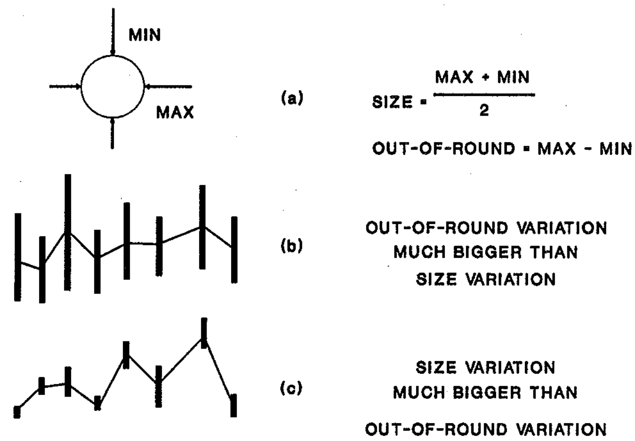

FIGURE 3 - PROBLEM DEFINITION FOR AN ENVELOPE CHARACTERISTIC

SOLVING PROBLEMS AT VIRTUALLY NO EXPENSE. In order to reach fruitful and permanent solutions to problems the distinction between **problem investigation** and **trials of possible solutions** must be understood. Many problem solvers think they are investigating a variable, when in fact they are trying a new level of the variable and, in the process of trying it, incur an expense. The trial approach, as opposed to the investigative approach, is ingrained in their thinking, having been guided by a process of elimination approach to problem solving for so long. During the problem solving process, the problem solver must keep focused on the problem and remain open minded about possible causes. Remaining in an investigation mode rather than a trial or implementation mode is aided by four execution principles.

The first execution principle is that variables first selected for investigation must be inexpensively changeable. That is, trying different settings of the variable must involve minimal hardware expense. For example, if cleanliness of a machine is to be investigated as one variable, there are two approaches. One way would be to shut the machine down, clean it up, restart it, examining the output before and after cleaning. Another way would be to observe it just prior to and after the normally scheduled cleaning. If characteristics of certain components in an assembly are suspected to contribute to a problem, an expensive approach is to have special components made to represent change in the variables. An inexpensive way to investigate the variables is to observe the changes as they naturally occur in production and see how they affect the process output.

The second execution principle is that suspected variables must be taken to their extreme settings as far as possible without destroying the product or process equipment. Operating personnel or process logs can give guidance on the limits of variable settings.

The third execution principle is that any defectives generated during the investigation should not exceed the historical level of defectives.

The fourth execution principle is that during the investigation efficiency should not be adversely affected. The creativity of the problem solvers must guarantee that real time samples can be drawn without interfering with production.

In addition to the execution principles, the problem solver can increase the probability of success by maximizing both the deterministic and probabilistic methods. Deterministic methods exploit existing knowledge about the process within the organization, while the probabilistic methods refine that knowledge and raise it to the next higher level. Keeping the execution principles in mind, the problem investigation and problem solving steps begin. A series of steps which make optimal use of both the deterministic (subject matter knowledge) and probabilistic (statistical methods) approaches is fit within the framework of Statistical Problem Solving (SPS). SPS consists of four basic steps which are explained below. Those steps are (A) listing variables suspected to influence the problem, (B) prioritizing the variable list to obtain a top few for in-depth investigation, (C) evaluating the top few variables, and (D) optimizing the process.

Step 1: Listing. Listing is an essential step in problem solving. It must be done by a knowledgeable team that is totally open to any and all influences on the problem. Two simple tools greatly facilitate the listing of variables, the cause and effect diagram and process flow charts. Once the list is generated, the variables in the list must be prioritized according to the ease with which they can be changed. Thinking of variables as "knobs" that control a process, they are listed in order of "turnability." Even when it appears that some knobs can only be turned expensively, with a little imaginative creativity ways can be found to turn them inexpensively, as in the example above regarding investigating the effect of cleaning a machine. To follow the zero cost path, the solutions requiring virtually no hardware cost of investigation or implementation should be studied first. Only if the present process hardware is unable to be utilized to solve the problem, should new hardware be generated.

Step 2: Prioritization. The purpose of prioritizing the variables in the list is to select a top few variables that can be economically investigated with full consideration of possible variable interactions. Prioritizing variables in the list is a reflection of the order in which the variables should be investigated. Prioritization impacts the cost of problem investigation in numerous ways. It will help to avoid the indirect cost incurred when bias causes the investigator to select the wrong variables from the list to investigate. Teamwork is an essential element in avoiding such bias, as each team member's perspective joined together will create a balanced and objective view of the problem. Also, the team discussions during the prioritization step will serve to validate that the variables ranked high are in fact likely to affect the problem at hand.

The prioritization methods that follow are listed in order of increasing expense, so following a zero cost strategy they should be tried in the order given. The first method to try is a subjective technique in which the team members vote. If that fails, existing data on the problem is reviewed using correlation analysis or contingency tables to find those variables most strongly associated with the problem. If those inexpensive methods which rely on existing data fail to generate the prioritized list, then screening experiments (fractional factorials or orthogonal arrays) can be used. The cost of conducting fractional factorials is high, so they are only used as a last resort during prioritization.

In addition to prioritizing the variables with respect to their impact on the problem, other execution principles should be considered. The ease and/or cost with which the prioritized variables can be changed will influence the strategy of evaluation. Also, the team should consider any variables in which they can reach a consensus that the desired level is already known. For instance, if "greasing the platens" is thought to have a favorable effect on the problem and all agree, then it should not be a variable, but should become part of the standard operating procedures.

Step 3: Evaluation. In the evaluation step, those top few variables selected during prioritization are investigated fully. The statistical tools used during the evaluation stage are the analysis of variance, the analysis of covariance, and/or multiple regression analysis. The method chosen is that which supports the least cost execution of the experiment during actual production, keeping in mind the execution principles that efficiency should not be disturbed, nor should the historical level of defectives be exceeded. Information gained in the evaluation stage will tell the problem investigators which variables are in fact most important with respect to the problem, what are the approximate best settings of those variables, and what degree of improvement can be expected if the solution is implemented.

During the evaluation step there are several things that can add unnecessary cost to the investigation. These are explained below.

(1) Since more than one trial will be conducted during an experiment there is an administrative cost associated with the changes that must be made during the trial. The cost of the changes must be minimized, which introduces the risk of jeopardizing the randomness of the experiment. However, the randomness can still be preserved if all the factors that might influence the randomness are carefully watched. For example, lack of consistently following standard operating procedures or touching other knobs (variables) during the investigation are two fundamental reasons that randomness seeks to counteract. In watching such risks carefully during the execution of an experiment, one can trade off administrative convenience and cost and still preserve the integrity of the investigation. Also, control charts can be drawn of the experimental output and they will indicate troublesome patterns that do not follow the variable changes during the experiment.

(2) Because of the cost minimization principles followed, sample sizes can be relatively large in an SPS investigation. The experimental output, after being measured, can be shipped, thus recouping much of the cost of the investigation. Thus, if any trial produces an unusual proportion of defectives, that trial can be suspended as soon as the problem is recognized, reducing the sample size significantly and saving scrap cost, without jeopardizing the integrity of the investigation.

(3) In a designed experiment, the investigator creates the variation in suspect variables. Yet in many problem investigations it is extremely expensive or virtually impossible to create the combination of variables dictated by a designed experiment. Problems associated with assemblies, batch processes, and continuous processes are particularly expensive to evaluate using designed experiment methods. In such cases, the variation of the significant variables is occurring naturally. Instead of creating the changes, careful planning of data collection will allow meaningful investigation of the problem using multiple regression analysis. Again, the cost minimization principles of the SPS approach allow for the economical collection of a sufficient quantity of data at virtually zero cost.

Step 4: Optimization. In most cases, the evaluation step will yield adequate improvement to resolve the problem. From a global view of a company's problems, the problem investigators may then find that it is best to turn their attention to another problem. However, the evaluating stage only yields estimates of the approximate best settings of the important process variables. In some cases refined determination of the variable settings is required to solve the problem. Optimization is the systematic and small changes made to the important variables around their approximate best values in order to pursue continuous improvement. Mathematical and statistical aids such as multiple regression and Monte Carlo simulation are very important tools for reducing the extent of hardware experimentation required. Most of the cost in the optimization step is due to the investigators' time, not in the alteration of actual hardware.

IMPLEMENTING SOLUTIONS IN WHICH THE BENEFIT EXCEEDS THE COST OF IMPLEMENTATION. When following the problem solving path, problems must be defined as outlined above. The problem investigation will reveal which suspected variables or their combinations can yield a solution. That **statistical** solution must be translated into a **hardware** solution. It is at this point that implementation occurs. Implementation is the important step between knowing a solution and realizing the benefits. Those designing the hardware should also apply their creativity in order to minimize the cost of implementing the hardware solution. It is possible that the cost of achieving a quality or productivity gain may exceed the gain itself. Therefore, in order to make business sense, the cost of implementation must be lower than the estimated benefits. The statistical information from the problem definition and investigation can provide the basis to estimate the gain. If a creative approach to implementing a solution proves too costly, one may have to consider advanced technology to offer a solution which will cost less than the benefit.

When confronted with the task of making the translation from the statistical to the hardware solution, the problem solvers are confronted with numerous options. Figure 4 shows the flow of logic that follows from the statistical solution that the problem resolution will come through timely and appropriate tool changes. Questions about the characteristics of the tools themselves, the nature of the signal that a change is needed, the degree to which the tool change is automated all impact what is the best hardware solution. The problem solvers must examine various scenarios and decide which is most appropriate for the given situation and what is ultimately the least cost solution.

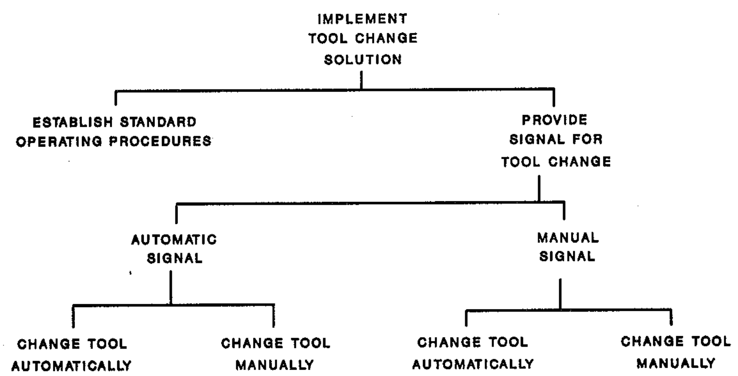

Figure 4 - Options Available toImplement Tool Change

CONCLUSION: WHY "IN FRONT OF LIVE PROBLEMS" IS A STRATEGY THAT CAN BRING OUT THE BEST

There are many improvement philosophies that can produce desirable results. Those philosophies that consistently produce results in practical situations are superior. Since companies are bombarded with so many good ideas from so many directions, the best way to sort them out is to apply them in actual situations. The sorting of good ideas can actually begin to unfold as the solution is being derived. As more and more problems get solved, a new philosophy emerges, the one that works. All the philosophical debates about what works and what does not work come to a definite conclusion "in front of live problems."

Many U.S. companies are correctly applying this approach. Some others are trying to associate improvement approaches with famous persons. To them, working or listening to many differing suggestions for improvement creates confusion more that it provides help. Companies often focus on who is the best improvement guru, instead of asking how to best synthesize the many good ideas. Countless classroom hours are spent in the debate about who and what are best, while the real problem solving opportunities remain unattended. Some companies manage to avoid the confronting the live problems and accept the comfortable slot of debating good ideas. This paper has provided suggestions for all the necessary execution elements nécessary to stop the debating and to start pursuing quality improvement in front of live problems.

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