CRITICAL THINKING IN CONVERTING

DAVID R. ROISUM

A REVIEW OF PROBLEM-SOLVING TECHNIQUES, TOOLS, AND COMMON PITFALLS.

IN ANY MANUFACTURING PLANT, THERE ARE SO MANY OPPORtunities vying for our attention that picking our battles is almost as important as fighting them *(1)*.

PICKING A PROJECT

The process begins by developing a thorough master list of problems we might be able to solve or mitigate. Since there is never enough time or resources to do everything, we can choose only a few items from that list to begin work on. The selected items are placed on an active list. Both the master and active lists of projects should be updated regularly. Items are added to the master list as they occur to us and deleted only when they will not benefit from additional effort. Items are added to the active list when they have reached a priority status and we have the resources to work on them.

Lists of opportunities can come from a variety of sources, many of which are obvious. Sometimes the boss tells us what to work on. It would be prudent to consider such requests, even though Rule #1 does not so universally apply as the maxim indicates. Sometimes customer needs and complaints monopolize our consciousness. This happens when "the customer is always right" mania replaces the more coolheaded "the customer is always the customer" approach to honest and fair dealings with a business partner. Other sources for project ideas are the most costly waste *(2)* and delay *(3)* items.

Operator squawks are an often-overlooked source of ideas. (The term "squawk" is used by pilots and mechanics to denote items that need attention on an airplane.) Operators will tell you much if you earn their trust, ask them for ideas, and listen carefully. Pay most attention to the seemingly small and unimportant "nuisance" items, which can have handsome returns. Often clients ask me how to spend earmarked money to rebuild their equipment so that it runs better. On more than one occasion, my advice was to install good lighting, since it would pay back sooner than any other upgrade. A lighting upgrade will pay for itself if only one roll is saved because the operator didn't misread the tape measure while setting slitters in the dark recesses of the winder.

Another source for projects is your own passions and hunches. If you really want to work on something badly, you will succeed where others less interested might fail. If you have a hunch that something will pay back, listen to that sixth sense. Take care, however, that you don't work on things that are personally interesting but not largely helpful to the bottom line.

After the list of project ideas is drawn up, it must be prioritized or ranked. If you are truly mired in problems, you must perform triage. (War wounded are separated into three groups: those that will probably survive without attention, those that need immediate attention to survive, and those that probably won't survive. You work on the middle group first.) If you have more sedate conditions, you can rank the opportunities by potential savings in waste and delay and then select your projects from the top few. There are shortcomings with this common approach, however. The top few problems are likely to be difficult or costly, else they would have been solved long ago. It is also possible that some of the top problems are currently insoluble for a variety of reasons, including insufficient technology or conditions that are overconstrained. For example, we currently don't have the technology to treat, much less cure, the rabies disease no matter how much we would wish otherwise.

A flip-side methodology is to work on the easiest problems even if they aren't the attention-getters. There is much to be said about improving something in a straightforward, low cost, low risk manner. If you really want to make a science of it, however, you rank opportunities in order of greatest cost–benefit ratios. Only then can you be certain that your efforts will be most helpful to your company.

PROJECT DEFINITION

Before diving into our ameliorative efforts, it is best to spend some time thinking about goals and formulating a good problem statement *(4)*. Even if the project is already defined and assigned, a critical examination is still a valuable exercise. For example, did you know there are always three aspects to a problem statement? The three aspects are: what they say it is; what they think it is; and what it really is. Differences among these aspects may not be subtle and unimportant, especially in regard to customer–supplier relationships. In most cases, technologists will seek to resolve the underlying physical problem. Nonetheless, how the solution will be received by the customer or boss must be considered for maximum success.

A good problem or goal statement has several important characteristics. First, its foundations are solidly built upon the business economics of reducing costs, increasing manufacturing efficiency, increasing product quality, increasing the scope and flexibility of manufacturing processes, and so on. It is important to know how much a problem costs or how much an opportunity is worth prior to accepting a project assignment. Second, progress should be reasonable and realistic. It does no good, for example, to assign goals that may require nonexistent resources of time and/or money. Third, progress should be quantifiable. It does little good to try to reduce customer complaints if, for example, defects are not measured and complaints are not tabulated to begin with. While progress might be made, the results would be subject to debate.

Unfortunately, poor problem statements abound. For example, I have been asked on many occasions to reduce the tightness of wound rolls. Yet tight rolls are rarely a defect. The assignment should have been posed as reducing the incidences of rejects due to baggy webs, blocking, or whatever. This definition allows additional solutions such as reducing caliper variation, redesigning the surface chemistry, and so on, which are usually much stronger and often overpowering influences. It is all too easy to let someone turn a symptom or observation into a problem if you aren't careful.

Another example of poor problem definition is the assignment to reduce the costs of the converting department. In many cases, the necessary homework hasn't been done to see first if the costs and efficiencies are comparable with contract converters or competitors. If they are, one can expect that significant progress will be either unlikely or could require significant efforts. Another reason this goal is poor is that one can easily reduce converting department costs by shutting down machines and laying off operators, but that may not be in the company's best long-term interests. When given these types of assignments, I often try to find quick and easy things to work on first. This has the benefit of determining whether modest resources and efforts can be sustained for a short time. If so, then the confidence gained from successful completion of a modest project can lend momentum to later efforts directed toward more substantial issues.

One pitfall to avoid is the arbitrary target. Too often one receives a commission to reduce defects by x %, increase speed by y %, and so on. Such numerical targets can be camouflage to make a poorly researched problem appear precisely defined. The law of diminishing returns teaches us that the cost–benefit ratios will quickly become unfavorable after a certain level of improvement. However, where this point of no return lies is very seldom known at the initial problem-definition portion of the project.

Most importantly, you never want to try to fight physics with your problem statement or constraints. As an example, I've been asked to reduce core crush without the leeway to change key variables such as the material (this is the product we make), winding tensions (if we wind looser, the material telescopes), or the core (too expensive to increase wall thickness). In the paper industry, NIDS (nip-induced defects) often fall into this category *(5)*. Even though the winder/unwind generates these defects, there is often little that can be done on a given winder to reduce the problem significantly when constrained to wind a given roll size of a given raw material. In extreme cases like these, all you can do is to offer one last piece of advice: Find another project to work on.

DETERMINING OPTIONS

The next step in problem solving is the most important, but it is also the most difficult to do well. That step is to make a complete list of options that will significantly reduce the problem severity or incidence. If the list is not complete, opportunities may be lost. If the list has nonfunctional "solutions," which is often the case, energy and resources may be expended to no avail. To illustrate the importance of the options step, consider this: If a good set of options is generated, even the poorest of decision-making processes—such as throwing darts—will yield results; but the converse is not necessarily true.

Homework is a requisite in developing a successful list of options. Obviously, one should gather information, observations, and data about the extent, timing, and character of the problem. However, data gathering alone is not sufficient. One should also perform a database search of the literature and possibly search through patents to see if the industry has already found hints or even a solution to your problem. To paraphrase a maxim from Bell Laboratories: "Four weeks in the lab will save four hours in the library." Unfortunately, many people are unaware of the wealth of basic troubleshooting guides that are available, such as TAPPI's *Roll and Web Defect Terminology (6)*.

Bounding and bracketing
DOE (design of experiments)
Divide and conquer
Envisioning
Exaggeration and sensitivity
FMEA (failure modes and effects analysis)
FTA (fault tree analysis)
First and worst
Logic
Process knobs listing
Science
Shape of cause matches problem
Statistics
Toggling
Truth tables

I. Problem-solving tools and techniques

Bias, prejudices, and preconceived notions
Data and information
Contradictory
Contaminated or incorrect
Excessive
Insufficient
Fallacies of logic
Goals
Poorly defined
Overconstrained
Instabilities
Resources—insufficient
Statistical savvy—nonexistent
Tool fixation
Why me?

II. Problem-solving pitfalls

After a search of written material is complete, you will want to contact industry experts. These experts may be suppliers of equipment or materials, competitors, or consultants. Suppliers, for example, are very good at suggesting how a machine or process can be brought to state-of-the-art condition through maintenance, rebuilds, or replacement. Be aware, however, that new isn't necessarily better and often doesn't solve the problem. Competitors can be a resource if the company cultures allow dialogue on nonproprietary subjects. Consultants and their areas of expertise can be found in computer databases such as those maintained by The Institute of Paper Science and Technology (IPST), Teltech, and other organizations.

If, the problem is clear, clean, and well known, then the search should reveal a good list of options. Unfortunately, this is seldom the case in the real world because the lists vary among the sources. At this point, the natural response is to look at options that are common to all or most of the sources and judge those options to be accurate. However, this is a fallacy of logic that goes by various names, including "science by consensus." While it is prudent to consider frequency of mention as evidence of truth, it is by no means irrefutable.

HOW TO BE A GOOD PROBLEM SOLVER

At this point, you are well immersed in a true problem-solving situation, where the solutions—and perhaps even the problem—are not known for certain. Since it is beyond the scope of this article to teach problem solving *(7)*, all I will do at this point is outline the steps and tools that can be used to proceed along the best path when a map is not available.

To be a good problem solver, you must first arm yourself with a depth of knowledge on the subjects or areas in which you commonly work. Equally important is the need to expand the breadth of your knowledge to interrelated areas, since most process problems are not simply compartmented into chemical, electrical, or mechanical categories. As the saying goes, "Change favors the prepared mind." Knowledge is most simply obtained through extensive reading of trade journals, technical journals, books, and reports. However, regular attendance at conferences, short courses, and seminars is also important. The trait that is most helpful here is a burning curiosity to know how things work.

To be a good problem solver, you must also be creative, imaginative, and often daring. You should be able to look at common machinery and processes from various angles and with fresh eyes. You also should be able to consider and eschew conventional wisdom when it doesn't seem to be leading in fruitful directions. Unfortunately, there is a tendency to lose creativity as we get older and more learned. In other words, knowledge can get in the way of seeing other possibilities. This is not to say, however, that ignorance is an advantage for problem solving, because both creativity and knowledge are useful in equal measures. The most useful trait here is the ability to brainstorm as an individual or in a group.

Finally, a good problem solver has and uses a variety of problem-solving skills. It is important to avoid the common trap of regularly using a preferred tool or technique to solve problems. Examples of tool fixation include the statistician who can't see beyond mathematical correlations or the process engineer who fixates on his/her new data-gathering instrument. Similar problems occur when a group has been taught one of the several formal problem-solving strategies that channel the group to constrain their thought processes to that particular technique. In all of these cases, one is handicapped much like a mechanic with only an adjustable wrench and pliers in his toolbox, or a surgeon with only a single scalpel and scissors on her instrument tray. **Table I** lists just a few of the useful tools and techniques for problem solving.

PROBLEM-SOLVING PITFALLS

A good problem solver must avoid pitfalls that can interrupt or preclude progress. Pitfalls can be as obvious as a lack of sufficient resources to work on a problem. On the other hand, pitfalls can be as subtle as the personal biases and preconceived notions of our bosses, coworkers, or customers. **Table II** lists just a few of the situations to avoid.

Type	Example
Errors in logic	Syllogistic, affirming the consequent, denying the antecedent, etc.
Rationalization	Card stacking, suppressing information
Circular reasoning	"We need to increase productivity because productivity is too low."
Irrelevant reasons (*non sequitur*)	"This car is fast because it is red."
Straw dog	Give the other side's weakest points and then knock them down
False dilemma	"Do you want to cut spending or increase taxes?"
Fallacy of ambiguity	"If all men are created equal, why are some poor?"
Fallacy of the general rule (*dicto simpliciter*)	"Speeding is dangerous; therefore never speed."
Post hoc fallacy	A rooster crowing causes the sun to rise
Reversing cause and effect	"People are overweight because they don't exercise."
Popularity; science by consensus (*argumentum ad populum*)	Compliant covered roller, coated winder drums
Appeals to (inappropriate) authority (*argumentum ad verecundiam*)	A sports hero in advertisement
Arguments against person (*argumentatum ad hominem*)	"He is a drunk, so his opinions are unreliable."
Slippery slope; the camel's nose is in the tent	"If we distribute contraceptives to teenagers, then promiscuity will result, causing a breakdown of family values and an increase in lawlessness."
Appeals to ignorance (*argumentum ad ignorantiam*)	"There is no evidence that God exists; therefore he doesn't exist." "No one has disproved that God exists; therefore he must exist."
Wishful thinking; Pollyanna principle	Overestimating the probability of success
Red herring	Beautiful woman in a product advertisement
Faulty analogy	"The NRA is militaristic, just like the Nazis."

III. Common types of fallacies

Factor (weight)	Machine A	Machine B
Performance (5)	8 × (5) = 40	3 × (5) = 15
Price (3)	2 × (3) = 6	9 × (3) = 36
Delivery (2)	1 × (2) = 2	8 × (2) = 16
Service (1)	2 × (1) = 2	3 × (1) = 3
Total	**50**	**70**

IV. Weighted-factors technique applied to hypothetical machine purchase

Perhaps the most common and insidious pitfall is the "Why me?" syndrome. One manifestation of this many-headed monster is to explain why a defect appears on one roll but not the next, on one machine but not its neighbor, and so on. Determining why a particular roll will have a defect is like trying to predict the time and location of an earthquake. This is at least an order of magnitude more difficult than determining that quakes occur near faults or that any of the rolls could have experienced that defect. Unfortunately, the "What's different?" version of the "Why me?" syndrome is the basis for one of the most popular of the formal problem-solving techniques.

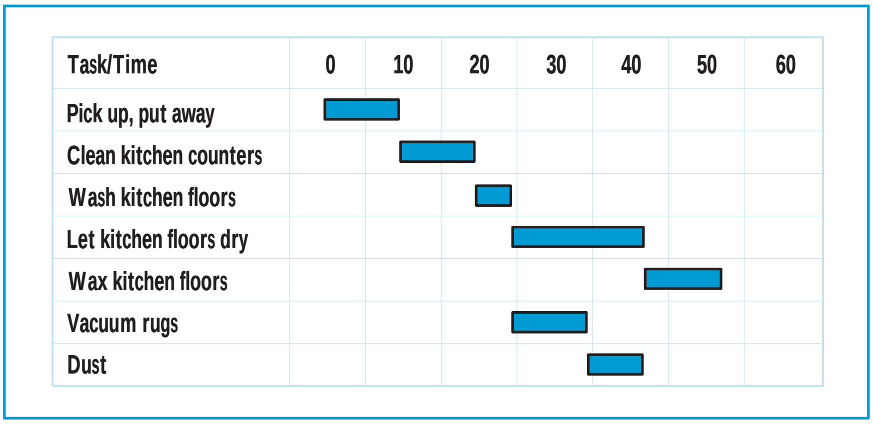
FALLACIES

In order to make decisions, we must evaluate the applicability and strength of data, observations, and the claims of others. This is especially important when systems are complex and data appear to be contradictory, which is often the case. Relevant data are worth more than data that are too general, too specific, or are not directly connected to our particular concern. Data carefully compiled and challenged are stronger than data that are anecdotal, hearsay, or conjecture.

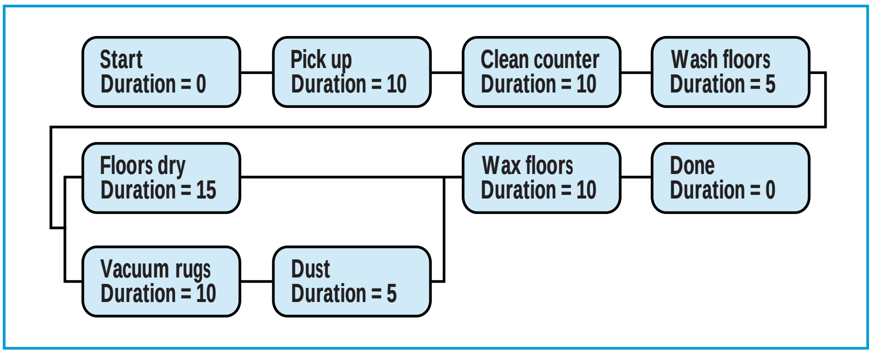
After weighting the data for applicability and strength, we can use the information as evidence to support or discount hypotheses of cause and effect. However, we must always guard against fallacies that are a fault of reasoning. Perhaps the most well-known fallacy is rationalizing one's pet ideas. Rationalizing focuses on supporting evidence while suppressing or ignoring contrary evidence. Depending on the source, there are between 10 and 100 types of fallacies. **Table III** names and gives examples of some of the most common fallacies encountered in industrial problem solving.

DECISION MAKING

After options have been listed, one or more must be selected for implementation. In an ideal world, one could select the options with the greatest economic advantage. Examples of economic measures include ROI (return on investment), payback period, or cost–benefit ratios. However, in the real world, the costs of an option are not usually known with precision. While the direct costs of changing materials or machinery can be estimated



1. Gantt chart for housecleaning activities



2. Critical-path chart for housecleaning activities

closely, options usually have indirect costs that are not easily predicted. For example, it is common for an adjustment of a process variable to reduce the incidence of one defect while increasing another.

Moreover, it is even more difficult to determine a priori the magnitude of improvement for a given process change. Stated another way, every option has risks. It is quite possible that, even with the best of intentions and skills, we will fail to make an improvement and perhaps even make the problem worse. How then do we proceed in the presence of such uncertainty?

Deciding on a course of action can be done informally or formally. In either case, good judgment is required. Informal decisions are made by intuition, hunches, and gut feelings. Even so, it should be possible to verbalize the reasoning behind the decision in most cases. Informal decision making is most often an individual rather than a group effort.

The literature abounds with methods and variations of formal decision-making techniques. Examples suitable for groups of decision makers include obtaining consensus (widely practiced in the Japanese culture) and voting (the basis for democratic government). The selection of a decision-making method is often based on the culture of the company. It is perhaps most important that the participants are comfortable with the method.

The "weighted factors" technique is one decision-making method that is both common and suitable for either individuals or groups. It begins by first screening options against needs. Only options that satisfy hard requirements are processed by the second stage, where wants or desires are weighted by importance. Next, the options are graded for each factor. Finally, the cells in the matrix are computed and the results summed.

Table IV shows an abbreviated illustration of the weighted-factors technique applied to a fictitious machine purchase. Here, the factors in order of importance were performance, price, delivery, and service, as shown by their weights of 1–5, with 5 being the most important. Machine proposals from builders A and B were judged on a scale of 1–10 against each of these factors. The outcome is that Machine B seems preferable because of price and delivery advantages, even though Machine A is clearly the superior performer and performance was the most important attribute.

PROJECT PLANNING

Of the many formal planning tools, the Gantt chart and the critical-path chart are the most common. The Gantt chart, as shown by example in **Fig. 1**, gives the time lines for various tasks and resources. On the other hand, the critical-path chart is better suited to show the order and relationship between tasks to identify bottlenecks in a project, as shown in **Fig. 2**. Most software for planning is able to generate either of these charts as well as other displays from the same data set.

SUMMARY

Problem-solving skills are as important as knowledge and experience. Therefore, we should exercise our critical thinking skills so that we become more proficient and thus more valuable to our companies. To begin, we should study the scores of problem-solving tools that are available rather than focusing on the ones that we or our company are most accustomed to. We should try various approaches to see if they yield the same conclusions. If they do, we can proceed with greater confidence than if we had applied only a single method of analysis or obtained different remedies using other methods of analysis. Finally, prudence suggests that we learn from our mistakes, as is inevitable in problem solving. Try to figure out what went wrong with the analysis so that you can avoid those pitfalls of problem solving in the future. TJ

Roisum is president of Finishing Technologies, Inc., 1305 Orchard Ct., Neenah, WI 54956.

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