A SYSTEMATIC APPROACH TO PERFORMING EFFECTIVE EQUIPMENT ROOT CAUSE INVESTIGATIONS

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INTRODUCTION

As we move towards competition there will be increased pressure to improve unit capacity factors while reducing operating and maintenance costs – doing more with less. Solving equipment problems quickly and efficiently must be a key element in every manager's strategy for improving the "bottom line."

This presentation will show how Kepner-Tregoe's (K-T) Analytical Troubleshooting (ATS) process has helped one utility improve its troubleshooting skills. Good troubleshooting is like good detective work. A good detective proceeds carefully and methodically, first looking over the scene, then questioning the witnesses in his search for information. Conclusions are not based on feelings or assumptions. The detective uses facts to prove the suspect's guilt**,** or innocence. Effective troubleshooters do very much the same thing: they get information about the problem, come up with possible causes, then test the possible causes against the information to identify the actual cause.

Effective problem solving does not depend on "super knowledge"**-** knowing all things about the problem. Rather, it depends on the efficient use of the troubleshooter's experience, knowledge, and judgement. It also involves having a process or framework to gather, organize, and evaluate information. Problems that we investigate are the visible effect of a cause that resides somewhere in the past. Effective problem solving requires good cause and effect thinking skills.

One way of troubleshooting and finding cause is to use our knowledge and experience and list all the possible causes. Then we, investigate them one at a time until the **"**cause**"** that caused the current problem is identified. While this method will certainly identify the cause it's very time consuming and resource intensive, and it may even drive a company into bankruptcy before the cause is determined. I term this troubleshooting method as the "Easter egg" method." The investigator looks everywhere without focus or priority, he is covering all the bases just to be sure.

Another popular investigative method some troubleshooters use is to search for cause is to use their experience and apply fixes that solved a similar problem in the past. We have all experienced this troubleshooting method. For example, your car won't start, won't even turn over, so you call the garage. After the car is towed in, the mechanic tells you the battery is weak and you need a new alternator. You spend $300 and get the car back. The next morning it won't start again, frustrating to say the least. You go to another mechanic and he finds a loose electrical connection on the starter. The first mechanic used his experience and applied a fix that worked in the past. However, he only focused on one factor that could prevent a car from starting. He did not consider other components in the starting circuit.

Effective troubleshooters can solve problems quickly because they can maintain their objectivity by using a methodical step-by-step approach to troubleshooting. By using a methodical step-by-step approach to troubleshooting they don't jump on the first "pet" cause or use the "Easter egg" approach and try fix after fix until one solves the problem.

PROCESS

CCNPP encourages troubleshooters to use a methodical approach to solving problems. Kepner-Tregoe's (K-T) Analytical Troubleshooting (ATS) method has been endorsed by Calvert Cliffs as an effective troubleshooting method. The key steps in ATS are as follows:

> State what the problem is,
>
> Describe the problem in detail,
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> Develop possible causes,
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> Test possible cause against the problem description,
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> Verify the most probable cause,
>
> Select a fix, and finally
>
> Identify other places that may need the same fix.

Defining the Problem

An accurate *problem statement* is very important. Troubleshooters need to know what problem they are solving. A poorly stated or inaccurate problem statement has often caused many troubleshooters to waste precious time and resources. It may take several hours or even days to develop a precise problem statement. People often say why do we need to spend the time developing a problem statement because everyone knows what the problem is. In reality, each troubleshooting team member may have a different idea of what problem needs solving. Taking time to develop a good problem statement is time well spent. A well-worded precise *problem statement* helps to quickly focus the investigation resources on the search for the root causes. Let's look at a hypothetical example:

> A problem report stating the Reactor Coolant Pump (RCP) won't run states**,** "There is a problem with the reactor coolant pump operating." However, the operator could have been more precise by providing additional information about why the pump will not start. He knows the breaker tripped free while attempting to start the pump. By making a more precise description of the problem, the investigator can focus the investigation on determining why the breaker won't close rather than other problems with the pump. Therefore a more precise *problem statement* would be "11A RCP breaker tripped free while attempting to start the pump."

When developing a *problem statement* we should always ask, "Can the effect of the problem as we have described it in the *problem statement* be explained now?" If it can, we must back up to the point where we can no longer explain the cause for the deviation. What we're doing is trying to explain the "cause of the cause" until we no longer have an answer. This is where we want to start our problem analysis. In the case of the RCP we were told that the pump would not start. We asked, **"**Do we know why the pump would not operate? The answer was the breaker tripped free. We then asked, **"**Do we know why the breaker tripped free? We were told "No." Therefore, the problem that we need to investigate is a problem with the breaker failing to close, i.e., "Why is the breaker tripping free?"

If the troubleshooting team had not taken time to clarify the problem and develop a precise *problem statement* the team may have wasted time looking for a problem with the motor, rotating assembly, electrical bus, or other parts of the breaker.

Once we have a precise statement of the problem, we need to describe in detail, *what* the problem is, *where* the problem is occurring, *when* the problem happened, and the *extent* of the problem. Detailed information about the four dimensions of the problem will provide the kinds of information that will be needed for the search for cause.

Problem Analysis		
Describe Problem		
State the Problem	*What object (or group of objects) has the deviation?* *What deviation does it have?* *What do we see, hear, feel, taste, or smell that tells us there is a deviation?*	
Specify the problem	**IS**	**IS NOT**
WHAT	*What specific object(s) has the deviation?* *What is the specific deviation?*	*What similar object(s) could reasonably have the deviation, but does not?* *What other deviations could reasonably be observed, but are not?*
WHERE	*Where is the object when the deviation is observed (geographically)?* *Where is the deviation on the object?*	*Where else could the object be when the deviation is observed, but is not?* *Where else could the deviation be located on the object, but is not?*
WHEN	*When was the deviation observed first (in clock and calendar time)?* *When since that time has the deviation been observed? Any pattern?* *When, in the object's history or life cycle, was the deviation observed first?*	*When else could the deviation have been observed first, but was not?* *When since that time could the deviation have been observed, but was not?* *When else, in the object's history or life cycle, could the deviation have been observed first, but was not?*
EXTENT	*How many objects have the deviation?* *What is the size of a single deviation?* *How many deviations are on each object?* *What is the trend? (…in the object?) (…in the number of occurrences of the deviation?) (...in the size of the deviation?)*	*How many objects could have the deviation, but do not?* *What other size could the deviation be, but is not?* *How many deviations could there be on each object, but are not?* *What could be the trend, but is not? (…in the object?) (…in the number of occurrences of the deviation?) (...in the size of the deviation?)*

Figure 1

After we describe what the problem *is*, we can obtain additional information that can be useful in our search for cause by describing what the problem could be but *is not*. Such information is useful in our analysis because it gives us a basis for comparison. By comparing the four dimensions (what, where, when, and extent) of what the problem is to what the problem could be but is not, we can the isolate particular factors that make our problem unique. These comparison factors will lead us closer to cause.

A typical *problem description* will have answers to the specific questions as shown in figure 1, Kepner Tregoe Problem Specification questions.

Developing Possible Causes

A proficient troubleshooter intuitively knows that a decline in formerly acceptable performance usually suggests something has *changed*. The search for cause can be extremely frustrating when the troubleshooter is faced with numerous *changes*. What we find is that over time parts have broken and been repaired, equipment has been modified, new slightly different parts have replace old worn-out ones. Or perhaps, operating procedures vary slightly from one piece of equipment to another.

To help sort out relevant *changes* the troubleshooter looks for unique characteristics of what the problem *is* as compared to what the problem *could be but is not.* In comparing our RCP breaker example, our troubleshooter notes that only one breaker is having the trip free problem. There has to be something different about the breaker that is tripping free. Looking *differences*, unique characteristics, will help bring out things that are odd, unusual, peculiar, special, unique or distinctive about the object that is having the problem. In our RCP breaker example, when our troubleshooter asks what is *different* about the breaker that is having the problem as compared to the breakers that are not having a problem, he finds that the breaker has a new tripping mechanism.

In the RCP breaker case our troubleshooter found that the new tripping mechanism was installed two weeks ago as part of a breaker modernization program. Further questioning found that the alignment procedure was much more complex and the craft had not received training on the new procedure.

After looking for *differences* and *changes* our troubleshooter noted several areas of sharp contrast, one being this was the first beaker to have the modification installed without vendor support. He noted it, along with several other areas of sharp contrast in a problem specification worksheet. See figure 2.

Problem: 11A RCP Breaker is tripping free while attempting to start the pump

	IS	**IS NOT**	**Differences**	**Changes/Date**
WHAT	11A RCP Breaker	Other RCP breakers, other 13KV breakers	Different crew installed up-grade on this breaker	No vendor support used for upgrade installed two days ago. Crew had not been trained on new tripping device and relied on procedure for guidance
	Tripping free	Failing to close, failing to trip, fault signals		
WHERE	Installed on the 13KV bus	Installed in the breaker cubicle in the test position, out of the cubicle in the switchgear room	Breaker connected to the bus, breaker located deeper in cubicle	New tripping mechanism installed two days ago
	In the operating mechanism of the breaker	NA	New operating mechanism	New design installed two days ago is much more complex
WHEN	Today at 8:05 a.m.	Anytime prior	None observed	
	Every attempt to operate the breaker	Periodic, or sporadic	Non observed	
	First attempt to operate the breaker after on the bus after upgrade	Operating the breaker in the test position after upgrade	Breaker connected to the bus (See above)	
EXTENT	11A RCP Breaker	One or more 13KV breakers		
	Tripping mechanism	Other parts of the breaker		
	NA	NA		
	Unknown trend	Unknown trend		

Figure 2

Our troubleshooter developed several possible causes from his own experience and knowledge in addition to input from the vendor and ideas he got from differences and change on the problem specification worksheet.

After developing a list of potential causes, our troubleshooter had to find which of the *possible causes* was causing the breaker to trip free

Evaluating Possible Causes

Then next step in search for cause is to test each *possible cause* against the *problem specification* by asking, “If ____ is the cause of this problem how does it explain what the problem is and what the problem could be but is not?” The *true cause* must explain each dimension of the problem specification for both what the problem is and what the problem is not.

When testing *possible causes* against the *problem specification* sometimes an assumption is required to fully explain both what the problem is and what the problem is not. For example, in our RCP breaker case, three of the breakers have been modified but only one has the problem. One proposed *cause* was that the modified trip assembly did not meet the manufacturer’s tolerance specification. For this to be the *true cause*, our troubleshooter has to make the assumption that only the trip mechanism on the breaker that is having the problem does not meet the tolerance specification. Another proposed *cause* was, there was no training provided the aligning the new trip mechanism. The lack of training resulted in a misalignment causing the breaker to trip free. For this cause to be true, we must assume that the electricians lack the necessary skills and knowledge, and the current trip mechanism procedure lack proper guidance on how to properly align the trip mechanism.

By testing *possible causes* against the *problem specification*, our troubleshooter can quickly eliminate causes that do not explain the facts. For example, one of the proposed possible causes was there is a ground on the bus. Our troubleshooter was able to eliminate the cause because it did not explain why there was no ground fault flag, nor was the ground fault device activated. See figure 3 for a summary of the process for confirming true cause.

Possible Causes	
Identify Possible Causes ***Use knowledge and experience, or…*** ***…use distinctions and changes to develop possible cause statements***	*From experience, what could have caused the deviation?* *What is different, odd, special, or unique about an IS compared to its IS NOT?* *What was changed in, on, around, or about each distinction?* *When did the change occur?* *How could each change have caused this deviation?* *How could a change plus a distinction have caused this deviation?* *How could a change plus a change have caused this deviation?* *What about the distinction suggests a cause for this deviation?*
Evaluate Possible Causes ***Test possible causes against the IS and IS NOT specification*** ***Determine the most probable cause***	*If ___ is the true cause of ___, how does it explain both the IS and IS NOT information?* *What assumptions have to be made?* *Which cause best explains the IS and IS NOT information?* *Which cause has the fewest, simplest, and most reasonable assumptions?*
Confirm True Cause ***Verify assumptions, observe, experiment or try a fix and monitor***	*What can be done to verify any assumptions made?* *How can this cause be observed at work?* *How can we demonstrate the cause-and-effect relationship?* *When corrective action is taken, how will results be checked?*

Figure 3

Figure 4 provides an example format for testing causes for our RCP example.

Possible Causes

Possible Cause	Explains only if:	Is this a probable Cause?
New breaker trip mechanism does not meet tolerance specifications	Only 11A RCP breaker does not meet tolerance specifications	Yes: will need to disassemble and check tolerances
There is a fault on the bus or in the motor causing the trip condition	The fault protection flags for the breaker are not working	Low probability, the fault protection equipment was calibrated for all RCP breakers last week
New tip mechanism not aligned properly	The current alignment works in the test position but not in the connect position. Procedure lacks sufficient guidance for proper alignment	Yes: can have crew align trip mechanism with tech. Rep. Present. Can retest with breaker in test position **This is the most probable cause**
Latching mechanism broken	Latching mechanism broke after breaker tested in test position	Yes: can rack out breaker and inspect.

Figure 4

Verifying True Cause

After evaluating the possible causes against the problem specification and eliminating the ones that cannot explain our situation and listing the assumptions needed to explain the remaining possible causes, we need to identify and *verify* the most probable cause, identify the smoking gun.

Usually the *most probable cause* is the cause with the overall simplest, fewest and overall most reasonable assumptions. In the RCP breaker case, our troubleshooter selected lack of training on the new trip mechanism alignment procedure as the most probable cause. Before, any corrective actions can be proposed and implemented, he needs to confirm that lack of skill and knowledge, because the electricians were not trained in the alignment procedure, was the cause of the problem. Comparing the electrician’s alignment method to the technical representative’s alignment method is a good way to confirm the proposed cause for the breaker tripping free.

It is always important to attempt to verify cause. By not doing, so we are at risk of implementing an incorrect corrective action and having a repeat event, similar to the automobile example cited above. In our RCP breaker example, our troubleshooter was able to confirm the electricians were not properly trained on the new alignment procedure by having a factory representative observe the electricians perform an alignment. After verifying the true cause of the problem, our troubleshooter can now proposed an effective corrective action to prevent a similar problem.

Selecting the Fix and Thinking Beyond the Fix

As part of every effective corrective action process our troubleshooter should be attempting to head off future problems by asking where else are we vulnerable to this problem? Our troubleshooter could limit the corrective action to training the electricians on the new alignment process and revise the alignment procedure to make it detailed. However, our troubleshooter may have found a weakness or breakdown in the modification process. By not asking, “Have there been other occurrences where inadequate training on a plant modification has caused an unexpected plant response?” we may be left vulnerable to a similar event. If there have been similar problems, or a review of the modification process confirms a weakness, then the corrective action should focus on strengthening the modification process. Another line of reasoning might be, “Why wasn’t our new alignment procedure communicated to the training department so that we could make a decision on the need for training or qualification?”

By looking beyond the immediate problem and asking where else are we vulnerable to this problem we can head off future problems and reduce operating and maintenance costs.

RESULTS

At Calvert Cliffs all System Engineers and most maintenance personnel are trained to use the K-T Analytical Troubleshooting. Having a common troubleshooting approach has proven to be an effective and efficient method for solving equipment problems. One of the benefits of embracing a process like ATS, is that everyone knows the approach that the troubleshooting team will use to solve the problem. The team works much more efficiently and no one is going off and “doing their own thing.” The ATS approach also keeps people from prematurely jumping to cause. Also, favorite causes are evaluated against the facts, not emotion.

People used to say, “We don’t have time to do a K-T analysis.” System Engineers have found that by spending a little extra time up front gathering and analyzing information about the problem the less time they spend “Easter egging” solutions.

Recently, we experienced an overheated turbine bearing during an overspeed trip test of an auxiliary feedwater pump. A troubleshooting team was assembled to determine the cause of the problem. The problem was baffling because no maintenance had been performed on the unit since the last successful test in 1998. In addition, the unit had just successfully passed its full flow test. The only difference that was noted between the last successful overspeed trip test and the current test was that maintenance personnel used a different coupling strongback. The overspeed trip test requires the turbine to be uncoupled from the pump. To hold the turbine coupling hub in place during the test, an aluminum plate (strongback) is installed. The 1998 test used a flat aluminum bar and jackscrew assembly. The 2000 test used a round plate with three setscrews that allowed the mechanic to maintain proper coupling alignment. Both strong backs were successfully used on other pump turbines in 1999 and 2000. The dilemma was, “What changed to cause the bearing to over heat?” A preliminary inspection of the bearing revealed that the turbine shaft had contacted the bearing journal. What caused the bearing to shaft to rub the bearing?

The troubleshooting team developed a list of differences and changes and a list of possible causes. Two causes best fit the problem specification: Cause 1, the strongback caused a rotor imbalance, or Cause 2, the unit is much more sensitive to excitation from rotor imbalance because of recent changes in the bearings. Cause 1 was tested by adjusting the alignment of the coupling hub to achieve near zero face and rim run-out on the coupling hub then attempting another overspeed trip test. Before the retest, additional vibration monitoring equipment was installed to capture information about the turbine’s performance in case the test failed. The test failed. The bearing overheated again.

After the re-test the problem specification was refined to include the additional data. With the additional data the team met to review the specification and confirm that the second most probable cause was the true cause. To confirm the cause, the team recommended disassembling the turbine and send the rotor to the vendor to measure the amount of imbalance. The rotor was found 18 gm. out of balance in two planes vs. an acceptable balance of 0.3 gm. After the rotor was balanced, the unit was reassembled and satisfactory tested.

By using a methodical approach to troubleshooting the team saved several days of maintenance time. In the past, when we were faced with similar symptoms, we would have attempted to adjust the bearing alignment, change the turbine governor, change the governor gear drive, change the thrust of the turbine, and change the bearings, before we looked at the turbine rotor. This time we spent a total of five hours over two days developing the problem specification, possible causes and testing the causes against the specification. The result was an efficient investigation with a defendable recommendation to perform an expensive disassembly and overhaul of the turbine. The decision was made quickly enabling repairs to be made on a critical piece of equipment without impacting the ongoing refueling outage.

Conclusion

Calvert Cliffs has found K-T's ATS troubleshooting process an effective tool for helping system engineers and maintenance personnel to find the cause of equipment related problems. The ATS process helps the troubleshooter to organize his information and provides a methodical and logical flow path for using the data in his search for cause.

A logical investigation process prevents the troubleshooter from leaping on a favorite cause and prevents the "Easter egg" approach to finding cause. As shown in the above AFW turbine example, the use of ATS helped the troubleshooters keep focus on the symptoms, which enabled them to eliminate many possible causes that did not fit the problem description. The end result was reduced out of service time for a critical piece of plant equipment.

Quick efficient troubleshooting will be reflected in your company's "bottom line." You will have less repeat failures because equipment will be fixed right the first time. Equipment out of service time will be reduced which should improve plant availability and capacity factors.