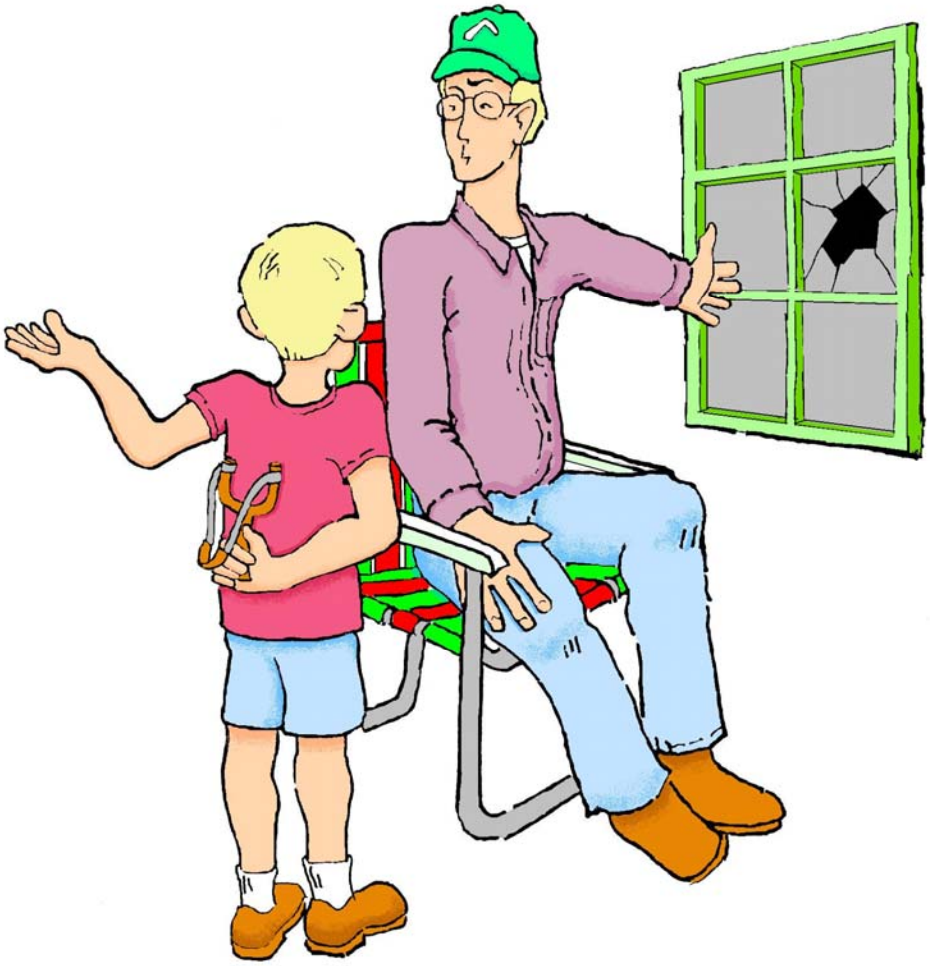
TRIZ POWER TOOLS

Skill #6 Discovering Cause

May 2012 Edition



Getting to the Problem you Really want to Solve

TRIZ Power Tools
Skill #2 Discovering Cause
May 2012 Edition

TRIZ Power Tools by Collaborative Coauthors
43 Pages

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The Algorithm

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Introduction

(If you are reading the PDF format—navigate the algorithms with the "Bookmarks" to the left. L1, L2, L3 correspond to levels of the algorithm. The levels are hierarchal; you can go as deeply as required to resolve your problem. Lower levels (L1, L2) have consolidated methods. If you are using the book then use the Table of Contents for the Algorithm)

Cause and effect are two sides of one fact

~Ralph Waldo Emerson

All Solutions Address Causes

How common is this situation? You are invited to a "brainstorming session". Someone presents a problem and then suggests that everyone brainstorms solutions. This format is so typical that it is rarely questioned. Jumping straight from problem to solutions bypasses the very important step of identifying what is causing the problem. This is shortcutting a natural process because all solutions *must* ultimately address problem causes. Conversely, there is no such thing as a solution which does not address a problem cause. Once we deeply understand and believe this truth, we will never return to the old days of "brainstorming solutions".

Why Perform Causal Analysis?

One benefit of a thorough causal analysis is that sometimes we discover knobs that can be easily turned to solve the problem. This surprise can happen after many years of working a problem. Causal analysis is designed to find as many knobs as possible. The more knobs we discover, the more likely it is that we will also discover knobs that nobody has thought to turn before.

When we first start a causal analysis, we are not certain about what is causing the problem; all we have is theories. The evidence is what ultimately establishes the truth of our theories. Before the evidence is available, we need guidance for where to look for existing evidence and what tests to run. A causal analysis diagram is an effective way to document our theories on what is causing our problem. This is especially important when working with teams of people.

Performing causal analysis increases the number and quality of solution concepts. Since the typical problem has many causes, identifying and addressing these causes leads to multiple solutions. Conversely, if we do not consider the causes, it is more likely that we will focus on attributes that we are familiar with. We are trapped by our own psychological inertia. The curse of knowledge is that once we think we know something, it is easy to rely on this knowledge again and again. Let's consider the problem of the acid container. If we were materials engineers, we could easily jump to the conclusion that we need to change the material of the container to one that is not affected by the acids or to one that is less inexpensive. This is only natural since that is what we are familiar with. Unfortunately, we are focusing on only one piece of the puzzle. When we ask what is causing the problem, we are forced to consider more than the familiar possibilities.

The benefits of a good causal analysis can continue for many product or service generations. The knowledge gained becomes a tremendous competitive advantage.

Obvious Solutions

Having performed a causal analysis allows the problem solver to consider knobs that nobody has yet considered. The more thorough the causal analysis, the more likely this will happen. In some cases a new knob can be easily turned without incurring any penalty. This is fortunate and a common occurrence when a detailed causal analysis is performed. However, there is a caution. Some people perform a causal analysis to exclusively look for knobs that nobody has thought of. This ignores the multitude of knobs that could also be turned if it was only known how to resolve contradictions.

Other solutions may be found after performing causal analysis that are not related to “easily-turned” knobs. On the other hand, simply understanding what is causing the problem may lead the problem solving team to rapid solutions.

Different Forms of Causal Analysis

There are several forms of causal analysis. It is common to see initiatives promoting one form or another. For instance, “Six-sigma” tends to promote process-centric (process maps or process charts[1]) or model-centric (statistical models) analysis. “Lean” initiatives tend to promote process-centric analysis. Most IR&D initiatives promote some form of model centric analysis which is built on physical, chemical or statistical descriptions. Numerous TRIZ software companies promote function-centric analysis where the problem is described as a chain of interactions or functions. “Failure-Analysis” initiatives often promote Fault Trees[2] [3] [4] [5] which are attribute-centric forms of analysis.

“Root-Cause” initiatives usually promote Why-Why analysis[6], Fishbone Diagrams[7] or Fault Trees which are attribute-centric. Each of these forms of causal analysis has their place. They help to organize the problem and give insights into what is causing it.

Combining Different Forms

Since each of the methods gives a different perspective of the problem, we will be using a combination of these methods. The combination will be referred to as a Causal Analysis Diagram. The basis of organizing this analysis will be a form of Attribute-Centric analysis similar to Fault Trees. The reason for this is that this form of analysis can be easily modified to show functions and contradictions that are central to understanding the causes of the problem. At each step of the diagram, we use models of the physics and process maps to guide us in our selection of attributes that branch. This form of analysis will also lead us to understand the alternative problem paths and why elements are required in the system. The combination of these methods will be more compact and more easily assimilated than their separate use.

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[1] Frank Gilbreth, “Process Charts—First Steps in Finding the One Best Way" American Society of Mechanical Engineers (ASME) in 1921

[2] Ericson, Clifton (1999). "Fault Tree Analysis - A History". Proceedings of the 17th International Systems Safety Conference.

[3] Rechard, Robert P. (1999). "Historical Relationship Between Performance Assessment for Radioactive Waste Disposal and Other Types of Risk Assessment in the United States". Risk Analysis (Springer Netherlands) 19 (5): 763–807.

[4] Winter, Mathias (1995). "Software Fault Tree Analysis of an Automated Control System Device Written in ADA" . Master's Thesis (Monterey, CA: Naval Postgraduate School).

[5] Benner, Ludwig (1975). "Accident Theory and Accident Investigation". Proceedings of the Society of Air Safety Investigators Annual Seminar.

[6] Also know as a Five Whys analysis, based on a Japanese quality technique and its description by quality consultant Peter Scholtes. See Peter Senge’s ”The Fifth Discipline Fieldbook.”

[7] Also known as Ishikawa diagrams were proposed by Kaoru Ishikawa in the 1960s, who pioneered quality management processes in the Kawasaki shipyards. Hankins, Judy (2001). Infusion Therapy in Clinical Practice. pp. 42.

Contradictions

The concept of contradictions and their resolution[8] is one of the most useful and fundamental aspects of TRIZ. It is fundamental from the viewpoint of creativity because it greatly expands the solution space. Imagine that you need to fly a complex aircraft in which all of the control knobs and levers are fastened so tightly that you cannot move them. This is what many people feel like when they perform a causal analysis and discover the many knobs that *would* solve the problem if they *could* only be turned. Let's consider a technical problem that illustrates what a contradiction is.

If we would like to increase the carrying capacity of a vehicle, it is almost certain that we will need to increase its volume. Increasing the volume often increases the aerodynamic drag, thus expending more energy. This increased expenditure of energy costs more and requires more fuel which causes more exhaust and pollution of the environment. Thus, we would like to increase the carrying capacity without increasing the cost of operation and without fouling the environment. We want to increase something without making something else worse. We have already mentioned that the knob we were trying to turn to improve the carrying capacity of the vehicle is the volume. Without explaining the exact method for how we got here, we can state the contradiction as follows:

In order to carry lots of cargo, the volume needs to be large.

In order to have low drag, the volume needs to be small.

The contradiction helps us to understand the parameter that needs to have opposing values *and* it helps us to understand when the solution is good enough.

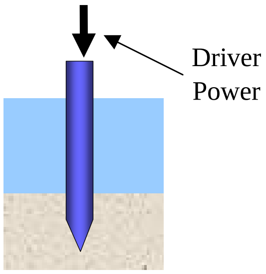
We are usually tempted to compromise and make the volume larger but not "too large". The problem with this thinking is that we now guarantee risk. Some days, the volume will be insufficient. If we are building the vehicle for public sale, we may find that the cost of operation is too high for some customers. In addition, we have created a risky situation that will be perpetuated for generations. Finally, in order to perform an artful compromise requires a lot of data and analysis. This can be time consuming.

What we would like to do is to find a way to resolve the contradiction without compromising. When we learn how to do this, we will find that there are a lot more knobs that we can consider turning to solve problems. This skill is liberating to problem solvers who find that the solution space is much larger than they supposed.

Turning Knobs to Find Contradictions

In general, we try to turn knobs or change object parameters in order to find contradictions. When a physical parameter has one extreme value, we get a desirable and undesirable result. Changing the parameter to the other extreme reverses the effect making desirable outcomes undesirable and undesirable outcomes desirable.

There is a natural eagerness to turn some knobs and a reluctance to turn others. This tendency limits us in the range of solutions that are possible. Let's take a closer look at different types of knobs.



Type 1: *Easily Turned.* With this knob, there is full control of the dependent variable and nothing gets worse when it is changed to the required level. These are the knobs that most people are looking for when they perform causal analysis. Turning these knobs makes for great solutions, but they are usually rare in legacy problems. They are found because someone has taken the time to dig into the physics and perform a

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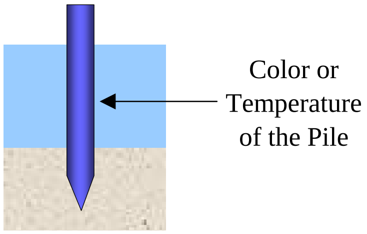
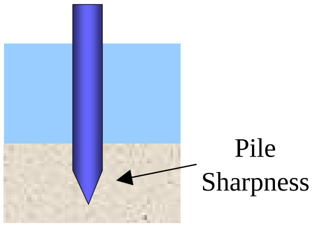
[8] First paper published by G.S Altshuller and Rafael Shapiro was "Psychology and Inventive Creativity" which was published in the Journal Voprosi Psichologii--- (Problems of Psychology)

thorough causal analysis. They may have also been found by applying the Table of Knobs or "Relative To" tools. In our pile driver problem, it may be possible to increase the driving speed by increasing rate of striking the pile. In order to make this happen, we will likely need to increase the power of the driver. It is possible to increase the power without changing the striking momentum. For instance, we can greatly reduce the cycle time between strikes by increasing the power.

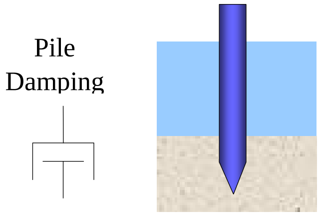
Type 2: *Little Effect.* Turning these knobs through the full range of possibilities has little effect. These knobs are usually not worth considering because they have little bearing on the problem. In this case, the color or temperature of the pile will have little effect on the driving speed.



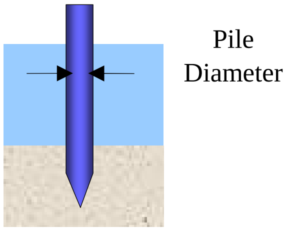
Type 3: *Something Else Gets Worse.* Changing these knobs degrades another important attribute. These are your typical problems where people feel obliged to compromise. Making the pile sharper may improve the driving speed, but the pile is less able to bear the final load if it were driven to the same depth. It is likely that the pile would have to be driven further, thus removing the advantage we thought that we had gained in driving time. The contradiction is stated: the pile must be sharp in order to drive faster and it must be blunt in order to support vertical loads.



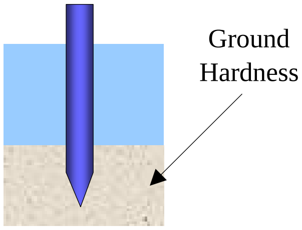
Type 4: *Difficult to Turn.* With these knobs, it is not apparent how to turn them. No known physical phenomenon can be found, or so many knobs must be turned at once that it appears impossible. In this case, we may realize that the damping of the pile is an important factor in the driving speed. If the pile damping is high, a lot of energy is lost to heating the pile while it is being driven, thus reducing the energy available to make it drive faster. While we recognize that this is an important parameter in driving, we may not have the experience or knowledge necessary to identify a means for changing this important parameter. This knowledge may be available in another industry.

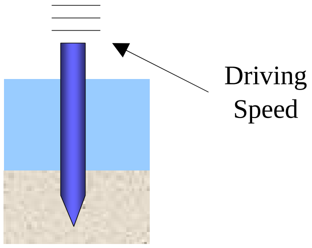


Type 5: *Only One Flavor or Setting.* This knob cannot be turned because it has only one setting. The most typical way that this happens is that an element is simply off limits for change. Perhaps you are working with a customer part and the customer has demanded that it remain unchanged to perform well with the customer's processes. Let's assume, in this case, that there is an artificial restriction placed on the diameter of the pile. When we form the contradiction, we will say that the pile diameter must be small in order to drive fast and it must be large because it only comes in that diameter. This is not the typical contradiction discussed in mainstream TRIZ literature. The pile diameter causes a problem. Problems of changing the diameter are not even considered. The change of diameter is simply not allowed.



Type 6: *Highly Variable Knobs.* This knob cannot be turned because it is so highly variable that you never know what setting it will be at. In this case we never know from day to day, or in some instances from pile to pile what the ground hardness will be. Most people are reluctant to consider changing this knob or forming a contradiction. You will note that when we come to identifying the contradictions that it is not out of bounds. While it is true that this appears to be more complicated, do not forget that there are a variety of tools at our disposal for solving these types of contradictions.





Type 7: *Outcome Knobs.* This knob cannot be turned because it is a dependent variable and dependent on other knob settings. We are going to consider turning this knob without changing any identified dependent variables. In this case, we are going to consider changing the driving speed without changing any of the dependent variables that affect it. At first, this may appear illogical, but the contradiction which follows will help to explain why we do this. The driving speed must be high in order to save time and expenses. The driving speed must be low because I am not going to change any of the independent variable that affects the speed. In effect, I am saying that the driving speed must be slow and fast. As we will come to see, every box in the causal analysis diagram is a candidate for solution. We are already considering the independent variables in other boxes that input to the outcome knob. This allows us to form a contradiction for the outcome knob alone. Novel solutions will become available when we consider this.

These last four knobs “something gets worse” “don’t know how to turn” “one flavor” “highly variable” and “outcome” are the least likely to be turned, but turning them often allows us to find very satisfying but unconventional solutions. We cannot say that turning every knob will solve our problem. But, we cannot discount a knob because it does not suit our taste. We need to learn how to turn each type of knob.

Why is Exposing of Contradictions Necessary in Causal Analysis?

It might be tempting to think that a causal analysis is complete when we understand the knobs and settings that are causing the problem, but it isn’t. Our understanding is incomplete *until we understand why the knobs have been hard to turn*. The normal tendency is to think that most of the knobs are un-turn-able. In reality, they are merely difficult to turn.

Additionally, some types of contradictions also alert us to alternative problems and *their* causes. These alternative problems can be solved in order to “bypass” the original problem.

In summary, a causal analysis is not complete until it is understood why the knobs are difficult to turn. It is not complete until we understand the contradictions.

“Root Cause Analysis”

Some disciplines use the title “Root Cause Analysis[9]”. The name “Root Cause” implies that if we keep asking “why”, we will eventually come to *the* root cause. For those who are six-sigma minded, remember that there is a difference between problems which are special-cause and those with common-cause. Special cause implies that the output of a process is outside of the control limits and is therefore highly unlikely. For these problems, we can often find a single *root* cause. However, for variation *within the control limits* there is a branching chain of causes. It is advisable to avoid the use of the term “Root Cause Analysis” when we are trying to understand a problem which is not special cause.

How Far Should We Allow Ourselves to Go?

We have already answered this question to some degree, but it bears repeating. Remember when we reviewed related requirements? We also considered the constraints on the solution. We considered how much time we had; how much budget we had to work with; how many alternatives we needed to generate. So, we should have a fairly good idea how much rope we have to solve the problem.

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[9] The origins of Root Cause Analysis can be traced to the field of Total Quality Management (TQM) It is believed that it has been in use in the fields of engineering since the early 1980s. (Andersen & Fagerhaug, 2006, p. 12).

During problem solving, causal analysis and implementation need the most time. The actual time to come up with solution concepts is usually short. When it comes to performing a causal analysis, a full causal analysis can take a great deal of time. It may be necessary to perform experiments which can be very time consuming. If we have a very short fuse, or we are not that invested in the answer and just want to help someone out, we may perform a simple causal analysis. The final answer to this question is that it takes experience to know how far to go, but we can never be entirely certain that we have gone too far or far enough. There is no way to know for sure without following all solution paths.

Solve as You Go

All of the tools in the causal analysis section go hand-in-hand and no special order is required. In fact, there is value to begin the solving process as soon as an important function or knob is verified as a strong contributor in the causal chain. The act of solving often brings other causes to light. It forces the solver to become more knowledgeable about the problem. Even if the problem solver waits for the completed causal analysis to start solving, the act of implementing the solution will cause more information on the causes to come to light. A causal analysis is never “complete”. There is always more to learn. Usually, the constraints of time and resources will constrain the analysis from continuing. Therefore, it is important to be as efficient and effective as possible.

Quality of a Causal Analysis

In summary, by the End of a Good Causal Analysis You Should Understand:

—The knobs that cause the problem

— How the knobs chain together

—How the problem progresses in time

—The contradictions that make the problem hard

—Alternative problems (Solve these instead)

—How evidence matches theory

Functional Nomenclature

Some of the steps in this book require the reader to understand how to work with functions. Please refer to the book TRIZ Power Tools book concerning this topic.

L1-Causal Analysis

Level 1 Causal Analysis

For simple causal analysis or beginners, this method of causal analysis can be very illuminating. While it is not rigorous in determining the chain of causes, it helps the problem solver focus on the contradictions and faulty functions. This method is particularly useful when you are in a classical brainstorming session, while relaxing in a chair or when a work colleague wants help with a problem. For many problems, this simple analysis is sufficient. Note that the simple causal analysis includes the consideration of functions and interactions. This may be a little advanced for the beginner but it is useful for advanced users that just want to use the simple analysis. It is easier to explain the method with an example and then follow the example each time that we do this type of analysis. Let’s take the pile driving problem as an example of how the simple causal analysis is performed.

$$Y = f\,(X_1, X_2, X_3\ldots)$$

L1-Method

Step 1: Decide what you are trying to improve. This is written as a knob (object attribute) and a setting.

Step 2: Identify the objects, and fields that you think are involved in the problem.

Step 3: Brainstorm the Knobs and Settings related to these objects and fields.

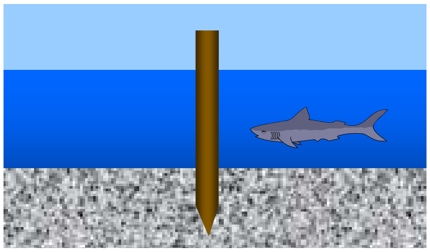
Step 4: Add Functions that Cause the Problem

Step 5: Turn the Knobs to Settings that Fix the Problem

Step 6: Form Contradictions

Step 7: Discover Alternative Problems

Example—Pile Driving Speed



The driving speed of piles is very slow. Often expensive equipment and personnel wait while driving progresses. How can the driving speed be improved?

Step 1: Decide what you are trying to improve. This is written as a knob (object attribute) and a setting.

In this case, the driving speed is slow. Identify the main problem as a knob and a setting.

Driving Speed is Slow

Step 2: Step 2: Identify the objects, and fields that you think are involved in the problem.

The objects are the driver, the pile and the soil.

Step 3: Brainstorm the Knobs and Settings related to these objects and fields.

Write these in a column as independent variables of the attribute that you are trying to improve. Each new attribute is also written as a knob and setting. The driving speed is slow because the pile diameter is large, the driver mass is low, the ground is hard and the pile is flexible, etc. Note that most of these are design parameters.

Driving Speed is Slow **= f** {

Pile Diameter is Large

Driver Mass is Low

Ground Hardness is Hard

Pile Flexibility is Flexible

⋮

Step 4: Add Functions that Cause the Problem

Notice that up to this point, we have only considered knob settings or attributes of the driver, the pile and the ground. There are also functions which cause the problem. One action in this instance is that the ground is pushing back on the pile. We can treat these functions in the same way that we treated knob settings. They may or may not cause a contradiction.

The inclusion of functions is a little advanced for most beginners since functions are not taught in school. A beginner may skip this step until they are more experienced with the use of functions.

Driving Speed is Slow **= f** {
Pile Diameter is Large
Driver Mass is Low
Ground Hardness is Hard
Pile Flexibility is Flexible
Functions → **Ground Pushes the Pile**
⋮

Step 5: Turn the Knobs to Settings that Fix the Problem

These are the opposite settings. Write this as a column next to the attributes that cause the problem. We must temporarily ignore what becomes worse when we turn the knob. Turn it far enough in our mind's eye to solve the given problem (slow driving speed) for several product generations.

Driving Speed is Slow **= f** {

Pile Diameter is Large	**Pile Diameter is Small**
Driver Mass is Low	**Driver Mass is High**
Ground Hardness is Hard	**Ground Hardness is Soft**
Pile Flexibility is Flexible	**Pile Flexibility is Stiff**
Ground Pushes the Pile	**Ground Doesn't Push the Pile**
⋮	⋮

Step 6: Form Contradictions

We can now allow our critical self to suggest what we have been rebelling against all along. We need to identify what gets worse when we turn the knob far enough to improve the main parameter that we are trying to improve. Write what gets worse as another column.

Note that the two middle columns give us the parameter which must have two different settings. The pile diameter must be large and small; the driver mass must be high and low; the ground hardness must be soft and hard and the pile must be flexible and stiff.

The last column, gives us what is getting worse. While improving driving speed, breakage or depth of driving gets worse. While improving driving speed, breakage gets worse. While improving driving speed, driving depth becomes deeper. While improving driving speed the pile costs become high.

Contradictions

Driving Speed is Slow	**= f**	**Pile Diameter is Large**	**Pile Diameter is Small**	**=**	**Breakage is High (Or Driving Depth is Deep)**
		Driver Mass is Low	**Driver Mass is High**	**=**	**Breakage is High**
		Ground Hardness is Hard	**Ground Hardness is Soft**	**=**	**Driving Depth is Deep**
		Pile Flexibility is Flexible	**Pile Flexibility is Stiff**	**=**	**Pile Cost is High**
		Ground Pushes the Pile	**Ground Doesn't Push the Pile**	**=**	**Pile Support is Poor**
		⋮	⋮		⋮

When the contradictions are created in this manner, it seems natural. Remember to *always* start with a parameter that you would like to improve and then discover the attributes that control it. This will work on problems that you are familiar with and those that you are not.

Note that some knobs may be turned and no problem arises. This is a good thing and one should not decide that they have done anything wrong. For instance, what if we increase the speed of the driver so that it lifts the mass back more rapidly? Nothing actually gets worse and the driving speed is greatly increased. While this type of solution is rare, a good job of causal analysis can often find these types of knobs.

We might be tempted to immediately begin resolving contradictions. However, there is another tactic that we will explore next.

Step 7: Discover Alternative Problems

Alternative problems[10] are discovered by *permanently* turning any one of the knobs to the settings that fix the main problem. These knob settings are found in the 2nd column from the right. If we start with these permanent settings and do not attempt to resolve the contradiction by turning the knob to both settings, then we have an alternative problem to the original problem. We need to somehow compensate for what we have done. For instance, let us assume that we have solved the primary problem of driving speed by using a small diameter pile. Now we have two alternative problems to solve. How can we improve breakage and how can we improve the support of the pile given a small diameter? Having two alternative problems to solve is not ideal. If we chose, instead, to increase the mass of the pile driver to solve the problem of slow driving speed then we have one alternative problem to solve. How can we improve the breakage of the pile given a heavy driving mass? We will later consider how we may solve this problem by compensating. In other words, we fix one problem by turning a knob and then find another knob to turn to fix the problem that we have just solved.

The simplified Causal Analysis is now complete. Notice that we have identified several knobs and settings that are causing the problem and also the reasons that these knobs are hard to turn. We have also identified a harmful interaction or function that occurs while driving piles. In further sections, we will look for ways to resolve the contradictions, compensate for the alternative problems and idealize the interactions that are causing problems.

Exercise—Corrosion of Acid Container

Cubes are placed in warm acid to investigate the effect of various acids on the cubes. Unfortunately, the container that holds the acid and cubes is corroded. The container is made from gold and is very expensive to replace. Because the acid is so reactive and the test is performed often, the pan must be replaced frequently. Using what you know about corrosion, perform a simple causal analysis to identify some of the knobs, contradictions and alternative problems. Recall that “Cost of Replacement Is High” is the base problem.

Exercise—Garden Rake

Let us consider the situation of a common garden rake. When the rake is used to collect loose debris such as rocks and loose weeds over an uneven surface, a problem arises: The rake “leaks” some of the debris that is to be collected under the tines and several strokes are required to fully collect the debris. Using what you know about raking, perform a simple causal analysis to identify some of the knobs, contradictions and alternative problems. Recall that “Debris Leakage Is High” is the base problem.

Exercise—Year End Review

The yearly performance review process is very time-consuming, especially when you have a large number of direct reports. Using what you know about performance reviews, perform a simple causal analysis to identify some of the knobs, contradictions and alternative problems. Recall that “Review Cycle Time Is High” is the base problem.

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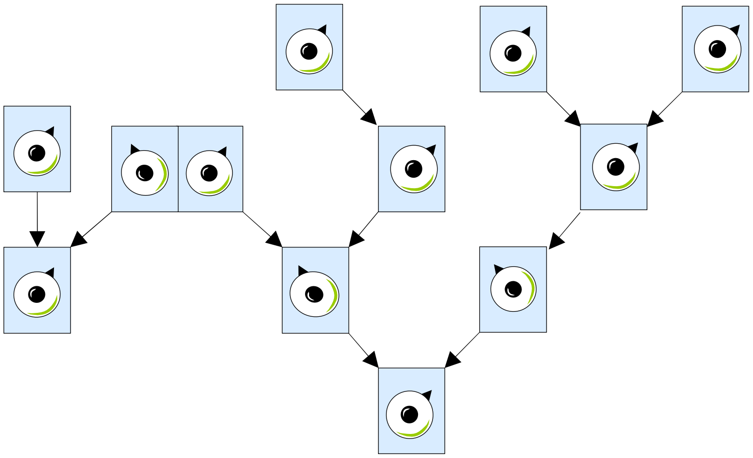
[10] The concept of “alternative problem” was used by G.S. Altshuller in most versions of the Algorithm for the Solution of Inventive Problems (ARIZ) . The intent was to identify an alternative problem that could be solved and compare it to the original problem. It was recognized that the alternative problem might be easier or more obvious to solve. For an example of this see step 1-2 on page 111 of The Innovation Algorithm by G.S. Altshuller.

L2-Diagram Cause

Some people ask "Why is constructing a diagram so important? I already know this stuff." My experience is that the organization of what we know is very valuable. Most subject matter experts have this information floating around in their minds in unconnected ways. Typically, they are not thinking in terms of contradictions and alternative problem paths. It is precisely because we think about a subject often that we create familiar routes of thinking. The more expert a person is on a given subject, the more likely they are to assume certain things. What we assume is called paradigms. They are mental ruts that are difficult to extract ourselves from. Organizing our thinking, ironically, allows us to question these assumptions. Note that we challenge assumptions by identifying the contradictions, alternative problem paths and questioning why objects are required in our system.

The causal analysis diagram is an important tool for determining the knobs and settings that lead to the disadvantage. They help us to understand the relative importance of every cause. They expose underlying contradictions and help us to understand alternate problems to solve rather than the one we start with. In short, they help the problem solver to look at all sides of the problem.



An additional benefit of causal analysis diagrams is that they help teams work together, even under emotional or contentious conditions. Once a team agrees on what is causing the problem, the course of action is clear. Consequently, the team is more likely to pull together. Also, the diagram will help to highlight the areas where team knowledge is lacking and data needs to be collected or tests run. They also allow everyone a voice in understanding the problem. This can keep more vocal members from dominating the discussion.

For many beginners, constructing a causal analysis diagram can be somewhat confusing. The confusion comes from applying unfamiliar rules and suggestions. These are given to keep the problem solver from falling prey to known pitfalls. Nonetheless, creating a causal analysis diagram can take considerable thought, the first few times that it is attempted. With each use, it becomes more intuitive and ultimately takes a small percentage of the total causal analysis time. Eventually, most of the time is spent in study, analysis, performing experiments, quantifying variables, observation and other activities.

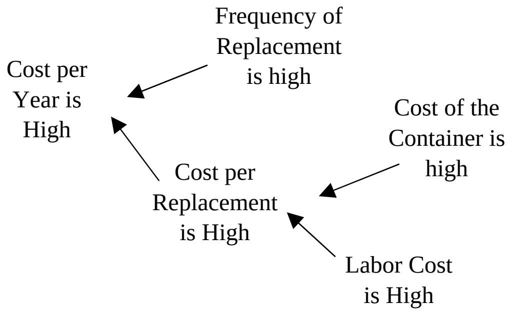
Not only do people become used to the rules, but most people will eventually personalize these diagrams to work better for them. The formats and software tools used to create them can vary widely. This is to be expected and actually encouraged. On the other hand, the fundamental rules should probably not be abandoned.

Chains of Cause—Decomposing Causes

A simple approach to identifying causes is to brainstorm the causes from our experience. (As a reminder, we are not brainstorming solutions, but rather the causes). We can do this by thinking of the *dependent variable* that we are trying to improve as a mathematical function of several *independent variables.* Recall your high school algebra class: y = f(x1,x2,x3…). Let's apply this functional thinking to the corrosion of the acid container. We brainstorm the independent variables as shown to the right. While this looks somewhat simple, this humble beginning can lead to useful solutions, as will be shown later.

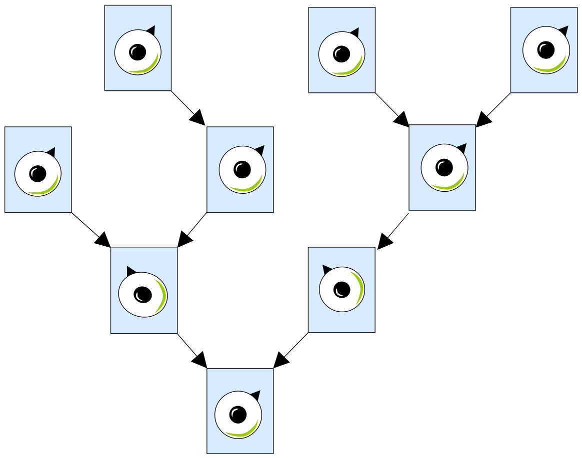
$$\text{Cost /Year} = f\left(\begin{array}{cccc}\text{Cost of the} & \text{Cost of the} & \text{Activity of} & \\ \text{Container} & \text{Container} & \text{the Acid} & \cdot\cdot \\ & \text{Material} & & \end{array}\right)$$

Notice that some of the independent variables of the math function are dependent on each other. For instance, the cost of the container is dependent on the cost of the material. We can write the function in a form that takes into account the interdependencies. Consider the diagram to the right. The dependencies are now easily visible. This type of analysis creates a cause-effect chain of dependencies which relate back to the original problem.



A further refinement comes when we recognize that every knob is associated with an interaction or function which causes the problem.

The diagram at the right is a symbolic representation of a generic cause-effect chain.[11] Each box in the chart represents a knob setting or a function which leads to the problem that we are trying to solve. Causal analysis diagrams can be formed with the base problem at the bottom or the top or sides. The arrows signify the direction of causality.



This is where we think in terms of causes. What variables and settings cause the problem? This is exactly what we did in the simplified causal analysis. Now we are going to put the knobs and settings into boxes and build a chain of causes. We will construct the diagram very carefully, concentrating on each box as we go. Every "cause" is the "effect" of something else. All Xs will eventually be considered as Ys. This could, theoretically, go on forever. We will only continue this until we reach causes over which we have little control.

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[11] There are a number of ways to construct causal analysis diagrams. The method that is used in this book is an adaptation of the methods described by John Terninko, Alla Zusman and Boris Zlotin in Systematic Innovation An introduction to TRIZ, St. Lucie Press, pages 47-63.

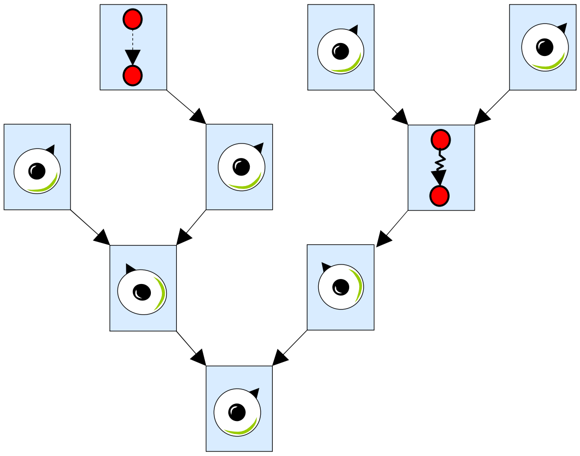
Most of the Work is not in the Causal Analysis Diagram

There is much more to doing a good causal analysis than constructing a diagram. The bulk of the time will be spent away from the diagram, creating models, thinking about what is causing the problem, understanding the physics and performing tests. What we learn is eventually incorporated into the diagram.

Precision and Self Consistency are Worth the Price

This brings up a final warning about creating these diagrams. It is worth the time to make sure that the logic of the diagram is very precise. One should be able to go through the diagram and feel that there are no missing branches. Missing a branch eliminates a number of solution possibilities. Consistent logic creates trust in the team that they are working on the most important aspects of the problem. Using equations and values allows the analysis to become "self consistent". This reduces the possibility that we are fooling ourselves.

Going Beyond this Basic Template



So far, our focus with causal analysis diagrams has been to show how object attributes or knobs and their settings can lead us to understand contradictions and alternative problems. This is very useful but also somewhat narrow. Focusing on knobs, alone, does not drive us to consider alternative systems which use *different* objects to perform their main functions. In other words, the resulting solutions will tend to evolve *the current system*. This can be somewhat limiting, especially if the team is allowed the luxury of changing the system to a greater degree. Here we will consider additions to the basic causal analysis diagrams that will prepare us to make larger system changes.

We will also add some new features that will aid less involved team members to understand these diagrams.

Adding Functions

Most Problems can be traced to useful objects that do not perform their function as well as they should or also cause harm. What are these objects? The causal analysis diagram can be used to illuminate these objects with their attending functions and the object parameters which connect these functions. Another way to think of this is that we are going to link together flawed functions through their object attributes.

Functions focus our minds on how parameters change with time. One could ask "why is maintaining this oven so expensive?" The answer to this question is "The pan is corroded by the acid and needs to be replaced". The corrosion of the pan takes place in time.

This answer describes two functions. The acid is corroding the pan and the pan is being replaced. Notice that neither of these two "causes" has shown up on the diagram yet. Everything that we have accomplished to this only point *implies* that a function is involved.

A second reason that we need to include functions is that this focuses our minds on the *objects* and *physical phenomena* that are involved and *why* they are required. This is particularly important when trying to discover the knobs or independent variables associated with the dependent variable. Each object in the function has features or knobs that control the dependent variable under investigation. It is easy to forget that these knobs exist if we have forgotten that the associated objects aren't a part of what is going on.

Later, we will attack these functions, individually, when we go to solve the problem. We will "idealize" them. In other words, we will be questioning what the elements of our system do. We will consider removing or replacing elements or having them take on other functions. The net effect is to solve the problem and simplify the system at the same time.

Drawing Pictures

The author has found that teams which are untrained in the use of causal analysis diagrams can come up to speed very quickly and make important contributions if they can just become engaged. Creating a causal analysis diagram can build a shared understanding of a problem that will unify a team making them far more effective.

While it is not absolutely necessary to perform this step, it is very helpful when working with teams. Adding graphics to the diagram helps group members to participate and follow it easily. Without such graphics, the uninitiated reader will usually fall asleep before you can finish the story. Drawing pictures helps team members to follow what is happening, even if they do not have a deep understanding of the physics behind the analysis.

L2-Method

Step 1: Show the Base Problem as the Starting Box on the Causal Analysis Diagram

Rule: Every Box Shows a Knob and a Setting—Every Setting is "Bad"

Rule: Quantify the Current Setting (If It is Known)

Step 2: Determine the Causes and link them together.

Rule: Think in Terms of Equations or Models $Y = f(X_1, X_2, X_3 \ldots)$.

Rule: All Causes are Assumed to be at the Worst Setting

Rule: If You Cannot Use an Equation, Think in Terms of $Y = f(X1, X2, X3 \ldots)$

Rule: Highlight Important Branches And Abandon Branches of the Diagram that Have Little Effect

Suggestion: Consider Putting Models into the Diagram

Step 3: Discover Contradictions

Rule: Turn the Knobs as You Go

Rule: Turn the Knobs Far Enough to Fix the Main Problem

Suggestion: Consider Extreme or Unusual Settings from the Table of Knobs

Step 4: Requirements Are Not Caused By Anything—Develop Alternative Problem Paths

Step 5: Add Functions.

Rule: Functions are added by asking which dependent variables are changing or controlled with time. These elements would typically not be design parameters or parameters that are fixed or constant (unless they are controlled). They are changed or controlled by something else. If a dependent variable is changing with time or is a measure of change with time, then a function is involved.

Rule: We insert the function by mentally sliding the dependent variable downward, thus creating a space for the function. The function is then inserted in the space that the dependent variable occupied.

Suggestion: Draw Pictures in the Boxes.

Example—Corrosion of Acid & Cube Container

Step 1: Show the Base Problem as the Starting Box on the Causal Analysis Diagram

The starting box can be placed anywhere on the diagram that you would like. Some people are used to making “Fault Trees” and like to start at the top. The author is used to starting at the bottom. Do what feels comfortable. Sometimes we can identify problems that are more basic than what we thought was the base problem. This is fine. Just put it further down the chain.

As we have already stated, the main problem is the high cost of replacing the corroded boxes. In our case, this will be located at the bottom.

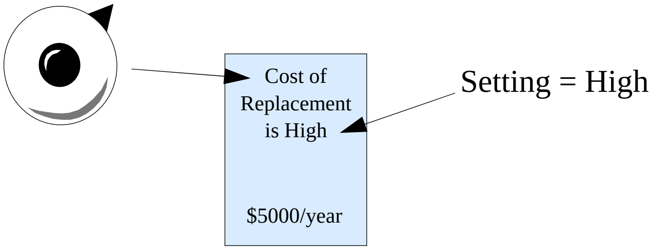
Rule: Every Box Shows a Knob and a Setting—Every Setting is “Bad”

At the top of each box is a knob and setting (object attribute and the level of the attribute). *Every* box that is shown has a “bad” setting. In this case, the knob is “Cost of Replacement”. The setting is “High”. Note that this is a bad setting from the perspective of the problem solver. Some problem solvers become confused and start putting in good settings to indicate solutions. The solutions can be placed elsewhere on the diagram.

Further confusion can be caused when people identify knob settings that they have always thought of as nominal. They don’t think of these settings as “bad”. However, if the knob *could* be turned could you make the base problem better or worse? If you could, then assume that the current nominal setting is “bad”.

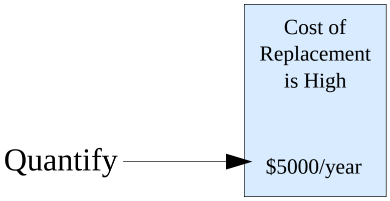
The knob is the cost of replacement of the container. The setting is High

Rule: Quantify the Current Setting (If It is Known)



We do this so that later, we can tell the relative importance of each parameter and to create the discipline to make the evidence self consistent.

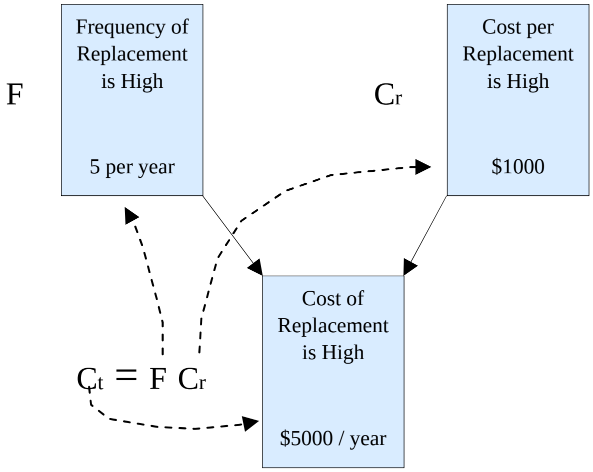
In this case we see that the cost of replacement is \$5000/year.



Step 2: Determine the Causes and link them together.

Rule: Think in Terms of Equations or Models $Y = f(X_1, X_2, X_3\ldots)$.

The "effect" is the dependent variable (Y) and the "causes" are the independent variables ($X_1, X_2, X_3\ldots$).



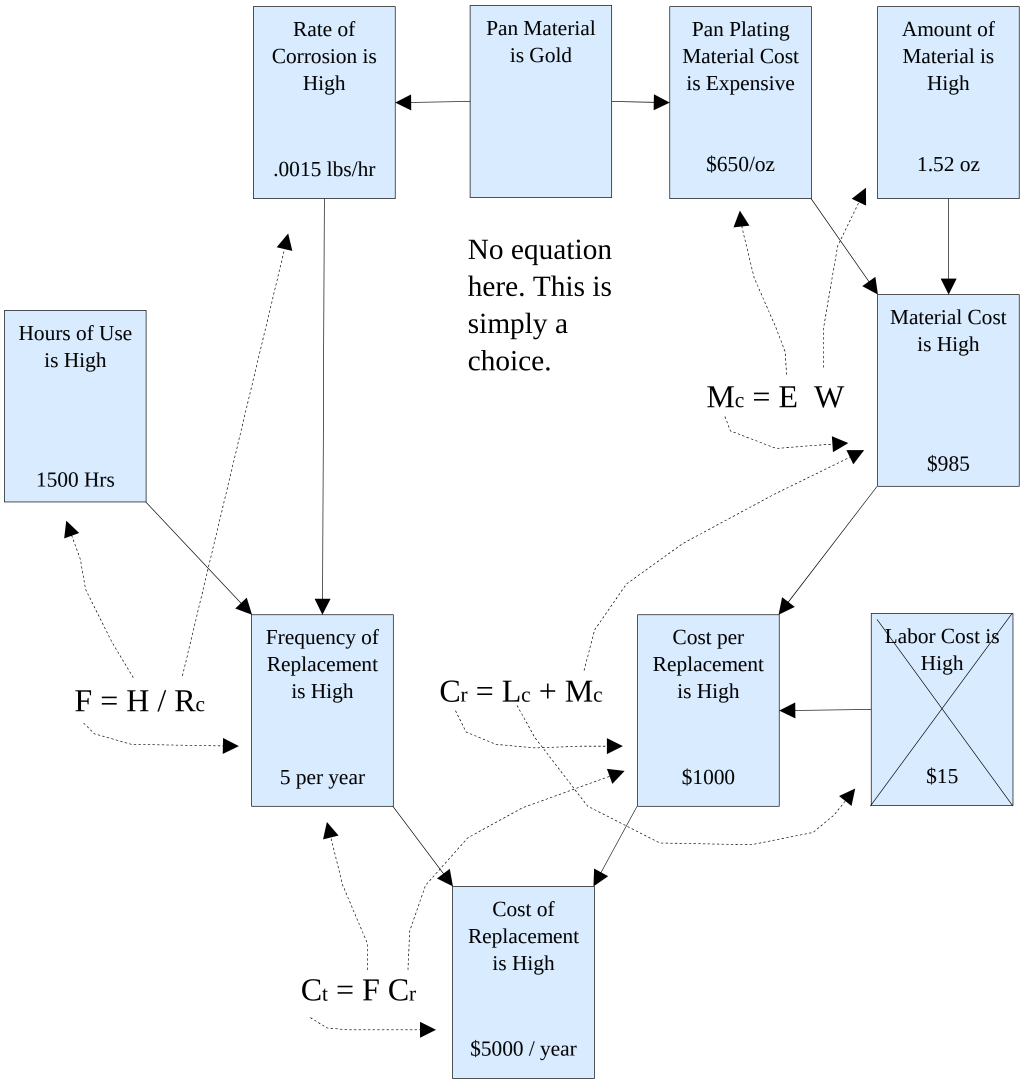
Referring to the diagram the effect "cost of replacement" (C_t) is the dependent variable. We model what is happening with the equation $C_t = F\ C_r$. This means that the cost of replacement is a function of the "frequency of replacement" (F) times the "cost per replacement" (C_r). The Causes are placed in their own separate boxes. Note the direction of the arrows from the cause boxes to the effect box. The direction of the arrow indicates which boxes are the "causes" and which is the "effect". As we move up, each cause will then be considered as an effect which has its own input causes.

Rule: All Causes are Assumed to be at the Worst Setting

This may not be intuitive, but note that according to any equation, the outcome could be improved by changing the value of any variable, regardless of the value of the other variables. In the acid bath problem, making the frequency of replacement high or cost per replacement high drives the total cost to the worst possible condition.

Note, in the previous diagram, that we have continued to follow the previous rules by using a knob and a setting and by putting the level or setting of each knob at the bottom of the box. While it is not possible to put the whole diagram for this problem into this page, we continue in the diagram below, with this process to show how these rules are used to extend the causal analysis.

The value of thinking in terms of equations or models cannot be overemphasized. This makes it possible to find causes that nobody has considered before. When we find a cause, we have sown the seeds for a solution. One important class of solutions comes by turning the knobs and discovering that nothing gets worse. It is important to find the most knobs possible and thinking in terms of equations will help to identify many options that otherwise would not be considered.



Rule: If You Cannot Use an Equation, Think in Terms of Y = f (X1, X2, X3…)

In order to write an equation, it is necessary to understand the "physics" of the problem. This is not an inborn skill for most people, but needs to be developed with practice and application. Models and equations are second-hand to most scientists and engineers due to their extensive training in "analysis". To others, it is awkward and sometimes impossible. Helping people to think in terms of mathematical models is beyond the scope of this book, but it is possible to use causal analysis by using intuition. Even for engineers and scientists, it is not always possible to write an equation. Sometimes, the model is a complex simulation or the relationships are unknown. In either case, it is sufficient to "intuitively" identify the variables that we believe to be involved and their values. In other words: "If I could write an equation it would contain these variables…" However, there is a pitfall to doing this. It is easy (even for engineers and scientists) to fall back into the trap of brainstorming variables rather than looking for equations. If you do this, you will miss important parameters. Make it a habit of developing models and simple equations where possible.

Rule: Highlight Important Branches And Abandon Branches of the Diagram that Have Little Effect

If we know the values of the object attributes (parameters levels or knob settings) and record these values within the boxes, we now can compare various legs of this causal analysis diagram to determine which legs are not worth pursuing. For instance, the affect of the acid on the container may not be affected much by the cost of labor when compared to the cost of the actual container.

If we do not know the values of the object attributes, we may need to seek out data or perform screening tests in which only one variable is changed at a time. These tests will further help in understanding the relative importance of each knob.

Note from the above diagram that reducing the labor cost below $15 dollars will have little effect compared to the $985 material costs. There is no need to continue to develop this leg of the diagram. The diagram shows this crossed out.

Branches that are important can be highlighted in some manner to show where to focus. I like to use thick arrows. If we could always identify a branch as being unimportant in the beginning, there would be no need to highlight any particular branch. Usually this is determined at some point further up the branch so we need some way to identify important branches. In the acid container diagram, all of the branches are important except the one that is crossed out. Personalize the diagrams in ways that help you to see the important branches.

Suggestion: Consider Putting Models into the Diagram

For convenience, large models can sometimes be written into the tools which contain the diagrams. It is possible to convert Microsoft Excel into a more powerful flow charting tool by making boxes with more attachment points and using the connectors from the AutoShapes toolbar. Now it is possible to put the mathematical models directly into the sheets. It is even possible to make the results of the calculations update the values in the boxes of the causal analysis. Another feature of Excel is that you can break up the diagram into sheets and link between the sheets to navigate around the diagram. It is the author's opinion that using common software tools such as Microsoft Excel are preferred over flowcharting tools because they are found everywhere. Anybody can open such a file to view or modify it, making it much more transportable. This can help when deploying TRIZ in large companies.

Step 3: Discover Contradictions

Now we come to one of the most powerful aspects of causal analysis diagrams, discovering the contradictions that are holding back the system development. Many people ask how to reveal contradictions in their systems. This is a very effective and efficient way, especially if the problem is complex or "tangled" or if we have never encountered it before.

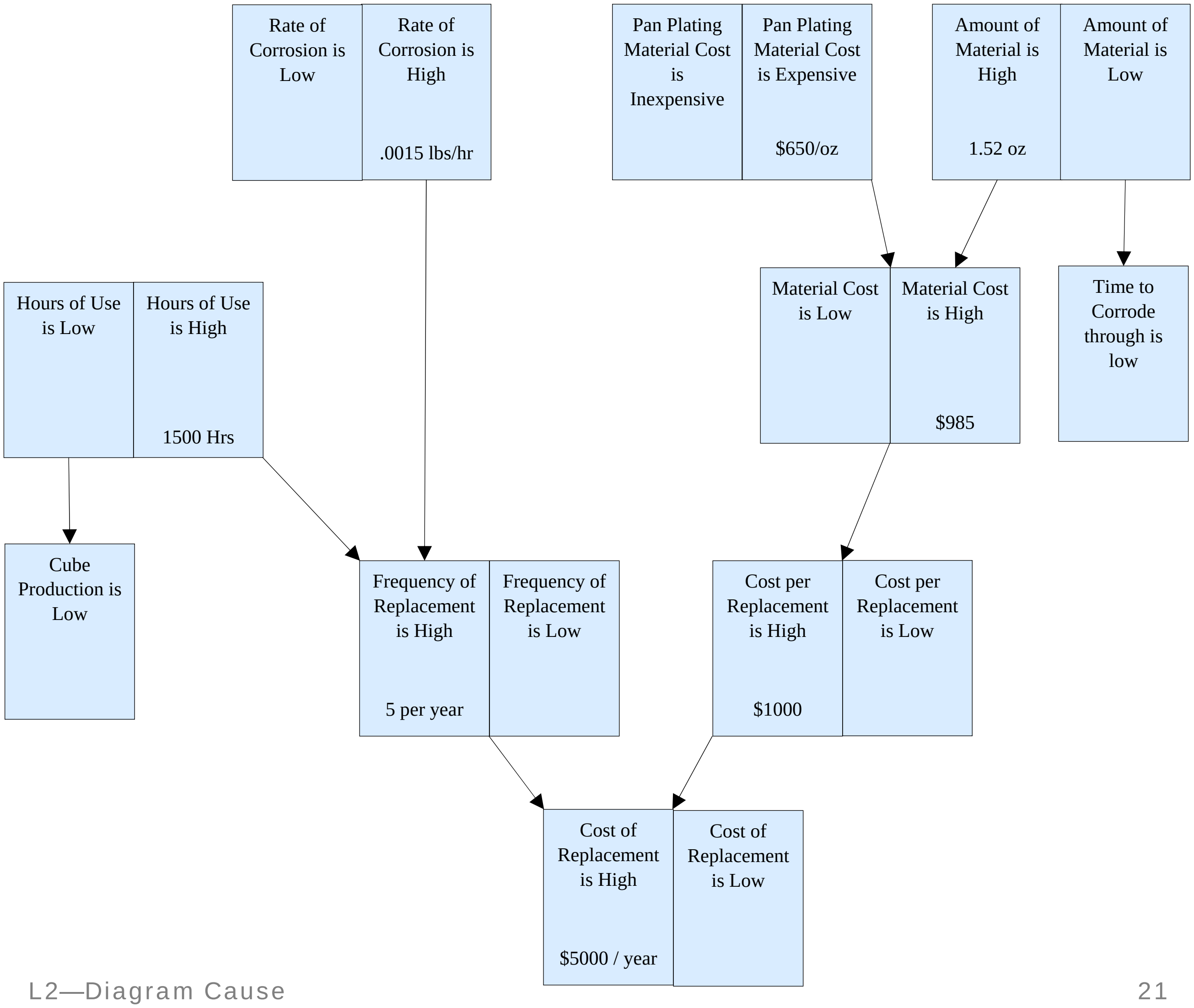
A good causal analysis is incomplete without a good understanding of the contradictions. We will show that there is a relatively simple systematic approach to accomplish this.

Rule: Turn the Knobs as You Go

When we identify a new box with a knob and setting, we should ask ourselves each time "What happens if I turn the knob to the opposite setting? Does something else get worse?" We do this by mentally placing a box by the side of the box that we are considering and showing the opposite setting in the box. If something gets worse, we draw an arrow from the box to a new box showing what gets worse.

We could have done this as we built the diagram beginning with the very first box. We could have asked "If the cost of replacement is low, does something else get worse?" In this case, nothing gets worse and we move on and do not physically draw the box that we were contemplating. Because something does not get worse when we turn a knob does not mean that there is no contradiction, it only means that the contradiction is implied. There is an implied contradiction for each box. The reason that we do not show these contradictions is that the diagram is more compact when they are not shown.

Here is what the diagram would look like if the implied knobs were turned and we left the boxes (minus the equations and a couple of boxes to save space).



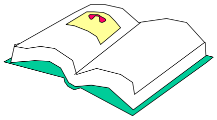
Notice that only two of the contradictions show something getting worse. When the amount of material is low, the time that it takes to eat through the material is low. Also, if the hours of use are low, then we must process fewer cubes. The rest are *implied* contradictions that we many want to resolve. While contradictions where nothing becomes worse may not be familiar, it presents an opportunity to create solution concepts. “The cost of replacement is high and low”. We will not know until we try. When we get to the section on contradictions, we will explore the different types of contradictions in more depth.

Rule: Turn the Knobs Far Enough to Fix the Main Problem

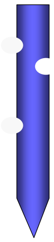
Some objections stop people from turning knobs as far as they should. Most would rather turn the knob part way and compromise. Unfortunately, compromise *guarantees* risk and leaves the problem to be solved later. *We must turn the knob far enough to fix the primary problem.* So, if a little medicine is good, then shouldn’t a lot of medicine be even better? We ask “why not be even more extreme?” While extreme thinking can be good, it can also get one into trouble on occasion. It is possible to excessively perform a function and suffer other problems as a result. The answer is to turn the knob sufficiently to solve the problem for several product generations. While this may not be an entirely satisfying answer, it comes to the heart of the problem of system evolution. Systems evolve because their needs change. What was excellent performance 5 generations ago may now be considered poor performance. We don’t want to address this problem again for several product generations.

Suggestion: Consider Extreme or Unusual Settings from the Table of Knobs

On the other hand, our knob turning skills may not be as good as we think. There is often more than one way to turn a knob. We might have missed some knob-turning possibilities. The Table of Knobs (Attributes) gives a number of extreme or unusual knob settings to consider.



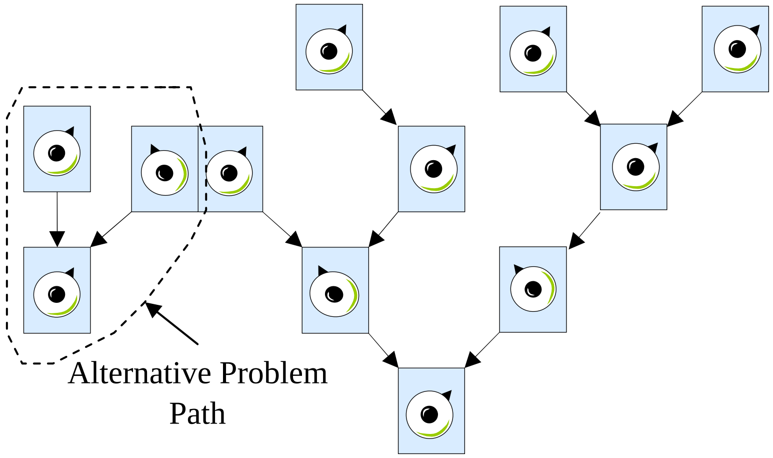
Go to the Table of Knobs (Object Parameters) and consider extreme conditions for the object attributes that you have chosen. Having looked at the table, we might have considered the use of voids. The extreme case of this is many voids that allow for good driving, but later as the soil settles, it interlocks with the pile giving high load carrying capabilities.



Step 4: Requirements Are Not Caused By Anything—Develop Alternative Problem Paths.

While setting up a causal analysis diagram, we will ultimately come to object attributes (knobs) which are not “caused” by anything. This may be a design parameter such as the length of something, or it may be that this attribute only comes in one “flavor”. A design parameter does not have a cause. The reason for the knob setting is because we chose it. There may be very good reasons for the settings we have chosen. In many cases the design parameter is required because if it does not have that setting, something else gets worse. We can think of this setting as a “requirement”. Neither design parameters nor requirements have causes. It makes no sense to look for a “cause” for these variables. We chose the setting because we realized that if it did not have that setting something else would get worse. Unfortunately, this setting also causes our main problem. In this type of contradiction, when we improve the main problem by turning the knob, something else gets worse. We can express the thing that gets worse by introducing an adjacent box showing the setting that would fix the original problem. This new box then causes an alternate problem[12].

This alternative problem path is illustrated below by the added boxes. Whenever we see the double boxes, we know that we have a contradiction *and* an alternative problem path. The alternative problem means that if we choose the knob setting that fixes the base problem, then we are left with the alternative problem. We can solve this alternative problem in a variety of ways, including compensation.



For instance, the high reactivity of the acid is one of the causes of the corrosion. If it is not high, the cubes take longer to corrode. "High acid reactivity is a requirement". We show this with a double box having the opposite value. This opposite box starts an "alternate problem" path. The implication is that if the reactivity of the acid were low (in order to help corrosion), we would need to solve a new problem having to do with a slow corrosion rate of the cubes. Alternate problems are an important part of all causal analysis diagrams. They show us what is getting worse when we try to improve something. While improving the corrosion rate of the pan, the corrosion of the cubes gets worse. The acid needs to have low reactivity and high reactivity. The contradiction can be stated: the reactivity of the acid must be low in order to not corrode the pan and it must be high in order to corrode the cubes.

Because we start with something that must be improved and finding the things that it is a function of, when we go to solve the problem (by turning the knob) something else gets worse. This is identical to the method that we used in the simple causal analysis. When we turned the knob, something got worse, thus exposing the contradiction.

Below is the diagram with a few new causes. Three contradictions and alternative problem paths are shown. Only the top one is highlighted. The beginning of each alternate problem path is always a contradiction. (There is another contradiction with the pan material being made of gold. The material might have been some more exotic corrosion resistant material which would have cost even more. While this is true, it will not be addressed here for brevity).

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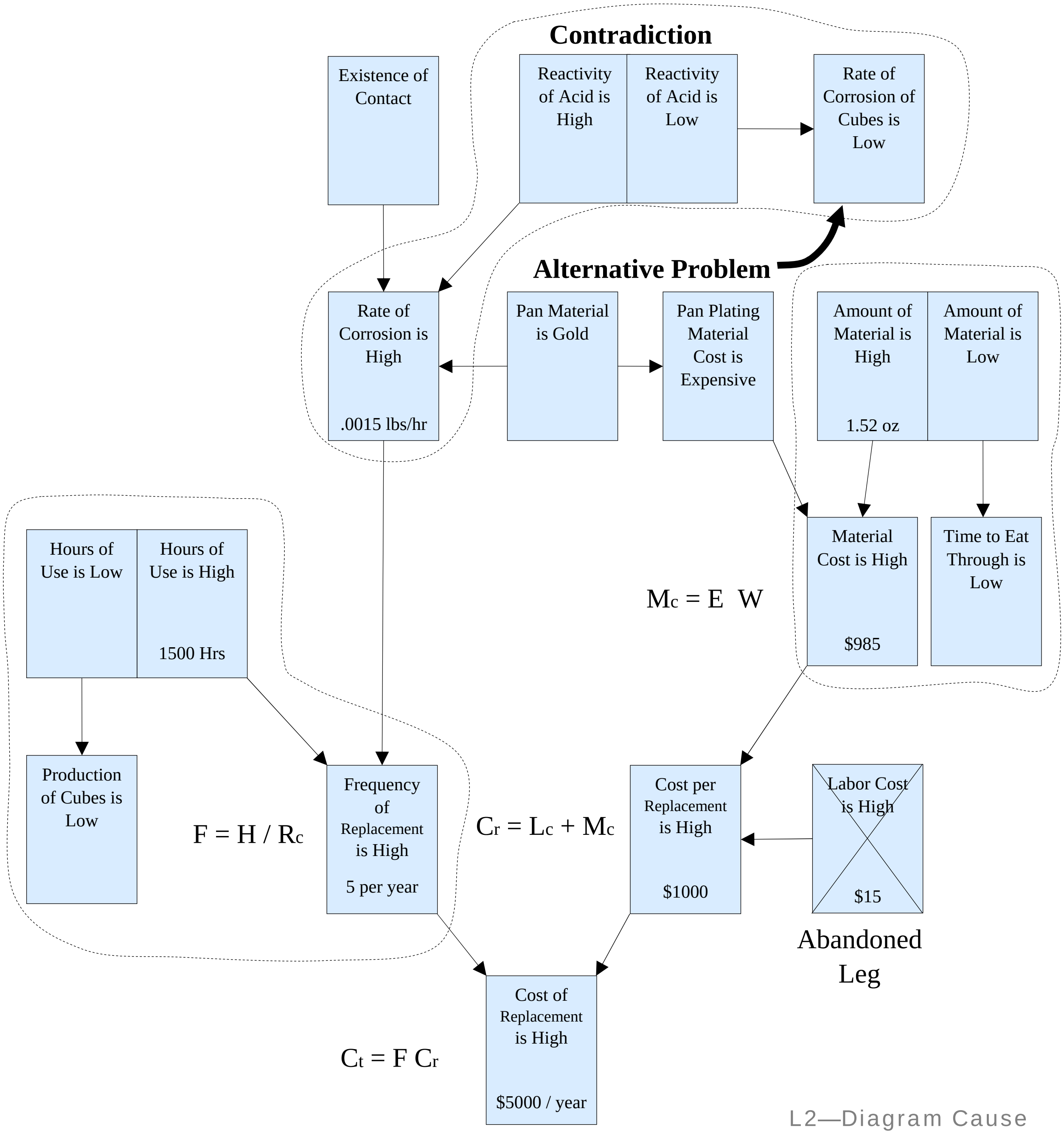
[12] The concept of "alternative problem" was used by G.S. Altshuller in most versions of the Algorithm for the Solution of Inventive Problems (ARIZ) . The intent was to identify an alternative problem that could be solved and compare it to the original problem. It was recognized that the alternative problem might be easier or more obvious to solve. For an example of this see step 1-2 on page 111 of The Innovation Algorithm by G.S. Altshuller.

Further development of the highlighted alternative problem would consider all of the causes which cause the rate of corrosion of the cubes to be low. The alternative problem path should be developed in the same manner as the original problem and with the same diligence. When the diagram is finished, it may look like we were trying to solve five different "main" problems at the same time. This is just fine because a powerful possibility is created: we may discover that multiple problems (more than two) may be solved by resolving one contradiction. These contradictions are "lynch pins". When they are solved, everything changes. Understanding the alternative problem paths and the contradictions that cause them allows us to see more sides of the problem.



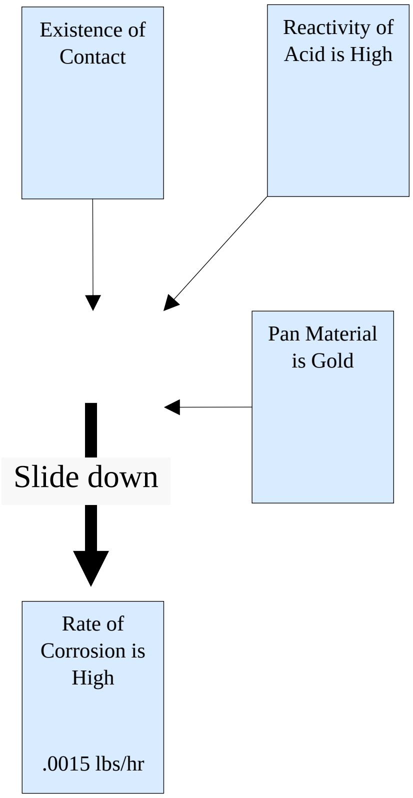
The diagram above has three contradictions or alternative problem paths added. We have not discussed two of them. If we allowed the hours of use to be low then we would have to deal with the alternative problem of how to increase productivity of corroding the cubes. If we allowed the pan material to be of minimal amount, to reduce the cost when it corroded, then we would have to deal with the alternative problem of short time to corrode through the pan.

Practice and familiarity will help to prepare you for the more advanced diagrams that follow. It is suggested that several diagrams be constructed and used. This will make the following section more meaningful.

Step 5: Add Functions.

Rule: Functions are added by asking which dependent variables are changing or controlled with time. These elements would typically not be design parameters or parameters that are fixed or constant (unless they are controlled). They are changed or controlled by something else. If a dependent variable is changing with time or is a measure of change with time, then a function is involved.

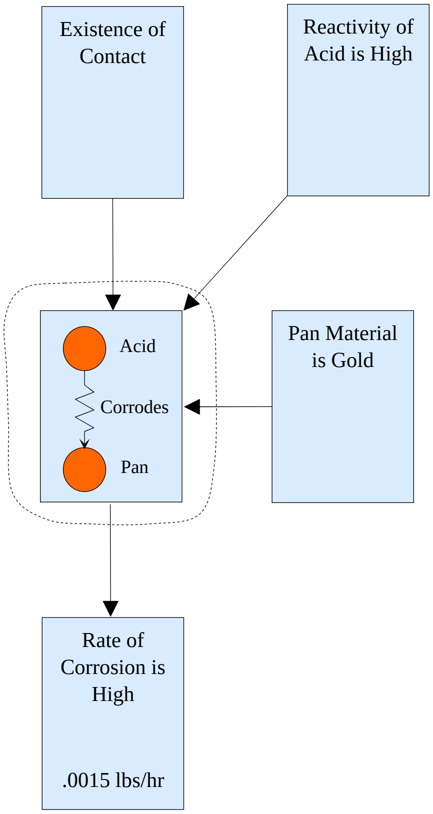
In the above diagram we note that the rate of corrosion of the pan and the cubes are measures of change. This tells us that we need to have two functions. The other parameters are relatively constant, so we will not require functions for them.



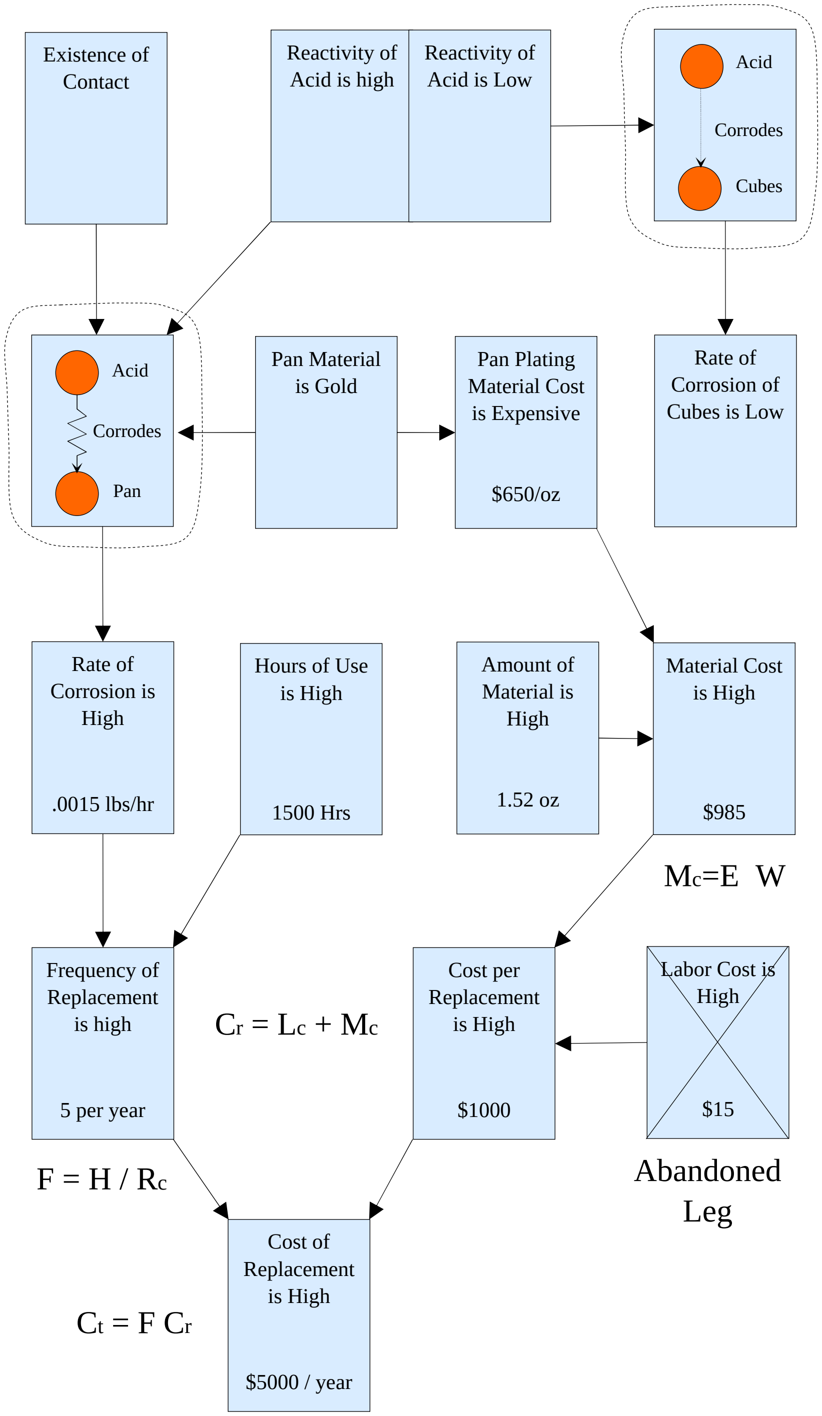
Rule: We insert the function by mentally sliding the dependent variable downward, thus creating a space for the function. The function is then inserted in the space that the dependent variable occupied.

Let's consider the function related to the rate of corrosion. First, we slide down the box associated with the rate of corrosion being high.

We then insert the function associated with the dependent variable and its associated independent variables.

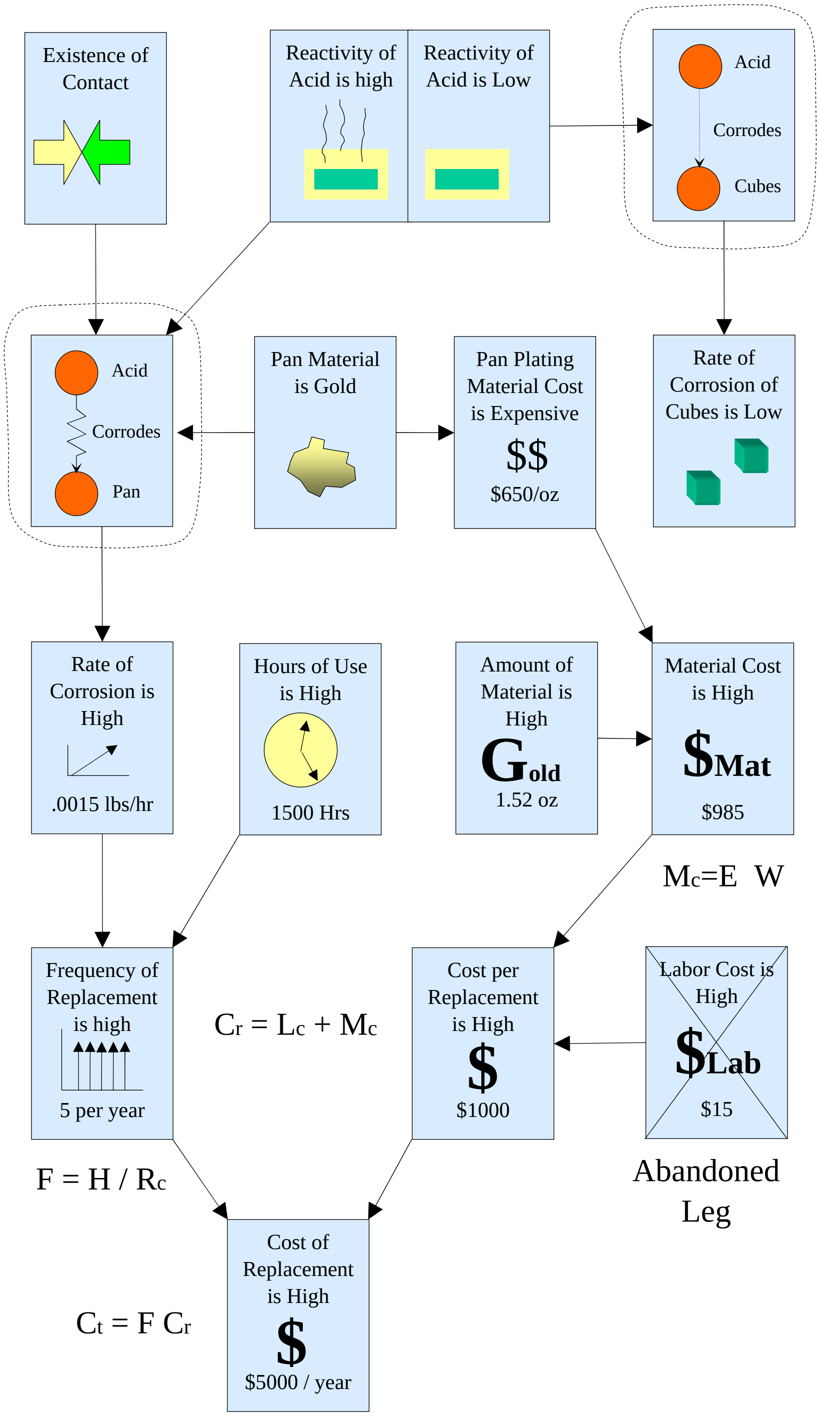


Let's add applicable functions to our causal analysis of the acid and cubes problem. This is how it looks (note that some of the diagram has been rearranged to make room).



Suggestion: Draw Pictures in the Boxes.

Below is the result.


Existence of Contact
Reactivity of Acid is high
Reactivity of Acid is Low
Acid
Corrodes
Cubes
Acid
Corrodes
Pan
Pan Material is Gold
Pan Plating Material Cost is Expensive
$$
$650/oz
Rate of Corrosion of Cubes is Low
Rate of Corrosion is High
.0015 lbs/hr
Hours of Use is High
1500 Hrs
Amount of Material is High
Gold
1.52 oz
Material Cost is High
$Mat
$985
Mc=E W
Frequency of Replacement is high
5 per year
Cr = Lc + Mc
Cost per Replacement is High
$
$1000
Labor Cost is High
$Lab
$15
Abandoned Leg
F = H / Rc
Cost of Replacement is High
$
$5000 / year
Ct = F Cr

Exercise—Pile Driving Speed

The driving speed of piles is very slow. Often expensive equipment such as cranes or barges is rented to perform the work. Personnel must be on hand should anything go wrong. All of this adds up to great expense while driving the piles. None of this is necessary for the primary function of the piles. Using what you know about driving stakes, create a causal analysis diagram to identify some of the knobs, contradictions and alternative problems. Recall that “Pile Driving Speed Is Slow” is the base problem.

Exercise—Garden Rake

Let us consider the situation of a common garden rake. When the rake is used to collect loose debris such as rocks and loose weeds over an uneven surface, a problem arises: The rake “leaks” some of the debris that is to be collected under the tines and several strokes are required to fully collect the debris. Using what you know about raking, create a causal analysis diagram to identify some of the knobs, contradictions and alternative problems. Recall that “Debris Leakage Is High” is the base problem.

Exercise—Year End Review

The yearly performance review process is very time-consuming, especially when you have a large number of direct reports. Using what you know about performance reviews, create a causal analysis diagram to identify some of the knobs, contradictions and alternative problems. Recall that “Review Cycle Time Is High” is the base problem.

L2-Create the Hypothesis from Evidence

Now that we have a good system for organizing our causal analysis, we will spend some time talking about the actual investigative work. These activities usually occur away from the causal analysis diagram and represent the majority of the time in causal analysis. Having a causal analysis diagram is not the goal. Actually going through the thinking and really understanding the causes of the problem is the goal.

If a subject matter expert is not available and the problem is not well understood, finding the cause and effect relationships can be very time consuming. Be prepared to dig into the physics and perform the necessary experiments.

In the beginning, we may think that we know what is causing the problem or we have no clue. Thinking that we know what is causing the problem may be as dangerous as not knowing anything. Assumptions are the essence of psychological inertia. We need to let the situation speak to us and we need to listen carefully. As we go, we need to form hypothesis so that we can direct our questions and experiments, but we should suspend judgment and not become too vested in any hypothesis.

As we collect evidence and listen to subject matter experts, we will naturally begin to a hypothesis of what is happening. The best problem solvers are usually those that are patient and willing to observe for long periods of time. Some might say that they are extreme in their observations. It is important to do this as each new observation will create many loose ends that need to be tied up to become a self-consistent analysis. Being self consistent does not mean that we “know” what is going on, but our beliefs will become stronger as things tie together.

Eventually we come to the point of “verifying” the solution. We do this by controlling the “knobs” and turning the problem off and on. This still does not mean that we “know” what is happening. What it means is that we can predict the outcome with enough accuracy to make it go away.

There are many pitfalls to performing a good causal analysis. It takes time and experience to become skillful investigators. Following are some suggestions for performing a thoughtful and thorough causal analysis.

L2-Method

Study what the subject matter experts have to say

Identify when the problem showed up

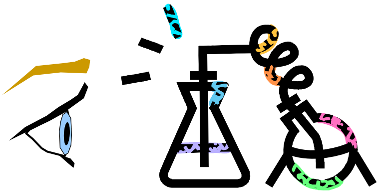
Observe the Situation Firsthand

Try to catch what is happening as it happens

Observe any evidence which is left behind

Look at past history

L3-Observe the Situation Firsthand

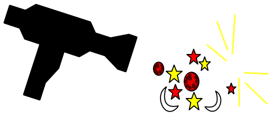


The Causal analysis process begins with a thorough look-over of the system. While this may appear obvious to some, it is amazing how often the author has skipped this step, only to be embarrassed later by someone who performs this step and notices some important, but obvious fact about the situation.

Method

Go to where the problem and effects are occurring and watch for yourself. Do not just look at pictures or imagine what is happening. Pictures remove a large portion of the data. Lost is the three-dimensional view. Pictures are only placeholders for actual experience. Touch the hardware.

L3-Catch It in the Act



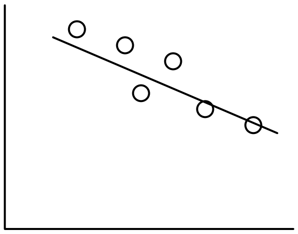
Many causes are obscured because they either happen so rapidly or by the time that we see the aftermath, the evidence of what happens is wiped away by secondary effects. Mechanical parts may fail and then rub against each other to destroy the evidence of how they failed. A failure may happen so rapidly that it is impossible to watch. Often, the most important invention of an investigation is the creation of an approach to catch something in the act.

Method

Step 1: Devise an experiment to watch the interactions. Consider slow motion, etc.

Step 2: Jump to the chapter on Idealizing Informing Functions to find ways to look at what is happening (copies, etc.)

L3-Statistical Methods



There are many ways that statistical data can be used to help determine what is happening. Of particular interest is Weibull analysis, regression analysis and run charts. Statistical correlations can be a powerful tool to determine what is influencing the problem, especially when the physics is not well understood. Please note that statistical methods may clarify the common cause issues but will not work with the special cause ones.

Method

Step 1: Use Statistical Analysis to Group and Subgroup the data.

Step 2: Use statistical software and thinking to correlate known object attributes to the problem and to determine the degree of influence.

Step 3: Compare the results with the expected outcome of the model.

Step 4: Look for outliers

Step 5: Determine whether these are artifacts of the measuring system or if they are really trying to tell you something.

L3-Negative Evidence

Negative Evidence[13] is an observation of what did *not* happen and where the problem does not occur. It is especially important to consider this under conditions where we expected things to happen. For example, cancer eventually leads to cells traveling to adjacent organs. But you never hear of cancer of the heart or the muscles. So what is the mechanism that prevents metastasis to these organs? The negative questions give rise to thinking that might not arise otherwise.

Method

Step 1: What does not happen that would normally happen?

Step 2: What continues to behave normally that should not?

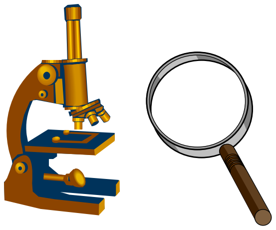
Step 3: Where does this problem not occur in my system…and why?

Step 4: What is not there that we usually expect?

Step 5: What is the difference between where it happens and where it does not?

L3-Crime Scene Analysis

The hallmark of a good "whodunit" mystery is a self-consistent analysis of the evidence. In everything that we do, we are trying to both uncover evidence and tie it all together to make the analysis self-consistent. There should be no loose ends. A lot of what we do is to look. We need to look at all levels. It is often microscopic evidence that we cannot see that makes the difference. Sometimes how we look is the greatest invention of all.



Method

Step 1: Examine all objects carefully under magnification (microscope or magnifying glass) or with the best tools available. Look for "witness marks" of what happened. Investigate microscopically.

Step 2: Take pictures and/or ***draw*** *what you see. Drawing will force you to see more than you normally do. Carefully compare what you are drawing to the actual object. Look for discrepancies. Try to use good art technique such as shading and perspective. Drawing forces observation. You will see more when you draw.*

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[13] Don Rossi from personal conversation and email during 2009. Don pointed out that identifying where something did not occur could be as important as identifying where it did occur and gave an example of cancer. He asked: What organs of the body seem unaffected by cancer? Why should they be spared? What are the differences between unaffected organs and organs that are more easily affected?

Step 3: If possible, line up many objects that have the same problem. They will all likely be at different stages of the problem. Compare the objects for differences. Look for patterns which show you how the problem progresses.

Step 4: Verify what you see with others' observations.

Step 5:Consider measuring properties of the object such as resistance, density and hardness. Look For Discrepancies.

Step 6: Look for ways to tie everything together into a self-consistent story.

L3-Problem History

How does the evidence compare to what you have seen in the past or to similar situations? This is usually based upon experience, but often there is someone around that can tell you what is unusual if you don't know. Studying the history of a problem can tell you where to dig and NOT to dig. It can save a lot of time.

Given enough experience, sometimes it is possible to determine when the problem showed up and link the occurrence with a change of objects or object attributes.

Method

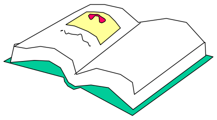
Step 1: Review the history of the problem—particularly if you have test data.

Step 2: Determine what changes occurred at that time which might correlate to the problem

L3-Subject Matter Experts

Usually, there is a subject matter expert. If this is a legacy problem, it is likely that this expert has, also, not been able to solve the problem. (Ideally, the problem solver is also the expert). All of the pieces to the problem are floating about in the mind of this expert. Organizing this information with a causal analysis diagram is an important step to solving the problem.

Based upon what we have seen or monitored, we need to change or reinforce our expectations. Our expectations are formed by how we think that the world works. That understanding can be a vague understanding or a deep model of the physics of the problem. There is really no substitute for understanding the physics of a problem. Thus, the important thing in this step is to understand the physics of the problem. What are the interactions between objects and what controls these interactions? Sometimes it is difficult to understand what causes a problem.



Method

Step 1: Study what the subject matter experts have to say:

—-Search Books, magazines, internet

—-Talk directly to subject matter experts

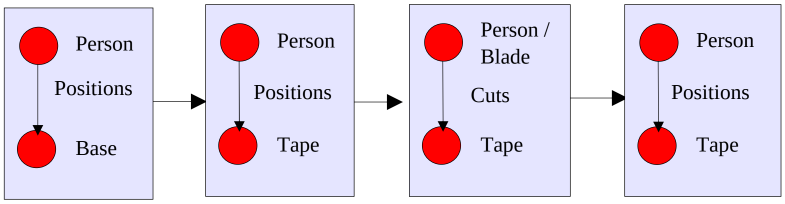
L3-Break Event into Smaller Steps with Process Maps or Story Boards

Whether you are describing a process or a product, you are describing what happens in time. Products are a collection of objects that operate in time. The value of a process map[14] is mostly found in the ability to break a process down into increasingly finer steps. A process map gives a snapshot of the sequence of functions with little reference to causality and may not include all of the possible elements of the system or super-system. If you can "story board[15]" the problem, sometimes this is even more effective due to the graphic nature of story boards.

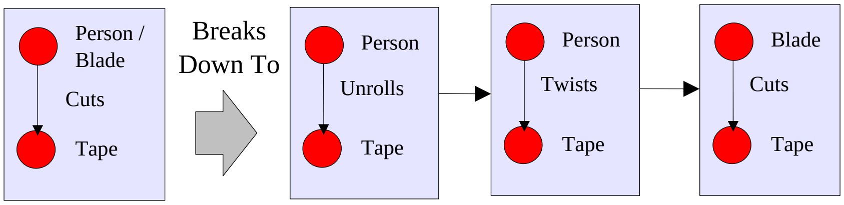
Example—Dispensing Tape

Step 1: Describe each step of the process in functional terms. We begin by "walking the process" in time, as a series of functions.

Step 2: Describe the process as a process map or storyboard. It might start with "person positions base" and then the second step could be "person positions tape" and so on.



Step 3: For increased understanding of critical steps, break down process steps into finer detail. In this case, we break down "person/blade cuts tape" into more detailed steps.



Step 4: Look for functional problems that you have not noticed before. It may not have occurred to us before that a person usually twists the tape to start the cutting process.

Step 5: Consider performing the previous steps graphically with a story board.

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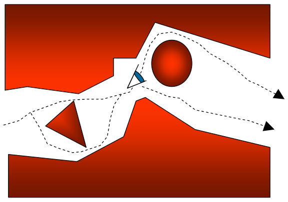
[14] The first structured process maps were made by Frank Gilbreth and presented to members of ASME in 1921 as the presentation "Process Charts—First Steps in Finding the One Best Way".

[15] The first story boards were created at Disney studios by Webb Smith in the early 1930s. It originated from cartoon panels that were pinned up on a wall to tell a story. The idea of story boards then spread to other studios. The idea is easily adapted to problem solving.

L3-Empathy

Method



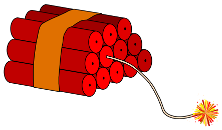
Step 1: Put yourself in the place of the objects that you are investigating

Step 2: Follow through process from beginning to end

L3-Subversion Analysis

Subversion analysis[16] [17] or Anticipatory Failure Analysis [18] [19] is a way to overcome psychological inertia to discover new ways that a system can fail. This method was first introduced in the approaches for looking for problems. Effectively we ask: If you were a **Saboteur**, how would you cause the problem?

Method



Step 1: Identify the unwanted effect..

Step 2: Act as if you were a ***Saboteur****, how would you cause the problem given the existing system? How would you keep this from being detected? Find a physical phenomenon that could be used to create or hide the desired effect.* ***Use the Effects Database to perform this.*** *(The effects database is too large to be provided in this material. More complete versions can be found in for-profit software. A simplified version can be found at function.creax.com)*

Step 3: Identify the required resources to make the effect work at all. For instance, if the effect is mechanical strain, look for objects or resources in the environment that might potentially push on the object. If the resources do not exist, then consider how they might temporarily exist or be formed through chemical reactions, etc. Consider how these harmful resources might exist naturally in small quantities from what is available. If no way can be found then consider that this effect may not be possible.

Step 4: If the resources are available then ***Boost the effect*** *until it is sufficient to cause the problem.*

--Identify the parameters (knobs) of all components (those acting and those being acted upon) which have an effect to make things worse. This means that either the effect of the

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[16] Genrich Altshuller, Boris Zlotin, Alla Zusman, Vitalii Filatov. "Searching for New Ideas." Kishniev: Kartya Moldovenyaska Publishing House, 1989.

[17] Boris Zlotin, Alla Zusman, "Solving All Scientific Problems" Kishniev: Kartya Moldovenyaska Publishing House, 1989.

[18] Stan Kaplan, "Finding Failures before They Find Us: An Introduction to The Theory of Scenario Structuring and the Method of Anticipatory Failure Determination." Proceedings of the 9th Symposium on Quality Function Deployment, June, l997. http://www.qfdi.org

[19] Kaplan, S., Visnepolschi, S.,Zlotin, B., Zusman, A., 'New Tools for Failure and Risk Analysis; Anticipatory Failure Determination (TM), Ideation International Inc, Detroit, 1999.

thing that is acting is boosted or the weakness of the object which is being acted upon becomes worse.

--Change these parameters so that the effect becomes large enough to cause harm.

Step 5: Repeat all steps with each way that the system could fail.

L2-Catch Missing Knobs—Table of Function Resources

The first pass through the cause-effect chain will identify the more obvious knobs. However, we can discover new knobs which are not as obvious. Because others may not have considered these knobs, they can sometimes be turned without harmful consequences.

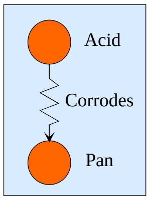
The Table of Functional Resources (Knobs) is a restructuring and reinterpretation of the parts of the "Inventive Standards[20]" which deal with standard approaches for handling common inventive situations. Many of the standards give hints as to object and field parameters (knobs). The concept of knob may be objectionable to some, but is easily learned and so used in the text. The idea is that objects and fields have structure or architectural and functional features which can be varied. Once we know the structure, we can vary the measurable parameters. This is like turning knobs on a device. Apologies are made in advance if the concept of "knobs" trivializes object and field parameters.

The book TRIZ Power Tools—Skill #8 Identifying and Mobilizing Functional Resources is a resource for discovering the resources that objects, fields and interactions that lie dormant within a system. Using the Table of Functional Resources will help the problem solver uncover several unanticipated ways to control functions.

L2-Method

Go to TRIZ Power Tools—Skill #8 Identifying and Mobilizing Functional Resources to identify function resources that might otherwise have been missed in the causal analysis.

Example—Acid Bath



Go to TRIZ Power Tools—Skill #8 Identifying and Mobilizing Functional Resources to identify function resources that might otherwise have been missed in the causal analysis.

New knobs were found: (1) Acid contact area. (2) Surface area of pan.

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[20] The Inventive Standards can be found in a variety of texts including Yuri Salamatov, TRIZ: The Right Solution at the Right Time by INSYTEC pages 226-244

L2-Relative To

Here is yet another way to find knobs. One might ask why we need so many knobs. The discovery of new knobs is quite important. Sometimes we are able to find knobs that nobody else has found. When we turn knobs, we find new solutions. It can be appreciated that a newcomer may feel overwhelmed by the number of independent variables in each situation. Having more options is a good thing. You can have some consolation in knowing that in the end, we will most likely only turn a few knobs to find the solution. Here, we are still exploring what is available.

Every knob is measured relative to something. Consider changing that "something" instead.

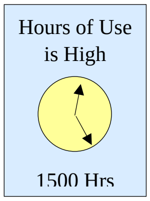
Method

Step 1: Let us pick one box in particular.

Step 2: What is this parameter compared to? The answer to this question in the new knob.

Step 3: Look through all of the boxes to determine whether there are more "relative to" knobs.

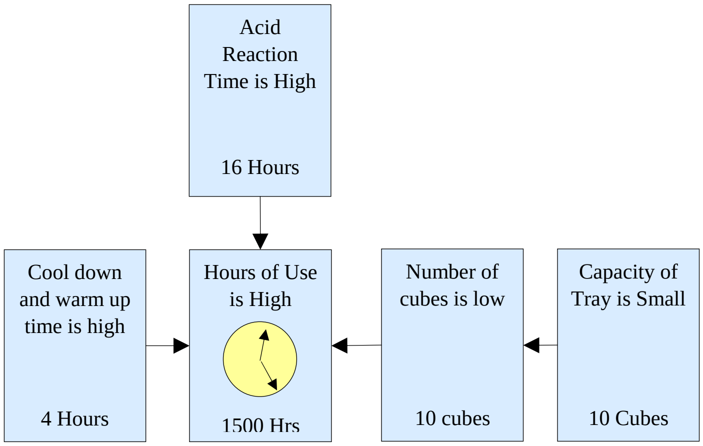
Example—Acid Bath



By this point, we realize that there are a number of knobs involved in the acid bath problem.

Step 1: Let us pick one box in particular.

The hours of use are high: 1500 hours

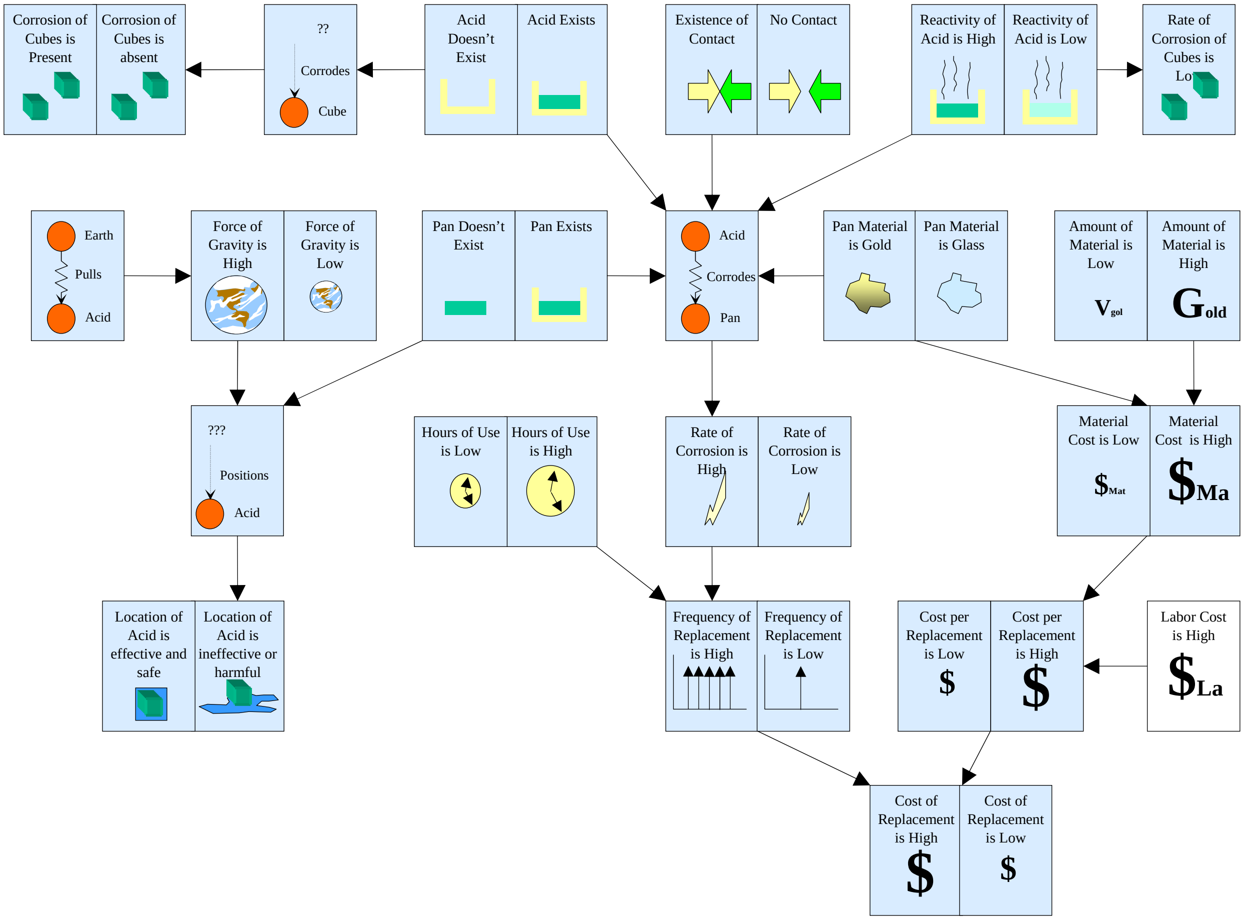


Step 2: What is this parameter compared to? The answer to this question in the new knob.

Answer: Number of Cubes and the total oven time. These are new knobs.

Step 3: Look through all of the boxes to determine whether there are more "relative to" knobs.

A completed causal analysis diagram is shown below. The implied contradictions are included to underscore the point that they are also valid contradictions. Normally, these diagrams would be shown without the implied contradictions, for brevity.


Corrosion of Cubes is Present
Corrosion of Cubes is absent
??
Corrodes
Cube
Acid Doesn’t Exist
Acid Exists
Existence of Contact
No Contact
Reactivity of Acid is High
Reactivity of Acid is Low
Rate of Corrosion of Cubes is Lo
Earth
Pulls
Acid
Force of Gravity is High
Force of Gravity is Low
Pan Doesn’t Exist
Pan Exists
Acid
Corrodes
Pan
Pan Material is Gold
Pan Material is Glass
Amount of Material is Low
Amount of Material is High
V gol
G old
???
Positions
Acid
Hours of Use is Low
Hours of Use is High
Rate of Corrosion is High
Rate of Corrosion is Low
Material Cost is Low
Material Cost is High
$ Mat
$ Ma
Location of Acid is effective and safe
Location of Acid is ineffective or harmful
Frequency of Replacement is High
Frequency of Replacement is Low
Cost per Replacement is Low
Cost per Replacement is High
$
$
Labor Cost is High
$ La
Cost of Replacement is High
Cost of Replacement is Low
$
$

L2-Verify Causes (and Maybe the Solution)

When we can turn the problem off and on by changing parameters, then we have a stronger case for a solution. Some would say that we now know the solution. Well, not actually. Often, we find a knob that, if turned, will solve the problem. Unfortunately, another problem gets worse.

On the other hand, we may find that there are easily turned knobs. These knobs solve the problem without causing any significant problems. If this is the case and you do not need more solutions, then you may be done with problem solving. You can move on to the implementation. In cases where there are many time constraints, this may be prudent. On the other hand, if we need a number of solution alternatives or we want to simplify the system at the same time, then we should consider going to the next step of the algorithm and begin solving the problem in earnest.

L2-Method

Step 1: Perform tests to verify that you can turn the problem off and on by changing the parameters of the system.

Step 2: If nothing gets worse, then you have a solution.

Step 3: Verify that there are no "loose ends". All evidence should be self-consistent and tell the same story.