Southwest Center for Microsystems Education (SCME)
University of New Mexico

A Systematic Approach to Problem Solving Learning Module

<u>Learning Module Contents</u>

This learning module introduces a systematic approach to solving problems by using a six-step process. This approach is used throughout industry to solve simple to complex problems. Activities provide the opportunities to this six-step process in a real life situation as well as MEMS process problem.

Target audiences: High School, Community College, Industry Technologists, University

Made possible through grants from the National Science Foundation Department of Undergraduate Education #0830384, 0902411, and 1205138.

A Systematic Approach to Problem Solving
Primary Knowledge
Participant Guide

Description and Estimated Time to Complete

Problem solving is an important skill to bring to any job that you have. It is an extremely important skill for jobs in microtechnology and other technology and manufacturing industries. In manufacturing, some type of problem is being solved every hour of every day. Some problems are small, but some are large enough and serious enough to require a team of employees to tackle the problem, analyze it, solve it, fix it, and then make sure it stays fixed.

As an employee in any manufacturing field, you are required to solve problems. When the problem is large enough, you could be placed on a problem solving team. No matter whether you are working alone or with a team, your employer is going to require you to think logically and solve the problem systematically. Shooting from the hip or doing something because you have a gut feeling is not acceptable.

This learning module helps you to develop a systematic approach to solving problems by having you practice on several hypothetical, but practical problems and then apply your skills to a real problem that can occur during the fabrication of micro-sized devices.

So open your mind, allow your creative juices to flow, and be sure to communicate effectively with the people you work with while completing this module. Have fun and learn!

Learning Module Objectives

- Work with others to develop a list of solutions using a brainstorming process.
- Apply a systematic approach to solving at least two problems – a practical everyday problem and an applied problem that one might face in a microtechnology fabrication facility.
- Using good communication skills, work effectively with other participants to solve at least two problems.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).

Introduction

At some time during the night, the power goes out. You call the electric company and are told that it will be 24 to 48 hours before it can restore power. You immediately think of two major problems: getting your morning coffee and the freezer full of food! How would you solve both of these problems? Think about it and be prepared to share your solution.

What is your solution to getting your morning coffee? O.K. – you may not drink coffee, but if you did, what would you do?

What is your solution to taking care of that freezer full of food?

What was the process that you used in solving these two problems?

Did you first determine the seriousness of the problem? For example, did you ask questions like these?

a. Can I live without my coffee for a day?
b. Will the food thaw out in 24 hours if I just leave the door closed? Do I want to chance it?
c. What is the value of all of the food in the freezer? Can I afford to lose it all?

Would you consult with someone else to help solve the problems?

Would you decide on an action plan and then implement it (hypothetically) for each of these problems?

Do you think your action plans would work (hypothetically)?

If this is the process that you followed, then you just applied a systematic approach to solving a problem. It is something that a lot of us instinctively on daily, personal problems. In industry this same system is applied, but in many cases you are working with a team and the problems you are solving are bigger and harder to solve.

Types of Problem That Need to Be Solved

On a personal level, I'm sure that you solve problems all of the time. Here are a few practical problems you may have had to solve recently.

- You have a lot of work to do, and not enough time to do it; however, you manage to get it all done anyway.
- All of your clothes are dirty, but you still find something to wear.
- You were really low on cash last month, so you budgeted wisely to make what you have last to the next pay check.

In industry, problems occur all of the time; therefore, problem solving tasks are common place.

- Technicians determine the cause of equipment failure and eliminate the cause. At the same time, they fix any problems created when the equipment failed.
- When the product being manufactured is defective, technicians, operators and engineers work together to find the cause of the defects and then prevent them from happening again.
- Computer technicians identify and correct problems with their customers' computers.
- Mechanical assemblers work with supervisors and engineers to find ways to assemble the product faster and more efficiently.

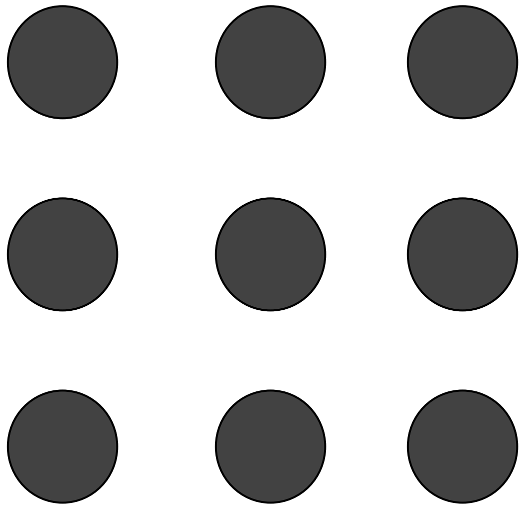
[Image of Plasma Etcher courtesy of the Manufacturing Technology Training Center (MTTC), University of New Mexico]

In all of these problem-solving tasks, people use a variety of tools to get the problem solved. Employers want all of their employees to have these tools and know how to use them. Employers also need new employees to bring skills such as problem-solving, teamwork, and communication with them when they get hired. Therefore, your chances of getting hired and being successful in a manufacturing field improve by developing these skills now. That is what this learning module will help you do.

Creativity

How creative are you? Let's see.

Connect the following set of nine dots with four straight lines without taking your pen or pencil up off of the paper.

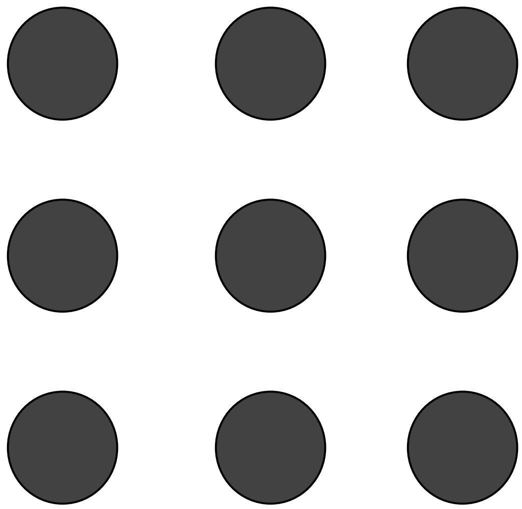


Did you do it? Are your lines straight lines? Did you have to pick your pen up at any point?

If you weren't able to do it, work with another person to see if together you can solve this puzzle.

Let's try it again, but with only three straight lines.

Again, do not lift your pen or pencil off of the paper and connect these nine dots with THREE STRAIGHT lines.



Did you do it? If not, maybe you aren't "thinking outside the box". Try again and this time, remember that there are only 2 rules – three straight lines and don't pick up your pen from the paper.

If you had difficulty solving these puzzles, what were some of your constraints?

Creative problem-solving encourages new ways of thinking, new ways of getting the problem solved. Your own creativity can be enhanced when working with others, because we tend to impose unnecessary limitations on ourselves when solving problem.   We need to learn how to identify "real" limitations and let the other ones go. For example, if you tried to solve the nine dots problems by staying within the perimeter formed by the dots, then you were working with a limitation imposed by you, and only you. That was not a limitation of the problem itself.

If you still haven't been able to solve the nine dots problems, try again. This time, "think outside of the box", outside of the perimeter defined by the nine dots.

SIX STEPS TO PROBLEM SOLVING

Creativity and being open-minded to solutions are two things that everyone needs to bring to a problem-solving table. Using these tools along with a systematic approach to solving problems can speed up the process and get the job done more efficiently and more effectively.

This module uses a Six Step Problem Solving process. Below are the six steps:

Recognize that a problem exists

Analyze the problem - Collect information

Identify possible causes (solutions) to the problem

Evaluate the possible causes (solutions)

Develop an action plan to correct the problem and take action

Verify that the problem has been corrected.

Each of these steps requires an open-mind and a creative mind. In addition, in the workplace especially, each step requires teamwork and effective communication between team members as well as those outside of the problem-solving team. Let's look at each step in detail.

Step 1: RECOGNIZE THAT A PROBLEM EXISTS

In order to recognize that a problem exists, you must have some "knowledge" of the situation, the job, the equipment, the product. It is possible to know so little, that you do not know that there is a problem to begin with. Gaining knowledge about your job helps you to "recognize" –
"***Hey, we have a PROBLEM!***"

Become an information addict. Ask questions. Learn everything you can. When you are put into a situation that you don't understand ASK QUESTIONS. Get enough information to work safely and correctly.

Here's what can happen when you don't have enough information.

Jake and Junior like to hunt. Hearing about the moose up north, they went to the wilds of Canada to hunt. They had hunted for a week, and each had bagged a huge moose. When their pilot landed on the lake to take them out of the wilderness, he saw their gear and the two moose. He said, "I can't fly out of here with you, your gear and both moose."

"Why not?" Jake asked.

"Because the load will be too heavy. The plane won't be able to take off."

They argued for a few minutes, and then Junior said, "I don't understand. Last year, each of us had a moose, and the pilot loaded everything."

"Well," said the pilot, "I guess if you did it last year, I can do it, too."

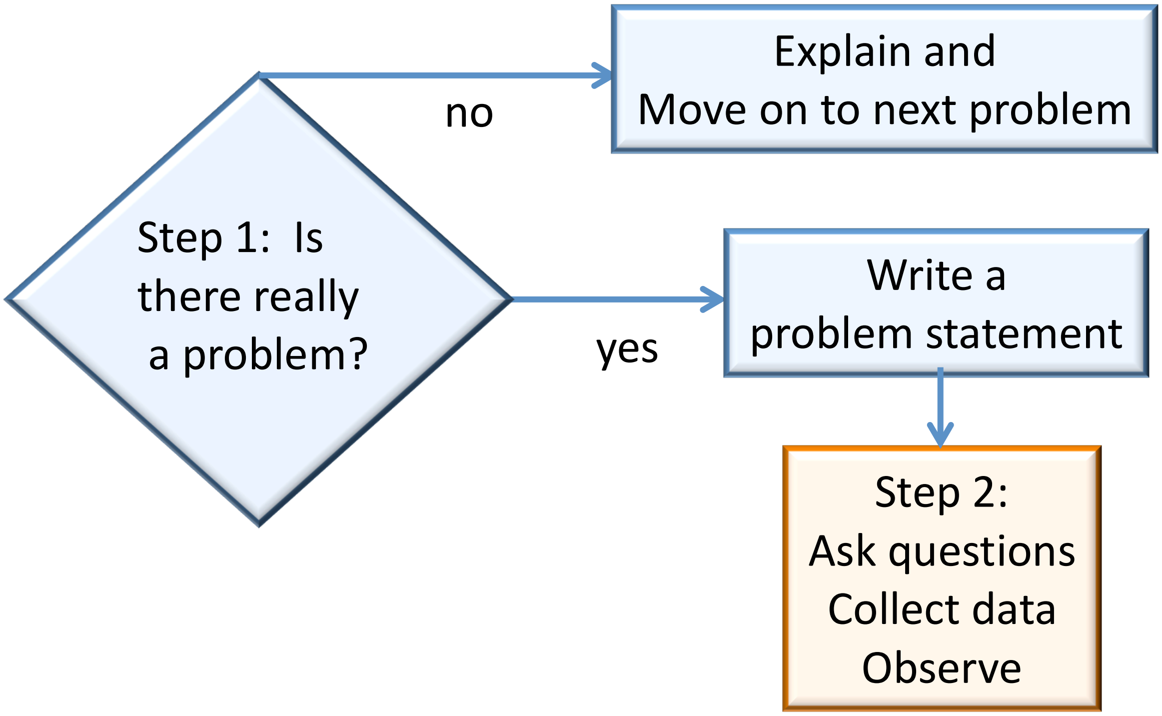
So they loaded the plane. It moved slowly across the lake and rose toward the mountain ahead. Alas, it was too heavy and crashed into the mountain side. No one was hurt, and as they crawled out of the wreckage, Jake asked, "Where are we?"

Junior surveyed the scene and answered, "Oh, about a mile farther than we got last year."

--from a speech by Carl Wayne Hensley, Professor of Speech Communication, Bethel College.

Do you think the pilot should have gotten “a little” more information before taking off?

Step 1: Recognize that a problem exists



1. A problem exists when there is a deviation from the standard for which the cause is not known. Examples:
   a. My car is making a noise that I've never heard before.
   b. An unacceptable amount of finished product is defective.
   c. The uniformity of photoresist on the process wafer is "out of control", beyond the acceptable control limits.
2. To recognize a problem, ask,
   a. "Is it doing what it should be doing?"
   b. "Is the outcome the correct outcome?"

   In order to answer these questions, people who work in a manufacturing environment should know the equipment, the product, and the process - what it sounds like, looks like, smells like, and feels like. The more one knows, the better problem solver one becomes.
3. Once it is recognized that a problem exists, write a problem statement that states exactly what is affected, what is wrong, and the extent of the problem (the degree of deviation from accepted performance levels.)
4. If working with others, everyone must agree on what the problem is and agree with the problem statement.

Examples of Problem Statements:

a. My electricity will be out for at least 24 hours and I have at least $600 worth of food in the freezer that could thaw out. I need to keep the food from thawing.
b. (Microtechnology processing example) The photoresist uniformity data on the last batch of wafers is outside acceptable limits; therefore, the process needs to be halted and the uniformity problem corrected.
c. (Microtechnology processing example) Product yield (the per cent of good die) has dropped from 78% to 58% over the past month. Our lowest acceptable yield is 66%.

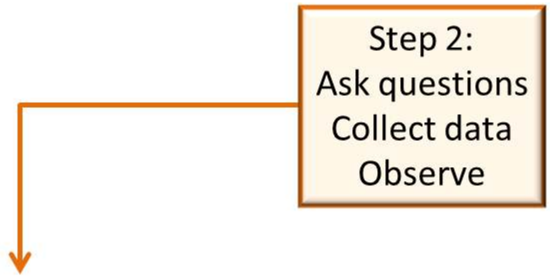
Step 2: ANALYZE THE PROBLEM

Situation: You go out one morning to leave for work and your car won't start. What is your immediately response / action? Do you start pulling out tools or calling a tow truck or do you start thinking about "why" it won't start?

Responses:

a. Time waster: If you start pulling out tools to start working on your car before you know the cause of the problem, you'll end of wasting a lot of time and could end up breaking something else. The cause of the problem could just be that you're out of gas and didn't know it.
b. Non-thinker: If you called a tow truck, then you're asking someone else to solve your problem. Again, you may just be out of gas and you're going to end up paying a mechanic a lot of money to tell you that. And don't forget the cost of the tow truck!
c. Problem-solver: If you immediately started thinking about "why" it won't start, then you have already started to "analyze the problem". You instinctively started the question and answer game with yourself.
    a. How old is the battery?
    b. Have I been having problems with the car starting or has it been starting easily each time?
    c. Has any maintenance been done recently?
    d. Do I have gas in the car? When did I fill up last?
    e. Has someone else been driving my car and let it run out gas?

Steps to Analyzing the Problem



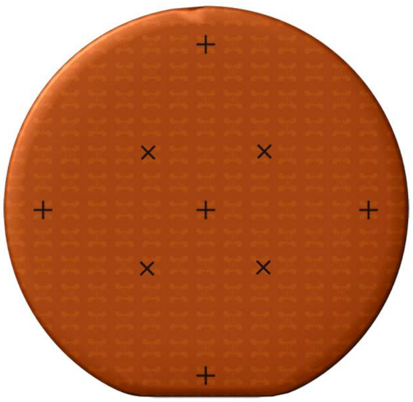
1. Determine the "degree of deviation" from the standard.
   a. How bad is it? (e.g., Is the uniformity problem with the photoresist bad enough that the wafers can't be processed?)
   b. What is the urgency of the problem? (e.g., Do I need to stop processing wafers altogether until the problem is fixed?)
2. Will the problem get worse if left unattended?
3. Is the problem worth the time and effort?
4. Are you **100%** sure that you know the cause of the problem?
   a. If so, then start thinking about "how" to fix it.
   b. If not, continue to analyze the problem.
5. Gather as many facts about the situation as possible.
   a. Take your time gathering information. This will save you time in the long run.
   b. Talk to anyone associated with the problem that can provide you with information.
   c. Collect any data associated with the problem (e.g., Statistical Process Control (SPC) charts, quality assurance data, maintenance records, shift passdowns)
   d. Re-enact the situation if possible. For example, if a piece of equipment is not working correctly, run the equipment yourself if possible.
   e. Location
      i. **Where** was the problem identified? **Who** identified the problem – the operator, quality assurance, the customer?
      ii. Where is the problem on the defective part? Determine exactly what the defect is and where it is on the defective part?
      iii. Where is the problem on the equipment? Locate the exact location of the problem if possible.
   f. Timing
      i. **When** did the problem start or when was it first noticed?
      ii. Is the problem continuous, sporadic or intermittent?
      iii. **How** often does the problem occur?
      iv. Is there a pattern?
   g. Degree
      i. **What** is the degree of deviation from the standard?
      ii. Are there any trends?
      iii. Is the problem static? (Can it get worse?)

iv. How severe can the problem become?
v. How fast can the problem worsen from its current state?
vi. Are there more than one "units" having the same problem?
vii. Is there more than one machine producing the same defects?
viii. How many defects are there?

h. Trouble Specifics
   i. Analyze the problem for **what IS** happening and, for every what "IS", determine **what "IS NOT".**
      (1) WHAT IS wrong with it? WHAT IS NOT wrong with it, but could be?
      (2) WHERE IS the defect on the part? WHERE could the defect be, but IS NOT?
      (3) WHEN was the problem first noticed? WHEN could the problem have been noticed but wasn't?
      (4) HOW MANY defective parts have been produced? HOW MANY defective parts COULD have been produced, but haven't?
      (5) HOW BIG is the problem? HOW BIG could the problem be, but isn't?
      (6) WHAT IS happening? WHAT could be happening, but isn't? What is NOT happening?
   ii. Look for CHANGE
      (1) **Problems occur when something has changed**.
         (a) A previous maintenance procedure
         (b) A new part installed
         (c) New materials being used
         (d) New employee
      (2) Where did the change take place?
      (3) When did the change take place?
      (4) What is there about the change that could have caused the problem?

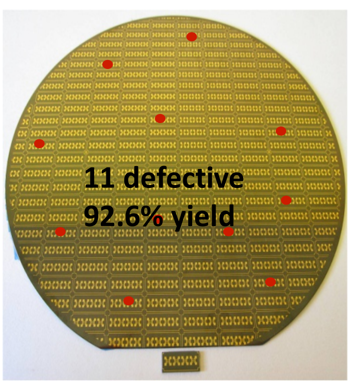
Take a moment and relate some of these questions to the two problem statements below. Be sure to read the information provided about "uniformity" and "product yield" so you can understand the problem better. Determine which of the "analyze the problem" questions you would ask and what kind of data you need to collect?

a. The photoresist uniformity data on the last batch of wafers is outside acceptable limits; therefore, the process needs to be halted and the uniformity problem corrected.



A photoresist uniformity test involves measuring the photoresist thickness at several points on the wafer, as shown in the left image with an "x" and "+". The range (thickest point – thinnest point) and the mean (sum of all measurements / # of measurements) are calculated. This data is then compared to what is acceptable to determine if the thickness is correct and uniform.

b. Product yield has dropped from 78% to 58% over the past month. Our lowest acceptable yield is 66%.



To determine product yield the percent yield is calculated for each batch of end product wafers. Using the wafer on the left as an example, there are 150 die, 11 of which are defective. Therefore, the yield for this wafer is 92.6% or (150-11)/150 *100. For the batch yield, the mean yield of the batch is calculated.

Can you see for manufacturing problems such as these, the more you know, the easier and faster it would be to solve these problem? If you aren't familiar with the photolithography process you are probably scratching your head right now saying "What?".

Step 3: IDENTIFY POSSIBLE CAUSES (SOLUTIONS)

By the time you reach step 3, you should know what the problem is and what the problem looks like. Now it's time to think about what may be causing the problem. Here's where being a creative thinker helps.

Many times the cause is obvious.

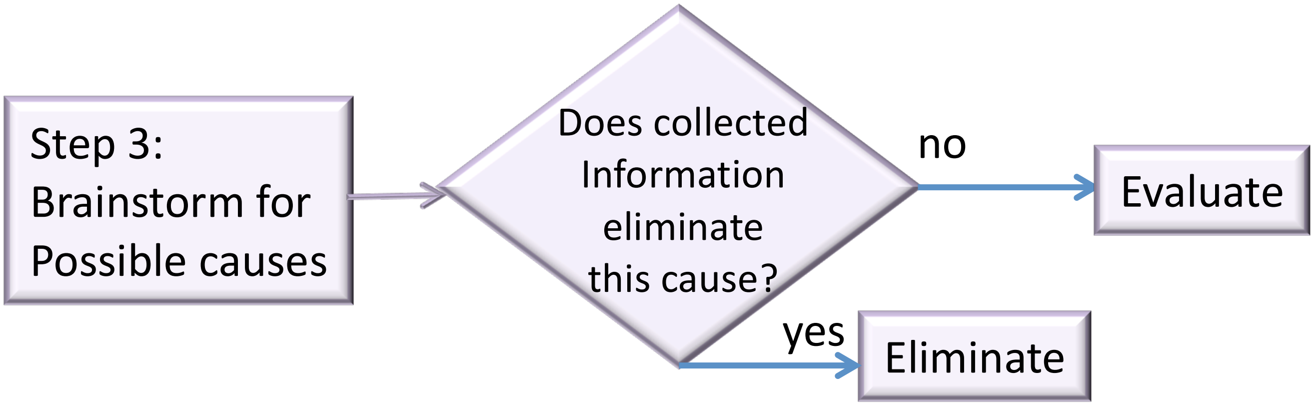
- The motor won't run. Cause: WHOOPS, it's not plugged in!
- The car won't start. Cause: OH NO, I'm out of gas.
- We lost vacuum to the equipment. Cause: The vacuum pump is off. (Of course, now you need to figure you why the vacuum pump is off.)
- The sale of Kleenex has suddenly dropped off. Cause: The allergy and cold seasons are over.

Then there are times when the cause it not so obvious.

- Employee absenteeism has steadily increased during the past 12 months.
- The car won't start and I know it has plenty of gas and the battery is only 6 months old.
- Photoresist uniformity has gradually been decreasing over the last six batches of wafers.
- Final product yield has dropped to unacceptable levels in just one month!

When the problem is not obvious, then BRAINSTORM and develop some possible causes (solutions) to the problem.

Brainstorming



Brainstorming is a method used by a two or more people to generate ideas and possibilities. The goal is to come up with as many ideas as possible, focusing on quantity, not quality. As a person throws out an idea, others can build on it. Group brainstorming sessions lead to more good ideas than an individual working alone. People piggyback off the ideas of others and ideas evolve as the group works its way through the process.

Once a list is created, the group evaluates it using everyone's combined knowledge and the collected data to identify the probable cause(s) of the problem. During the evaluation process, the team discusses the ideas and determines which ones are worth further investigation.

At this time, let's break away and practice brainstorming a couple of problems.

Complete the Brainstorming Activity.

Brainstorming is a great way to "identify possible causes" to a problem and, depending on the type of problem, possible solutions. As you saw in the activity, when working as a team you are able to come up with some causes that you, alone probably would not have thought of. Standard practice for a systematic approach to problem solving is to list ALL of the possible alternatives (causes) BEFORE making decisions.

In the second brainstorming activity, you developed a list of possible causes for "poor resist uniformity". Now it's time to EVALUATE your list using the information you could have gathered in Step 2: Analyze the Problem.

Step 4: EVALUATE THE POSSIBLE CAUSES

Before discussing this step of problem-solving, we're going to do another short activity.

Scrambled Cities

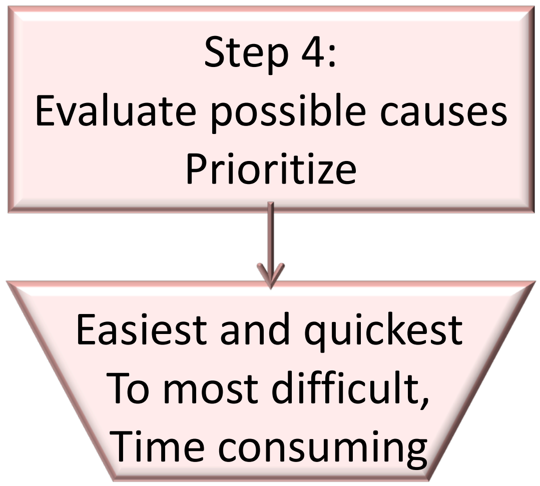
<u>Procedure:</u> Unscrambled each of the following to identify a city. (All cities are in the United States.)
Example: OIAPER is Peoria

1. REEDVN ________________
2. ITSUAN ________________
3. TEEATSL ________________
4. LE OASP ________________
5. WNE ALROESN ________________
6. SNA TANNOOI ________________
7. AKNSSA ITCY ________________
8. SOL SEELGNA ________________
9. REEDVN ________________
10. ACHIWTI ________________
11. XNOIEPH ________________
12. AAPTM ________________
13. ULTAS ________________
14. LE OASP ________________
15. THOUSNO ________________

<u>Questions:</u>

1. Did you get them all?
2. How did you go about solving this puzzle?
3. Did you eliminate duplicates first?
4. Did you go through and solve the easiest ones first, then go back and solve the harder ones?

If you saved the hardest ones for last, then you already have a good evaluation method going for you. Now you just need to apply this method to solving a problem.



When evaluating possible causes, you are developing probable solutions. Take the results of the second brainstorming session (Poor Resist Uniformity) and evaluate the items in your list.

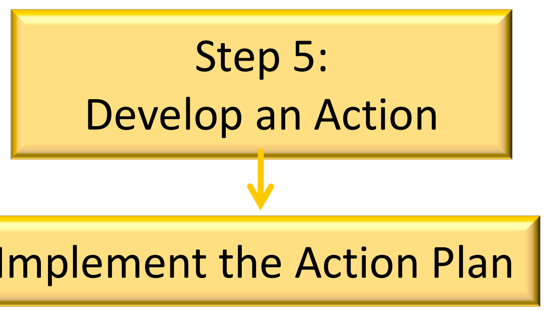
1. Eliminate duplication.
2. Eliminate those causes that have already been checked out or that you know couldn't cause the problem because of your knowledge of the process and equipment. *(In a real situation, you would also use the data that you collected in Step 2 to eliminate some of the possible causes as well as using the data to support an item on the list as a probable cause.)*
3. Once you have eliminated as much as you can, prioritize the possible causes from the easier and quickest to eliminate to the most difficult *(just like you probably did when you unscrambled the cities*).
4. Determine the methods and the processes to verify each of the remaining causes. A checklist can work well for this step. You'll also find that you problem need more data or more information.
5. Begin eliminating additional possible causes if you can.
6. The elimination of a cause requires asking more questions:
   a) How could this have caused the problem?
   b) Would it account for everything that IS and IS NOT happening?
   c) Would this have caused the full extent of the problem?
   d) Does this correlate to the discovery of the problem?
   e) Would this explain everything that is happening?

Step 5: DEVELOP AN ACTION PLAN TO CORRECT THE PROBLEM AND TAKE ACTION

At this point in the problem solving process, there should be only 2 – 3 possible causes that stand out as the most probable solutions to the problem. Go for the solution that gets the most done with the fewest adverse consequences – the Most Probable Cause. Ask some more questions:

- How much time is required?
- How much money is needed?
- How much manpower is needed?
- Do we need additional information?
- Do we need to involve others and if so, who?
- Is there an easier way?
- Do we need to step back to see if something else is "causing" the "cause" of our problem?
- Which solution will "fix" the problem?
- Will the "fix" be permanent or temporary?

If possible, divide up the tasks necessary to test out the probable causes.



Develop an action plan. A good action plan serves you in much the same way a road map serves a traveler - it's your game plan. A good action plan includes the following:

a. The steps or actions required
b. The sequence in which these should be carried out
c. The responsibilities of the various people involved
d. Time requirements
e. Tools and equipment needed
f. The provisions for follow-up and control
g. Methods for communicating the plan and the results

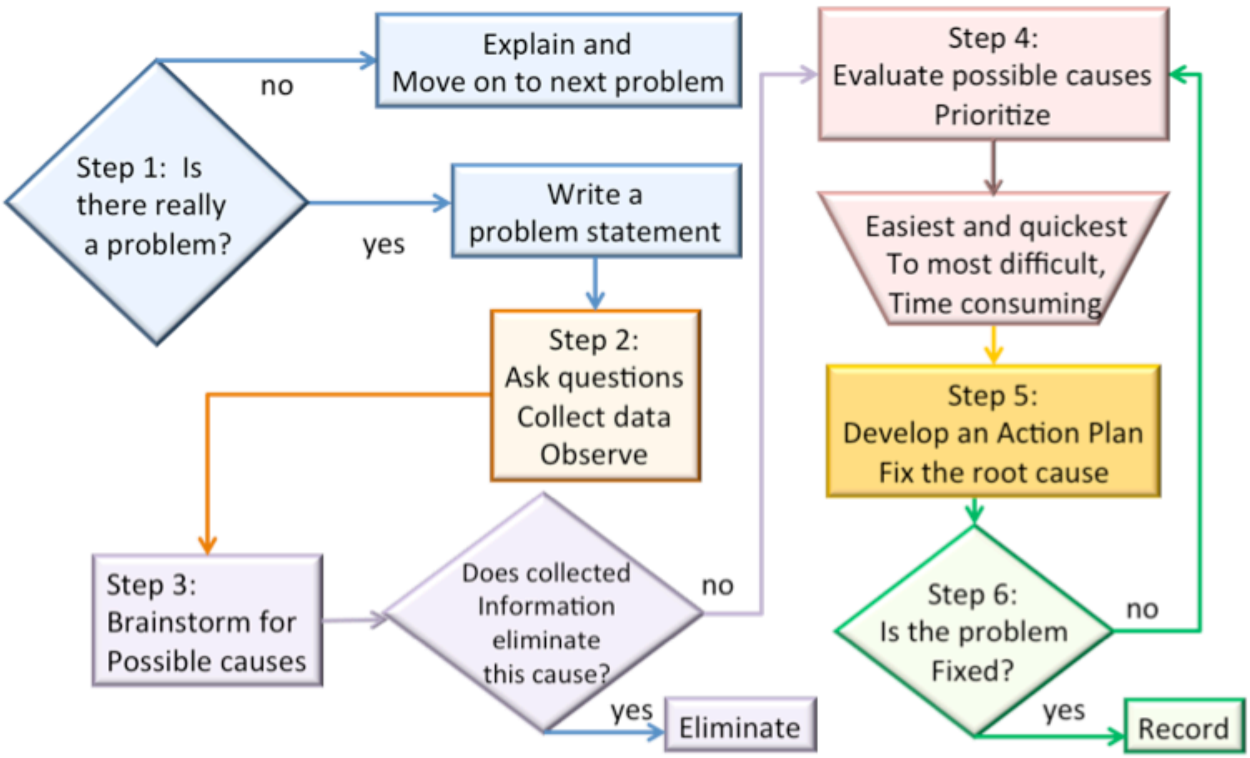
Before taking action you need to show the action plan to those directly and indirectly affected. Be ready to answer questions from your supervisor in order to support your plan. Here are some examples of questions a supervisor might ask:

- What is the reason for the decision?
- Whom will it affect and how?
- What benefits are expected for individuals, for departments and for the company?
- Specifically, what is each person's role?
- What adjustments will be required in terms of how the work will be done?
- When does the action go into effect?

By answering such questions, you can head off many problems that could slow down implementation of your plan. By letting people know what is happening, you are less likely to get resistance and more likely to get assistance.

Step 6: VERIFY THAT THE PROBLEM HAS BEEN CORRECTED

1. Once the solution has been implemented, the results should be evaluated for the effectiveness of the most probable cause. This evaluation should take place several times to ensure that the problem doesn't return.
2. Problems have been corrected if they do not reoccur.
3. If the problem reoccurs, then it did not get fixed. Evaluate WHY and attack the problem again.



Types of Problems

Problems can be classified into two types, well-structured and ill-structured. Well-structured problems are problems that have a simple and well-defined solution. In most cases, there is only one solution and the problem can be solved quickly and easily. An example of a well-structured problem is when your car won't start and the best possible causes are that your battery is dead or that you ran out of gas. If your car won't start and the cause is neither, then you have to look into your problem further. Perhaps your starter is shot, but that will take some more investigation, now making your problem less simple and more difficult to solve. This leads us into ill-structured problems.

Ill-structured problems are problems that cannot be solved quickly and easily, and do not have an obvious cause. Ill-structured problems can also be problems that have more than one root cause or two things contributing to the problem. In either case, there are usually numerous possible causes to an ill-structured problem thus requiring a systemic approach to solving the problem.

Well-Structured Problems

Let's look into well-structured problems a little further, looking at some problems that are relevant to microsystems. To the right is a spin coat chamber for applying photoresist to the surface of a wafer. The wafer sits on a wafer chuck through which a vacuum is applied. The vacuum holds the wafer on the surface of the chuck keeping it from flying off during the spin coat process. Our problem: There has been a loss of vacuum to the wafer chuck in a spin coat chamber.

There are two things that an experienced technician would quickly check to see if one could be the cause of the problem.

- Is the vacuum pump on?
- Is there a kink in the vacuum hose to the chamber?

These are obvious possible causes to the problem and fairly simple to solve if one proves to be true. In many cases an experienced technician can identify the cause of a well-structured problem pretty quickly because it has been seen before, it has happened before, or something very similar has happened on another machine. If a problem can be solved quickly and easily, it is a well-structured problem.

Ill-Structured Problems

Ill-structured problems are problems that can't be solved quickly and easily and do not have an obvious cause or in some cases, only one cause. Here are some examples of an ill-structured problem.

- The yield or number of good die per wafer has been steadily decreasing over the past two weeks.
- The gas mileage on your car has been steadily decreasing over the past year.
- During the past year our on-time delivery rate has gone from 98% to a 65%.
- Particle counts on the wafers have slowly been increasing over the past 4 weeks.

Notice the difference between well-structured and ill-structured problems? Well-structured problems usually happen suddenly. Things are working fine, then they aren't. In the particle count example, if the particle count increased suddenly rather than over a 4 week period, then it was probably due a recent "event" that could be quickly identified and corrected. This is well-structured. In the example where the particle count gradually increases over a 4 week period, the cause of the problem is not easily seen, and thus we have an ill-structured problem. Ill-structured problems appear over time and are not identified until the problem is already out of control.

Problem Solving vs. Troubleshooting

At this point, you may have asked the question "what is the difference is between problem solving and troubleshooting?" Well, not a whole lot. Sometimes these terms are even interchangeable, but the difference comes with the type of problem you are solving, a well-structured, or an ill-structured.

Troubleshooting is normally what a technician does with well-structured problems. If the cause is an obvious one, then it can be fixed and you can move on. Trouble shooting requires critical thinking and quite a bit of knowledge and experience on the job. Such skills are developed over time through the experiences of doing your job and solving problems as they occur.

Problem solving is engaged when troubleshooting or the quick-fix doesn't work. Problem solving is used when the cause of the problem isn't obvious or there may be many possible causes. Problem solving is used to solve ill-structured problems and requires critical and creative thinking because there is no quick fix to ill-structured problems.

Summary

The six-step process described in this learning module may seem cumbersome to you right now, but in a manufacturing environment, when a problem like "Poor Resist Uniformity" comes up, you'll find that it works! With enough practice, you'll start applying these steps out of habit because you have found that, in the long run, they save time and money. Also, the information you gather helps to justify any actions that may require a complete shutdown of the equipment or the line, or the purchase of new equipment.