Finding the Root Cause Of Process Upsets

George Buckbee, P.E.
ExperTune, Inc.

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Summary
Today’s process plant is a complicated place. Multiple raw materials combine with multiple energy streams to produce primary and secondary products. Process variability comes from the raw materials, operating practices, weather, process upsets, maintenance issues, and hundreds of other sources. Finding the root cause of a process, quality, or cost issue can be extremely difficult.

Why Root Cause is So Important
Finding the root cause of a process upset is critically important to permanently solving process upsets. Trying to tune all the affected control loops is simply chasing after symptoms, rather than getting to the heart of the issue.

Furthermore, solving the root cause issue saves both time and money. It is common to see a single root-cause issue affecting 10 or more additional control loops in a plant. By focusing the effort in the right place, you can actually reduce the workload by a factor of 10. No need to fix 10 control loops, just fix the one root cause.

In process plants, there are two types of upsets that we must address:

1. Cyclical Upsets
2. Step, Ramp, and Random Upsets

These have very different causes, and different solutions.

Overview
Process Upsets
Modern process plants are dynamic places. There are countless efforts to minimize variation on a process plant, including:

- Rigorous specifications and testing for incoming raw materials.
- Process controls
- Equipment qualification and commissioning
- Quality sampling and controls
- Standard Operating Procedures (SOPs) or Best Practices.
- Operator training
Yet, variation enters the process in a variety of ways. The weather changes, operators make different choices, and equipment degrades or fails. Batch operations can create cyclical upsets. Raw materials vary within their specifications, and conflicting management directives forces operations to make tough decisions. These incoming variations are the source of many upsets, and will be examined later in this paper.

**Interactions**

Within a single unit operation, it is well known that many variables are inter-dependent. Change the feed rate to a distillation column, and you will upset the temperatures, flow rates, heat and cooling demand, purity, yield, and efficiency. Make an adjustment to temperature, and you will again see changes in pressures, flows, purity, yield, and efficiency. Each variable is inter-dependent on the others.

Beyond a single unit operation, there are many interactions between units. These interactions stem from many factors, including:

- Feeding materials to other units
- Sharing or competing for common utilities
- Recycling materials
- Heat recovery between units

An upset that starts in one area of the plant will quickly spread into other related areas. What started as a single oscillating controller can become a plant-wide upset, with major impact on cost, quality, and stability.

**Cyclical Upsets**

**The Source of Cyclical Upsets**

Cyclical upsets, or oscillations, can come from a variety of sources, including:

- Sticking control valves
- Poor controller tuning
- Process recycle streams
- Scheduled repeating operations, including batch cycles
- 24-hour day/night cycle

Cyclical upsets may be sinusoidal, or they may have other wave shapes.

The key to solving cyclical upsets is determining the period of oscillation. Keep in mind that all process upsets that share a common cyclical root cause will be oscillating at the same period.

**Measuring Cyclical Upsets**

To solve cyclical problems, it is important to measure several key parameters. This includes:
• Magnitude of oscillation
• Period(s) of oscillation
• Strength of oscillation (as a percent of loop variation)
• Shape of the oscillation

For each control loop, the shape of the oscillation, and a little bit of logic, can be used to determine whether the oscillation came from poor tuning, a faulty control valve, or some other control loop. We will call this the Oscillation Type.

According to Fourier’s theory, any periodic signal can be broken down into its component frequencies, as shown in Equation (1).

\[
f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)]
\]

The individual coefficients a and b can be found from equations (2) and (3)

\[
a_n = \frac{\omega}{\pi} \int_{0}^{2\pi} f(t) \cos(n\omega t) dt
\]

\[
b_n = \frac{\omega}{\pi} \int_{0}^{2\pi} f(t) \sin(n\omega t) dt
\]

Modern computers can crunch through these numbers with ease. Simply look for the largest coefficients to find the highest frequencies. These are in fact, measured and reported with PlantTriage control loop monitoring software, as shown in Figure 1.
**Figure 1. Automatic Identification of Period and Strength of Oscillations**

**Solving the Root Cause of Cyclical Upsets**

When you have measured the cyclical upsets for all loops in a plant, solving for the root cause becomes fairly straightforward:

1. Develop a list of all loops that are cycling, along with their period, strength, and oscillation type.

2. Sort the list by Oscillation Period, as shown in Figure 2. All the related loops are now shown together. All loops within 10% oscillation period can be assumed to be oscillating at the same period.

3. Within the group of related loops, most will show oscillation type of “Osc-Load”. The root cause loop will show a high value for “Osc-Tuning” or “Osc-Valve”. You can also apply some process knowledge to identify the control loop that is furthest up-stream in your plant.

![Figure 2. Find Root Cause when Sorted by Period of Oscillations](image)

With this information, you now know which loop is likely to be the root cause, and whether you are facing a valve or a tuning issue.

### Step, Ramp, and Random Upsets

**The Source of Step, Ramp, and Random Upsets**

Some upsets occurs as a step or ramp. Examples include:
• Start-Up of a unit operation
• Shut-Down of a unit operation
• Change in raw materials
• Change in production rate
• Change in product code
• Blow-down of a boiler

These events tend to occur at odd intervals. They do not repeat on a regular basis. To find the source of the upset, we will need to correlate data over a long time period, looking for the first sign of an upset.

**Measuring Step, Ramp, and Random Upsets**

There are thousands of these upsets in a plant on a daily basis. Some are large, some small. Some occur in tucked-away corners of the plant. Combine this chaos with some random noise, and it would seem an impossible task to ferret out the root cause.

Lucky for us, we live in an age of inexpensive computing power. One way to identify process interactions is to perform a correlation study using an extensive set of data. If we correlate each control loop in the plant against all others, we should see some patterns begin to appear. Figure 3 shows a cross-correlation analysis comparing two variables. The peaks indicate strong correlation, and the left-right shift indicates the lead/lag time.

![Figure 3. Cross-Correlation of Two Variables](image)

**Solving the Root Cause of Step, Ramp, and Random Upsets**

Performing a cross-correlation analysis for every combination of control loops in a plant seems like a daunting task! There will be thousands of combinations, millions upon
millions of calculations. How to process all this information, analyze it, and determine results?

In the PlantTriage software, a complete correlation analysis is completed. The single largest correlation peak is identified, and represented by a color in the “Interaction Hot Spots” chart, as shown in Figure 4. The strongest interactions (correlations) are shown as bright red spots.

On the chart you see many loops in a row that are related/correlated. The key to solving for root cause is to see the lead/lag factor for each interaction. The root cause will be the leading interaction. A “Process Interaction Map”, shown in Figure 5, clearly shows which loops lead, and which loops lag. Note that the root cause will always be one that “leads” the others…it happens first.
The Process Interaction Map shows lead/lag time as the left-right axis. So the root cause is a strong-colored block on the right. This approach immediately shows the most likely root cause of a process upset.

Further drill-down to show the PV Trends of related variables can confirm the interaction, as is shown in Figure 6.

**Figure 5. A Process Interaction Map shows root causes on the right side.**

**Figure 6. A trend showing two closely correlated variables.**

**Case Study**

**Background**

A plastics plant in Alabama experienced wide swings in a key hydrogen flow rate. The upset was near the finishing end of the plant. Loop tuning was not effective for this problem.
**Interactions**

Using the Process Interaction Map, the plant engineer determined the source of the upset to be the cooling tower, located almost a half mile away. While he found this surprising, he investigated the problem. He discovered that the cooling tower upsets were caused by a problem with the temperature control strategy.

The tower was controlled by two variable-speed fans. When tower load was low, one fan shut off. As load picked up again, the second fan came back on. The upset caused by the fan on/off cycle was significant. Furthermore, it upset the chilled water temperature throughout the entire plant.

**Results**

**Hydrogen swings** were eliminated using PlantTriage’s Process Interaction Map (PIM). The PIM correctly identified the source of the problem as a cooling tower temperature controller. By changing the temperature control strategy, the hydrogen was stabilized, and there was a reduction in nuisance process alarms throughout the plant.

The engineer says “By tightening this upstream control and optimizing the hydrogen process we are able to save over $1 million per year in energy consumption.” Of course, the added stability help both operations and quality results as well.
Summary of Experiences

Finding process interactions is greatly simplified through the use of modern tools and techniques. Many plants worldwide have used these techniques, with some surprising results. A few key findings are worth noting here:

1. The causes of many process problems have gone undetected for years. It was simply assumed that upsets were a natural part of operation.

2. The root cause of problems is rarely obvious. Engineers often report a degree of surprise when finding that they have been working on symptoms, not root cause, for many years.

3. Common utility systems are very often the source of process upsets. It is very important to include steam, water, air, and other common utility operations in the interaction analysis.

Conclusions

1. Process plants are complex, interacting facilities.

2. Process upsets come from cyclical and non-cyclical sources.

3. Cyclical sources of upset can be characterized by oscillation strength, period, and waveform. These characteristics can be used to pinpoint the root cause of the upset.

4. The source of non-cyclical upsets can be determined through large-scale correlation studies, which are graphically displayed as process interaction maps and interaction hot spots charts.

5. The potential for savings is quite large. In many plants, solving a single problem can result in millions of dollars in annual revenue.
About the Author

George Buckbee is V.P. of Marketing and Product Development at ExperTune. George has over 20 years of practical experience improving process performance in a wide array of process industries. An experienced manager and instructor, George holds a B.S. in Chemical Engineering from Washington University, and an M.S. in Chemical Engineering from the University of California.

About PlantTriage®

PlantTriage is Control Loop Performance Monitoring software that optimizes your entire process control system, including instrumentation, controllers, and control valves. Using advanced techniques, such as Active Model Capture Technology, PlantTriage can identify, diagnose, and prioritize improvements to your process.