

# Realtime Metrics for Process Performance

**By focusing on realtime measures, plant operators can improve bottom-line results**

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Process performance, quality and reliability depend directly on how a plant performs in real time. Yet many plants track and respond only to longterm averages. By measuring and responding to realtime measures, you can ensure:

- Quick recovery from process upsets
- Fast change-over to another product
- Shortened batch-cycle times

Measuring and responding to the right dynamic measures will give you insight into the process, and help you to drive plant improvements.

Plants that use realtime metrics perform substantially better than plants that do not. According to the recently-released "Metrics That Matter" study [1], those who use plant dashboards were 37% more likely than others to improve against operations' key performance indicators (KPIs). These plants were also 53% more likely to improve bottomline business metrics by more than 1%.

## Criteria for realtime measures

Many plants tend to focus on statistical averages of performance, such as average cost, percent rejects, or percent uptime. These are excellent measures of process results, but in order to make improvements, we need to focus on realtime measures of performance. To be useful, these

measures should meet the following three criteria:

1. Meaningful
2. Measurable
3. Actionable

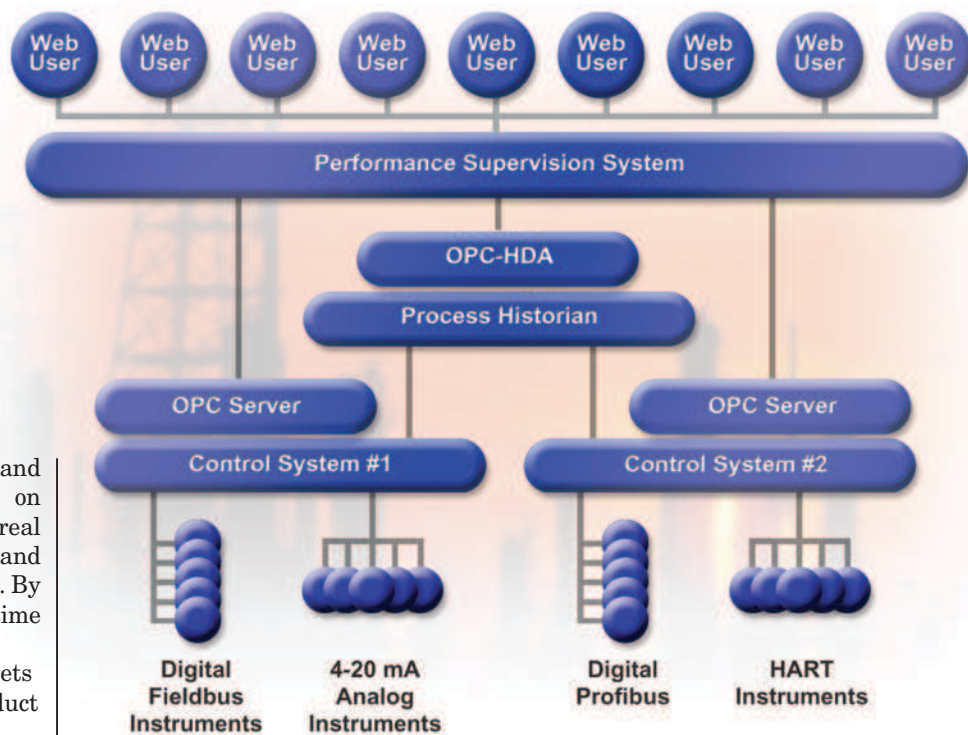
When a measure is actionable, it helps to lead you directly to a corrective action. The key to making process improvements is to measure the right things, and then to respond with the right corrective actions.

Some of the most common realtime measures that meet this criteria are presented in this article, along with a discussion on how these measures can be made available via a performance-supervision system (PSS). A PSS monitors realtime data, calculates performance metrics, presents the information using plant dashboards, and provides the tools needed to make performance improvements.

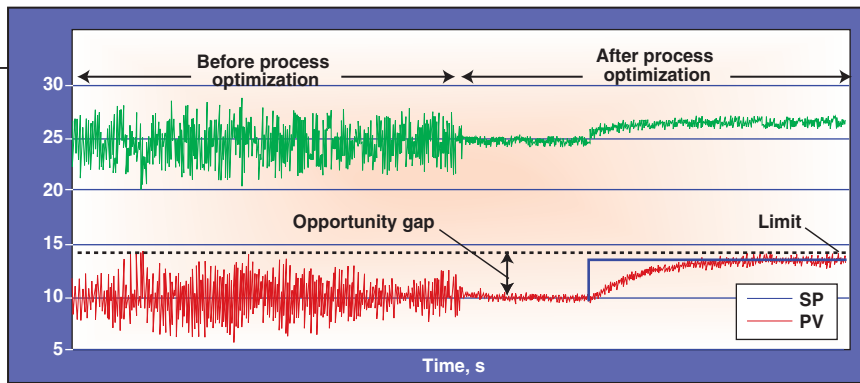
## How to get realtime data

With the advent of modern distributed control systems (DSCs) and open communications technologies, such as OLE for Process Control (OPC), today's process plant has access to a wealth of realtime information. A realtime PSS can crunch through all the raw data and develop meaningful realtime performance measures, the most important of which are described below.

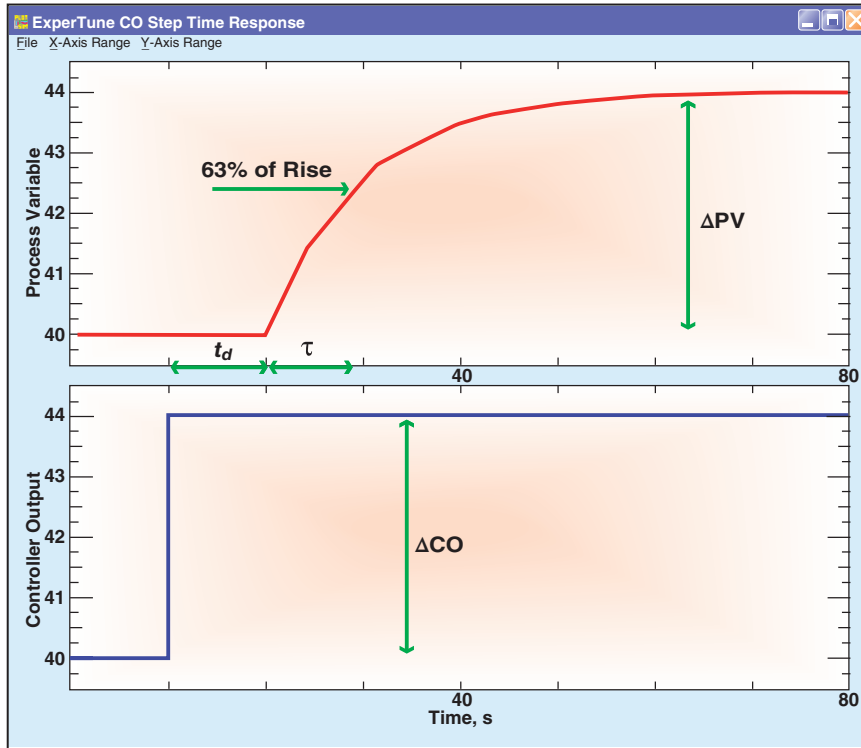
With a DCS or PLC control system, the process plant is already gathering realtime data from instruments throughout the plant. In fact, control systems have been doing this for years. More recently, control-system vendors have opened up their proprietary systems. OPC is a series of communications standards that provide open connectivity in indus-



**FIGURE 1.** How to bring realtime data from plant instrumentation into a performance-supervision system



**FIGURE 2.** In most processes, there is an economical incentive to shift operations toward one of the set points. Opportunity gap provides actionable measures



**FIGURE 3.** Shown here is a graphical technique that can be used for calculating a process model

trial automation systems. (See glossary, top right)

Once the data is available via OPC, it can be shared with:

- Other control systems
- Supervisory controls
- Realtime data historians
- Performance-supervision systems

Performance-supervision systems, in fact, will perform many of these calculations automatically, based on the available realtime data. Figure 1 shows how realtime data from plant instrumentation can be fed via OPC or historians into a PSS. For these systems, web-based plant dashboards can make the data accessible to users throughout the plant or even the corporation.

The remainder of this article focuses on how to calculate a number of realtime performance measures.

### Basic measures

**Standard deviation.** The standard deviation is a basic statistical measure of process performance. It is calculated over a period of time, from all the available data in that time period ( $x_i$ ) and the average value of the data ( $\bar{x}$ ), as shown in Equation (1).

$$\delta = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (1)$$

The standard deviation can provide some insight into the variability of the process. For example, trending standard deviation over time will help to identify changes in process variation. Standard deviation is often used to develop some interesting performance measures, as will be discussed below.

**Variance (regular and normal-**

## GLOSSARY

CO	Controller output
DCS	Distributed control system
OLE	Object linking & embedding: A Microsoft standard for communication between applications.
OPC	OLE for Process Control: A series of standards specifications for open connectivity in industrial automation
PLC	Programmable logic controller
PSS	Performance supervision system
PV	Process variable
SP	Set point

**ized).** Variance ( $V$ ) is defined as the square of the standard deviation ( $\delta$ ):

$$V = \delta^2 \quad (2)$$

Standard deviation and variance depend, of course, on the engineering units of the raw measurement. It would not make sense, for example, to compare the variance of a temperature measurement with that of a tank level. In fact, it can even be challenging to interpret the value of the regular variance.

In a control system, realtime process measurements are bound by both upper- and lower-range limits. The upper and lower process variables ( $PV$ ) can be used to convert variance to a normalized version ( $V_{normal}$ ), as shown in Equation (3).

$$V_{normal} = \frac{V(100)^2}{(PV_{hi} - PV_{lo})^2} \quad (3)$$

Normalized variance can be compared between sensors in the plant. In fact, if you sort all sensors in the plant according to normalized variance, you are likely to immediately find some poorly-performing sensors:

- Sensors with the highest normalized variance may indicate installation errors, poor wiring termination, or excessive manipulation of the control loop
- Sensors with very low normalized variance may be “flat-lined,” indicating a loss of communications, unintentional removal from service, or a failed sensor

### Process performance

Beyond the basic statistics, meaningful process information can be gathered from realtime data.

**$P_p$  and  $P_{pk}$ .**  $P_p$  and  $P_{pk}$  are statistical measures of process capability. In effect,  $P_p$  and  $P_{pk}$  measure the ratio of the process specifications to the demonstrated capability of the pro-

cess. Process-specification limits can be given as  $USL$  (upper specification limit) and  $LSL$  (lower specification limit). Equation (4) demonstrates the calculation of  $P_p$ .

$$P_p = \frac{(USL - LSL)}{6\delta} \quad (4)$$

$P_{pk}$  is a better measure when the process is not centered between the specification limits. Equations (5–7) demonstrate how to calculate  $P_{pk}$ .

$$P_{pl} = \frac{(\bar{x} - LSL)}{3\delta} \quad (5)$$

$$P_p = \frac{(USL - \bar{x})}{3\delta} \quad (6)$$

$$P_{pk} = \text{Min}(P_{pl}, P_{pu}) \quad (7)$$

When  $P_p$  and  $P_{pk}$  are greater than 1, the process is capable of meeting the specification. Values less than 1 indicate that the process has so much variability that it cannot be expected to meet specifications.

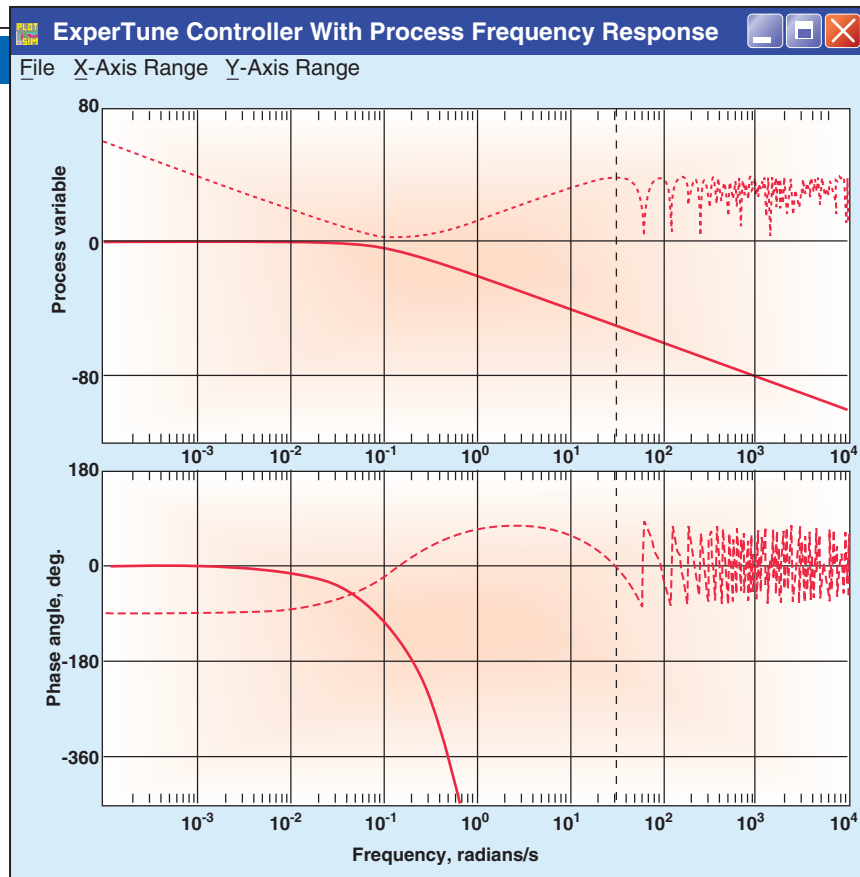
## Opportunity gap

The *opportunity gap* takes  $P_p$  and  $P_{pk}$  one step further. In most processes, there is an economic incentive to shift process operations toward one of the specification limits. In drying systems, for example, energy is saved by operating as close to the upper moisture specification as possible. This is sometimes referred to as “crowding the spec,” and it is **one of the fastest ways to save money in a process plant**.

Opportunity gap provides an *actionable* measure. Basically, it recommends a setpoint adjustment that will move the process closer to the spec limit. Figure 2 shows how the opportunity gap is calculated.

**Savings with opportunity gap.** Opportunity gap saves money directly. When the operator closes the opportunity gap, the plant starts saving money instantly. As a practical matter, it is usually simple to calculate the savings potential from opportunity gap.

For the most important process quality variables, operating departments are well aware of the value of incremental improvement. For example, a paper mill will likely know the value of a 1% moisture shift. An example of



**FIGURE 4.** Frequency-domain model shows the controller response to a range of frequencies

this calculation is shown below, for a typical drying operation.

$$\text{SavingsRate} = \frac{\$883/\text{hour}}{\% \text{Moisture}} \quad (8)$$

$$\text{Savings/day} = \text{OppGap} \times \text{SavingsRate} \times 24 \frac{\text{hours}}{\text{day}} \quad (9)$$

With an Opportunity Gap of only 0.5% moisture, making the setpoint change is worth over \$10,000/d, in reduced energy costs.

## Oscillation detection

Oscillations of a process variable create many problems in process plants. They propagate throughout the plant, increasing variability, increasing energy costs, and destabilizing many operations. In a recent study, we have found that it is typical for 20–40% of control loops to be oscillating.

Detecting and eliminating oscillations in real time will help to drive the plant to its peak performance. Imagine the difference between driving a car down the highway at a steady speed, versus driving while cycling pressure on the accelerator. While the car may average the same speed, its fuel efficiency is much better without the oscillation.

## Fourier analysis finds the cycles.

According to Fourier’s theory, any periodic signal can be broken down into its component frequencies, as shown in Equation (10).

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)] \quad (10)$$

The individual coefficients  $a$  and  $b$  can be found from Equations (11) and (12)

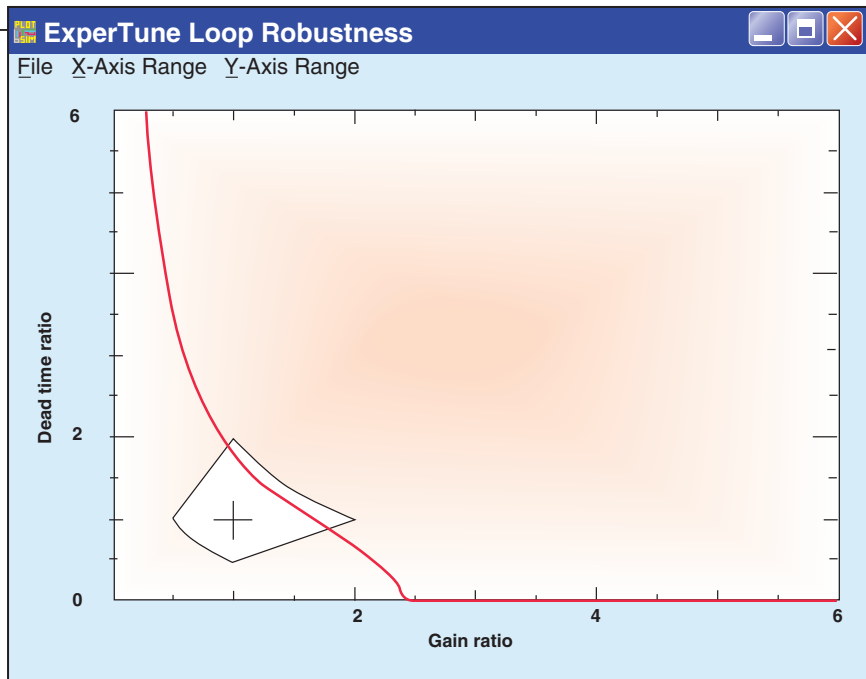
$$a_n = \frac{\omega}{\pi} \int_0^{\frac{2\pi}{\omega}} f(t) \cos(n\omega t) dt \quad (11)$$

$$b_n = \frac{\omega}{\pi} \int_0^{\frac{2\pi}{\omega}} f(t) \sin(n\omega t) dt \quad (12)$$

Luckily, modern PSS systems can crunch through these numbers with ease. Simply look for the largest coefficients to find the highest frequencies.

**Sources of oscillation.** All loops that oscillate at the same frequency are probably oscillating due to a common cause. Sort all the loops in your plant by oscillation period, and you will quickly see which ones are interacting, and which are not.

Start upstream in the process. Look



**FIGURE 5.** A robustness plot helps to design a stable controller, based on a process model

for loops that oscillate at the same frequency in the upstream process. It is very common to see a boiler loop, for example, driving an oscillation through an entire refinery.

Another way to isolate the root cause of an oscillation is to open the control loop. If the oscillation disappears when the loop is put in manual, then you have found the root cause. If the oscillation remains when the loop is in manual, then you should continue looking upstream.

### Controller performance

There are countless ways to measure the performance of process controls. Some of the most common performance metrics are shown in this section.

**Integral of absolute error (IAE).** This classical measure of control performance will tell you how well the process variable tracks to the setpoint. This calculation is quite useful for comparing the results of different control strategies on a single control loop. The basic relation for *IAE* is shown in Equation (13).

$$IAE = \int_0^{\infty} |(SP - PV)| dt \quad (13)$$

To be practical, we can't integrate to infinity, so we typically integrate over a fixed period of time for comparisons.

*IAE* is affected by many other factors, such as number and size of setpoint changes, and load upsets. When comparing *IAE* or other control perfor-

mance measures, you should be sure to compare under very similar conditions.

**Harris index.** The Harris index,  $I_H$ , is used to compare the performance of your controller ( $\sigma_{act}$ ) to the "best possible" feedback control, otherwise known as Minimum-Variance control. Calculation of the Harris index is shown in Equation (14)

$$I_H = \frac{\sigma_{act}^2}{\sigma_{MinVar}^2} \quad (14)$$

A Harris index close to 1 means the controller is performing very well, and a large Harris index indicates opportunity to improve the control.

### Dynamic process models

In the past, process models were calculated using offline graphical techniques. Figure 3 shows a graphical technique for calculating a first-order, plus time delay model. Three model parameters are calculated: dead time ( $t_d$ ), process gain ( $G_p$ ) and time constant ( $\tau$ ).

To use the graphical technique, gather process-variable and controller-output (*CO*) data from your control system, using a step test. The dead-time is determined by inspection. For a first-order, plus time delay system, calculate the values for process gain and dead time as shown in Equations (15) and (16).

$$G_p = \frac{\Delta PV}{\Delta CO} \quad (15)$$

$$\tau = t \text{ at } 63\% \text{ rise} \quad (16)$$

Higher-order models require more complex approaches.

The modern approach, using techniques such as Active-Model-Capture technology, uses software to automatically capture process-bump data, determine the form of the model, calculate the model parameters, and validate the results.

### Frequency-domain models

For even more capability, a frequency-domain model can be generated. This will allow you, for example, to identify resonant frequencies for the closed-loop system. This information can help to coordinate responses among controllers. For example, coordinated responses are required to ensure the success of cascade, ratio, and feedforward loops. An example of a frequency-domain model is shown in Figure 4.

### Robustness

Robustness is a measure of how well a control loop will respond under changing process conditions. One way to measure robustness is using a robustness plot, as shown in Figure 5.

In a robustness plot, the controller tuning is represented by a line on the chart. The process model is shown by the cross-hair at the bottom left. Different sets of controller tuning will draw different lines. As the tuning line approaches the cross-hairs, the control becomes oscillatory, and eventually will become unstable.

When model dynamics are automatically determined by Active Model Capture, robustness calculations can be done in real time. Control engineers can be immediately notified of any stability or control issues.

### Expertise built into metrics

With the trend of reduced internal personnel, there is a need for more and more expertise to be built into automated systems. A modern PSS will incorporate dozens of years of engineering expertise into its software.

With this embedded expertise, junior engineers increase their capability. Senior engineers quickly drill into the critical process information,

greatly reducing the time required for data collection, analysis and review. This helps to keep engineers and technicians at all levels focused on the value-added work of performance improvement.

### Metrics deliver results

Process improvement, variability reduction, and savings go hand-in-hand. This has been proven time and again throughout the process industries. A few examples of this include:

- Kruger Paper saved over \$1,000,000 using a PSS for its realtime diagnostics during a new process startup
- Columbian Chemicals, producer of chemicals such as carbon black, has saved over \$1,000,000 in energy costs. Columbian tracked realtime process performance to reduce product variability, save energy and increase production rates
- A U.S. cement plant saw a 16% pro-

duction increase by eliminating cycling problems

- An oil refinery in Asia improved annual profits by millions of dollars. Using the right metrics for robustness was key to their success

According to Larry Spickard, senior vice president of manufacturing at Columbian Chemicals, "The results and benefits are very important to our business. These are part of standard key operating metrics that we track at the senior management team of the company. They directly relate to our financials, and are really just part of the overall performance that we bring to our customers."

### Final remarks

Realtime metrics deliver substantial benefits to process plants. Meaningful, measurable, and actionable metrics are readily available in real time, using a performance supervision system. These performance metrics can

be used to uncover plant performance problems, to improve process control, and to drive continuous improvement. Using these metrics, plants can focus efforts and quickly get to the root cause of performance issues. ■

*Edited by Gerald Ondrey*

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