

Performance Assessment for Management

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INTRODUCTION

Assessing the performance of an entire plant is generally straightforward; this is not the case for assessing performance *within* a plant. For the plant as a whole, performance can be based upon profit, generally the revenue from product less the cost of raw materials, equipment, energy, and labor. Within the plant these data are often not available for intermediate products, unit operations, and individual equipment. Even if they were, the cause of non-optimal performance would not be apparent.

A continuous performance monitor can identify, down to individual equipment, areas that are under-performing and which of these will offer the greatest economic returns on corrective action. The performance monitor architecture generally includes a server grade PC, connectivity to the process control system, (e.g. OPC Server), and software. The software is the key component and must be able to continuously identify and sort cycling, tuning, hardware, and disturbance problems and weigh these factors and a variety of statistical measures to pinpoint the greatest contributors to economic loss in the plant. Performance trends and lists of control loops that exceed predetermined performance limits are typical outputs. These outputs pinpoint areas to focus on, optimizing work force efforts.

BENEFITS OF A PERFORMANCE MONITOR

The key benefits of a performance monitor are a more efficient plant and increased profit. These benefits are realised through improved equipment performance after corrective action based on the performance monitor outputs. Troubleshooting time is reduced. Problems that are difficult to uncover are more readily diagnosed. Engineering and maintenance resources are focused where they provide the biggest economic gains. Maintenance practices are refined. Increased process knowledge is also a

result and production engineers, staff engineers, area managers and maintenance forces share a common tool. This encourages communication across the plant. Another benefit is that the plant performance is benchmarked for continual improvement.

HOW TO USE A PERFORMANCE MONITOR

A continuous performance monitor uses real-time data from the process to determine how well the process is performing and what problems exist. It automatically combines many types of assessment measures (e.g. Variability, Harris Index, Integral Absolute Error, Time in Normal) into a single measure. The data used are from the temperatures, pressures, flows, levels, etc., from the process. In addition to standard statistical indicators for these process variables (PV), data from the regulatory loops (PID Controllers) is also used. These regulatory loops represent the handles to the process. Including these data provides additional assessments such as whether the loop is oscillating, how much time the loop is in normal mode (automatic, cascade, ratio), recognition of valve problems (e.g. hysteresis, stiction), whether the valve is working harder recently than it has in the past, and so forth.

ECONOMIC AVERAGE % TOWARD THRESHOLD

A measure of overall regulatory control performance is the **economic average % toward threshold**. This measure, as calculated below, shows if an individual loop is hurting your production. Averaging this measure for all loops in a unit operation determines which unit operation in the plant is the weakest performing unit. Averaging this measure for all loops in the plant provides an overall performance indicator for the entire plant. Track economic average % toward threshold over time to gauge improvement efforts.

The economic average % toward threshold is determined through the use of an average % toward threshold (%T). For each measure that is of importance to a particular loop's performance (choose one or more from Variance, Time in normal mode, Valve travel, Valve reversals, etc.), a % Toward Threshold is calculated:

$$\% \text{ Toward Threshold} = 100\% \left(\frac{\text{assessment} - \text{baseline}}{\text{threshold} - \text{baseline}} \right) \quad (1)$$

Where: % Toward Threshold = a measure for each assessment used to determine loop performance
Assessment = one of the measures chosen to determine performance (e.g. Variance)
Baseline = the target or ideal value of the assessment
Threshold = the upper or lower permissible value of the assessment

For example, Table 1 shows %T using Variance as a measure for temperature in a reactor.

TABLE 1: %T USING VARIANCE AS AN ASSESSMENT FOR REACTOR TEMPERATURE

Assessment Period	Assessment	Assessment Value	Baseline	Low Threshold	High Threshold	% Toward Threshold
1	Variance	2	1.8	0	2	100.00%
2	Variance	2.6	1.8	0	2	400.00%
3	Variance	4	1.8	0	2	1100.00%

The %Toward Threshold for the Variance is more useful than the absolute value of the Variance, since the absolute value is meaningless for comparison purposes between loops. A high value may indicate a critical problem for some loops, but the same high value may be normal for other loops. The %T measure takes into account the *normal and permissible operating conditions* of the loop. The further outside the permissible limit (high or low threshold), the higher the %T, and the more significant is the problem.

Variance may be just one of many important indications of performance for a loop. By averaging the %Toward Threshold for *all assessments* chosen from a large list (Variance, Time in normal mode, Valve travel, etc.), for a particular regulatory loop, we can obtain a snapshot of this loop's *overall performance*:

$$\text{Average \% Toward Threshold} = \sum_{n=1}^i (\% \text{ Toward Threshold}_i) \quad (2)$$

Where: Average % Toward Threshold = the average of all assessments chosen to measure loop performance
 % Toward Threshold_i is the %T for *each* assessment deemed important for that loop

However, average % toward threshold (%T) by itself does not take into account the relative importance of different loops. Some loops will be critical to your manufacturing process, whereas others will not be. To factor how much an individual loop impacts the process, two approaches could be taken: (1) set the thresholds used above wider on the less critical loops, or (2) use an economic weight factor. Setting the thresholds wider requires more thought and process understanding and would take more time. A simpler approach may be to weight the average % T display format into:

$$\text{Economic Average \% Toward Threshold} = \frac{\text{Average \%T}}{\text{Economic Significance Divisor}} \quad (3)$$

Where: Economic Average % Toward Threshold = a measure of the loop's performance, weighted for importance to the plant operation
 Average % T = the average % toward threshold for the loop, calculated in (2)
 Economic Significance Divisor = a value based on the loop's economic significance

A larger Economic Significance Divisor indicates that the loop is less critical to your production.

PERFORMANCE MEASURES

The assessments used to measure a loop's performance should be different depending upon the type of loop and the control objective. To reduce the effort required to establish the measures for each loop, templates allow ease of setup. For example, there can be templates for single flow loops, inner cascade flow loops, tight level control loops, and loose (or level averaging) level control loops. A template for an inner cascade flow loop would use IAE as one indicator of good performance, as this measures the deviation from set point. This is a good measure for a loop with a moving set point. On the other hand, a template for a loop with a fixed set point should use % Variability. This measures deviation of the PV from the mean (set point). Many of the assessments that can be utilized to gauge performance, and their helpfulness in diagnosing problems, are shown in Table 2.

TABLE 2: ASSESSMENTS THAT CAN BE USED TO DETERMINE LOOP PERFORMANCE

Assessment	Helpful for Assessing:
Variability	Variance as a % of mean
Average Error	Deviation from set point
Set Point crossings	Cycling, Valve problems
Output Standard Deviation	Range of valve movement
Noise Band	Measurement problems
Harris (Normalized)	Control problems, Process or performance change
Harris Index	Control compared to minimum variance controller
Oscillating	Cycling
Oscillating (Hardware)	Cycling due to valve problems
Oscillating (Tuning)	Cycling due to tuning problems
Oscillating (Disturbance)	Cycling due to another loop
Integral Absolute Error	Deviation from set point (for moving set points, cascade loops)
Variance	Deviation from mean
Time in Normal	Controller or operating problems
Valve Reversals	Valve wear, movement of variability elsewhere in the process
Valve Travel	Valve wear, movement of variability elsewhere in the process
Output at Limit	Valves under or over-sized
ExperTune Index	Control improvement by tuning the loop
Response time	Synchronization among loops or interaction
Robustness	Ability of loop to handle process changes
Model Quality	Suitability of last SP or CO step for tuning
Process Gain	Process changes (if suitable data exists)
Process Dead Time	Process changes (if suitable data exists)
Process Lag 1	Process changes (if suitable data exists)
Process Lead	Process changes (if suitable data exists)
Oscillation Strength (1-3)	Contribution of cycling to variability
Oscillation Period (1-3)	Loops that interact, sources of oscillation

USING A PERFORMANCE MONITOR IN AN OIL REFINERY

A screen capture of a performance monitor display is shown in Figure 1. This is a table containing data for a plant and several unit operations, over nine months, in one-month snapshots. The data shows that nine months ago the Economic Average %T for the entire plant was 65.6%. This has been reduced to 24.9% one month ago. Each unit operation shows a similar reduction in the Economic Average %T over time.

Economic Average Percent Towards Threshold
(Use Economic Weighting)

Divided Up Into Windows Over the Last

Location	1 Month	2 Months Ago	3 Months Ago	4 Months Ago	5 Months Ago	6 Months Ago	7 Months Ago	8 Months Ago	9 Months Ago
Entire Plant	24.9%	35.6%	32.8%	38.9%	46.2%	52.8%	68.9%	56.2%	65.6%
Crude Unit	22%	20%	12%	25%	10%	29.8%	28.4%	32.2%	29.5%
Sat Gas	40%	50%	52.8%	63.9%	56.2%	35.8%	74%	58.2%	70.6%
Cat Crack	38%	44%	42.8%	30.9%	36.2%	42.8%	55.9%	66.2%	68.6%

Reduction

FIG. 1 – ECONOMIC AVERAGE % TOWARD THRESHOLD FOR A PLANT AND FOR UNITS WITHIN THE PLANT OVER NINE MONTHS

The reductions in Economic Average %T for this plant were achieved by using the performance monitor to identify, track and correct the worst performing loops. Starting with the worst performing unit, the performance monitor can display the Economic Average % T for each loop (data not shown). The data can be sorted in descending order to view the worst performing loops. A detail of each loop would show specific problems, such as oscillation, high variability, etc.

If a specific problem for a loop were oscillation, a display such as that show in Figure 2 would help to identify the cause. This display offers significant value in troubleshooting the problem. The performance monitor can indicate if the loop oscillates continuously, or only some of the time (Column 3). If the software detects cycling ten assessment periods in a row, the oscillating value is 100, so is oscillating all of the time. The loops can be sorted by oscillation period, showing interaction (Column 7). The performance monitor also classifies the cause of oscillation as hardware, tuning, or load (Columns 4, 5, and 6). If two loops share an oscillation period, one loop is the cause and the other merely following the disturbance. The software will identify the latter in the 'Load' Column (e.g. 50FC014, a '100' in Column 6). Up to three oscillation periods can be detected (data not shown). Once the problem has been identified, corrective action (e.g. new tuning, valve repair) will reduce the

Average %T, and will improve the loop and plant performance. An example is shown as a screen capture in Figure 3. For loop 50LC350, corrective action was taken before the assessment at 3:00 PM on 09/10/2002. Prior to this, the loop was oscillating, had high variability, and high valve work (Columns 3, 6, 7, and 8). Following corrective action, the oscillation index is reduced by 10% each assessment period, and will eventually go to zero. Repairing all problems in a similar fashion for all key loops will improve the overall plant performance.

Loop name	Unit operation	Oscillating	Osc - Hardware	Osc - Tuning	Osc - Load	Oscillation period 1	Oscillation strength 1	Mod quali
Sort	Sort	Sort ↓	Sort	Sort	Sort	Sort	Sort	Sort
50FC2025	EV-Evaporators	100	0	100	0	341.3	49.93	
50FC349	CW-Condensate Water	100	100	0	0	1024	61.14	
50FC157	RF-Recovery Furnace	100	0	100	0	146.3	23.04	
50FC014	RF-Recovery Furnace	100	0	0	100	97.52	6.224	
50FC156	RF-Recovery Furnace	100	0	100	0	204.8	25.98	
53LC097	BB-Bark Boiler	100	0	0	0.001	682.7	13.03	
53TC099	BB-Bark Boiler	100	70	30	0	682.7	27.19	

FIG. 2 – DETAILS OF LOOPS DETERMINED TO BE CYCLING. 50FC014 IS OSCILLATING DUE TO A DISTURBANCE. 53LC097 AND TC099 SHARE A DISTURBANCE PERIOD AND ARE INTERACTING (53TC099 IS IDENTIFIED AS THE CAUSE – BOTH TUNING AND HARDWARE PROBLEM.

Loop History for 50LC350 during the previous 12 Days of assessments.

Show assessments as % towards threshold

[Site map](#) [Help](#)

Time	Avg % to threshold	Variability	Average error	Harris (normalized)	Oscillating	Valve reversals	Valve travel
3:00 AM 9/11/2002	-12.2%	0.1525	0.1776	0.4046	60	1908	1049
11:00 PM 9/10/2002	-14.9%	0.1537	0.183	0.3779	70	3173	1427
7:00 PM 9/10/2002	-11.8%	0.213	0.2341	0.4108	80	2843	1376
3:00 PM 9/10/2002	-5.2%	2.962	0.4513	0.3377	90	3084	1915
11:00 AM 9/10/2002	no data	no data	no data	no data	no data	no data	no data
7:00 AM 9/10/2002	no data	no data	no data	no data	no data	no data	no data
3:00 AM 9/10/2002	5.1%	0.6225	0.6931	0.3177	100	17540	4298
11:00 PM 9/9/2002	5.4%	0.5726	0.6499	0.357	100	17460	4105
7:00 PM 9/9/2002	12.5%	0.4875	0.5205	0.3164	100	22180	5366
3:00 PM 9/9/2002	20.8%	0.8525	0.9862	0.556	100	19680	4993
11:00 AM 9/9/2002	48.3%	4.906	4.342	0.761	100	12820	4411

Reduction

Corrective Action Taken

FIG. 3 – LOOP PERFORMANCE IS SHOWN BEFORE AND AFTER RE-TUNING AT 11:00 AM ON 9/10/2002. TESTS FOR TUNING WERE DONE BEFORE THE 3 PM TIME ASSESSMENT ON 9/10/2002. AFTER TUNING, OSCILLATION MEASURES, VALVE WORK, VARIABILITY, AND AVG %T ARE REDUCED.

CONCLUSION

We have shown how a performance monitor combines key assessments to provide a snapshot of loop, unit, and plant performance. A wide range of assessments can be selected that will accurately reflect a measure of the loop performance. A measure of how close an assessment is to the ideal is the % T. The economically weighted average of all %T's for a single loop measures the loop performance in terms of economic significance. This value can be used to identify problem loops and prioritize work in a plant, leading to increased profit.

Though not specifically addressed in this paper, the performance monitoring discussed also fits into a company's six-sigma program, by providing a means to:

Define - categorize the process into unit operations (the loops are placed into Units),
Measure - continually monitor the process (the outputs allow one to monitor process performance),
Analyze - assess the process performance (the monitor provides continuous assessments),
Improve - identifying problems and tools to correct (specific problems are identified)
Control - track performance over time (plant assessments and performance are trended over time).

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