HOW DOES YOUR PLANT MEASURE UP?
DEVELOP A PRODUCTIVITY PROFILE TO FIND OUT

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ABSTRACT

How can the overall performance of your plant be determined? Most plants calculate availability, or the percent of the time the plant or a particular circuit is operating, as well as overall production and recovery. But, is this information enough? Does it provide sufficient fine-grained information on where improvements can be made? Consider the following questions:

- Although the plant is operating, how well is each circuit performing?

- How productive is each process?

- How efficient are your operators and maintenance personnel?

- How much variation is there in each circuit's performance?

- Where are the best opportunities for improvement?

This paper suggests five quantitative factors applied to a plant or to individual parts of a plant that identify the productivity of the plant—in other words, its *productivity profile*.

THE FACTORS GOVERNING PRODUCTIVITY

The five factors on which this paper focuses are:

- *Critical process variables* and how closely they are controlled.

- *Equipment availability*—both with regard to planned and unplanned downtime.

- *Productive efficiency*—what percent of the time maintenance personnel actually work and how many tons are produced per manhour expended.

- *Actual production rate compared to design*.

- *Actual production rate by crew compared to average production rate*.

Critical Process Variables

Any process plant consists of an arrangement of equipment designed to move feed stock through a process that effects a physical, chemical, and/or thermodynamic change on the feed that results in a suitable product. Variables associated with the process dynamics, if

appropriately controlled, will result in the desired changes to the feed as it progresses through the process. At any particular stage of the process, these variables may include size, temperature, flow rate, density, reagent concentration, and many others.

Over time, any particular process variable will exhibit values that vary around a mean value. Higher variation indicates less effective control, while lower variation indicates more effective control. To ensure statistical validity, sample groups are used to determine the dispersion around the mean value. To obtain a statistically valid process variable productivity score, do the following:

1. Subdivide the measured values into sample groups of two to six. For example, measure the pulp density as percent solids and take a sample once every two hours.

2. Establish a sample group as four measurements encompassing one shift of eight hours.

3. Take the arithmetic mean of the four measurements each shift. Call the result of each group $\overline{X}$, denoting an arithmetic mean of each sample group.

4. For each sample group, measure the *total dispersion*, which is the difference between the highest of the four measurements and the lowest. Call the result **R**, denoting the range of values within each sample group.

5. Collect the $\overline{X}$ and **R** values for at least 100 sample groups (100 shifts in this case).

6. Call the arithmetic mean of the $\overline{X}$ values $\overline{\overline{X}}$ and the arithmetic mean of the **R** values $\overline{R}$.

7. Divide $\overline{R}$ by $\overline{\overline{X}}$ to obtain the process variable control score for the variable being measured.

8. The standard deviation of the **R** values around $\overline{R}$ and $\overline{X}$ around $\overline{\overline{X}}$ will indicate the degree of variation as a function of time.

This approach can be taken for each critical process variable. Additional statistical process control (SPC) analyses can be made to identify how much of the variation is random, caused by the nature of the control system, and how much is non-random, caused by other controllable factors. Refer to Performance Associates' white paper *Total Quality Management—the Time Has Come For Metallurgical Plants* for more information on SPC. This is important as corrective actions to reduce random variation are completely different from the actions necessary to reduce non-random variation.

Factors Affecting Control of Critical Process Variables

The following represent only some of the factors affecting the control of process variables:

- Effectiveness and accuracy of samples.

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- Control loop design, including accuracy of sensors and the feedback loop control duration, i.e., the length of time between the process variable measurement and the resulting controller output signal received at the control device.

- Plant operator training in the process, procedures, control loop design, and how to troubleshoot a control loop problem.

- Effectiveness of operating procedures, including timely routine shift inspections.

- Effectiveness of shift reports.

Equipment Availability

The key availability measure in a process plant is the availability of a process train such that the train is producing product. Within a particular train, there may be equipment such as spare pumps that allow one pump to operate normally while the other is shut down or being maintained.

The availability of a process train should be calculated as follows:

Process-Train Availability = [Operating Time]/[Operating Time + Downtime]

The above equation assumes that the process plant is nominally scheduled to operate 24 hours a day, 7 days a week, 365 days a year. Downtime should be subdivided into scheduled downtime and unscheduled downtime. The plant availability score represents the total plant availability and the relative percent of downtime that is scheduled.

Total plant availability can be calculated based on the number of process trains. For example, if a concentrator has two trains, each consisting of a SAG mill and two ball mills, plant availability can be downgraded by 50 percent if one train is down for scheduled or unscheduled maintenance and the other train is operating.

Scheduled Downtime

Equipment availability is greatly affected by the degree of planning. All identified and planned work associated with the equipment in the process train that can be completed during a scheduled shutdown's duration should be scheduled.

Unscheduled Downtime

Unscheduled downtime is primarily caused by equipment breakdowns. In a well-run process plant, most of the downtime will be scheduled such that backlogged work is accomplished after planning during a scheduled shutdown.

Factors Affecting Plant Availability

Factors affecting plant availability include:

- A well-functioning preventive maintenance (PM) system that provides valuable feedback on necessary work to the planning department. Ideally, tablets are used in the plant to facilitate efficient input of identified work required to the backlog database.

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- An effective spare parts inventory control system. Refer to Peformance Associates' white paper *Spare Parts Planning For New Metallurgical Plant Start-Ups—Why You Need a Spare Parts Inventory Model* for more information on setting up an effective inventory control system for a plant start-up.

- An effective maintenance planning system, including a computerized maintenance management system (CMMS), as well as effectively trained supervisors and planners.

- Well-trained maintenance tradesmen. Troubleshooting equipment problems requires highly trained tradesmen using logical procedures. Ineffective troubleshooting can greatly extend unscheduled downtime.

- A sound organizational approach to managing the factors affecting maintenance performance and costs. For more information, refer to Peformance Associates' white paper *Maintenance Cost Control—Is Your System Active or Passive?*

Productive Efficiency

General productivity measurements such as tons produced per man-hour are useful, and these measurements can be allocated to individual production cost centers. Ideally, objectives are set for each cost center with respect to this measurement. However, for a process plant, we like to handle maintenance productivity differently.

Maintenance Productivity

To assess the productivity of maintenance personnel, we suggest conducting work sampling on a periodic basis. Performance Associates handles work sampling such that the primary focus is on the percent of time a maintenance employee is actually working on a job. This is sometimes defined as the percent of time that "a tool is on the work."

With this definition, the following are not counted as work time:

- Discussing the job.

- Obtaining parts for the job.

- Traveling to the job.

- Watching someone work on the job.

Examples of work time include:

- A wrench on the work.

- A cutting torch cutting the work.

- An arc welder welding the work.

- Lifting components as a part of the work.

- Installing or removing parts from the work.

To conduct a work sample during the course of the shift, trained observers randomly walk around the plant observing maintenance personnel. Each observation can be de-

fined as an instantaneous "snapshot" of what is happening. Work is either being performed or it is not.

For example, imagine taking a mental snapshot of a crew of three mechanics working on changing a cyclone feed pump impeller. As part of the mental snapshot, one mechanic is removing bolts from the casing while the other two watch. You write in your logbook the time, ratio of working, and location of the work. For example, this entry might read: 0932, 1 / 3 removing bolts, No. 1 Cyclone Feed Pump.

During the course of the shift, the observers will take many mental snapshots of each job. It is essential that each observer is using the same definition of what is working and what is not. After many observations, the statistics can be summarized as to the arithmetic mean of the percentage of time actual work is being performed. Comparisons can also be made regarding whether there are differences between crews with respect to the work sampling score.

Based on this rigorous definition of work, any crew achieving a work percentage of 50 percent is doing quite well. Obviously, the better the work is planned, with staged parts and tools available, the higher the percentage of work will be and the higher the productive efficiency score.

Factors Affecting Maintenance Productivity

Factors affecting maintenance productivity include:

- The effectiveness of the maintenance management system, including whether a computerized maintenance management system (CMMS) is used.

- The effectiveness of planning and scheduling meetings between operations and maintenance supervisors/planners.

- Having the necessary parts in the warehouse such that they can be staged for the work ahead of time.

- The degree of maintenance personnel skills training. Well-trained personnel can troubleshoot equipment problems, allowing corrective actions to be taken quickly after a breakdown occurs.

- The degree of maintenance supervisor management training, such that work is closely controlled during the course of doing the work. Refer to Performance Associates' training program *Supervisory Skills Development Program (SSDP)* for additonal information.

Actual Production Rate Compared to Design

One of the critical measures of plant performance is the actual production rate as compared to the design production rate. This factor can be calculated using the following equation:

$$\textbf{Production \% of Design} = \left[\frac{\frac{t}{Hr}Actual}{\frac{t}{Hr}Design}\right]$$

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Typically, the production in tons per hour is averaged over a month of production by taking the total production and dividing by the hours that the plant operated in the month. In order to ensure that plant availability issues do not contaminate this factor, the tons per hour actual should only be counted while the plant is operating at full capacity. If the plant is down, issues that are a function of plant availability should be addressed. This factor is designed to assess performance while the plant is operating.

This equation can be applied to subsets of the entire plant. For example, the production rate through a grinding circuit, the product of which is cyclone overflow, can be measured as compared to design. A separate measurement can be made in the downstream flotation circuit and then subsequent circuits.

Factors Affecting Production Rates Compared to Design

Factors affecting production rate comparisons include:

- Bottlenecks. One of the common problems causing shortfalls in achieving design production rates are bottlenecks. Each equipment item in a process train has an objective throughput rate and function. Careful analyses of these factors around each item of equipment can shed light on whether a process is bottlenecked at a particular location. Remember, as each bottleneck is corrected, another bottleneck is revealed. In any given process, there is normally one equipment item that is bottlenecking the process.

- Process control. Are control parameters affecting critical process variables under effective control? For example, the size distribution of hydrocyclone overflow—a critical process variable—is greatly affected by the cyclone feed density as well as the pressure drop through the cyclone. Another example is control of the flux added to a smelting furnace. Effective control results in a clean slag; ineffective control results in more metal losses in the slag.

- Operator training regarding the process. For example, the correct response to a process alarm can prevent losses that can accrue quickly if the problem is left uncorrected. We expect that process operators should be able to correctly troubleshoot process problems and know when extra assistance is required. For example, a well-trained operator can quickly assess the performance of a control loop by checking the process variable, set point, and controller output to determine if the controller is acting appropriately.

Actual Production Rate by Crew Compared to Average Production Rate

This factor is determined by taking the total production for each crew over a period of time, e.g., one month, and dividing by the number of plant operating hours for that crew. This factor is then divided by the total plant production divided by the plant operating hours for the entire plant, i.e., all crews. This factor allows for comparing the operating effectiveness of each crew.

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This factor can be calculated using the following equation:

$$\textbf{Production Rate for Crew A} = \left[\frac{\frac{t}{Hr} Actual - Crew\ A}{\frac{t}{Hr} Actual - Average} \right]$$

For example, if a plant uses a four-crew schedule covering three shifts per day, seven days per week, a calculation can be made for each of the four crews. If there is a statistically significant difference in production rates between crews, a detailed analysis can be made to determine what factors explain the difference. The factors associated with the most successful crew can then be applied to the other crews. Conversely, if one of the crews is an outlier on the low side, deleterious factors of that crew can be identified and eliminated.

Factors Resulting in Differing Production Rates by Crew

Factors affecting production rate comparisons include:

- Management effectiveness of each crew's supervisors.

- Availability of an effective shift control. Ideally, each shift supervisor is provided with a shift control document used to measure production and variables against hourly milestones, with room to identify problems and corrective actions. For more information, refer to Performance Associates' training program *Supervisory Skills Development Program (SSDP).*

- Consistent operating practices governed by procedures. If plant management does not provide suitable operating procedures, the tendency is for each crew to come up with their own. Obviously, some crews will do a better job than others.

- Operator training. A thorough plant-specific training program covering *safety*, *process description*, *process variables*, *control loops*, *interlocks*, *alarms*, and *operating procedures* is essential if all crews are to operate effectively and in accordance with management policies and procedures.

START WITH AN EVALUATION TO DEVELOP A BASELINE

The first step is to develop a productivity profile, which provides a detailed baseline from which priorities for improvement can be identified. The profile is a function of the following factors:

Productivity Profile = F{PV, Avail, t/mhr, % working, $t/hr_a/t/hr_d$, $t/hr_{crew}/t/hr_{avg}$}

Where:

PV = process variable control.

Avail = plant availability.

t/mhr = tons produced per manhour.

% Working = maintenance personnel productive efficiency.

$\textbf{t/hr}_a\textbf{/t/hr}_d$ = actual tons per hour/design tons per hour.

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$\mathbf{t/hr_{crew}/t/hr_{avg}}$ = tons per hour of each crew/tons per hour average.

Improvement Strategy

Once the baseline profile is complete, careful evaluation can be made of which factors can be improved at what cost. This cost-benefit analysis provides the necessary information to plan the improvement strategy.

It is essential that the improvement strategy will actually result in the desired outcome. For example, if the work sample analysis of mill maintenance personnel indicates a working factor of 38 percent and a formal maintenance planning system is not in place, the strategy becomes very apparent. However, if there is already a planning system in place, the strategy may not be so obvious. If the factor is broken down in a more fine-grained way, it may indicate that another approach is necessary.

For example, assume that the working factor for Crew A is 55 percent, but it is significantly lower for the other crews. Further, assume that a planning system is in place. A careful assessment of what Crew A is doing differently must be conducted.

Improvement Plan

The strategy considers priorities, costs, and potential results; the plan provides the methodology to implement the strategy. Once the improvement plan is in place, the costs of implementing the plan can be assessed against the expected financial benefit, allowing for a return on investment (ROI) to be estimated.

Each segment of the improvement plan can be evaluated based on the estimated ROI for improving each specific factor. Implementation can then be effected, starting with the highest potential ROI to the lowest.

CONCLUSION

The productivity of virtually all process plants can be improved. However, to identify where these improvements can best be made, it is necessary to do a fine-grained analysis of the type discussed in this paper. In the absence of this kind of analysis, the identification of potential improvements can be lost in the noise inherent in the myriad data collected by the process control system and shift reports.

For more information on developing a productivity profile, or on setting up a first-class plant operator or maintenance skills training program, contact:

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