



## Process Optimization Begins with Better Process Control

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### Abstract:

Although the science of process control is reaching maturity, application of that science is still poorly understood and severely underutilized. Plant-wide process optimization is well within reach, at least as far as the technological issues are concerned. Modeling techniques and artificial intelligence-based analyses coupled with standardization efforts in communication provide the means to incorporate sufficient data into an analysis engine that is powerful enough to respond to the physical dynamics of an entire plant. However, as with any computer-based tool, the analysis and results are only as good as the data that is fed into the engine. Looking at measurement and control in a typical process facility, the instrumentation, control elements and individual PID-based controllers are generally not performing adequately. In order for sophisticated, model-based and/or artificial intelligence advanced controllers to provide the benefits they are capable of providing, there must be well-tuned PID loops and analysis tools with which sensors and control elements can be examined for improper calibration and excessive wear. Good process control breaks down into three essential elements - access to data, analysis tools to analyze the data, and procedures for carrying out corrective action. This paper details fundamentals for establishing good process control using these three key elements.



## Implementing Process Optimization for Better Process Control

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### Situation Today

Profit margins in the chemical industry are tightening, and process control engineers are continually feeling the pressure to “do more with less.” Economic value-add is a term that is becoming ever more pervasive throughout the manufacturing organization, and engineers must balance product quality and cost more than ever, meet production requirements and decrease or eliminate downtime, while lowering expenses. These are not simple challenges. To improve chemical plant efficiency and compliance, engineers are looking to process optimization tactics to ensure that the process is running as smoothly as possible.

Process optimization eliminates waste, reduces variability, improves delivery, assures compliance with regulations and reduces customer order delivery lead-time. These goals are directly in line with the economic goals of the chemical production facility and the corporation at large. Process control optimization can be viewed as tiered, with equipment and PID control optimization at the most basic level and increasing in complexity and scale to economic optimization and ultimately production planning and scheduling. Traditional optimization tools are large matrix multi-variable control systems and more sophisticated first principal model-based economic optimization software solutions. The reality of these large-scale solutions is that they cannot deliver on their stated goals if the individual pieces of process equipment are not properly controlled. Solid process control at the equipment level is necessary for the large-scale optimization offerings to be successful.

Whether a chemical manufacturing facility produces bulk/commodity chemicals or fine/specialty chemicals, lost revenue and/or poor profitability ultimately point back to lack of effective process control. At the process control level, the aim is eliminating process upsets, meeting or exceeding quality measures, and reducing (or eliminating) waste while delivering finished goods on or ahead of schedule without violating any form of regulation (e.g. environmental). Ideally, the only process control challenge a chemical plant faces is responding to production rate and product line change quickly and effectively. However, the typical chemical plant experiences unacceptable variability, quality problems, compliance, and delivery problems on a fairly regular basis.

The traditional focus has been on optimization of the core process with neglect for the rest of the facility. A batch reactor area, for example, measures its effectiveness on the ability to maintain acceptable polymer levels in the polymer storage area. Little, if any, thought is given to sharing real-time process data with the downstream process area. Laboratory tests combined with intensive data analysis can be performed manually to give the downstream process area a general sense of a few salient process parameters, such as tensile strength, elasticity or perhaps residual chemical content. However, this generates a relatively small, narrow set of data that is collected manually at indeterminate intervals. The result is poor inventory control, rejected product and potential process downtime.



Today, some companies are creating mathematical models of their processes to better understand and view the interdependencies between process areas. Not only are these models able to obtain real-time data from throughout the process, but they also are able to make changes to process parameters in real-time. In order for such a program to be effective, it is essential that the model be accurate. Process time-constant and gains for controllers throughout the process are typically required for these mathematical models, and quantifying these values requires a solid understanding of the behavior of the individual controllers and their dynamic performance over their respective control ranges. If you don't have good "basic" process control, you won't have a good model.



Large-scale optimization software provides tremendous economic benefit. Accurate models of the plant depend entirely on effective process control. Without it, the information is not available for the model to make useful decisions regarding process optimization. Also, some of the process control analysis tools that are available are not widely used because they are not easily understood. Regardless of whether the plant is applying large scale model-based advanced process control software, or looking more for a small-scale modular approach, solid process control is the required foundation for success.

### Process Optimization

Implementing process optimization helps to ensure that the process equipment is working as effectively as possible over the entire control range on a plant-wide basis. Load changes and setpoint changes are controlled with optimal efficiency and unplanned upsets have minimal negative impact. Not only are individual controller tuning parameters required to best suite the process conditions, but the equipment itself must be properly designed and in good working condition. The data analysis and statistical tools available for process optimization make it possible to effectively diagnose and troubleshoot poor performance whether from improper controller tuning or poorly designed or maintained process equipment. Once process variability from these sources is identified and minimized, an accurate process model can be derived.

At least half the challenge of effectively reducing or eliminating these profit-eating problems is identifying and understanding the root cause. Data accessibility is the basis of identifying process control problems. Once the data is gathered, it must be analyzed. The analysis leads to a fingerprint of the process problem, whether it is poor process design, poor process control technique, or defective process equipment. At that point, the problems are identified, but without plans and procedures in place to correct process control issues, the data gathering and analysis are of no use.

### Data Access

In today's environment of open-system architecture, access to data is becoming less of a challenge. However, legacy systems persist, and the underlying technology of the legacy system often does not support the open-system philosophy. Fortunately, control system vendors and third party support companies have developed communication drivers in support of industry standard communications (e.g.



COM) for many of the older control system platforms. In the event data can not be extracted from a legacy control system in any automated fashion, a decision must be made on whether the control performed by the legacy system is critical enough to influence the model of the process. Although data can be manually entered and evaluated, any manual operation introduces a source of unpredictable error.



## Analysis

Process data analysis offers many benefits — increased yield, reduced downtime, optimal energy consumption, better quality control, improved safety, effective inventory management, reduced waste and increased throughput can all be realized through process data analysis. A mathematical model, or system function, is required even for individual PID control loops. The model is typically derived from the frequency response, which in turn is derived from analysis of real time data. A variety of data analysis software tools are available that will derive the model of the controller based on real-time data. Once this happens, more advanced statistical analysis tools can be employed to evaluate the real-time data relative to controller performance and equipment performance. There are a variety of such tools that can be used to implement effective process PID controller optimization.

Regardless of whether analysis is focused on controller tuning or equipment behavior, the goal is to reduce variability to the greatest extent possible. In general, variability can be thought of as a relative measure of the degree to which the process deviates from desired behavior. In strict mathematical terms, variability is the relative value of variance, where variance measures the spread or dispersion of data:

$$\text{Variability} = 2 * (\text{standard deviation}) * 100 / \text{mean}$$

$$\text{Sample variance} = \frac{\sum (\text{Mean} - x(i))^2}{(npts - 1)}$$

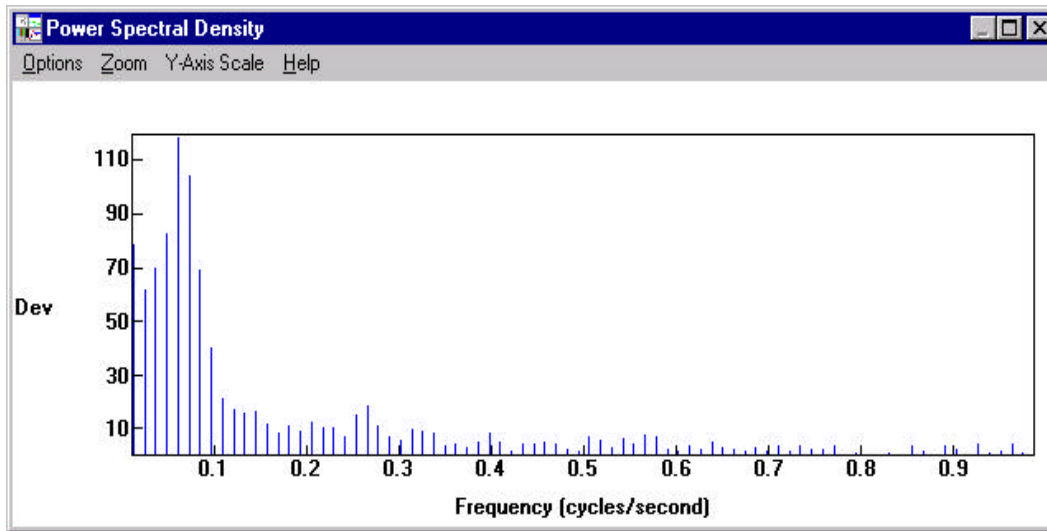
NOTE: Standard deviation is the square root of variance.

Variability is expressed as a percentage of the mean and so allows comparison between the level of variability in different processes. Understanding and effectively measuring variability is critical to measuring and optimizing controller performance.

## Power Spectral Density Analysis (PSDA)

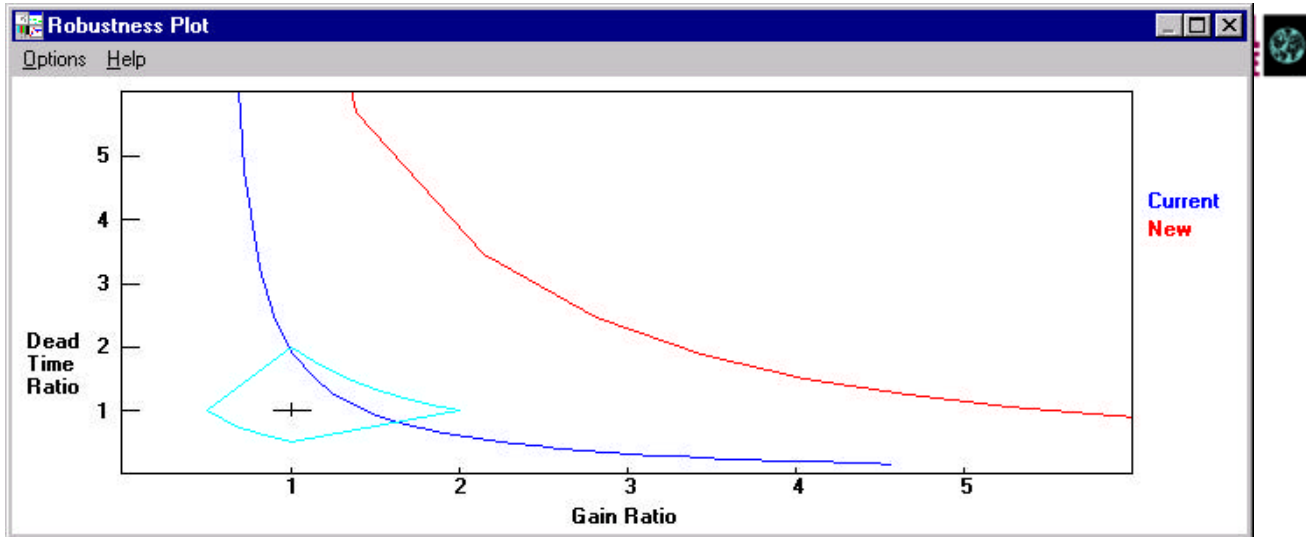
PSDA is useful for identifying cyclic disturbances and the frequencies at which they occur. PSDA plots show the relative power in the signal (typically the Process Variable) at various frequencies across some range (typically from twice the sample time to twice the data collection time). Open loop analysis is useful for identifying disturbances that may be caused by defective or poorly designed process equipment, and closed loop analysis is a good measure of controller performance. PSDA is arguably the most effective analysis tool available for identifying and troubleshooting process equipment problems. For example, PSDA can be used to identify a specific pump impeller wear problem if high and very high frequency data (< 1 sample/50 milliseconds) is attainable.





### Robustness Analysis

Robustness analysis shows how sensitive (or robust) a PID control loop is to process gain or process deadtime change. Robustness plots graphically show the tradeoff between tight tuning and stability. Using robustness analysis and understanding the requirements of the process, the controller can be tuned according to the best behavior for the application. For example, when a load change occurs, it may be much more important that a given flow loop respond as quickly as possible, sacrificing a small amount of fluctuation around setpoint, than to have the flow loop respond relatively slowly, ensuring that there is little or no settle at the new setpoint.



### Correlation Analysis

Correlation analysis is useful for determining the relative amount of interdependency between PID controllers. Correlation is also used to determine whether variability is introduced by controller tuning or by process equipment issues.

### Hysteresis Analysis

Hysteresis analysis is a measure by which control elements are monitored for excessive wear or for other equipment maintenance issues such as pump cavitation.. The most typical example is given with control valves, which can suffer from stiction or backlash, or have seat wear problems. Whether from valve seat wear, stiction or backlash the valve may become less responsive when directed in one direction than when directed in another.

### Relative Response Time

Relative response time refers to the means by which interacting PID controllers are decoupled. Once the relative response time is known for a pair of interacting PID loops, it is possible to identify the faster reacting control loop. Then, following established rules of thumb for interacting loops, the slower acting controller can be de-tuned.

Adaptive control strives to provide effective control over the entire control range for controllers that behave in a non-linear manner. With adaptive control, changes in process gain and response time are accommodated dynamically using on-line adaptive algorithms. Adaptive control is accomplished using

either conventional PID controllers with add-on adaptive capability, or with relatively newer small-scale multivariable controllers. Some of the more intriguing small-scale multivariable controllers leverage neural net technology and have proven to be remarkably robust. Model identification and data analysis apply to these newer multivariable controllers, but many provide these functions either with toolsets or built directly into the controller software.



### **Procedural Process**

Finally, the plant must consider whether or not there are clearly defined procedures in place for correcting process problems. For example, if the process (control) engineer detects process equipment problems, a mechanism should be in place for the maintenance technician to quickly and effectively correct the problem. Procedures should also include documenting and checking control performance over time. Because physical parameters and equipment conditions change in the harsh environment of the manufacturing facility, the process must be continually and regularly monitored to ensure satisfactory performance, even after the plant is considered to be in (relative) optimal operating status.

### **Implementation of Process Optimization**

Implementation of large-scale multivariable control and optimization has tremendous benefit when applied correctly in a plant that has employed solid basic process control tactics. There is a basic prescription to follow when endeavoring to apply these solutions:

1. Create a cross-functional team comprised of process (control) engineers, production workers and management, maintenance staff, and engineering from all areas of the plant. The team will be integral and directly involved with all aspects of the project.
2. Evaluate vendors' offerings. Not merely the product capability, but more importantly the experience level of the application team relative to your process. Measure their understanding of the control challenges you face in your plant. The better vendors will understand and convey the importance of good controller performance in the plant.
3. Evaluate the current control capability. If there are no records of variability, begin measuring controllers and the variability introduced by them. Identify and if possible correct any process equipment problems.
4. Evaluate production requirements. This is most critical of all the steps in beginning an advanced process control project. Understanding the specific requirements of the production capability will steer the team's investigations. The process (control) group may consider quality the most important issue, the maintenance group may consider throughput most important, and engineering may be convinced that energy consumption is the critical consideration, when all along production has been struggling with inventory control.



5. Evaluate maintenance requirements. The better the maintenance staff understands and accepts the strategy, the better chance it has of having long-term success. Maintenance is second only to operations in their interaction with the process and often provides insight that is critical to success.
6. Determine the training requirements for operations personnel, process control engineers, maintenance, engineering, and management. Training may not be required for some and may need to be quite intensive for others.
7. Monitor and evaluate the progress and effectiveness of the advanced control solution against all requirements.



It is critical to have process optimization procedures in place and to continue using them on a regular basis to maintain the process. You should develop a plan for predictive or preventative maintenance and generate reports on a regular basis to help ensure that each process is being optimized to its fullest potential.

## Outlook

The process industry is continuing to move toward systems that offer the maximum benefits of flexible manufacturing. Many valuable lessons have been learned with regard to advanced process control. Large-scale multivariable control and optimization software has proven to be extremely difficult and expensive to install and commission. While the potential economic benefit of implementing these software solutions is quite substantial, there also are many caveats. One typical requirement when configuring these solutions is a large team of very experienced process and control engineers. Large-scale advanced control application projects can last for well over a year. Once the application is commissioned, the plant typically is at the mercy of the software vendor for all maintenance issues.

Industry analysts<sup>1</sup> have stated in recent studies that large to very large monolithic mathematical models provide benefit only to those companies that have very large capital budgets, typically in commodity industries. The belief is that introduction of standards in computing and in process control application will lead to realization of modular plant wide control across all process industries. The lowest level in this modular model is basic process control optimization. Before sophisticated non-traditional control methods are implemented, process facilities must first come to grips with the statistical tools available for quantifying the effectiveness of the algorithms. Creating smaller, easier to apply and less expensive optimization software tools will bring the goal of plant-wide optimization within the reach of all process manufacturing facilities. Employing the statistical tools available today will enable process manufacturing facilities to measure and track their effectiveness.

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<sup>1</sup> AMR July 1999 study: One Process Plant Model Not Feasible Yet: Focus on Components Instead

Aside from adoption of open-system architecture technology (Ethernet, COM, Windows NT, etc.), further standardization in message or packet content will further the efficiency of process-specific communication. Object Linking and Embedding for Process Control (OPC) holds promise for process control optimized communication standards. Technologies such as this and the further adoption of artificial intelligence capabilities in process connected devices will empower the plant control and maintenance engineers to leverage their process experience using the most powerful control tools available. Rockwell Automation maintains a strong presence with process control standardization committees in the belief that the future of process optimization will leverage interconnected modular process control entities. These will be an enhancement to existing PID controllers, with small matrix multivariable control capability. The requirement will be ease of application and maintenance.



Regardless of the future technologies available to process manufacturing professionals, we believe that statistical analysis methods will continue to be the mechanism with which process professionals measure and track the effectiveness of their control solution. The successful process manufacturing facilities today and in the foreseeable future will be those that most effectively broaden their strengths and respond to the needs of consumers with the greatest agility. The most agile process facilities are those that employ solid process control practices and procedures.

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