OPPORTUNITIES IN PROCESS CONTROL

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Abstract

Benchmarking results from visits to twelve chemical companies indicate a large variety of opportunities in process control to increase profits and revitalize manufacturing. Enough possibilities exist in the selection of process control technologies to allow a wide diversity of technical orientations that all provide significant operating benefits. Further study into the selection and application of instruments and control systems reveals principles important to getting the most out of these efforts. In addition, a mind trap of doing one control technology to the exclusion of others due to predispositions or glamour was recognized in the course of this investigation.

The results of the benchmarking visits are categorized by placing the companies visited into four groups based on the types of control technologies emphasized. In addition nine classes of process control technologies are identified that are used in varying degrees by these four groups of companies.

In this paper, the benefits of process control are explored. The "why" of process control are the benefits; the "what", are the different technologies; and the "how" are the principles and practices followed in selecting and supporting these installations. The application principles are developed from practical examples.

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INTRODUCTION

The Integrated Manufacturing Control committee sponsored by the Manufacturing Management Council of Monsanto initiated a dozen benchmarking trips to companies in the process industry [Proctor and Gamble is one - UCC was not included]. The details and final conclusions will be issued as a report to the participants at the completion of the study. What follows are the thoughts of G. K. McMillan stimulated by these visits. (This is not the official report.)

PROCESS CONTROL TECHNOLOGIES

The benchmarking visits opened up the participant's eyes to a wider range of possibilities than previously visualized. Each company was proud of its accomplishments, convinced of the value of the installed process control systems, and dedicated to the future use of the chosen technologies.

For analysis, nine classes of control technologies that can be structured in a building block order were developed by the benchmarking team. The order is not sacred, and it was observed that no company progressed from one technology-to-another in the suggested order. Most companies specialized in the use of particular sub-sets of these nine control technology classes.

The **Regulatory and Discrete Control (RDC)** class covers the use of new sensors, smart transmitters, valve diagnostic packages, smart valves, analyzers, alarm filter systems, failure protection techniques, smart interlocks, coordination of loops with interlocks, fixed sequence control applications, self-tuning algorithms, and cascade control. It also includes the proper selection and pairing of controlled and manipulated variables either manually or automatically via coordination techniques such as signal selection and override control.

The **Unit Operation Control (UOC)** class covers the use of variable sequences, coordination of controls, and supervisory control for the automated operation of batch equipment and the automated startup and shutdown of continuous equipment on a
unit operation basis. The mind set that reserves this class for batch processes prevents people from recognizing some important opportunities. A continuous operation can be viewed as a long batch in terms of operational requirements. This is an important conceptual hurdle to facilitate a recognition that automated transitions of operating states of continuous equipment can and should be done as a matter of course. The parallels and lessons to be learned from batch control are numerous.

The Production Management Control (PMC) class covers the variation of sequences and set points for the automated transition from one product type or grade to another for flexible product manufacturing and the coordination of unit operation control strategies to meet customer requests. Just as with the UOC class, this class should not be limited to batch processes.

The Advanced Regulatory Control (ARC) class covers the use of feedforward signals, decouplers, dead time compensators, adaptive control, signal characterization, neural networks, fuzzy logic, expert systems, local optimizers, Internal Model Control (IMC), and Forward Model Control (FMC) for single loop or sequence control. It generally involves a process model and incorporates knowledge of the process, equipment, and instruments to achieve a higher level of regulatory or discrete control.

The Advanced Multivariable Control (AMC) class covers the use of neural networks, fuzzy logic, expert systems, local optimizers, and matrix based techniques such as Dynamic Matrix Control (DMC) for multivariable closed loop control. While the objective is the same as the ARC class, the level of sophistication and complexity are considerably higher. It is particularly useful for interacting systems and facilitates global online optimization.

The Global Online Optimization (GOO) class covers the periodic run of program such as the Dynamic Matrix Optimizer (DMO) that gathers data automatically and includes economics to adjust set points to optimize the production of a plant or several plants.
The Advanced Advisory Systems (AAS) class covers online, open loop monitoring systems that gather data automatically. This class includes expert systems, statistical process control (SPC), and fuzzy logic for diagnosis and analysis of plant operation. The distinction here is that the results are advisory and human intervention is necessary.

The Process Data Access (PDA) class includes functions that provide access for a variety of users to console messages, alarms, lab data, and production data. This class includes data validation to assure that users receive only valid data. The direction of information flow is from the plant automation system via its status and diagnostic messages and measurements to the user.

The Manufacturing Data Integration (MDI) class covers those enabling functions that permit integration and validation of manufacturing data between systems. It is multi-sourced and multi-directional. This set of functions is necessary for implementing Computer Integrated Manufacturing (CIM) and Computer Integrated Enterprise (CIE) systems. Information on raw materials purchasing and receiving, equipment vendors, product cost, regulation compliance, sales, market forecasts, plant performance, waste management, inventory, schedule execution, human resources, and customer requirements is available for intelligent decision making.

The large number of technology classes is an indicator of the diversity of process control opportunities. Also, the many distinctions are necessary to differentiate companies. For example, if single loop and multivariable model-based-control were combined into one class, a company that uses flow feedforward would be equated to a company that uses Dynamic Matrix Control (DMC). Objections to the use of a spectrum of technologies limits a company’s opportunities from process control and contributes to a self-defeating company culture.

COMPANIES BY TYPE OF CONTROL TECHNOLOGY EMPHASIZED

The twelve companies visited could be placed into four groups distinguished by the emphasis placed on differing control technologies. This grouping is indicated in the following Table:
**COMPANY GROUPING** | **CONTROL TECHNOLOGY EMPHASIS**
---|---
1 | Type of company that has installed a DCS in nearly every major control room. The field instrument upgrades that accompanied many of the DCS projects; the improved reliability and operator interface of the DCS; and the addition of coordination techniques have resulted in a modestly high return in benefits from improved Regulatory and Discrete Control. However, alarm filter systems (i.e., alarm management functions) and smart instruments were rarely used. Nearly all of the benefits from Unit Operation Control (UOC) are for batch processes and are largely due to the superior nature of the batch language of the DCS. The startup and shutdown of some continuous reactors and neutralizers have also been automated but these are the exception rather than the rule. The Production Management Control benefits are smaller and are exclusively for batch processes. Benefits have been realized from Advanced Regulatory Control (ARC) such as feedforward control and signal characterized, but ARC use is hindered by the low level of the continuous control blocks in the DCS. The DCS implementation has been a tremendous drain on the human resources and precluded exploitation of the full potential of the DCS and various control technologies. A significant effort has been launched in open loop expert systems and process data servers and benefits have started to roll in from Advanced Advisory Systems (AAS) and Process Data Access (PDA). This type of company is seeking accomplishments achieved by the next type of company.

2 | Companies that have done less with the DCS. Control is not emphasized. The company concentrates its efforts on open loop technologies such as expert systems and statistical process control and has noted relatively high benefits from Advanced Advisory Systems (AAS), Process Data Access (PDA), and Manufacturing Data Integration (MDI).
<table>
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<th>3</th>
<th>Companies that have done an exceptional job in the use of smart instrumentation and a personalized DDC system for, intelligent alarms, coordination techniques, automated startups and shutdowns, production management, and model based single loop control for continuous processes. The performance of a plant is measured by the number of operator actions and alarms. The goal is zero for both. The benefits claimed from first four technologies are impressive. SPC is only used until the root cause of a problem is found. This type of company sees little benefit from SPC because it has achieved low process variability. The potential benefits from an open loop expert system are discounted. New efforts are directed in Advanced Multivariable Control (MVC) and Global Online Optimization (GOO) via the implementation of Dynamic Matrix Controller and Optimizer (DMC and DMO) software. These are areas of accomplishment for the last type of company.</th>
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<td>4</td>
<td>Companies that have installed numerous analyzers and implemented model based control for single loop and multivariable control. The benefits realized in ARC, AMC, and GOO are outstanding. These benefits were obtained with the use of a supervisory computer.</td>
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**BENEFITS OF PROCESS CONTROL APPLICATIONS**

The major points of leverage to increase profits from process manufacturing are (1) product yield, (2) inventory reduction, (3) utility minimization, (4) maintenance effectiveness, (5) capacity increases, (6) manufacturing flexibility and (7) responsiveness, and (8) product quality. The first five points reduce the cost of goods sold (COGS), the last four can increase product volume, and the last three can increase product value and price given appropriate market conditions. Other points of leverage for process control contributions to manufacturing excellence are operational safety and environmental control that are essential to retain the right-to-manufacture but whose relationship to profits is more situational.
Business advantages achieved by investment in these nine classes of process control technologies were estimated as part of this study. The baseline for comparison sake is a typical control room of the 1970s with single loop analog controllers, relays, and drum sequence programmers. The baseline is also 1970s process technology, i.e., processes with significant storage between unit operations, little heat integration, and products with wide variability in acceptable product specifications. If the process is highly heat integrated with close-coupled unit operations or if the operating limits are so tight that control using a 1970s vintage control system is not feasible, the modern control technologies required can be viewed as manufacturing enablers. Consequently the value of the control technology is a significant part of the incremental advantage resulting from the complex process enhancements.

Implementation of modern control technologies necessitates the addition of programmable, computing devices. Some of the benefits of the Global Online Optimization (GOO), Advanced Advisory Systems (AAS), Process Data Access (PDA), and Manufacturing Data Integration (MDI) technologies can be obtained by layering computing platforms on top of the 1970s architecture. However, this approach reduces the effectiveness, narrows the scope, and limits the expansion of these powerful computing technologies. This architecture was seldom seen in benchmarking. The companies visited implemented these technologies by means of Programmable Logic Controllers (PLCs), Distributed Control Systems (DCSs), and Direct Digital Control (DDC) on process computers. The hardware reliability and redundancy options of these industrial computer systems have improved to the degree where onstream time of the system was generally no longer a concern. The reliability and human/machine interface of these control systems, particularly the DCS, provide some incremental benefits as just a replacement of the 1970s hardware without the introduction of the described classes of control technologies.

The benefits realized for each of the nine control technologies by the four groups of operating companies have been estimated as part of the benchmarking study. The benefits are expressed in per cent of manufacturing profits instead of cost of goods sold (COGS) to show the effect of price and volume and to help equilibrate benefits received from commodity products where volume is high and value added products where price is high. Equation 1 (benefits as per cent COGS) and equation 2 (benefits as per cent profit) show
in a simple fashion the relationship between the alternative expressions of benefits.

\[
M = (P-C)Q + CQ\frac{B_1}{100}
\]

\[
M = (P-C)Q + (P-C)Q\frac{B_2}{100}
\]

where:
- \(C\) is the baseline cost of goods sold ($/pound)
- \(P\) is the baseline price of goods ($/pound)
- \(Q\) is quantity of goods sold (pounds/year)
- \(B_{1,2}\) is benefits as per cent COGS(B1) or profits (%) (B2)
- \(M\) is manufacturing monetary profit ($/year)

The first two types of companies have newer architecture DCS systems with multiloop controllers that have a flexible low-level control-oriented language and a superior operator interface. Company organizations emphasize data access more than control. Virtual point limitations in the DCS restrict plant wide data coordination. Process control benefits for each of the control technologies are shown in the following graphs:

![BENEFITS REPORTED FOR PROCESS CONTROL TECHNOLOGIES GROUP 1 COMPANIES](image-url)
The last two types of companies have older architecture DDC systems with a large scale computer, a flexible high level process oriented language, and organizations with the human resources and the orientation to push closed loop control towards its performance limits. While the last two types lack the latest operator interface, they have exploited the functionality of what they have. The need for improved operator interface diminishes with the need for the operator. A "Horizon" plant is possible according to Renzo Dallimonti, the father of the DCS, where an operator doesn't exist in the conventional sense, but is replaced with a person of higher technical training to coordinate maintenance activities and optimize the enterprise (reference 1). Such a plant uses a high degree of coordination and process models for superior closed loop control and total automation. It is best implemented per Richard E. Morley, the father of the PLC, in a large parallel processing machine with a powerful control language (references 2 and 3). The benefits arise not from a reduction in manpower, but in an elevation of performance and safety of operation to another plane. Automatic transitions of operating state are faster, more consistent, and more accurate, and represent the best of accumulated expertise (reference 4). In contrast, manual plant control actions are affected by varying staff competence, interpretation, motivation, mood, and excess baggage. Process control benefits for Group 3 and 4 companies are shown in the following graphs:
Complete automation is considerably more feasible for a process plant than an automobile plant because there is no complex hand-eye coordination to duplicate. Process variables are measured and flows are either throttled or started and stopped. There are examples of what a "Horizon" plant might be like for the process industry. Monsanto and W. R. Grace have continuous plants that can startup and shutdown automatically through extensive Unit Operation Control (UOC) and Production Management Control (PMC). Many of the W. R.
Grace plants according to Andrej Martinovic, a visionary in process control, can handle disturbances and unusual operating conditions without operator intervention (reference 5).

The monetary benefits from UOC and PMC applications are expected to be less for large fixed continuous processes that run several years before a planned or unplanned shutdown. In these cases, superior performance of the RDC systems have eliminated trips caused by disturbances or individual instrument failures. However, the most hazardous and action intensive operation is shutdown and startup. UOC and PMC control functions significantly reduce the risk and the workload burst during these periods.

It is difficult to generalize the potential benefits from each technology because they vary with the product and process. The potential benefits from all control technologies applicable to an operating unit that incorporates 1970’s technology controls can conservatively be estimated to exceed 5% profit. Returns on investment are probably greatest for Regulatory and Discrete Control (RDC), Global Online Optimization (GOO), and Manufacturing Data Integration (MDI). The Dynamic Matrix Optimizer (DMO) for GOO is layered on top of the Dynamic Matrix Controller (DMC) for Advanced Multivariable Control (AMC). MDI requires proficiency in Process Data Access (PDA). The MDI potential stems from the sheer magnitude of users affected.

PRINCIPLES TO GUIDE CONTROL TECHNOLOGY APPLICATIONS

How does a company focus its efforts in process automation when technology choices easily outstrip resources? With restricted monetary and human resources, it is important to maximize the benefit-to-cost ratio for each new application. Changes in process control technologies and competing methodologies will be briefly described to support the development of some principles that provide guidance when planning to move from one process control technology to another.

For decades, performance of differential head meters were improved at considerable expense and complexity by the installation of long pipe runs, meter provers, and the addition of pressure and temperature compensation. Still, the mass flow measurement accuracy rarely was better than 1% of measurement span. Along comes a new sensor based on the Coriolis effect that provides single
sensor flow metering with a demonstrated accuracy of 0.15% of measurement reading. *Performance shifts have occurred in some process control elements.*

- When the error of a pressure transmitter is checked for installation effects, it is often found to be ten times larger than the stated catalog accuracy (based on tests at bench conditions) (reference 7). Smart transmitters are now available that compensate for most of these extraneous effects so that the catalog accuracy is achievable (reference 8). *Smart process transmitters are now state of the art devices for process control.*

The supplier of a controller tuning package states that most of the controller tuning problems encountered are due to poor control valve performance (slip-stick, deadband, and altered throttle range). A microprocessor-based valve diagnostic package can correctly identify problems with actuators, springs, positioner and I/P calibrations, valve packing, and trim in valves if stroked full scale (reference 10). A smart valve can do this automatically. A properly designed variable speed drive can eliminate concern about slip-stick, deadband, or flow range (reference 11). *Movement to the smart valve positioners and use of a smart control valve diagnostic tool as part of a preventive maintenance program is prudent.*

A real time expert system can diagnose, dead, off scale, and model error for controllers, measurements, and valves and alert the operator. Loop Current Step Response (LCSR) and Fast Fourier Transform (FFT) noise analysis methods can determine the accuracy and speed of sensors on-line, (reference 12). Similar rules and methods buried in the controller can initiate a strategy to automatically select more valid signals or capture signals before the failure. *New sensors, smart transmitters, and smart valves can eliminate the need for these supervisory expert systems.*

Sometimes nuclear devices are needed for non intrusive level measurements. Point nuclear sources may be used for these applications, but this approach creates a variable radiation path length and a nonlinear measurement signal. Signal characterizers, shims, and pressure and temperature compensation are used to help
linearize the signal and prevent false readings at low levels. A strip nuclear source is considerably simpler, easier to implement, and more accurate (reference 6). *Selection of control loop components can add complexity and limit practical effectiveness.*

- The error of pH electrodes is at least ten times larger than the stated catalog accuracy due to varying reference liquid function potentials and measurement glass surface conditions and are high maintenance items (reference 9). Middle select of three measurements can improve the accuracy and reliability. Intelligent transmitters can diagnose cracked, non-wetted, and coated electrodes. Special assemblies can wash and buffer calibrate electrodes online. Microprocessors incorporated into the electrode can compensate for some installation effects. Solid state glassless electrodes with special coatings and geometry can prevent the origination of the errors and coatings.

The ready availability of alarms in some DCS systems have increased the number of nuisance and unnecessary alarms by an order of magnitude. During a shutdown or an unusual operating state, the operator can be barraged with several hundred alarms per minute when he/she needs to be most focused. Alarm loggers can print each alarm, note repetitive alarms, and send the list to various users for screening. Alarm groups can be configured to permit the operator to manually disable meaningless alarms when process equipment is down. Alarm management including an alarm event filter system can eliminate all but valid alarms from ever getting to the operator. The only alarms sent to the operator are those signaling a change of state (i.e., power failure or shutdown), or the need for maintenance (i.e., instrument or equipment failure). *Alarm management systems should be built into every process control system.*

A statistical process control (SPC) package can show the variation in lab results, and studies can decipher how much of the variation is caused by the lab and by production. An online analyzer can eliminate error from sample degradation and lab techniques. Smart instrumentation, self-tuning controllers, unit operation control, and model based control can eliminate variation of the process variable
from the set point. Global online optimization, GOO, can find the best set points automatically. Once the set points are found, excellent implementation of RDC and UOC can make further runs of the steady state optimization program unnecessary.

- A steady-state optimizer can be used to search for the best feed set points from pH, temperature, and density measurements of a reaction that consists of a neutralization and precipitation with recycle of mother liquor from the centrifuge. Knowledge that the minimum solubility occurs at a specific mole ratio for each product, the use of Coriolis mass flow meters, precise valves, simple ratio control, and automated startups and shutdowns can produce the maximum yield without an on-line optimizer. Knowledge of humidification and flow and temperature control of air introduction into the reactor can maximize production rate without an optimizer.

Equalization tanks and multiple stages of feedback and feedforward pH control can be used to overcome the adverse effects of dissolution time of lime and poor mixing geometry of sumps for neutralization of wastes. Liquid reagents and precise valves can be used with a simple static mixer followed by a wide spot in the line. Liquid wastes can be cross-neutralized with static mixers near the sources to eliminate the need for reagents. Waste can be brought within pH range without pH control by exposure to air (i.e., absorption of carbon dioxide) or by a change of temperature (via changes in dissociation constants).

Interlocks may be added to prevent each individual event that leads up to an undesirable event, but this leads to an incredibly complex system that usually neglects one possible event in the multitude of events and effects. As an alternative approach, a high integrity interlock can be put on the most direct and distinct cause of the undesirable event (reference 4). The safety system equipment, piping, and/or process can be designed to assure that the end event is highly unlikely.

These examples illustrate many important principles that can guide the user to a cost effective selection of process control technologies. *Transition to smart instruments applied to minimize control system design complexity*; to
modification of the process to achieve operability objectives; and to application of control measures close to the disturbance source are general needs.

Many companies have a tendency is to get stuck in the open loop data intensive control technologies (AAS, PDA, and MDI) since it is easier to bring a computer science graduate up to proficiency in doing process data movement and control implementation than it is to develop a chemical engineering graduate with these programming skills. Furthermore, the control applications that focus on the latest computer system is much more glamorous than work that requires detail knowledge of the newest control valve. A well-structured CIM system can tell you exactly what the customer wants and what you are producing, but without plant regulatory performance, the all-important balance will not be achieved. While all of the control technologies have a place, the user must continually use the advantage gained to improve the source of product (i.e., the chemical process) and the source of process signals (i.e., the basic control system elements; sensors, basic controllers, and valves).

The need for process data, SPC rules, and process models increase exponentially as the performance of the signal source decreases.

Open loop control methods as they mature should become closed loop. The user needs to look to automate as much as possible. In CIM diagrams, there are interrelationships that look suspiciously like the loops that could be closed. Finally, the user should be ready to capitalize on inventions that improve the performance of the source.

While it may not be necessary to use the latest computer, it is necessary to use the best process, sensors, and final elements to maximize return from manufacturing. Also, the performance of control strategies applied for first three classes (RDC, UOC, and PMC) is more important than the performance of the control applications for the last three (AAS, PDA, and MDI). This is not meant to imply that software for these last three technologies is not important. The following sketch describes the phases of a process plant improvement beginning with the invention of a better processing procedure.
All of the process life phases are worthy of exploitation, but the largest benefits are gained from automation and invention.

*The capital cost of automation escalates with the number of instruments and is most influenced by the number of on-off valves.* The performance of the signal source, particularly the process and the sensors, lowers the inflection point and final cost for total automation as illustrated in the following graph.
Control technologies available are generally applied in a layered manner as is indicated in the following figure. This structure allows a user to reach higher returns from a manufacturing facility, but all higher level control functions depend upon the support of the lower layers and, ultimately, on the integrity of the RDC technology base. Not shown in the familiar pyramid is the fact that the RDC technology sits on a foundation of process technology.

**HEIRARCHY OF CONTROL TECHNOLOGIES PRACTICED**

**ORGANIZATIONS THAT SUPPORT PROCESS CONTROL**

The companies more successful in control technology exploitation have some common organizational features. There is a process engineer in each production unit devoted to continuous improvement in the manufacturing of a product by the application of process control. The process control engineer is not distracted with hardware and software implementation or upgrades. He/she concentrates on the maximizing the use of installed systems by small incremental changes.
The site has as many as four control systems specialists to support each process control engineer. Thus, if there are about 20 production units at a site, there would be a technical staff of about 100 specialists in process control, software, and hardware. An informal mentor relationship is promoted. In addition to tutoring, the process control engineer receives several days of instruction and "hands on" practice in a well equipped site training center.

A corporate staff responsible for development of control technology standards, visioning, coordination of resources, and improvement of vendor relationships is in place. The advantages of residence in a corporate staff are the exposure to a greater scope of process control applications and the escape from repetitive day-to-day problems. The disadvantages are the lack of a test site for ideas and the distance from the real action. Part of these drawbacks can be remedied by laboratory access to process control instrumentation and process computers and by participation in plant checkouts, startups, and audits.

The success of the organization in applying a broad spectrum of process control technologies depends upon the ability and willingness of all parties shown in the following figure to work on their relationships and to continually be in communication with each other. Individuals cannot effectively work in a vacuum, nor can teams successfully implement a technology without an exceptional level of support and contribution to each other (reference 13).
Working against this critical need for communication is the very technical training which makes engineers so effective in solving equipment problems. Engineers are taught that facts speak for themselves, and if you get the facts straight, all problems are resolved. However, where humans participate as part of the physical system, as is the case in most process control applications, facts and reality often are not the same thing. In fact distinguishing fact from interpretation is very difficult. Everyone seems to see it differently (reference 13). In addition, people simply forget to be supportive and they often engage in conversations that are not clear, direct, positive, or forwarding. Consequently, brilliant technical people often are performing at 25 percent of their potential productivity (reference 13).
On the upside, the power of positive conversations and friendly humor has largely been untapped and represents an opportunity to increase the productivity of team members by a factor of two or three. Working together in teams to address opportunities available from new control technologies can provide the catalyst allowing one to break out of old paradigm, experience synergism, and enhance creativity.

**PERSPECTIVE**

Good practices in the application and support of process control technologies by themselves are not sufficient. An increased allocation of financial and human resources to achieve increased process plant automation can be wasteful if a user is a slave to culturally determined technologies and methods. In other words, the old request of "just give me the resources" doesn't play anymore in today's competitive global economy. A view of the complete picture, the why (benefits), the what (technologies), and the how (practices) is essential, otherwise the tendency is to focus on a subset of technologies due to inclinations from the type of business, expertise, computer hardware, language, and data base, and culture. **A company needs to continually seek the greatest benefits across the whole spectrum of control technologies** (reference 14).

**CONCLUSION**

There is a myriad of opportunities for more profitable chemical manufacturing through the use of new and better integrated process control technologies. Proficiency in key control technologies can yield a world class plant. Users should continually look at improving the performance of the signal sources (process and process control loop elements) through automation and invention to get the most out of efforts expended in the application of control technologies. In addition, long term success in the use of this technology requires a supportive organization that begins with a Process Control Engineer in the unit
and that makes broad use of communicative teams in defining and deploying new control applications.

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