7 Control Equipment

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Topic Highlights

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- *Standard Electronic Analog I/O – 4-20 mA*
- *Discrete I/O*
- *Serial Communication*
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- *Emergency Shutdown Systems (ESD)*
- *Programmable Logic Controllers*
- *HMI-SCADA Systems*

Future DCS Evolution

7.1 Introduction and Overview

Sensors, actuators, and control algorithms were discussed in previous sections. Integrating the hardware and software of these three elements to produce a control loop is the subject of this section.

The earliest process plants were characterized by numerous local measurement indicators and many local control valves. Operators would walk around the plant and make manual adjustments to valves, based on their experience and readings on the indicators. Perhaps they might carry a clipboard or equivalent on which to record a few key measurement values and some overall coordinating instructions. The operator was the controller, as well as the connection between the sensor and the actuator.

The earliest direct integration between sensors and controllers is generally believed to be the governor on a steam engine, developed by James Watt in the 1780s, which regulated steam pressure via mechanical action. In the 1870s, William Fisher developed a regulator that adjusted steam flow to a pump based on its outlet pressure. Around 1900, pneumatic controllers appeared that combined a pneumatic sensor that detected flow, level, or pressure; calculated a required change in output; and sent a pneumatic signal to a diaphragm valve. These controllers were mounted locally and, again, the operator would walk through the plant and make individual adjustments to the controller settings.

Pneumatic transmitters appeared in the 1930s and permitted remote display of variable response and remote adjustment of controller setpoints. This led to the first centralized control rooms where coordinated control action on many different controllers could be made in one location. Typically, large circular charts were used to display responses, and the control rooms would have walls filled with these charts. Electronic single loop analog controllers appeared in the 1940s and 1950s. They eventually were adopted in place of pneumatic controllers because of improved control response, increased accuracy, reduced size, and reduced maintenance costs.

In the late 1950s through the 1960s there were several installations of control systems using centralized computer systems to execute all plant control algorithms directly. These systems were called direct digital control (DDC). However, cost and reliability issues limited widespread adoption of this technology. During the 1970s, distributed control systems (DCSs), based on commercial microprocessors, were introduced and widely adopted. These systems converted all data to digital form, executed multiple controllers in a single electronic component, used cathode ray tubes (CRTs) for the operator interface and keyboards for control, and connected all components together with a single digital data network. The “distributed” in DCS implies that various control software tasks are performed in different physical devices with an overall coordinating and scheduling software program. Development in the 1990s of lower-cost personal computers (PCs) with their associated servers, standard operating systems such as Microsoft Windows, external communication standards, and standard digital bus protocols permitted a new generation of DCSs to be introduced.

The elements of a modern DCS are shown in the Figure 7-1.

Major components of a typical system include input/output connectivity and processing, control modules, operator stations, system workstations, application servers, and a process control bus. Each is discussed further in the following sections.

7.2 Input/Output (I/O)

The first step in control is to convert the sensed measurement into a reading that can be evaluated by the control algorithms. It has been common in the past to bring all the I/O in the plant to marshalling panels located in a control building, from which connections are made to the controllers. This facilitates maintaining and upgrading equipment. There are many types of equipment that have to be connected to a modern DCS, with different specific electronic and physical requirements for each interface. Each input/output type discussed below requires its own specialized I/O interface card that will convert the signal to the digital value used in the DCS.

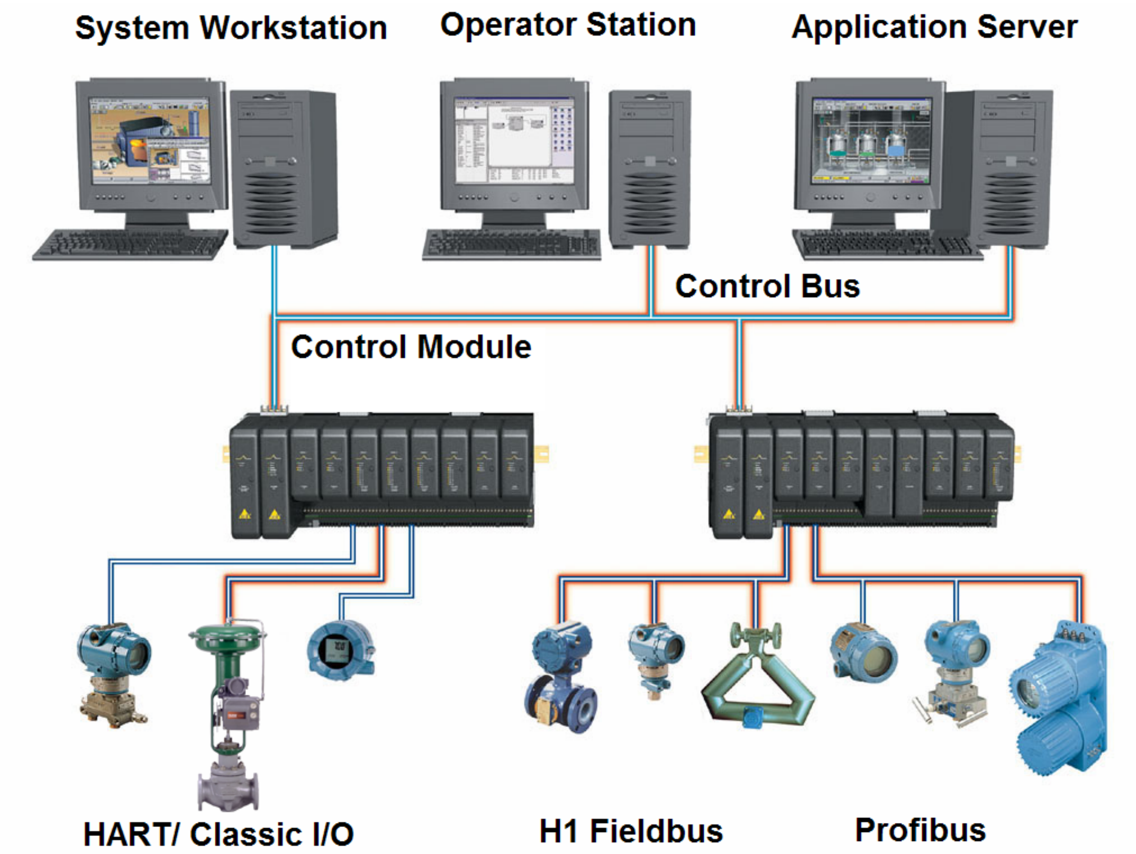

Figure 7-1: Elements of a Modern DCS

7.2.1 Pneumatic Component Interface – 3-15 psi

With the development of pneumatic controllers and transmitters, it became apparent that a standard input and output range was required so equipment from multiple manufacturers could be used in the same plant. The 3-15 pounds per square inch (psi) range was adopted with 3 psi representing 0% of span and 15 psi representing 100%. There are many pneumatic controllers still operating, and interfacing them to a modern DCS typically requires a pressure/current (P/I) converter on the input and an I/P converter on the output from the I/O card to the controller with the actual interface card a standard electronic analog type.

7.2.2 Standard Electronic Analog I/O – 4-20 mA

When electronic instrumentation was first introduced, there were also many different standards for the electronic I/O signals. Eventually the 4-20 milliampere (mA) analog direct current (DC) signal was adopted as standard and is still the most widely used input/output format. Each signal used for control has its own wire, which is brought back to the marshalling panel and then connected to the controller. The most common analog I/O cards used are 16-bit converters, meaning the maximum resolution is about 0.1%, i.e., 4 significant digits.

7.2.3 Discrete I/O

There are a number of devices, such as limit switches and motors, whose state is binary, i.e., off or on. These require separate I/O processing than the analog I/O and, most commonly, separate I/O cards.

7.2.4 Serial Communication

For relatively complicated equipment such as gas chromatographs, vibration monitors, turbine controls, and PLCs, it is desirable to communicate more than just an analog value and/or a digital signal. Serial communication protocols and interface electronics were developed to support this communication. Modbus is one of the most common protocols. I/O registers within the device support predefined read/write commands. Recent implementations support block data transfer as well as single value transmission.

7.2.5 HART

With continuing computer miniaturization, it became possible to add enhanced calculation capability to field devices ("smart" instrumentation). This created a need for a communication protocol that could support transmitting more information without adding more wires. The Highway Addressable Remote Transducer (HART) protocol was developed initially by Rosemount in the 1980s and turned over to an independent body, the HART Communication Foundation, in 1993. The HART protocol retains the 4-20 mA signal for measurement and transmits other diagnostic information on the same physical line via a digital protocol. A specialized HART I/O card is required that will read both the analog signal and diagnostic information from the same wire.

7.2.6 Digital Buses

Since modern DCSs are digital and new field instrumentation supports digital communication, there was a natural demand for a fully digital bus to connect them. Such a communication protocol reduces wiring requirements, since several devices can be connected to each bus segment; it is not necessary to have individual wires for each signal. There are several digital buses in use with some of the more popular ones described below. It is common to connect the bus wiring directly to the controller, bypassing the marshalling panel and further reducing installation costs.

Fieldbus

FOUNDATION fieldbus is a digital communication protocol supporting interconnection between sensors, actuators, and controllers. It provides power to the field devices, supports distribution of computational functions, and acts as a local network. For example, it is possible, with FOUNDATION fieldbus, to digitally connect a smart transmitter and a smart valve and execute the PID controller algorithm connecting them locally in the valve electronics—with the increased reliability that results from such an architecture. The FOUNDATION fieldbus standard is administered by an independent body, the Fieldbus Foundation.

Profibus

Profibus, or PROcess FieldBUS, was originally a German standard and is now a European standard. There are several variations. Profibus DP or *Decentralized Peripherals* is focused on factory automation, while Profibus PA targets the process industries. It is administered by the Profibus International organization.

AS-i

AS-i, or Actuator Sensor interface, provides a low-cost digital network that transmits information that can be encoded in a few digital bits. It is popular for discrete devices supporting on/off indicators such as motor starters, level switches, on/off valves, and solenoids.

DeviceNet

DeviceNet is a digital communication protocol that can support bi-directional messages up to eight bytes. It is commonly used for variable speed drives, solenoid valve manifolds, discrete valve controls, and some motor starters.

Ethernet

Some field devices, such as sophisticated on-line analyzers, are now supporting direct Ethernet connectivity using standard TCP/IP protocols.

7.2.7 Specialized I/O

There are many specialized measurements with equally special interface requirements.

Thermocouples

Thermocouples may be cold junction compensated or uncompensated. Each of these input formats requires different calculations to convert the signal to a reading. Multiplexers are often used for multiple thermocouple readings to reduce I/O wiring.

Pulse Counts

For turbine meters and some other devices it is necessary to accumulate the number of pulses transmitted since a predefined start time.

7.2.8 Wireless

Wireless communication is becoming more popular, particularly for non-critical readings. Standards in this area are rapidly evolving but should stabilize in the near future.

7.3 Control Network

The control bus network is the backbone of the DCS and supports communication among the various components. Data and status information from the I/O components is transferred to and from the controller. Similarly, data and status information from the I/O and controllers goes to and from the HMI. Transit priorities are enforced—data and communication concerning control is the highest priority with process information and configuration changes lower priority. Typically, the bus is redundant and supports high speed transfer. With early DCSs, each vendor had their own proprietary bus protocol that defined data source and destination addressing, data packet length, and the speed of data transmission. Today, Ethernet networks with TCP/IP base protocol and IP addressing have become the most common choice. The International Organization for Standardization – Open System Interconnection (ISO-OSI) model is the defining standard for the overall control networks implementation and is followed by most vendors. It consists of seven layers of implementation references from the physical layer through the application layer.

7.4 Control Modules

The control modules in a typical DCS are connected to the I/O cards by a high speed bus that brings the raw data to the module. The module contains a microprocessor that executes, in real time, the following actions:

- Process variable processing
  - Scan execution frequency control
  - Process variable status checking
  - Process variable engineering units conversion—this may involve flow element conversion, mass flow compensation, square root extraction, linearization, filtering, and/or totalization
  - Comparison of variable against alarm limits, and alarming if outside limits
  - Signal characterization
  - Calculated variable generation—combining one or more variables via addition, subtraction, multiplication, division, integration, accumulation, high/low select and dynamic compensation, such as lead/lag and dead time
  - "Bad" input propagation through the calculations
- Control algorithms
  - Mode change—manual, auto, remote, computer

  - Algorithm initialization on first execution of new mode
  - Control loop execution at defined frequency—PID, ratio, override, cascade, feedforward
  - Advanced control function execution—Model Predictive Control, Fuzzy Logic Control, Adaptive Control
  - Windup protection
  - Loop performance monitoring—mode, I/O condition, variability

- Controlled variable output processing

  - Output clamping and rate of change limit implementation

- Discrete input variable processing

  - Change of state detection
  - Set/reset flip flops
  - Logic calculations via Boolean functions—and, or, not, nand, nor
  - Comparison logic—equal to, greater than, less than, not equal to

- Discrete output processing

  - Execute pulse or latching outputs
  - Manual execution

- Sequential control

  - Execute step
    - Execute algorithm after preset delay
    - Execute algorithm after counter reaches preset value
    - Execute algorithm when comparison logic is true
    - Execute algorithm when Boolean logic is true
  - Hold step if condition exists
  - Restart step if condition exists
  - Skip one or more steps if condition exists
  - Recycle to previous step if condition exists

- Historian/Trending

  - Store analog and digital values and status for later retrieval and trending
  - Store alarm information for later retrieval
  - Store operator entered information for later retrieval

- Diagnostics

  - Execution of performance diagnostics on the functions above
  - Field instrument diagnostic information capture

- System access control enforcement

The microprocessors used for real time execution have limited processor capacity and memory, though these limits are continually being raised with the ongoing developments in the computer industry. As a result, the number of I/O points, the number of control loops, and the number of calculations processed in a single module are limited. Multiple modules are used to handle the complete requirements for a process. Control modules are usually located in a climate controlled environment.

7.4.1 Database

Each module contains a database that stores the current information scanned and calculated as well as configuration and tuning information.

7.4.2 Configuration

Configuration of the control module is normally performed off-line in the engineering workstation with initial configuration and updates downloaded to the control module for execution. Configuration updates can be downloaded with only momentary interruption of process control. Today, this configuration is usually done in a GUI based system with drop-and-drag icons, dialog windows and fill-in-the-blank forms, with no programming required. A typical screen for configuration is shown in Figure 7-2, where the boxes represent I/O or PID control blocks. Lines represent data transfer between control blocks.

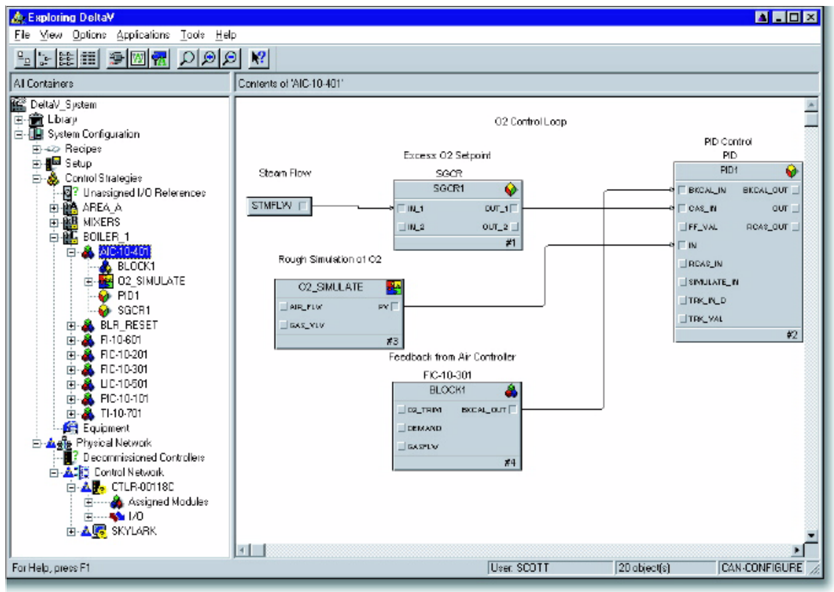

Figure 7-2: Typical Configuration Screen

Generally there will be predefined templates for standard I/O and control functions, which combine icons, connections, and alarming functions. Global search and replace is supported. Prior to downloading to the control modules, the updated configuration is checked for validity and any errors identified.

7.4.3 Redundancy

For critical control functions, redundant control modules are often used. These support automatic switching from the primary to the backup controller upon detection of a failure.

7.4.4 Backup

Current database and configuration information is normally generated without taking a control module offline and stored for backup purposes.

7.4.5 Online Version Upgrade

Hardware and software for DCSs continue to evolve, and it is desirable to be able to install new releases without taking the control module offline. If redundant modules are available, this can be done by running on the primary module, switching the hardware for the secondary module, and/or downloading the new release of software, switching to the secondary module for control (after appropriate initialization), and repeating the update for the primary module.

7.5 Human Machine Interface (HMI)

7.5.1 Operator Station

There are usually two different user interfaces for the DCS—one for the operator running the process, and a second one for system support used for configuration, system diagnostics, and maintenance. In a small application these two interfaces may be physically resident in the same workstation hardware. For systems of moderate or larger size, they will be physically separate. The operator interface is covered in this section and the system interface in the next section. A typical operator station is shown in Figure 7-3.

Figure 7-3: Typical Operator Station

The number of consoles required is set by the size of the system and the complexity of the control application. The consoles access the control module database via the control bus to display information about the current and past state of the process and are used to initiate control actions such as setpoint changes to loops and mode changes. Access security is enforced by the consoles through individual login and privilege assignment.

7.5.2 Keyboard

Standard computer keyboards and mice are the most common operator console interface, supplemented occasionally with dedicated key pads that include common sets of keystrokes preprogrammed into individual keys.

7.5.3 Standard Displays

The Graphical User Interface (GUI) consoles are equipped with standard display types commonly used by the operator.

Faceplates

Faceplate displays show dynamic and status parameters about a single control loop and permit an operator to change control mode and selected parameter values for the loop.

Custom Graphic Displays

These displays present graphic representations of the plant with real time data displays, regularly refreshed, superimposed on the graphics at a point in the display corresponding to their approximate location in the process. A standard display is shown in Figure 7-4, with a faceplate display superimposed.

Displays can be grouped and linked via hierarchies and paging to permit closer examination of the data from a specific section of a plant or an overview of the whole plant operation.

7.5.4 Alarms

Alarms generated will cause a visible display on the operator console such as a blinking red tag identifier and often an audible indication. Operators acknowledge active alarms and take appropriate action.

Figure 7-4: Standard Display with Faceplate Display Superimposed

Alarms are time stamped and stored in an alarm history system retrievable for analysis and review. Different operator stations may have responsibility for acknowledgement of different alarms. Alarm "floods" occur when a plant has a major upset, and the number of alarms can actually distract the operator and consume excessive system resources. Responding to these "floods" and providing useful information to the operator in real emergency situations is an area of active system development.

7.5.5 Sequence of Events

Other events such as operator logins, setpoint changes, mode changes, system parameter changes, status point changes, and automation equipment error messages are captured, time stamped, and stored in a sequence of events system—again retrievable for analysis and review. If sequence of events recording is included on specific process equipment, such as a compressor, it may be integrated with this system.

7.5.6 Historian/Trend Package

A historical data collection package is used to support trending, logging, and reporting. The trend package shows real time and historical data on the trend display. Preconfigured trends are normally provided along with the capabilities for user defined trends. A typical trend display is shown in Figure 7-5.

7.6 HMI—System Workstation

The system workstation supports the following functionality, which has been discussed previously:

- System and control configuration
- Database generation, edit and backup
- System access management
- Diagnostics access
- Area/plant/equipment group definition and assignment

Figure 7-5: Typical Trend Display

Other functionality includes:

Graphic Building
A standard utility is provided to generate and modify user defined graphics. This uses preconfigured graphic elements, including typical ISA symbols and user fill-in tables. New graphics can be added and graphics deleted without interrupting control functionality.

Simulation/Emulation
It is desirable to test and debug configuration changes and graphics prior to downloading to the control module. Simulation/emulation capabilities permit this to be performed in the system workstation using the current actual plant configuration.

Audit Trail/Change Control
It is common to require an audit trail or record of configuration and parameter changes in the system, along with documentation of the individual authorizing the changes.

7.7 Application Servers

Application servers are used to host additional software applications that are computationally intensive, complicated, or transaction-oriented, such as batch execution and management, production management, operator training, online process/energy optimization, etc.

7.7.1 Remote Accessibility

It is desirable for users to be able to access information from the DCS remotely. Application servers can act as a secure remote terminal server, providing access for multiple users simultaneously and controlling privileges and area access.

7.7.2 Connectivity

The application server is also used to host communication software for external data transfer. There are several standards that are commonly used for this transfer.

OPC
The Object Linking and Execution (OLE) standard was initially developed by Microsoft to facilitate application interoperability. The standard was extended to become OLE for Process Control (OPC), which is a specialized standard for the data transfer demands of real time application client and serv-

ers. It is widely supported in the automation industry and permits communication among software programs from many different sources.

XML/SOAP/Web Services

Providing a single Web-based user interface to multiple applications is the goal of many software applications. The eXtensible Markup Language (XML) is a standard message/document protocol to permit communication between applications and the user interface. The Simple Object Access Protocol (SOAP) uses XML and Remote Procedure Calls (RPC) to permit programs in different programming languages to communicate. Web services use SOAP and XML-RPC to provide the user interface to multiple applications and permit web access to the information. This framework is used in Microsoft's .NET software architecture.

7.8 Other Control Systems

7.8.1 Emergency Shutdown Systems (ESD)

Emergency shutdown systems are specialized control systems installed in plants with the objective to automatically shutdown a plant and bring it to a safe state in the event of a major emergency. Typically they will have separate valves and transmitters to those used for normal control. In place of a control module is a logic solver that is programmed to detect specified unsafe conditions. If these conditions occur, the ESD is activated to shutdown the equipment in question or an entire plant.

7.8.2 Programmable Logic Controllers

Comparing PLCs with DCSs, PLCs typically cost less initially per I/O point but have, in general, less functionality and less redundancy. PLCs are the common choice for systems that are predominately discrete I/O with relatively fixed logic, and also for machine control and motion control where very high speed scanning is required. DCSs are most often chosen for continuous, semi-continuous and process batch applications, and applications where the analog I/O count is high. Other differences include separate databases for the I/O, the control, and the human-machine interface (HMI) for PLCs, while DCSs have a common database for all of these functions. Configuration of PLCs is predominately done with ladder logic, while DCSs have automated fill-in-the-blanks configuration editing and high-level language support. Many PLCs require the system be taken offline for control logic modifications while most DCSs can be updated online. Advanced automation applications' support, like batch and advanced control, is typically greater in a DCS, as compared with a PLC.

7.8.3 HMI-SCADA Systems

The development of cheaper personal computers (PCs) led to development of lower-cost systems, based on these PCs, that could be used to monitor equipment conditions; concentrate data, perhaps from geographically distinct areas and display it to operators and managers. These systems are often called HMI-SCADA systems, where SCADA stands for supervisory control and data acquisition. Typically control functionality is limited in these systems.

7.9 Future DCS Evolution

New functionality is continually added to DCSs with the ongoing evolution of computation and communication capabilities. Several trends are evident. One is that central control rooms are being installed physically remote from the actual plant, in some cases hundreds of miles distant, with responsibility for many plants simultaneously. This increases the demand for diagnostic information on both the instrumentation and other process equipment to better diagnose and predict process problems so that corrective action can be taken before they occur. A second related trend is the increased requirement for "sensor to boardroom" integration that imposes ever increasing communication bandwidth demands. Good, real-time corporate decisions depend on good, real-time information about the state of the plant. Secure integration of wireless field devices and terminals into the control system is an active area of current development.

7.10 References

For further information on the evolution of control see:

Feeley, J., et al. "100 Years of Process Automation." *Control Magazine*. (Vol. XII, No. 12), December 1999 (Special Issue).

Standards

ANSI/ISA-50 Series, Parts 2-6 - *Fieldbus Standard for Use in Industrial Control Systems*.

IEC 61158 Series, Parts 1-6 - *Digital Data Communications for Measurement and Control – Fieldbus for Use in Industrial Control Systems*.

About the Author

Douglas C. "Doug" White is Vice President, APC Services, for the Process Systems and Solutions Division of Emerson Process Management. Previously, he held senior management and technical positions with MDC Technology, Profitpoint Solutions, Aspen Technology, and Setpoint. In these positions, he has been responsible for developing and implementing state-of-the-art advanced automation and optimization systems in process plants around the world and has published more than 50 technical papers on these subjects. He started his career with Caltex Petroleum Corporation with positions at their Australian refinery and central engineering groups. He has a BChE from the University of Florida, an MS from California Institute of Technology, and an MA and PhD from Princeton University, all in chemical engineering.