

Process Control Systems— Project Execution and Process Control System Ownership

API RECOMMENDED PRACTICE 554, PART 3
FIRST EDITION, OCTOBER 2008



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Downstream Segment

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Introduction

Advances in computing and digital communications technologies since the preparation of the first edition of API 554 have had major impacts on the way instrumentation and control systems function as compared to historical designs. The advances have also radically changed the way that the design and specification of such systems must be approached and have created major issues relative to system design and system security. These issues are as follows.

- The virtual disappearance of conventional central control room control panels.
- Advances in computing power, software standards and communications standards have resulted in many of the functions historically implemented in stand alone process control and historization computers being integrated within the process control systems. This has greatly expanded the scope of process control system design and blurred the division between real time control and historization functions and higher-level information systems that provide input to business and maintenance systems.
- Advances in field instrumentation design leading to the general use of “smart” digital field instrumentation. Further advances in fieldbus and related technologies allow these “smart” instruments to communicate directly with the process control systems or with each other. These instruments not only transfer information about the basic process measurement, but also communicate diagnostic information about the health of the device or other secondary information derived from the primary measurements.
- Further developments in standardization of operating systems and software practices have enabled use of standard computer components and peripherals operating on standard operating systems. This has resulted in a developing trend away from control systems applications being implemented on proprietary hardware and software systems, but rather being implemented on standard personal computer, workstation and network communication products running widely available operating systems.
- This standardization has reduced the cost and increased the flexibility of the systems. It has also resulted in greater exposure of the process control system to external interference and requires additional support to keep the operating systems current and secure. Security and virus-protection are major concerns of newer process control systems and must be addressed at both the design and operational phases.

The result of all these technical advances is that process control systems are no longer entirely based upon proprietary closed hardware and software systems offered by a single vendor. While these implementations are still available and form the preponderance of the existing installed base, there is a very strong trend away from closed systems provided by one vendor, to more open systems based upon industry standard hardware and software which have both proprietary and open system components.

These trends result in a far greater flexibility in selection of the control functions and the control hardware.

These trends place greater responsibility upon the design engineer and user to understand the interaction between process control systems and the business functions of an organization; select and specify the functions that are necessary for a given application; and implement those functions in a safe, reliable, cost effective and maintainable manner.

Therefore, this edition of API 554 has been reorganized and split into three documents in order to better define the processes required to properly scope, specify, select, install, commission, operate, and maintain process control systems. This recommended practice is not intended to be used as a purchase specification, but recommendations are made for minimum requirements that can be used as a specification basis.

Process Control Systems—Project Execution and Process Control System Ownership

1 Scope

This recommended practice (RP) addresses the processes required to successfully implement process control systems for refinery and petrochemical services. The major topics addressed are as follows.

- The basic functions that a process control system may need to perform, and recommended methodologies for determining the functional and integration requirements for a particular application.
- Practices to select and design the installation for hardware and software required to meet the functional and integration requirements.
- Project organization, skills and management required to execute a process control project and then to own and operate a process control system.

Figure 1 shows the general overall scope of refinery control and automation functions and the portions of which this RP addresses.

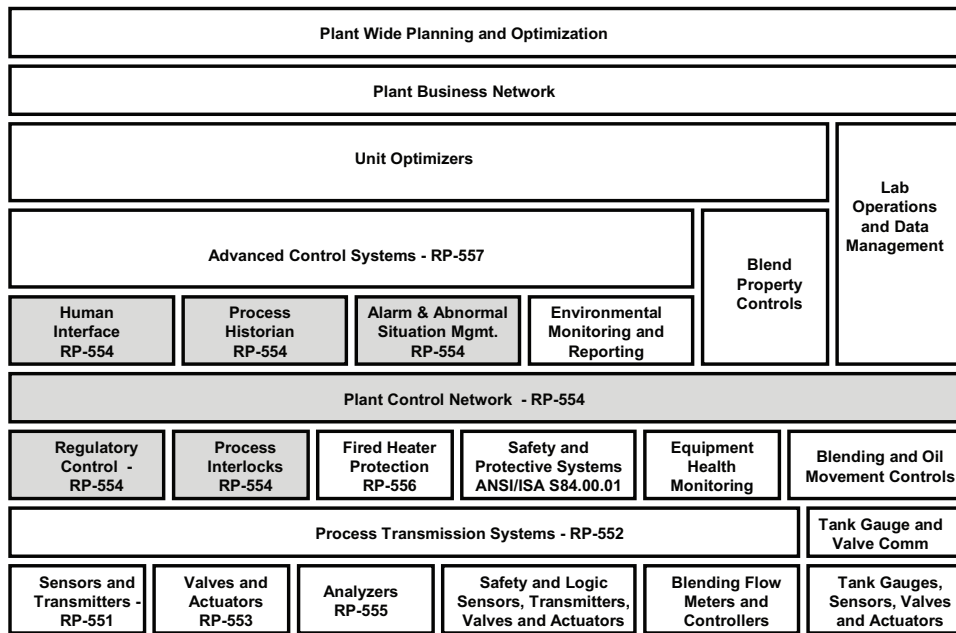


Figure 1—Refinery Control and Automation Functions

The first editions of API 554, Part 2 and API 554, Part 3 have been prepared by a collaborative effort of the API Subcommittee on Instrumentation and Control Systems and the Process Industries Practices (PIP) Process Control Function Team. As such, the general scope of the material contained has been expanded to cover general industrial process control topics that are applicable to both refineries and petrochemical facilities (PIP is a consortium of owner and engineering/construction contractor companies whose purpose is to produce a set of harmonized engineering standards in a variety of discipline areas, including process control).

Although the scope has been extended beyond traditional refining services, the user is cautioned to fully consider the requirements of the particular applications and circumstances that may exist and carefully apply the concepts

described in this RP as appropriate. This document is not intended to present a tutorial on the subjects discussed, but rather to aid the reader in identifying and understanding the basic concepts of process control systems. The references provided within the document direct the reader to publications that describe one or more subjects in greater detail than is necessary or desirable for the purposes of this document.

1.1 Document Organization

This document is organized to follow the sequence of activities associated with the typical life cycle of a process control system as summarized in Table 1.

The life cycle phases as they apply to process control systems are as follows.

- *Appraise*. Develop business goals and requirements and identify basic functions required. This step is often also referred to as the Conceptual Stage.
- *Select*. Further develop business goals and functions into a process control systems scope definition. This step often is part of the early portion of front end engineering design (FEED).
- *Define*. Finalize process control systems scope definition, select hardware and software and prepare all applicable design drawings, specifications and procure other hardware and equipment. This step often forms the bulk of FEED.
- *Execute*. Detailed design and procurement, construction/installation, checkout, commissioning.
- *Operate*. Commission operate and maintain.

API 554 has been divided into three parts, each focusing on a major aspect of process control systems. The three parts and the areas that they cover are as follows.

- *Part 1, process control system functions and functional specifications*. Covers the basic functions that a process control system may need to perform, and describes recommended methodologies for determining the functional and integration requirements for a particular application.
- *Part 2, process control system design*. Covers the hardware and software applied to process control systems and provides recommendations for implementation. Design considerations and references to design practices for control centers and other control system buildings and enclosures are also provided.
- *Part 3, process control system project execution and ownership*. Covers project organization, skills and work processes required to execute a process control project and then to own and operate a process control system.

The portions of API 554 that deal with each phase of the life cycle are identified in Table 1.

2 Referenced Publications

A number of publications are either directly referenced in the discussions in Part 1, Part 2 and Part 3 of API 554, or are part of general collection of standards and practices upon which process control systems are based. These are listed for reference. However, the user of a particular publication is responsible for identifying the applicability of any of the references to a particular installation. Local jurisdiction requirements may supplement or override the contents of any of these publications.

API Recommended Practice 551, *Process Measurement Instrumentation*

API Recommended Practice 552, *Transmission Systems*

Table 1—Process Control Systems Life Cycle Overview

API 554 Section Number	Phase	Objectives	Major Inputs	Major Outputs
Part 1, Sec. 2	Appraise/conceptual design	Document the business goals and basis for the project	Process design, PFDs, equipment list, existing systems and infrastructure, layout, business objectives, operations staffing plan, corporate master plan, control system standards	Process control system conceptual design basis
Part 1, Sec. 3, 4	Select/FEED	Develop a functional specification describing the scope of the project, functional requirements and overall implementation responsibilities	Design basis, P&IDs, equipment lists, process hazard analysis Process control system conceptual design basis	Process control system functional specification
Part 2	Define/execute (FEED/ detailed design)	Prepare request for quote, issue, and select a vendor Specify hardware, I/O layouts and communications Design control centers, field devices, interconnecting wiring, instrument power Define control systems interfaces to other systems and hardware	Process control system functional specification Design standards and practices Documentation requirements	Hardware and software selection. Detailed specifications and installation/construction drawings
Part 3	Execute—project execution and management	Execute designs to meet cost, schedule and technical requirements	Project objectives, cost and schedule	Complete design drawings and specifications. Procurement of all materials and equipment. Implementation and testing of all software based functions
Parts 2, 3	Execute—construction and installation	Install, calibrate, and loop test instrumentation and control systems	Design drawings and specifications. Configuration and programming. Equipment and systems manuals	Process control systems ready for operation
Part 3	Operate—commission	Prepare process controls system for operation	Performance requirements	Process control systems in operation. All deficiencies identified and corrected
Part 3	Operate—operation	Operate process control system to best operational effectiveness	Performance requirements	Business revenue and minimal costs
Part 3	Operate—maintain	Maintain, preventative maintenance (PM) and repair process control systems	As-built documentation and training	Maximum unit performance and availability

API Recommended Practice 553, *Refinery Control Valves*

API Recommended Practice 555, *Process Analyzers*

API Recommended Practice 556, *Fired Heaters and Steam Generators*

API Recommended Practice 557, *Guide to Advanced Control Systems*

API Recommended Practice 750, *Management of Process Hazards*

AICHE G-12 ¹, *Guidelines for Safe Automation of Chemical Processes*

AICHE G-66, *Layer of Protection Analysis: Simplified Process Risk Assessment*

AICHE *Guidelines for Safe and Reliable Instrumented Protective Systems*

EEMUA 191 ², *Alarm Systems—A Guide to Design, Management and Procurement*

EEMUA 201, *Process Plant Control Desks Utilising Human-Computer Interfaces*

IEC 61131-3 ³, *Programmable Controllers, Part 3, Programming Languages*

IEC 61158 Parts 1 – 7, *Digital Data Communications for Measurement and Control—Fieldbus for Use in Industrial Control Systems*

IEC 61508 Parts 1 – 7, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems*

IEC 61511 Parts 1 – 3, *Functional Safety Instrumented Systems for the Process Industry Sector*

IEC 61512 Parts 1 – 3, *Batch Control*,

ISA 5.1–1984 (Reaffirmed 1992) ⁴, *Instrumentation Symbols and Identification*

ISA 5.2–1976 (Reaffirmed 1992), *Binary Logic Diagrams for Process Operations*

ISA 5.3–1983, *Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems*

ISA 5.4–1991, *Instrument Loop Diagrams*

ISA 5.5–1985, *Graphic Symbols for Process Displays*

ISA 18.1, *Annunciator Sequences and Specifications*

ISA 84.00.01 (IEC 61511 Mod), *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*

¹ American Institute of Chemical Engineers, Center for Chemical Process Safety, 3 Park Ave, New York, New York, 10016-5991, www.aiche.org/ccps/.

² Engineering Equipment and Materials Users' Association, 10-12 Lovat Lane, London, EC3R8DN, United Kingdom, www.eemua.org.

³ International Electrotechnical Commission, 3, rue de Varembe, P.O Box 131, CH-121 Geneva 20, Switzerland, www.iec.ch.

⁴ The Instrumentation, Systems, and Automation Society, 67 Alexander Drive, Research Triangle Park, North Carolina 27709, www.isa.org.

ISA TR84.00.03-2002, *Guidance for Testing of Process Sector Safety Instrumented Functions (SIF) Implemented as or Within Safety Instrumented Systems (SIS)*

ISA 88.01, *Batch Control—Part 1: Models and Terms*

ISA 91.00.01, *Identification of Emergency Shutdown Systems and Controls That Are Critical to Maintaining Safety in Process Industries*

ISA 95.00.01, *Enterprise-Control System Integration—Part 1: Models and Terminology*

ISA 98.00.01-2002, *Qualifications and Certification of Control System Technicians*

ISA TR98.00.02-2006, *Skill Standards for Control System Technicians*

ISA 99.00.01, *Security for Industrial Automation and Control Systems, Part 1: Terminology, Concepts, and Models*

ISA TR99.00.02, *Integrating Electronic Security into the Manufacturing and Control Systems Environment*

ISA 99.00.03, *Operating a Manufacturing and Control Systems Security Program*

ISA 99.00.04, *Specific Security Requirements for Manufacturing and Control Systems*

OSHA 29 CFR 1910⁵, *Code of Federal Regulations Title 29—Occupational Safety and Health Standards*

PIP PCESS001⁶, *Safety Instrumented Systems Guidelines*

PIP PCED001, *Guideline for Control System Documentation*

PIP PICO001, *Piping and Instrument Diagram Documentation Criteria*

3 Definitions

The following terms and definitions are used in API 554.

3.1

batch control

Refers to control functions that occur in a series of complex steps or phases that may combine continuous control, sequence control and discrete control to execute a processing scheme.

3.2

business network

Refers to a digital communications network that is used for general purpose business use such as desktop computing, non-process control data base applications or other general purpose applications. Typically, business networks use industry standard communications methods such as ethernet.

3.3

commissioning

Refers to the process of preparing a process control system and all of its components and field instrumentation for operation after all loop testing and validation testing has been completed.

⁵ Occupational Safety and Health Administration, U.S. Department of Labor, 200 Constitution Avenue, NW, Washington, D.C. 20210, www.osha.gov.

⁶ Process Industry Practices, 3925 West Braker Lane (R4500), Austin, Texas 78759, www.pip.org.

3.4**continuous control**

Refers to control functions that are continuously and repetitively executed to control the values of process variables such as a pressure, temperature, flow, etc. that are part of a continuous process such as a refining process, or within a portion of a process associated with a batch control system.

3.5**control loop**

Refers to that part of an instrument control system which includes the input sensor, transmitter, communication path, control algorithm and final control element. Control algorithm may be executed as one of many such algorithms in a process control system or be performed by stand alone electronic, pneumatic or mechanical devices.

3.6**demilitarized zone****DMZ**

Refers to an additional digital communications network that is inserted between a network that is exposed to the internet and public use networks and a protected network. In practice relative to this RP, a DMZ is located between a business LAN and the process control network.

3.7**discrete control**

Refers to control functions that involve on-off operations and interlocks. Discrete control variables are generally associated with thresholds above or below which a control action is taken. The control action is a discrete function such as opening or closing a valve, starting or stopping a motor, etc.

3.8**encryption**

Refers to the coding and decoding of data transmissions using algorithms and encryption keys that are known only to the sending and receiving devices. A wide variety of encryption techniques and algorithms are available and have varying levels of security associated with them.

3.9**enterprise resource planning****ERP**

Refers to systems that are used to identify and coordinate supplies of raw materials, intermediate materials, finished products, consumables and other material or resources required to operate a manufacturing business.

3.10**ethernet**

Refers to a networking standard that uses a single cable consisting of four pairs of wires to connect multiple computing devices together in a manner that does not require that any of the devices be aware of the other devices. Ethernet is an asynchronous communications method that allows messages to collide and which provides for a collision detection and a random pause and retry means of allowing multiple devices to communicate. Ethernet standards are defined in the IEEE 1802.x series of standards.

3.11**extensible markup language****XML**

A meta-language written to allow for the easy interchange of documents on the world wide web or among computers using web based software tools.

3.12**factory acceptance testing****FAT**

Refers to the testing performed on a process control system at the manufacturers, system integrators or other designated facility during which the engineer or owners perform all testing necessary to determine that the system is sufficiently complete and operable to allow for shipment to the site.

3.13**fieldbus**

Refers to a digital communication network that connects the field sensors, transmitters and control actuators together and to either a controller or control network. A fieldbus network allows devices to send and receive messages over a shared path. Devices may send current measurements and/or diagnostic messages and receive commands or configuration data.

3.14**firewall**

Refers to a combination of hardware and software installed on computers and network connections to prevent undesired messages from a digital network from reaching or passing through the computers. A firewall may also hide the presence of a computer from other computers on the network.

3.15**field devices**

Refers to any sensors, measuring devices, control elements etc. that are used to sense or directly control process conditions

3.16**highway addressable remote transducer****HART**

Refers to a communications protocol which provides a means of device communications using a phase shift carrier imposed over a pair of wires. The wires may be dedicated to the communications path or may also carry standard 4 mA to 20 mA analog signals. See www.hartcomm.org for more details.

3.17**hazard and operability analysis****HAZOP**

A hazard analysis technique for process plant safety analysis in which potential hazards and existing or necessary safeguards are identified.

3.18**front end engineering design****FEED**

Refers to engineering activities performed during the identification of project scope and costs. These activities are generally those necessary to develop designs to the point where scope and cost estimates can be supported.

3.19**human machine interface****HMI**

Refers to a computing resource for a process control system that is used as an operator or engineering interface for displaying data or inputting information or operating commands.

3.20**local area network****LAN**

A computer network connecting computers and other electronic equipment to create a communication system. These networks commonly use ethernet or similar communications methods.

3.21**Modbus**

Refers to an open standard query/response communication protocol that enables communications of numerical and discrete data between automation system devices using a variety of data communications methods. See www.modbus.org for additional information.

3.22**object linking and embedding****OLE**

Refers to a Microsoft standard which defines methods for applications to share common data and applications.

3.23**OLE for process control****OPC**

Refers to a series of standards that define methods for computers to exchange process control related information and application data using extensions of OLE standards. OPC standards provide a common practice for manufacturers of process control systems to make real time data available to other devices in a structured and deterministic way. See www.opcfoundation.org for additional information.

3.24**operability**

Refers to the characteristics of a process control system that allow the control system to be operated and maintained in a simple and reliable manner, but still provide all of the functionality and security required of the system.

3.25**personal computer****PC**

Refers to a computing resource that has multiple uses. It is intended for use by a single user and may have a number of non-control applications installed.

3.26**pre-startup safety review****PSSR**

Refers to a formal process at the time of acceptance of a unit or unit modifications that verifies that all pre-requisites for starting and operating the unit or facilities have been met. This included verification that all required punch list items have been completed and that all necessary training, procedures and other support requirements have been met.

3.27**process control module**

Refers to some type of computing resource, either of proprietary design or a commercially available computer, which performs process control related functions including data acquisition and control functions.

3.28**process control network**

Refers to a digital communications network that is used by process control modules, HMIs or other process control support computers to communicate with one another. This network may use proprietary or industry standard communications methods.

3.29**process control system**

Refers to a computer-based implementation of the control and information functions necessary to operate and manage a specific process unit or area. This includes field instrumentation, the communications between field devices and the control processors, HMIs and any other computers and communications required to support or report upon process performance. It does not include general-purpose business computers and networks, desktop workstations or other computing resources not used exclusively to operate a process unit or area. Safety instrumented systems are not part of the process control system.

3.30**process interlocks**

Refer to discrete control functions that cause automatic actions to occur but which are not specifically designated as being safety related.

3.31**process safety management**

A management process that results in process hazards being identified and suitable safeguards established, and which provides management of change procedures that ensure that changes to processes are similarly addressed.

3.32**process hazard analysis****PHA**

A hazard analysis technique for process plants.

3.33**3.34****redundant arrays of independent disks****RAID**

A distributed storage system spanning disk arrays and automated libraries of hard disks, optical disks, tapes or other bulk storage. RAID applications are often applied to ensure that data is duplicated among disks so that failure of any one disk will not cause loss of function or of the data saved.

3.35**reliability**

Refers to the probability that a system or device will perform its function when required.

3.36**router**

A communications network device that learns the location of devices on a multi-segment communications network and reduces traffic on any one segment by repeating messages only for the devices connected to that segment.

3.37**RS-232**

Refers to a serial digital communication standard that is used to communicate data over short distances between a pair of devices.

3.38**RS-422**

Refers to a serial digital communication standard that is used to communicate data over long distances between a pair of devices. RS-422 is very similar electrically to RS-485, but will work only for two devices.

3.39**RS-485**

Refers to a serial digital communication standard that is used to communicate data over long distances, and allows multiple devices be connected to a single channel.

3.40**safety instrumented system****SIS**

Refers to a system that is intended to protect against specific identified process hazards.

NOTE SIS are not within the scope of this RP.

3.41
safety integrity level
SIL

Refers to the availability required for SIS. SIL is a measure of the probability that the SIS will operate when required to.

3.42
safety requirements specification
SRS

Refers to a specification associated with a safety instrumented system that specifies basic functional, implementation, documentation and testing requirements that are to be met in order for the system to satisfy its intended safety integrity level.

3.43
sequencing control

Refers to control functions that involve a series of steps, usually involving discrete controls, that are executed in a pre-defined order and which may be repeated after all steps are completed. Normally, sequencing control is a portion of a larger processing scheme and does not produce a final or intermediate product.

3.44
site acceptance testing
SAT

Refers to the testing performed on a process control system at the operating site with the system fully installed in its operational configuration. During this testing, the engineer or owners perform all testing necessary to determine that the system is ready to be placed into service.

3.45
validation

Refers to the process of functional testing of protective, safety or other interlock functions to prove that the systems perform their intended functions. Validation is done after all underlying components, loops, etc. have been inspected, loop tested and accepted as complete.

3.46
virtual private network
VPN

The use of encryption to secure connection through an otherwise insecure network, typically the Internet. VPNs are generally cheaper than real private networks using private lines but rely on having the same encryption system at both ends. The encryption may be performed by firewall software or possibly by routers.

3.47
wide area network
WAN

A communications network that uses such devices as telephone lines to span a larger geographic area than can be covered by a LAN.

3.48
workstation

Refers to a computing resource that is used for general business functions such as e-mail, word processing, internet access, etc., but not used as a process control system HMI.

4 Scope and Objectives

API 554, Part 1 contains an extensive discussion of critical need to properly assess business requirements for a process control system and to develop a complete definition of functional requirements for the systems. As discussed in Part 1, process control systems technologies and applications have evolved to the point where they have become integral parts of business functions and their performance can have extended effects upon the business. This has

been done because of the numerous benefits associated with exploiting the technology, and a well designed process control system substantially contributes to high reliability and high performance operations.

API 554, Part 2 describes implementation of the functional requirements, but only contains minimal guidance on how these activities are executed or managed.

API 554, Part 3 is intended to identify and discuss key issues of organization, management, skill levels and resources associated with process control systems. These issues must be addressed as part of the design and ownership of these systems and the processing units which they operate. Failure to assure that adequate skills and resources are applied to execution and ownership can have serious impacts upon business success.

Among these issues are the following.

- The extremely close correlation between well planned, executed, operated and maintained process control systems designs and high reliability operations.
- The need to fully consider life cycle issues when making process control system related decisions.
- Major issues presented to projects relative to staffing and qualifications of personnel involved with design, testing and commissioning.
- The extremely important concept that procurement and physical design is only a portion of the tasks associated with process control systems. Functional design, maintainability, testing and training are extremely important requirements.
- Skills and qualifications of operations, maintenance and site technical personnel.
- Management obligations and responsibilities.

This document addresses recommended practices for identifying scope, planning, executing automation and owning and operating the results of projects associated with instrument and control systems. This document does not address implementation of advanced control system applications that may accompany an instrument and control system project. See API 557 for recommendations for advanced control systems.

5 Project Planning

As mentioned above, the increased business roles of process control systems requires that these functions be carefully considered when executing a project and that the process control system receives proper attention during project execution. The typical steps in execution of a project are briefly described below along with the additional considerations required for a well designed process control system.

API 554, Part 1 identified that a process control functional specification should be prepared for all projects as part of the project scope development. This specification should be carefully reviewed to assure that all requirements are recognized and included in the project execution plan. This may require specialized resources and additional schedule development.

Most instrument and control systems projects fall into one of several broad classes. The resources, skill levels and planning and coordination requirements will usually be strongly dependent upon the class of project.

These are:

- instrument and control systems required for a new processing unit or set of units that are associated with a new grass roots facility or expansion of an existing one;
- instrument and control systems modifications and additions required for a modification to an existing unit;
- a general retrofit of the automation systems for an existing unit or set of units.

If a project's scope, quality, cost and schedule are to be controlled, it is imperative that sufficient preliminary engineering be done to develop a project plan in enough detail to support the level of estimate required. The management of a project should assure that sufficient resources are supplied to allow for adequate process control system engineering be done and that this work not be deferred in favor of mechanical or other activities. Insufficient front end engineering for process control systems can easily cascade into the inability to execute detailed design activities in a timely and efficient manner.

The planning process for any of these types of automation projects consists of:

- identification of major portions of the work to be performed;
- quantification of the numbers and types of equipment involved; and
- the schedule for engineering and installation.

This process also must provide time and resources for activities that are not necessarily equipment oriented, such as application development, safety protective system identification and design, advanced control or complex applications, system security requirements, etc. The amount of information necessary for scope definition and planning of these projects will vary with the type of project and the phase of the planning for the overall project.

One often neglected aspect of instrumentation and control projects are modifications that are required in areas outside of the immediate area of a plant being constructed or modified. These scope items often deal with process control system infrastructure, power distribution, utilities, feed, intermediate and product distribution, tankage and similar areas. These areas are often the most difficult to engineer because they tend to be geographically scattered, may interface to different existing control systems, existing systems may be poorly documented and infrastructure may not be adequate to support the new work without upgrade.

5.1 Define/Execute Project Scope

During the initial project phases, the process control system functional specification should have been developed and used as the basis for preliminary estimates and for further scope development for project definition and execution. The define/execute project scope development process should address hardware and software selection as well as more detailed analysis of the project execution plan and schedule. The following discussions highlight several of the significant items that should be addressed during these scope development activities.

5.1.1 Project Characteristics

Scope and planning activities must consider the type of project involved and the limitations that may be placed upon schedule and execution of work.

- Projects that involve new installations on new units are the most straightforward to plan. Completion of design specifications and drawings, delivery of material, installation and loop check and commissioning follow well understood practices and can generally be scheduled to maximize efficiency.

- Projects that involve modifications to existing facilities can be much more complex to schedule and execute. The scope and planning process must recognize constraints that working with an ongoing operation and infrastructure place upon a project.
- Projects that are upgrades of existing process control systems involve relatively little equipment compared to process modifications, but usually have a much higher engineering content as a percentage of total budget. These projects also usually involve hot cut-over of the process control system which must be carefully planned, scheduled and executed.

Installation and commissioning schedules will often be governed by expected unit turnarounds.

Installation and commissioning time may be quite limited and may be affected by other turnaround activities. Scheduling of work during a turnaround generally has to be meticulous and be coordinated with other general maintenance activities.

The turnaround schedule may require that the amount of pre-installation, pre-testing and pre-commissioning be maximized. Work done while a unit is in operation will not be as efficient and will have to be carefully executed and special permitting and work rules may be necessary. In some cases, on-stream transfers of control functions may be required. This will require careful planning and coordination with operations and maintenance personnel to safely isolate systems and to test and commission the modifications, and usually require that step-by-step isolation, tie-in and commissioning procedures be prepared.

5.1.2 Process Control System Life Cycle

Table 1 summarizes a typical project life cycle and identifies major inputs and outputs associated with each step. All process control system scope and execution decisions must be made with this life cycle clearly in mind. All components must be selected to be consistent with the overall business goals of the projects and must provide the reliability and maintainability necessary to meet those goals.

Many times it may appear that simplification or scope reduction would benefit a project, but any proposals to do so must be carefully examined against the long term business aspects. A decision to reduce costs or compress schedule by changing the process control system design may have profound impacts upon the overall business plan and require remedial actions later in the project when such actions may be expensive and disruptive.

5.1.3 Process Control System Functional Development

Development of process control systems functions involves both physical design, such as identification and installation of system hardware, and non-physical design on a variety of activities such as system configuration and programming and implementation of many software functions such as historians, advanced control schemes, complex logic, sequences and protective shutdowns. The project execution plan and schedule must identify the non-physical project scope items and tasks and provide adequate resources, cost and schedule.

The project execution plan must be able to incorporate the needs for both the physical and non-physical design and implementation activities. For example, more often than not, control system design shown on P&ID's may still be only indicative of intent and not necessarily complete although other mechanical and piping aspects are substantially complete. The design engineers must be able to modify control system P&ID representation to fit developments in control systems detail despite the frozen state of the piping and mechanical information on the drawings.

At the same time, it is incumbent upon the design organization to make P&ID representation of control systems as complete as possible, and to understand the difference between development of design intent versus items that may be true scope changes. Artificial freezing of designs that are not complete as a means of scope control is seldom good economics. The work not completed in the design office usually translates to significant changes in the field during construction, checkout and commissioning and ultimately affects the quality of the overall design and shows up in operating and maintenance costs

5.1.4 Process Control Systems Selection

Selection of a process control system for a project is usually not a decision that can be based solely upon cost and performance. If a facility has an existing process control system, its operation and support is typically a strong contributor to the facility operations and maintenance culture. Normally, a new process control system in an existing facility is chosen to match the existing systems, and there must be substantial justification from a life cycle cost and required function evaluation to make a change.

Even with such an analysis, selection of the process control system for a project must involve the participation and buy-in of the facility personnel from a number of job functions. Normally the selection of a process control system must consider the long range process automation and information systems plans for a facility.

The following are some of the life-cycle issues that must be considered when selecting a process control system.

- Is there an existing process control system that the project must expand or modify?
- If a new process control system is required for the project, does the facility have existing systems with which the new system must be compatible?
- If an upgrade or replacement of an existing process control system is involved, have the benefits of better using the capabilities of the new system to improve process performance been fully considered?
- What are the costs associated with training of engineering, operations and maintenance personnel to support the process control system? Prior training and experience with an existing system may far override any perceived cost savings associated with an alternative process control system.
- What are the costs associated with maintaining an inventory of spare parts?
- What is the scope and costs associated with interfacing functions such as historians and advanced process control systems?
- If an alternative process control system is being considered, does the facility have the personnel to support the system? This is often a very significant issue. While selection of an alternative process control system may appear to be attractive, even when training and support costs are considered, a facility may not have the staff available to support multiple process control systems in the same facility.

See API 554, Part 1 for further discussion of process control system selection considerations.

5.1.5 Field Instrument Selection

Definition of the scope for a project's field instrumentation is normally not as complex as for selection of the process control system, but life cycle costs must still be considered. Among the considerations for selection of field instruments are as follows.

- What are the existing instruments within an existing facility? Would selection of a specific line of instrumentation allow leveraging of existing training, spare parts and support hardware and software?
- What transmission methods will be used? If fieldbus or other digital communications methods are used, the selection of instruments must be consistent with those plans, and the list of allowable instruments may be considerably reduced.
- Does the facility have an instrumentation asset management system in place? If so, the selection of instrumentation may give strong preference to those devices compatible with the system.

- Are there any company-wide procurement agreements that would favor selection of one line of instruments over another? The impact of utilization of such agreements may have effects beyond the scope of the project as provisions may trigger or deny benefits to other projects or facilities.
- What local support is available? Does the manufacturer have a parts depot or repair facility nearby? Does the manufacturer have strong local representation?
- What support equipment and software must be purchased with the equipment? Can selection of one line of instruments leverage the use of this equipment?

API 551, API 553 and API 555 provide guidance on selection of field instrumentation and analyzers, as do other industry standards published by organizations such as ISA and PIP.

5.1.6 Safety and Protective Systems

While a detailed discussion of safety and protective systems design is not included in the scope of API 554, projects need to recognize the complex and specialized engineering and documentation requirements associated with these systems. See ANSI/ISA 84.00.01 and IEC 61511 for requirements and CCPS publications for application guidance.

Depending upon the potential quantity of such systems on a project, the services of a full or part time safety instrumented systems engineer may be required. The SIS engineer will generally be a senior level owner, contractor or third party control systems engineer who is knowledgeable in the requirements for SISs.

5.1.7 Analyzers

A specific process may require specialized product, feed or intermediate quality analyzers or may require analyzers for regulatory reporting. These systems can be very complex and require specialized and dedicated resources.

5.1.8 Other Sub-systems

A process control system may also have to incorporate specialized functions such as machinery monitors, package skid mounted equipment, etc. The project execution plan should take the design and support requirements of these systems into account.

5.1.9 New Technology

During the project development process described in API 554, Part 1, varying applications of new technologies may have been identified as part of the project scope. When this is done, the project plan must include all resources, cost and time required to properly implement this technology. Often this is recognized during project development activities, but may not carry over to the detailed engineering phases of a project unless care is taken to assure that these types of issues are recognized.

The use of new technologies may also have significant effects on how a project executed, subsequent operation and maintenance practices and personnel. The project execution plan also needs to provide for these issues.

5.1.10 Project Schedule

The procurement, installation and commissioning requirements for a process control system must be thoroughly reviewed against construction schedules for the rest of the project. It is not unusual for the time allocated to process control systems to be unacceptably compressed by slip in mechanical construction activities. The following items

should be reviewed and the required time for execution should be clearly defined relative to other project milestones and precursors within the project's engineering, procurement and construction activities.

- Adequate time needs to be allowed in the engineering schedules to allow for all non-procurement or physical design activities to be performed. It is especially critical that process control system and safety instrumented systems definition activities be completed prior to the start of significant procurement activities for these systems or associated field instrumentation.
- The construction schedule should explicitly show start and end dates and dependent precursors for installation of instrumentation and control systems. This schedule should be in enough detail to clearly identify the time needed for these activities after necessary supporting construction activities are complete.
- A testing and commissioning schedule should be created which shows all activities that need to be completed after the traditional mechanical completion milestone. These activities may include process control system field acceptance testing, instrument field calibration, safety instrumented systems validation testing, analyzer commissioning and testing and validation of sequential control applications. This schedule is critical to proper scheduling of other plant commissioning and startup activities as most of this activity cannot start until very late in the construction schedule and often cannot be completed until after mechanical completion. Commissioning and startup cannot commence until these activities are complete.
- A training schedule for process control system showing the duration and timing of all required engineering, operator and maintenance technician training required for both engineering activities and inspection, testing, commissioning and startup activities.
- A project close out schedule showing activities necessary to update and transfer to facility records of all process control system documentation.

6 Project Execution

6.1 Overview

The scope of process control systems are such that a variety of skills and experience will be required to successfully implement all of the required functions, and do so in a manner which will be safe, reliable and readily maintained. Project staffing plans should examine the requirements of the project against the available resources and skills. Typical skills and functional divisions of work are described below. It may be advisable to utilize specialized personnel for these functions and coordinate their activities with main stream project activities.

6.2 Resources and Staffing

6.2.1 Traditional Engineer-procure-construct (EPC)

The traditional engineering contractor typically brings strong project management skills along with the organization to provide necessary procurement and physical design services. However, it is not usual to find that the extensive specialized skills that are necessary to specify, engineer, test and commission many of the current complex process control systems currently available are not available within general EPC organization.

6.2.2 Specialty Resources—Main Automation Contractor

For many projects, especially those involving new process control systems and equipment or software that is not already being extensively used, the selection of a specialty organization to perform the design, configuration, testing and commissioning activities may be desirable. Such organizations are generally quite skilled in the application of specific systems and provide value in reduced costs, more skillful application of the systems, and improved final reliability and performance.

A main automation contractor may not be able to provide other services related to the system such as physical designs, building design, electrical distribution, etc. Therefore, often a main automation contractor performs specific functions within a larger design organization. When such organizations are selected care must be taken to ensure that third party participation is coordinated so that gaps do not exist, and that all deliverables meet the requirements of the end user.

6.2.3 Owner's Staff

Owner's staff, when available, can provide substantial value in guiding the designs for a project to ensure that they are consistent with existing practices and are of acceptable quality. However, this generally is an extremely limited resource.

6.2.4 New Technology Application Support

As mentioned above, a project scope may include applications of new technologies. When this is the case, it will often be necessary to obtain specialized assistance in implementing the technology and training personnel. It also may be necessary to provide for this support during testing, commissioning and initial operation.

6.2.5 Third Party Engineering and Package Systems Suppliers

Often it is desirable to assign scope of work to third parties, particularly suppliers of major equipment. This can provide value, but when process control systems are involved, the net value must be carefully evaluated. The viability of a process control system depends greatly upon the quality and consistency of work, and often it makes business sense to limit the scope of package suppliers to mechanical equipment and very basic instrumentation, and require that any more sophisticated controls be implemented by, or coordinated with the main contractor selected to perform all process control system work.

6.3 Standards and Practices

All instrument and control system projects should be governed by a set of engineering and design standards. These standards may be composed of a full set or combination of owner's standards, contractor's standards or industry standards. The standards to be used should be identified and prepared as early in the project as possible. If standards must be prepared for a specific project, sufficient time in the project schedule must be allowed for this activity.

The standards set should address the following major areas:

- general control system engineering and design practice including identification of local regulations that apply, device and tagging naming practices;
- the required review and approval process for the project;
- functional and physical requirements for various common devices found in instrument and control systems;
- applicable local codes and regulatory requirements;
- drawing and documentation requirements;
- process control system design, configuration practices and standards, including graphics standards and practices;
- safety Instrumented system design, documentation and test practices;
- standard Instrument installation details and installation material specifications;
- construction inspection requirements;

- calibration and loop check practices;
- safety and protective system testing, validation and acceptance practices; and
- as-built documentation requirements.

6.3.1 Documentation and Design Drawing Standards

Most facilities will have established practices on the types and format for various design drawings. The required documentation must be understood, as well as the formats and procedures associated with those drawings. If the project is associated with existing processes, there may be a significant procedure associated with access to existing drawings and return of as built versions to the permanent files. In some facilities, there may be many parallel projects active in the same area. In these situations, care must be taken to ensure that one project's as-built drawings do not affect those of another.

6.3.2 P&ID Development

On most projects, design efforts are centered on development of piping and instrument diagrams (P&IDs) which show all piping components, physical instruments, and, to varying extent, control functions implemented in programmable control system. P&ID practices vary widely from organization to organization. Some standards organizations such as ISA and PIP have developed standards for P&ID representations.

No matter what P&ID standard is used, it is important that control system functions be clearly and completely developed. Through necessity, control systems details may lag those of piping and equipment. It is a common practice to "freeze" P&IDs at some point in design effort as means of scope and cost control. It is of critical importance that the state of the process control system design at the time P&IDs are frozen be understood.

6.3.3 Process Safety Management Documentation

Many documents associated with process units may be designated as having process safety management (PSM) significance and may be required to contain specific information and be subject to approvals outside the normal project document handling procedures. These drawings may also have restrictions on how they are handled and who may change them.

6.4 Design Data Management

6.4.1 Electronic Documentation

Many facilities may have electronic documentation systems in place, or a project may have plans to use specific applications. Examples of these are P&ID and other drafting or database applications, electronic instrument data bases, or electronic process control system data storage and presentation applications. The project plan must identify these requirements and be able to comply with both the final documentation format and any procedures that exist for these applications.

6.4.2 Process Control System Configuration

Most process control system manufacturers provide tools that allow for system configuration to be substantially completed off line without the need for process control system hardware to be available. In some applications, such as fieldbus, it also may be possible to perform configuration of all or most field devices using these tools.

In some applications, an electronic documentation system may have capabilities to generate process control system configuration. These functions may have benefits, but must also be integrated with how the plant manages this data. The capabilities of the electronic documentation system need to be reviewed against other tools available prior to making a decision on how configuration tasks are completed.

6.4.3 Maintenance Management Systems

Many facilities have a centralized maintenance management system that may be used to contain engineering specification data, manufacturer's data, equipment numbers etc., and which is also generally used to schedule and track maintenance activities and record maintenance and repair records. The applications used and the scope of their use can vary widely from company to company and site to site.

The project must identify requirements in this area and establish how these data bases will be populated with new or revised data.

6.5 Procurement

Procurement activities consist of solicitation of proposals and selection of suppliers for all engineered and bulk materials required by the scope of a project. Procurement activities should consist of the following general functions.

6.5.1 Engineered Equipment Specifications

Engineered equipment requires that the functional and mechanical requirements for the instrumentation or process control system be defined in data sheets, narrative specifications, drawings or a combination of these. Any requests for proposals must have complete specifications provided to be the basis for the proposal.

When the scope of engineered equipment includes process control system components, it should be required that the supplier of the equipment adhere to supply and design requirements accepted by the plant. With the exception of specialty or proprietary designs, components that are provided with engineered equipment should be limited to those that are already in general use by the plant or which are the same as those being provided for other portions of the project.

6.5.2 Acceptable Supplier Identification

Most owners or operators have a list of preferred or required suppliers for equipment and material. Often these are based upon existing installations, plant familiarity and general procurement agreements that have been established outside of a particular project.

The list of acceptable or required suppliers should be prepared for a project. Procurement for the project should be required to adhere to the list unless otherwise provided direction. In some cases, the required suppliers list will require sole source awards based upon the owner or operator's commercial agreements.

6.5.3 Solicitation of Proposals and Supplier Selection

When proposals from prospective suppliers are received, conditioning of those proposals must be performed to obtain a true view of the technical compliance and commercial value of the proposals. This conditioning must properly weight owner or operator's existing installations and commercial agreements. A low bidder may not be acceptable for a variety of reasons, but a common reason may be that the low bidder is not an existing supplier or does not have a significant installed base, and that the proposal does not offer net value when training, spare parts and other support costs are considered.

6.5.4 Review of Supplier Drawings and Specifications

Once an award is made, the supplier is typically required to submit detailed drawings and specifications of the equipment or material to be provided. These drawings need to be reviewed with the intent of verifying that the design meets the requirements, equipment supplied complies with the list of acceptable suppliers and models, and that the supplier has provided sufficient data to allow for design of interfaces to the equipment.

6.5.5 Integration of Supplier Information into Design Drawings

Often supplier data needs to be integrated with a plant's basic set of design drawings. This is usually necessary to allow this information to be included within the drawings that are regularly maintained by the plant. Many owner operators have standards and practices that define what vendor supplied data needs to be incorporated into the basic drawing set. Some examples of these are as follows.

- Instrumentation datasheets may be required to be submitted in, or transferred to the owner or operator's standard format. Many times this involves importation of data or manual entry into plant data bases.
- P&IDs may need to be modified to include vendor equipment details.
- Documentation of logic systems may need to be presented in site standard format. This includes logic diagrams, descriptions and routine testing procedures.
- Schematics or interconnecting wiring drawings may need to be presented in a standard format.

The requirements for integration of supplier drawings into an owner or operator's drawing practices needs to be considered when preparing specifications, selection of suppliers and in planning for project close out.

6.5.6 Equipment Inspection and Testing

Engineered equipment typically requires some level of source inspection or testing. These requirements should be clearly defined in technical specifications and requests for proposal. The scope of inspection or testing may require witnessing by the design engineers and/or owner's representatives and will generally constitute a hold point for delivery of the equipment. In many applications for process control systems, use of inspectors not directly involved with the engineering of a project is not acceptable because of the detailed knowledge of the application and equipment required.

6.6 Physical Design

Physical design consists of activities required to support installation of the process control system equipment. This includes such items as locations of equipment, routing of wiring, conduit and process connections, instrument mounting, etc. A discussion of these practices is beyond the scope of this document, although API 551 and API 553 describe some physical installation practices.

6.7 Construction

Construction planning and scheduling must recognize activities associated with installing, testing and commissioning process control systems. This process needs to address the following:

- installation of field instrumentation and associated wiring and communications systems;
- installation of process control system control modules or other support systems such as historians, advanced control systems, etc. and the thorough testing of these systems;
- control centers and other buildings such as analyzer shelters, satellite equipment rooms or shelters;
- other complex systems such as machinery monitoring, process sequence controls etc.;
- power supply and distribution systems;
- communications networks;
- demolition scope and timing;

- hot cut-over and tie-ins;
- testing and commissioning of control, indication and alarm loops;
- testing and validation of protective systems such as SIS; and
- testing and commissioning of advanced control systems.

The required time and resources for all these activities must be made part of the overall construction schedule and that activities be identified in detail. Mechanical installation or other activities must be scheduled so that there is adequate time for process control system related work within the expected completion date. See Section 7 for additional information.

6.8 Training

Training of plant engineering, operations, maintenance personnel needs to be an integral part of project planning. Each project should have a training plan developed that addresses all training required to design, test, operate and maintain the process control system. This plan must include owner's personnel as well as project members. Training requirements may dictate construction and checkout schedule milestones as much of the necessary training may not be able to be done until construction and checkout are substantially complete.

Engineering training is frequently the first training offered. Some of the process engineers and/or control engineers will be intimately involved in the project and will be involved in configuration of the control application from the beginning of the project. Understanding the system is a requirement to be able to contribute to the project team as the control application is developed.

Operator training should be scheduled a reasonable time before the system is installed and the operators will be required to use the system. Scheduling this training immediately before installation will ensure that the training is fresh in the minds of the operators. Scheduling of limited operator training earlier may generate useful feedback from the operators that can be incorporated in the system; i.e. graphic layout, alarms, etc.

Usually all or part of the process control system must be available to support operator training, or a separate training system must be provided. Full simulators are often necessary to provide adequate training to operators in both the basic operation of the process control system and training for handling of abnormal situations. See API 554, Part 1 for a discussion of identifying the need for training simulators.

Maintenance training must be completed before installation and the instrument maintenance personnel should participate in the installation. However training should be conducted immediately before the equipment is to be installed and commissioned unless specific individuals require the training to support the project.

6.9 Testing, Validation and Commissioning

A plan should be developed during logic and sequence system design which identifies the testing, validation and commissioning activities that must take place before a logic or sequence system can be placed into service. Where appropriate, such as for safety and protective systems, detailed testing procedures should be prepared. See Section 7 for a more detailed discussion of the various testing and validation practices that should be followed.

6.10 Project Close Out

During loop checking and startup activities key process control system documentation should be updated to as-built status. Process safety management requires that a complete set of up-to-date documentation be available to operations and maintenance personnel. Therefore, until as-built documentation can be issued, it may be necessary to maintain a set of current mark-ups of construction drawings and data in the control center or other accessible location.

It is recommended that at a minimum the following drawings be updated to as built status and maintained in an as-built condition for the life of a plant:

- process flow diagrams;
- P&IDs;
- logic diagrams and descriptions;
- instrument datasheets;
- instrument loop diagrams;
- alarm lists and settings;
- critical instrument lists;
- instrument terminal box and control panel interconnecting wiring drawings; and
- control system configuration including process control system or PLC programs.

7 Testing, Validation and Commissioning

7.1 Planning

During construction planning activities, the scope and schedule for loop testing, safety and protective system testing and validation and cut-over should be established on a project by project basis. This planning should address the following.

- The schedule and extent of testing required for the main control system equipment and software including the scope of factory and site acceptance testing. Site acceptance testing (SAT) may become an extended activity depending upon the timeliness and completeness of the factory acceptance testing, or if extensive networks or interactions with other systems exist. Many times interfaces to existing systems cannot be tested until the process control system is installed and functional. See 7.2 for further discussion.
- The schedule for inspection, calibration and loop checking relative to mechanical completion. It is essential that adequate time be allowed for calibration and loop checking after mechanical installation work has been completed. A common issue with construction schedules is that mechanical completion schedules do not recognize the time it really takes to complete loop testing and protective and safety system validation.
- Identify the extent of bench calibration that will be done during construction, and the extent of calibration that will be done in the field during loop testing. Normally, current design digital instruments are not bench calibrated, but configuration data checks may need to be done.
- Define the procedure that loop testing will follow for each major type of loop. See loop testing procedures below.
- Identify all personnel required to support loop testing. This list should include sufficient resources at the process control system console to support loop checking, instrument supplier personnel to support specialty instruments,

and the owners maintenance and operations personnel that may be required to witness and sign off on loop testing.

- Identify all complex instrumentation, analyzer systems, etc. that require more than the routine amount of configuration, testing, commissioning and validation and show required support and time requirements.
- Identify all logic and interlock systems that require formal testing beyond the basic scope of loop testing. Define the personnel and time required to perform this testing. Identify systems that require formal written test procedures.

7.2 Main Process Control System

The planning and execution process for construction of instrumentation and control systems depends greatly upon the size and complexity of a project. Small projects may require little formal planning other than the normal workforce and schedule allocation work normally done by any constructor. Larger projects, particularly projects that involve interface with existing systems, installation of significant process control system equipment, or which involve interlocks or safety instrumented systems, require more significant planning. These activities will be addressed:

- hardware testing;
- factory acceptance test (FAT);
- physical installation;
- SAT;
- loop cutover/system validation; and
- commissioning and adjustments.

Prior to any system testing and commissioning, the technical staff must complete training on the new system. The process control system manufacturer will offer a variety of training courses, but as a minimum the process and control engineering staff will require training on application configuration, graphic building, etc. the instrument personnel will require training on hardware maintenance and all of the operators and supervisors will require training in use of the system.

Once an instrumentation and control project has been scoped, an overall construction plan should be developed. The plan should address:

- overall construction schedule with time lines for all activities identified;
- approved plans for system installation;
- approved procedures for hardware testing, factory acceptance, site acceptance and cutover;
- pre-start up safety review (PSSR); and
- management of change (MOC) procedures.

7.2.1 Hardware Inspection/Testing (FHT)

Prior to beginning the FAT, the process control system manufacturer should conduct an internal factory hardware test (FHT) which covers inspection of all parts as defined by the bill of material (BOM) and a 100% system I/O check.

NOTE The I/O check may not be possible in some cases; i.e. fieldbus I/O or remote I/O provided by others or shipped early. The FHT records are reference material for the FAT.

7.2.2 Factory Acceptance Test (FAT)

The FAT will usually test the system as defined by a functional design document, a detailed design document and system architecture drawings. A FAT will normally include testing hardware functionality, application functionality and integration with other systems.

The FAT will typically include testing of:

- operator stations;
- field control stations;
- process control system communication network(s);
- process control system I/O;
- engineering work stations;
- marshalling cabinets;
- historians;
- advanced control stations; and
- integration with other systems (safety systems, compressor controls, etc.).

Before beginning the FAT, a detailed FAT manual should be created and approved by the vendor and the end user. This document should list the scope of testing in detail, a schedule for the FAT, a detailed listing of the tests to be conducted and the acceptable results. The document will have space to document the results of the test and also for acceptance signatures and dates. In addition, a “punch list” of non-conformance will be created during the test. Each item on the punch list must be corrected and the correction demonstrated before beginning the loop cutovers.

7.2.2.1 FAT Procedure

The purpose of the FAT procedures is to identify the step-by-step procedure used for performing each test and to record the results of the test. Each test procedure should contain the following sections:

- objective;
- reference (documentation);
- procedure steps;
- criteria (acceptable results); and
- results check sheet/comments/test record sign-off sheet.

The FAT manual contains design information that was used to configure the process control system, and records any exceptions (variations) that may be discovered during testing.

7.2.2.2 Hardware Testing

The intent of the hardware testing is to ensure that the particular hardware components are correctly manufactured, integrated and configured as per the approved system specification.

This part of the FAT provides structured and step-by-step procedures to demonstrate that the hardware operates without any performance or communication errors. Testing activities include:

- system hardware inspection (appearance, construction and size);
- visual and mechanical examinations of system connectivity;
- inspect and verify all component and cable labeling or other identification;
- communications configuration and functionality;
- system redundancy, including testing of back up control, I/O, communications and power redundancy functions;
- power on and off sequences;
- peripheral connection and functionality, etc.; and
- random I/O check from field side of marshalling cabinet.

7.2.2.3 Configuration Testing

Configuration testing should provide a means of verifying the process control system software functions and application programming and configuration. The scope of this testing may vary with the scope of the process control system, but the following activities are typically included as part of the factory FAT:

- pre-FAT paper check;
- application software check;
- regulatory control;
- sequence control;
- historical functions;
- graphic display test;
- HMI assignment check;
- historian and sequence of events recording (SER);
- network function;
- time synchronization; and
- network loading.

7.2.3 Systems Integration Testing

This section addresses the need to test integration and communications links between the process control system and other auxiliary systems. See 7.5 for discussion of testing for these separate systems.

In many applications, the process control system will be assembled and tested as one or more separate systems. These may be a safety system, compressor control system, separate logic system, PLC, analyzer systems, etc. These systems may have a separate acceptance testing procedure. In the case of safety systems, other organizations provide guidance on testing procedures. See ISA 84.0.01 and IEC 61511 for information in safety requirements specifications.

In most cases, there will be requirements for information to be passed between the process control system and these other systems. These interface requirements will be defined in the process control system functional specification (see API 554, Part 1) and should be tested as part of the FAT. For small systems (PLCs, etc.), the sub-system may be integrated with the process control system on the factory floor and the interface tested as part of the FAT. In the case of larger systems, only a portion of the process control system may be taken to that factory floor and integrated. In these cases, testing of all communication functions between portions of the process control systems must be planned for and conducted in the field after the complete process control system has been installed. If this is the case, provisions need to be made in the overall construction and testing schedule.

7.2.4 Installation/Construction

This activity is separate from testing and falls between the FAT and the SAT. This involves, physically installing the process control system cabinets and consoles and wiring I/O to marshalling panels, junction boxes, etc. Physical connection to instrumentation and final control elements is not part of this activity.

During project planning activities, the organization responsible for process control system installation should be identified. For large process control systems, this may be handled by the main automation contractor. For small systems, the end user may take responsibility for this activity. In either case, there are a few important issues that must be addressed carefully.

Prior to the start of installation of the process control system equipment, control centers, satellite buildings or other enclosures for the equipment should have been completed with all basic power, HVAC, lighting and similar utilities complete and in service. Completion of buildings may require a separate testing and acceptance process and may require local jurisdiction inspection and permits to occupy. If the final facilities are not available at the time of equipment arrival on site, alternative protected and climate controlled storage may be required.

Power and grounding requirements must be specified as part of the process control system functional design. The requirements specified must be followed. In some cases, this may involve a main power source, a backup power source and/or an un-interruptible power supply (UPS). See API 554, Part 2 for guidance on power system and grounding design.

7.2.5 Site Acceptance Test (SAT)

Usually, the SAT will be much shorter and involve much less testing than the FAT. However, this depends greatly upon the scope and completeness of the FAT. The systems and all of the components of the system as well as interfaces to other systems should have been tested in detail and documented in the factory acceptance test. The site acceptance test will normally be a subset of the FAT. Testing may end at the process control system I/O terminations since each loop will be tested thoroughly during commissioning.

The SAT is generally the first opportunity for all network and communications interconnections to be tested. Even if these tests were performed in the factory, full validation of communications with field installed equipment is necessary to identify any unexpected problems due to installation or unidentified interactions.

A small, representative sample of the I/O should be retested to guarantee that all of the cables have been reinstalled correctly and the individual I/O cards are still seated correctly. Testing a few representative points should satisfy this requirement, but this is dependent upon local owner requirements. Also, each HMI console should be tested to guarantee that communications with the rest of the system components is functioning. Each interface to other systems should be retested. However, it is usually not necessary to check each individual point across the interface, provided that these points have been previously tested.

At this stage there is little need to retest the control configuration. However, once the process control database is reloaded, it should be spot checked to verify that the data is the same as used during FAT. In some simpler installations, the process control system data base may be loaded for the first time, in which case a full check should be performed. Also, individual tag and loop function will be checked as part of loop checking (see 7.3.3).

Regardless of the scope of the SAT, a test plan procedure should be written and accepted by both the vendor and end user before beginning the SAT. This procedure document should have the same format as the FAT manual and capture results of the test and approvals.

7.3 Field Installations

7.3.1 Inspection

The inspection process is intended to provide assurance that instrumentation is properly installed and is ready for testing and formal acceptance. Instrumentation inspectors should be independent of the installation organization. General functions of the instrument inspector are as follows.

- Perform a critical visual inspection for damage that may have occurred during installation. Check connections for correctness and obvious irregularities, such as loose piping or tubing fittings, loose wiring, and improperly secured printed circuit boards. Ensure that shipping stops, supports, or packing materials have been removed (note that at receipt of instrumentation, the instruments should have been checked by the constructor for compliance to the specifications).
- Inspect each instrument item to certify that it conforms to instrument datasheet and installation detail drawing.
- Verify that all applicable local electrical and piping codes and practices have been followed. Inspect also for correct hazardous area classification and proper environmental protection.
- Verify that the installation of the instrument is accessible for maintenance or any routine operational access and that the location of the instrument, piping and electrical does not interfere with walkways and operations or maintenance access to other equipment.
- Verify that all required wire tagging, instrument labeling and any advisory or warning labeling has been properly installed.

7.3.2 Calibration and Device Testing

New instrumentation and valves will typically be tested and calibrated before installation in the field. In these cases, records should be collected and included with other loop documentation prior to testing the loop itself.

7.3.3 Loop Testing

A record of inspection, calibration and testing should be kept for each instrument or instrument loop. This typically takes the form of a folder for each instrument or instrument loops which is used to record test results and field modifications. Worksheet guides for instrument records are available from a number of sources. Use of electronic technologies is expanding and use of handhelds or tablet PCs may be used for these applications.

The format should include the following:

- tag number;
- datasheets for each instrument including manufacturer, model, and serial number;
- reference P&ID, loop diagrams, interconnecting wiring drawings or schematic drawings as applicable;
- calibration data;
- date of acceptance test;
- condition of instrument, as found;
- corrective action taken;
- condition of instrument, as left;
- recommendation for further action or disposition; and
- sign-off forms for all witnessed inspections and tests.

Written loop testing procedures should be defined including the required witness and sign-off by the owner's designated representatives. General loop testing should include the following general steps.

- Follow the manufacturer's instruction manual carefully.
- Apply a suitable source of air and/or electrical power to the appropriate connections. For digital devices, verify that the device is properly configured.
- Provide an appropriate variable input signal to simulate the process variable.
- Connect the output to a suitable scaled electronic test meter or test gauge. Many digital instruments can be checked via a direct indication on a hand held device or at process control system displays.
- Verify process control system configuration data including control algorithms, direct and reverse action, starting turning constants or other configuration information. Verify that alarm settings and priorities are set per the design requirements.
- Perform a complete loop test. Verify that the correct transmitter is connected to the process control system input and that all process control system displays are correct.
- Check all process control system displays including operator graphics and any engineering detail graphics.
- For control loops, use the manual output to stroke the control valve or other output device. Check that the controller action (direct or reverse) has been set properly and the control valve failure position is correct. If the control valve is provided with a smart positioner, verify that the configuration set up has been properly performed (see API 553).
- Test control valve fail action and operation of any accessories such as boosters, positioners, transmitters, solenoid valves, etc.

Newer process control systems often have features that can greatly improve the loop check process. For example, fieldbus or other network applications such as instrument asset management systems can allow the bulk of loop

testing to be done from the process control system console with only minimal field interaction, generally only to verify valve movement and spot test field instruments. When such systems are available, loop check procedures should identify how they will be applied and how much traditional field instrument testing, such as valve stroking, pumping up transmitters, etc. is required.

7.4 Tie-ins and Hot Cut-overs

Depending upon the type of project, cut-over may be conducted “hot” (with plant running) or “cold” (with plant not running and in a safe condition). Hot cut-overs will require additional planning and coordination with operations. As each loop is cut over, responsibility for that loop is transferred to operations. Hot cut-overs may require detailed step by step procedures to ensure that the loops are properly isolated for cutover, fully tested and safely returned to operation.

7.5 Other Systems

The process control system testing plan should identify and make schedule and resource allowances for testing and validation of other systems that tie into the process control system.

7.5.1 Interlocks and Sequence Systems

The process control system testing plan should identify and make schedule and resource allowances for testing and validation of all discrete interlock and shutdown systems. These systems are separate from safety instrumented systems. During engineering, the integrity level, if applicable, of each application should have been identified and the appropriate level of testing and documentation established. System validation cannot start until loop checking and acceptance of each of the underlying loops has been completed, so this dependency needs to be recognized during schedule development.

A general procedure for testing of non-integrity rated interlock and shutdown systems should be prepared. Where the systems are complex, detailed test procedures may be warranted. Written test procedures are also often required to support routine maintenance. These procedures should also define frequency of testing required for each interlock.

7.5.2 Complex and Advanced Control Systems

Complex and advanced control systems will generally undergo a separate testing and acceptance process after the basic loop checking is completed. These strategies may be implemented on the process control system itself or on a separate control station that is connected to the network. These advanced strategies generally provide a very high economic return but are not required to run the plant. Therefore, commissioning may be scheduled after all of the other loops are cut over. See API 557 for a discussion of this process.

In general, hardware is not involved in these control loops. The control strategy will use one or more measurements that are part of the systems and will have been commissioned earlier. Output from these loops will usually be to the set point of a regulatory loop.

As with the testing of the basic control system, a written procedure should be written and approved by the customer. This should include procedure, expected results and approval signatures from both the customer’s representative and the process control system representative.

7.5.3 Safety Instrumented Systems

As discussed above, safety instrumented systems will have specific, detailed testing procedures that are conducted at the manufacturer’s site, and rigorous functional validation testing performed on site after completion of all underlying instrument loops. Often, this testing cannot be completed until any construction or turnaround activities that may damage or modify these systems is completed.

These testing and validation procedures are described in detail in other references such as ISA 84.00.01, ISA TR84.00.03-2002 and IEC 61511.

7.5.4 Complex Instrumentation

Many complex instrumentation packages are provided as stand alone third party supplied systems. Among these applications are:

- compressor control systems;
- machinery monitoring systems;
- analyzer systems; and
- various PLC-based systems such that usually involve sequencing or complex interlocks.

During planning of testing, validation and commissioning, the requirements for these systems must be identified and suitable staff and time allowances made. Typically, the same requirements for loop checking, and functional validation applicable to other instrumentation and process control system functions will apply to these systems.

Analyzers often require special testing and acceptance planning. Often, analyzers can only be partially tested during loop testing activities and must have additional performance testing and adjustment once the process is in operation. See API 555 for additional guidance.

7.5.5 Serial Interfaces

Many complex instrumentation systems are often connected to the process control system via serial digital interfaces. Often these interfaces cannot be tested until the equipment is installed. The testing and commissioning plan should allow adequate time for testing and validation of these interfaces. See API 554, Part 2 for a discussion of serial interface issues.

7.6 Commissioning

Commissioning consists of the activities required to take a mechanically complete and functionally tested process control system and placing it into operation. This may consist of the following activities:

- installation of any measurement elements or final control elements that were not installed or removed to support other activities such as pressure testing, flushing, etc.;
- providing fill fluids, calibration fluids, etc. as required to make instrumentation functional;
- placing all instrumentation into service by opening block valves, closing bypass valves, bleeding and flushing systems, etc.;
- final stroke testing of all valves;
- commissioning testing of complex instruments such as analyzers that require process fluids for FAT; and
- control loop tuning.

7.7 Acceptance

7.7.1 Startup Acceptance

During the inspection and testing phases, all loops should have been tested and accepted as operational by an owner's representative. Prior to startup, a final review should be performed to verify that all corrections have been performed and all documentation is signed off. The completed documentation including signatures of the owner representative and contractor representative becomes a permanent part of the loop folder. Typically, this is part of the owner's pre-startup safety review (PSSR).

7.7.2 Post Startup Acceptance

Some systems, such as those involving sequences or operations at alternate operating conditions may require additional in-service testing and validation in order to demonstrate that the system functions are per design requirements. These systems may include compressor control systems, analyzer systems or other PLC systems. These systems will have their own separate test procedures and must be identified during development of the check out and commissioning plan. Often, final acceptance of a project's scope is dependent upon completion of these tests.

8 Operation and Maintenance

Owner's staff should have played a major role in the identification of the functional requirements for a process control system (see API 554, Part 1), specifying the design and installation criteria (see API 554, Part 2) and in execution of the project itself (see Section 5 through Section 7). Depending upon the circumstances, local plant personnel may have had varying degrees of involvement, ranging from full participation to no participation at all.

During the completion phases of a project, the owners or operator's staff will assume responsibility for operation and maintenance of the process control system. In order to successfully and safely do so, the organizations responsible for operation and maintenance must have sufficient numbers of personnel with sufficient training to properly operate and maintain the process control system. This aspect of plant operation and maintenance is becoming increasingly complex and requires skill sets which may not already exist in a facility and which are not always readily available.

This section outlines some of the characteristics of operations and maintenance functions that are required to maximize the realization of the business benefits of operating a given process and the process control system and preventing the potentially substantial business losses and costs that can be incurred if the process control system is not properly operated and maintained.

8.1 Management of Change (MOC)

Once a plant is turned over to the owner or operator, the responsibility to follow proper management of change procedures also transfers to the owner or operator. Each facility should have a clearly defined MOC procedure consistent with API 750 and with local regulations. Some of the characteristics of this process are:

- all proposed changes are evaluated for impact upon process operations and safety;
- engineering follows established engineering standards and practices;
- modifications are inspected and tested and that operations and maintenance personnel receive appropriate training on the changes;
- modifications are promptly and completely documented; and
- a record of all MOC activities is kept.

Process control systems have the characteristic that many values, some of which may be critical to process operation and safety can be relatively easily changed. It is important that MOC procedures are also followed for these types of changes. Examples of process control system changes that should fall under MOC are listed below. This is not a complete list and the owner or operator needs to determine if other types of changes may need to be administered through MOC procedures:

- alarm setting, priority, enable/disable, etc. of all alarms that are identified as critical or protective;
- changes in control algorithms or control schemes, or operating graphics;
- changes in measurement device types, calibration or measured ranges;
- addition or deletion of measurements, transmitters, switches, final control elements, etc.;
- process control system hardware or software updates;
- changes in power distribution to process control systems; and
- changes in communications design, routing or equipment.

8.2 Operations

8.2.1 General Responsibilities

The primary function of an operations group is to safely and economically operate the process equipment and process to which they are assigned. This function requires a variety of skills, many of which are not within the scope of this document. However in almost all cases, the primary method that the operators use to interface with the process is the process control system—which at its most basic function serves as the nervous system of a process—it provides the sensing of process variables, transmission of the sensing to a means of displaying the information to an operator and provides varying levels of process control and abnormal situation alerts and response.

Therefore, one of the primary responsibilities of an operations group is to be able to properly interface with the process control system to be able to run the process and understand and respond to abnormal situations involving both the process and the process control system. The fundamental responsibilities are as follows.

- Monitoring the process through the process control systems. This includes understanding how to navigate among the various types of displays available and understanding how the data is displayed.
- Executing a variety of commands to the process through the process control system such as commands to regulatory controls, manual operations such as startup and shutdown operations and any other interactions required by the design of the controls specific to the process design.
- Accessing, interpreting and responding to process alarms, alerts and messages that are generated by the process control system.
- Operating any advanced control applications implemented in the process control system.
- Providing any routine inputs or reports required by process, safety or environmental status and reporting systems implemented in, or through the process control system.
- Monitoring the overall performance of the process control system hardware and software and responding to any alerts or alarms generated by the process control system monitoring systems. Usually, this response involves

recognizing that an alert has occurred and contacting the appropriate personnel to address the fault.

- Understanding and responding to any critical situations that require immediate remedial responses.

8.2.2 Training

Training programs for operations staff cover a wide variety of topics ranging from basic process understanding, operation of various types of process equipment and emergency response procedures. All operations personnel, including supervision and technical support personnel should have training on the design and operation of the process control system.

The training provided to operations staff on the process control system should address the following general categories:

- *Process control system overall architecture.* Descriptions of functions of the major system modules and their locations and how the operator may be required to interact with them.
- *Process control system communications.* How the various modules in the process control systems communicate with one another, how the communications are generally routed and how failures may impact the operation.
- *Process control system power sources.* Overview of the power sources and distribution. Identify critical UPS or other backup power. What the impact of power disruption or failures in the distribution system may be.
- *General operation of process control system.* Operator functions including basic displays, custom displays, alarms and alerts and process control system status indications and alerts.
- *Process specific training on operation of the process through the process control system.* This includes process control philosophy and process specific control algorithms. Training should address response to process based alarms and shutdown system operations.
- *Training on recovery from process control system failures.* Include the steps necessary to restart and reload data, and who should perform these functions.
- *Training on management of change practices followed by the site.* Relative to the process control systems this includes topics such as permissible changes to process control system settings, disabling or inhibiting of alarms, changes to alarm settings and bypass of process interlocks and shutdowns.
- *Training on monitoring of the process control system health and response to fault or failure alerts.* Identification of faults or failures that require immediate action vs. those that need less prompt response.

8.2.3 Qualification

The complexity combined with the generally excellent reliability of a well designed process control systems is such that initial training can only be retained for a limited period of time. The designs are such that reliability is generally very high from a process stability and failure perspective as well as faults and failures with the process control system itself. Therefore, without a rigorous and aggressive refresher training program accompanied with required demonstration of skills, operations staff will be ill prepared to respond to infrequent, but potentially severe events.

Each owner and operating facility should develop a qualification, refresher and re-training program that assure that operations are adequately prepared to respond to abnormal situations. This program should address:

- verification of basic core skills in the operation of the process control system;
- routine reinforcement of skills that may atrophy over time;

- formalized retraining in response to unusual events, especially those that can have the potential to impair operation of the process control system;
- test drills, preferably using a process simulator or test/hot spare system, on the behavior and response to process control system faults, including procedures to restart equipment and restore data bases; and
- general demonstration of skills maintenance with appropriate levels of supplementary training.

8.3 Maintenance Support

This section discusses some of the basic issues associated with maintenance of refinery control systems. The complexity and interdependencies that exist in process control systems have resulted in increased demands upon maintenance personnel over and above those historically required of them. In a modern refinery process control system, maintenance activities fall into the following broad areas:

- troubleshooting and repair of mechanical devices such as control valves and process sensors;
- troubleshooting and repair of electronic devices such as transmitters and other electronic instrumentation;
- troubleshooting and repair of control devices such as process control system components and PLCs and other complex systems;
- maintenance of digital networks that connect process control system components;
- troubleshooting and maintenance of process control system power supply systems;
- routine testing of critical instrumentation and protective and safety systems; and
- development and implementation of predictive maintenance systems that emphasize the use of preventative maintenance over breakdown repair.

Traditional refinery control systems maintenance programs historically focused upon reactive repair of breakdowns as they occurred. The high cost of breakdown-based maintenance programs has led to the development of preventative and predictive maintenance programs.

8.3.1 Technician Functions and Skills

The training and experience qualifications for all technicians should be clearly defined for each skill level classification. This should address the basic skills and the incremental experience and training requirements to move from one level to another. The definitions should address the minimum requirements for entry level positions and experienced hires.

8.3.2 Training and Qualifications

All technicians performing process control system work should be required to demonstrate their abilities to perform the types of work that is being assigned. It is recommended that technicians be certified in accordance with a recognized qualification and certification program such as the ISA Certified Instrumentation Technician program (see ANSI/ISA-98.00.01).

The qualification and certification program should address:

- verification of basic core skills in the operation of the process control system;
- general demonstration of skills maintenance with appropriate levels of supplementary training and accountability;

- verification of specialized skills when those skills are applicable to a technician's assignments;
- knowledge of site specific procedures and documentation requirements;
- routine reinforcement of skills that may atrophy over time; and
- formalized training in response to unusual events, especially those that can have the potential to impair operation of the process control system.

8.3.3 Maintenance Procedures

Written procedures for all maintenance activities should be prepared to address requirements for each activity in the areas of:

- permit and safe work requirements;
- specific hazards and personnel protection required;
- specialized test equipment required if applicable;
- equipment or performance specifications or documentation that should be available while the work is in progress;
- work procedures and requirements;
- post repair testing and commissioning;
- requirements for documentation of as-found, as-left and repairs performed; and
- work request sign-off and closure procedures.

8.3.4 Inspection and Repair Records

An instrumentation maintenance organization should maintain continuous repair and inspection records on instrumentation that is identified as being critical to operation and safety. Local regulations may require specific records and test intervals. These records provide evidence of good practice and facilitate minimization of total costs by allowing for identification of both good and bad actors.

8.3.5 Specialization

Process control system technology is extremely broad and often complex and arcane. Many modern devices require relatively complex and device specific configuration and maintenance procedures. The breadth and complexity of these applications are such that it is unreasonable to expect any technician to be even minimally qualified in all of the potential devices and systems.

All technicians should receive core training in measurement technologies and commonly used devices. This training should include items required to attain ISA Level 1 Technician Certification or its equivalent. Some sites may choose to require other qualifications.

Beyond core skills, some level of specialization should be considered when developing and qualifying technicians that maintain process control systems. Some broad categories for such specialization are as follows.

- Control valve technology, including repair and use of smart positioners and performance testing and evaluation programs, to assess in-service performance and diagnosis of potential failures and performance.

- Advanced measurement technologies such as nuclear, radar or similar complex instrumentation.
- Analyzer technologies, sample systems, calibration and certification, routine maintenance and testing.
- Maintenance activities associated with various fieldbus or similar communications network architectures that exist in a facility.
- Process control system regulatory control level monitoring, troubleshooting and repair.
- Specialized complex instrumentation maintenance and repair. This includes complex rotating equipment control and monitoring systems.
- Critical alarm and safety or protective rated instrument system testing, validation, repair and documentation.
- Asset maintenance software and hardware systems usage and support. This includes use of recording calibrators, calibration scheduling and management systems and review of maintenance records to provide proactive maintenance of instrumentation and process control systems.

8.3.6 Management of Outsourced Resources

Refineries are making increased use of outsourced maintenance personnel and organizations to perform a number of maintenance functions that were historically performed by in-house personnel. This presents challenges in maintaining the safety and quality of work performed. When outsourced resources are used, procedures should be in place to assure that the required performance and safety goals are met. These procedures should address the following points.

- Identification of work for which assignment of outside resources is acceptable. This may be either limitation of work assignments to commonly expected skills, or on the other end of the scale, work that is best assigned to external resources with the special training, tools and resources necessary to work on complex or specialized systems.
- Assurance that technicians assigned to the work are as qualified to perform the work as in-house permanent staff would be. The supplier of out sourced labor should be required to document how technicians are qualified for work. This documentation should address:
 - the training received for general control systems work as well as specialized work is adequate;
 - the means by which technician qualifications are measured and validated; and
 - the means that are used to monitor the quality and safety of work and to identify unacceptable work and correct deficiencies.
- Assurance that technicians are trained in local work practices, safety requirements, permit to work and similar safe work procedures and practices.
- Procedures for maintenance activities exist and are equivalent to those required for direct hire employees. Written procedures for documentation of the work results, including as-found and as-left conditions and descriptions of work performed should exist.
- Supervision of the work is adequate and that the owners' staff has the means of assuring that all outsourced work is being performed to the established work quality and procedure requirements.

Issues associated with screening of potential outsourced employees for non job qualification based items such as background checks, drug and alcohol screening, etc. are beyond the scope of this document.

8.4 Engineering and Technical Support

As with process control system maintenance requirements, the requirements for engineering and technical support are varied and complex and require that personnel be adequately trained and suitably experienced to support the multiple groups within a business that require process control system support.

8.4.1 Tasks

The tasks that process control system engineering and technical support personnel are expected to perform are extremely broad. These tasks include the following items.

- Ongoing operation and maintenance support on technical, performance, troubleshooting and repair items.
- Technical development—monitoring and development of process control system technology. This may cover an extremely wide range of technologies ranging from measurement technologies, transmission technologies, regulatory control system technologies, historians, and data handling reporting and advanced control technologies.
- Participation in, and often leadership or origination of, the processes described in API 554, Part 1 to develop process control system functions specifications.
- Varying levels of involvement in process control systems projects as described in Section 4 of this document. This involvement can vary from oversight to performance of detailed engineering functions.
- Development and maintenance of site or organization technical practices and procedures.

8.4.2 Specialization

As described above, engineering and technical support of process control systems covers an extremely wide range of practice and requires that the work be divided into a significant number of specialized assignments. These will vary from organization to organization, but a typical division of work is described below. Depending upon the size of the organization, each of these functions will require one or more qualified and experienced engineering personnel.

- Engineering resources devoted to support of maintenance activities, including support of technicians, troubleshooting, repair or replacement of devices and maintenance and engineering documentation activities. These individuals may also perform or assist with assessment of device performance and proactive maintenance activity planning.
- Engineering resources devoted to supporting routine operations of process control systems. These functions include activities such as loop tuning and troubleshooting, maintenance of process control system basic databases, operator support and training, etc.
- Engineering associated with field instrumentation and regulatory control systems for ongoing small projects.
- Engineering associated with process control systems such as system design and configuration, maintenance and programming of various control modules and similar activities.
- Engineering and engineering support for advanced control systems. See API 557 for additional information.
- Engineering and engineering support for SIS and other protective instrument systems. Note that process control system engineering responsibilities typically fall into design, commissioning and testing of SIS applications once

they have been identified and a required integrity level has been set by independent hazard evaluation processes. See ANSI/ISA 84.00.01.

- Engineering activities associated with identification of potential new technology applications, improvement of existing applications and development of standard, practices and procedures required to implement and maintain the equipment and systems associated with those technologies.

8.5 Testing Schedules

Process control system components should have a defined testing philosophy and strategy. The actual required testing and testing intervals will vary by the type of equipment and its application. Some examples are as follows.

- Custody transfer systems may have contractually defined test procedures and intervals.
- Safety instrumented systems will have test intervals defined as part of their safety requirements specifications.
- Other critical instrumentation may have intervals specified according to their application and severity of service.
- Minor instrumentation or instrumentation that can be readily accessed while a plant is in operation may have no required interval defined.
- Where a process control system has redundant modules, communications etc. routine testing of backup functions and backup equipment should be defined.
- Power systems for process control systems often use UPS, backup generators or multiple power source switching. The functions of power system backups should have test procedures and intervals defined. Battery systems associated with UPS and backup power must also have routine testing and/or replacement intervals.
- Process control system applications should have some form of testing and/or auditing to verify that the applications are still operating as intended and that no unauthorized changes have been made.
- Many instrumentation and process control system components will have maintenance intervals based upon unit turnarounds. Maintenance histories as described in 8.3.4 and 8.7 should be used to identify required routine service in absence of other scheduling requirements.

8.6 Documentation

A complete set of process control system documentation must be retained by each operating facility in order to provide assurance of system integrity and to enable efficient maintenance of the associated components. Each facility should identify the documentation that must be maintained and be readily available to operations, engineering and maintenance personnel. The list will vary with the type of plant and local engineering standards, but a typical list could include

- P&ID's;
- instrument data sheets;
- sizing or rating calculations for flow elements, control valves, pressure relieving devices and other similar devices;
- instrument loop diagrams or interconnecting wiring drawings;
- physical installation drawings;

- process functional descriptions;
- alarm lists with priorities, expected actions and required settings for critical alarms;
- interlock or other protective system logic diagrams and/or functional descriptions;
- configuration and/or programming records for all configurable and programmable devices;
- configuration and/or programming records for all control applications; and
- safety instrumented system documentation and testing procedures.

Process control systems make extensive use of various forms of data bases, data images, configuration data, etc. These need to be regularly backed up and kept in a secure location. See API 554, Part 2 for more information.

8.7 Inspection, Calibration, Test and Repair Records

Records should be kept which provide a historical tracking of process control system components and application maintenance and testing. The need for records is dependent upon the criticality of specific components. For example, the need for records for instrumentation associated with protective functions is much more important than it is for minor instrumentation such as pressure gauges or other minor local instrumentation.

Each facility should establish criteria for what levels of maintenance and testing records are to be recorded and to what classes of instruments and process control system components the requirements apply. Typically, records requirements apply to the general types listed below.

- Instruments which perform SIS functions require retention of data to support the SIL design basis and testing intervals. Testing records are required to demonstrate compliance with ANSI/ISA 84.00.01-2006.
- Instruments which have other protective functions including major commercial or environmental protective systems or initiators of critical alarms.
- Instruments which have regulatory requirements to demonstrate functionality and maintenance history.
- Instruments which have high value for tracking performance and repair history (i.e. control valves and analyzers).

8.8 Maintenance, Operation and Repair Manuals

Maintenance, operation and repair manuals for all process control system components and software must be available to operation, maintenance and engineering personnel prior to the start of any system testing and commissioning activities. These manuals should be continuously available as long as the equipment is installed. This may require rigid controls upon manuals for dated or out of manufacture equipment.

8.9 Spare Parts

Each process control system maintenance organization should establish required spare parts inventories necessary to assure that business operations will not be unacceptably interrupted by the inability to perform timely repairs. The spare parts program should consider the following.

- Are the parts applicable to specialty or limited quantity instrumentation or process control system equipment?
- Are parts readily available on the open market? Does a local supplier stock parts which can be readily drawn upon?

- Do specific agreements exist with suppliers that commit them to stock and supply parts upon demand?
- Must parts be retained for support of obsolete or out of manufacturing equipment?
- What is the local philosophy for retention of on-site parts, just-in-time supply from others, shared parts inventory with other same-company facilities, or purchase as-needed?



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Shipping (U.S. Orders) - Orders shipped within the U.S. are sent via traceable means. Most orders are shipped the same day. Subscription updates are sent by First-Class Mail. Other options, including next-day service, air service, and fax transmission are available at additional cost. Call 1-800-854-7179 for more information.

Shipping (International Orders) - Standard international shipping is by air express courier service. Subscription updates are sent by World Mail. Normal delivery is 3-4 days from shipping date.

Rush Shipping Fee - Next Day Delivery orders charge is \$20 in addition to the carrier charges. Next Day Delivery orders must be placed by 2:00 p.m. MST to ensure overnight delivery.

Returns - All returns must be pre-approved by calling the IHS Customer Service Department at 1-800-624-3974 for information and assistance. There may be a 15% restocking fee. Special order items, electronic documents, and age-dated materials are non-returnable.

THERE'S MORE WHERE THIS CAME FROM.

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