

Instrumentation and Control Systems Documentation

Introduction

This book is written to be easy to read, with many illustrations and little or no mathematics (and absolutely no calculus!). It will be of interest to engineers and technicians, not only in the control systems field, but in many other technical disciplines as well. Control system groups are unique in that they have to coordinate among all the other work groups in a plant, mill, or factory during design, construction, commissioning and operation. This book explains their varied, all-encompassing language. It will also be of value to plant operating, maintenance, and support personnel who are interested in plant design deliverables (the documentation that a design group usually develops).

The engineering design phase of a typical process plant may last from perhaps a few weeks to several years. Once the plant is built it may operate for thirty or more years. Common sense dictates that the documents developed during the engineering phase should have lasting value throughout a plant's operating life.

The purpose of this book is to provide you, the reader, with enough information to be able to understand the documents and the information on them and to use that understanding effectively. It is hoped this knowledge will be useful, not only in existing plants, but also as a basis for a review and reality check on future engineering design packages. Also—dare we say it—the authors hope to encourage effective discussions among the design team, the construction contractor, and the maintenance team that will lead them to agree on the document set that will most effectively meet all their requirements.

Significant material has been sourced from ANSI/ISA-5.1-2009 *Instrumentation Symbols and Identification* (hereafter referred to as ISA-5.1). Material has also been sourced from ISA-5.2-1976 (R1992) *Binary Logic Diagrams for Process Operations* (hereafter referred to as ISA-5.2).

Explanatory material has also been used from ISA publication, *The Automation, Systems and Instrumentation Dictionary, Fourth Edition*, Research Triangle Park, NC: ISA, 2006) (hereafter referred to as *ISA Dictionary*).

First, we need to understand some terms.

Instrument - as defined in ISA-5.1, is a device used for direct or indirect measurement, monitoring, and/or control of a variable, including primary elements, indicators, controllers, final control elements, computing devices and electrical devices such as annunciators, switches and push buttons.

Instrumentation - as defined in ISA-5.2, is a collection of instruments, devices, hardware or functions or their applications for the purpose of measuring, monitoring or controlling an industrial process or machine or any combination of these.

Process Control – as defined in the *ISA Dictionary*, is the regulation or manipulation of the variables that influence the conduct of a process in such a way as to obtain a product of desired quality and quantity in an efficient manner.

System - from the *ISA Dictionary* definition 4, is the complex of hardware and software that is used to affect the control of a process.

This book is about instrumentation and control systems documentation. The book can best be used in an advisory mode. Sometimes the advice is aimed at the control system personnel who are directing the implementation effort and sometimes aimed at the process control personnel who define what is to happen.

The documents we will look at in this book have been developed by industry over many years to efficiently meet the needs of plant design, construction, operation and maintenance. We will look at process control system documents in two ways. First, we will describe them with enough detail to help the reader understand their form and function. For some of these documents, no published industry standard is available to guide the user about their content. The book will therefore describe what the authors believe is a middle path—one that many will accept but, realistically, one that may not be accepted by everyone or in every detail, but what we believe will yield a typical document set.

You may have heard developers of documentation standards say, “My way or the highway” or “There are two ways to do anything, my way and the wrong way.” They take this approach from necessity, since a wishy-washy plant standard is not much of a “standard”; it has little value. The authors will not be as dogmatic, since we want you to develop a document set that works for your facility—one that meets your specific requirements. We believe it is appropriate to approach the development of plant documentation standards for your facility democratically—with input from all the parties that have a stake in the product. However, there is a need at some point for autocracy or maybe a “benevolent dictatorship.” Once the standards are set—democratically—they

must be consistently and properly used. Someone needs to monitor that use and educate users in the acceptable application of the standards. The plant also needs to establish a mechanism for change that controls standards revisions to ensure that all stakeholders review potential changes. The authors urge you, based on painful experience, to control modifications to the plant standards very carefully once a majority of users have defined the plant's documentation requirements. People lose interest in working with a standard that isn't. Rigid control is critical for an effective system. Develop freely; operate rigidly.

The second way we will look at a typical document set is to use a very simple simulated project to follow the sequence by which the documents are developed. There is a logical, time tested sequence to their preparation. Often the development of one type of document must be essentially complete before the development of the next type of document can be started. If the documents are not developed in the right sequence, work-hours will be wasted, since you will have to revisit the documents later to incorporate missing information.

While the sequence is of more importance to those interested in the design process, it is useful for operating personnel to understand how document sets are developed. If for no other reason, this understanding will help ensure that operating personnel modify all the information in all the affected documents as they make changes.

In the authors' experience, there are many different ways to define and document instrumentation and control systems. All the plants that we have seen which used markedly different document sets from the typical set described in this book were eventually built and operated. Of course, some projects ran smoothly, while others seemed to develop a crisis a minute. Some plants were easier to build, and some took longer, but eventually all the plants were completed. Sometimes, the document set's content had a direct influence on how well the project ran, and a smoothly run project is a less expensive project. In our experience, the quality of the document set has a DIRECT impact on the ease of construction, commissioning, start-up and operations.

The use of computers in engineering design now offers many options to better define the work to be performed. Indeed, the new ways available now with linked documents offer attractive efficiency and accuracy that may compel some to revisit the content of the standard design package document set.

You will see that the drawings, specifications and other documents generated in support of process control are unique in many ways. Most control system drawings are schematic in nature, showing how things are connected but not how far apart they are. They are not much concerned with orthographic dimensions; instead they concentrate on the relationships between elements. Unlike

with piping plans or structural drawings, the creators of control system drawings are less concerned that elements are X inches from each other and more that the documentation shows the interrelation between field measurement elements and final control elements.

The devices we deal with are becoming infinitely configurable, so our drawings and documents have evolved to capture each device's configuration for reference so the people working with the devices can understand why they were set up the way they are and how they will react to signals.

We use our documents to coordinate with the disciplines that install our control valves. The electrical designers provide power to them, and the mechanical designers provide pressurized air to drive the valves. The control valve specification form is developed by the control systems design group. It describes the flanges on the control valves. The piping group installs matching flanges as part of the piping design and construction.

Our designs must address device failure due to the impact that failure will have on the process, so our documents must state failure action and response parameters for record.

Some instruments require power. This information is defined by the control systems design group but supplied and installed by electrical design and construction.

We generate a lot of documents; it is not uncommon for a set of loop diagrams on a project to be far thicker than all the drawings generated by other disciplines combined (see Chapter 7 for definitions of a loop and a loop diagram). We have input, or draw critical information, from all the other technical disciplines as well, so control systems personnel have an obligation to play well with others: our devices have to meet the connection specifications of the piping group and our components must be appropriate for the assigned electrical area classification, to name a few.

Over the years the authors have noted that people working in process control tend towards an affinity for pattern recognition. Since the sheer volume of devices being controlled and, therefore, recorded on drawings is so great, control systems technicians tend to rely on each one being connected like the others. They understand that the uses vary and the operating parameters may change, but the devices and connections should be the same. Thus, people working in control systems rely on standardization. Without standardization of information and even devices, the work of a control systems technician becomes overly challenging. The standardization criteria may be contrary to competitive bidding goals, but the impact of managing change is ongoing and expensive, and can lead to confusion and perhaps unsafe conditions.

As a technical discipline, our work uniquely bridges between other disciplines. To be truly effective, control systems designers have to be aware of how their work affects other disciplines and how other disciplines affect their work. They have to work closely with those running a facility to ensure that the process control interface presents to an operator the information needed to run the facility effectively. Operator interface designs need to show just enough information to control the process without overwhelming the operator and to provide effective alarms for abnormal states so the operator can respond quickly and effectively.

Types of Processes

Some of the documentation needed for a control system is independent of the type of process, since it exists to define the components and their interconnection regardless of what they are doing. There are basically three types of industrial processes: continuous, batch, and discrete manufacturing. A brief description of each type follows:

Continuous: Material is fed into and removed from the process at the same time. Petroleum refining is a good example.

Batch: A defined quantity or “batch” of material is isolated, and is subjected to a modification; for example, a chemical reaction. The modified material is then frequently subjected to another step, or many. Many repeats of this process, perhaps using different equipment, may be necessary to make the finished product. Beer is a wonderful example of a product made in a batch process.

Discrete manufacturing is defined in the *ISA Dictionary* as the production of individual (discrete) items (e.g., automobiles, electronic devices). Separate components, parts or sub-assemblies are manufactured or assembled to produce a product. Automobile manufacturing is an example.

The “process industry” sector of the worldwide economy consists of plants that operate continuously and those that operate in batch mode. Since there are similarities in design and operation, plants that operate continuously and those that operate in batch mode are generally combined under the “process industries” label. The process industry sector is defined in the *ISA Dictionary* as follows: those processes that are involved in but not limited to the production, generation, manufacture, and/or treatment of oil, gas, wood, metals, food, plastics, petrochemicals, chemicals, steam, electric power, pharmaceuticals and waste material. All the documents discussed in this book are common in the process industries.

The nature of the documentation used to describe modern control systems has evolved over many years to maintain a primary objective: to efficiently and clearly impart salient points about a specific process to the trained viewer. As the processes become more complex, so then does the documentation. An ancient, simple batch process like making brine might be defined quite clearly without so much as a schematic drawing, simply by showing a few pipes, a tank and some manual valves. A modern continuous process that runs twenty-four hours a day, seven days a week, with specific piping and valve requirements, many interrelated controls, and numerous monitoring points, operator control requirements, pumps, motorized equipment and safety systems will, of course, require a more complex documentation system. Figure I-1 shows examples of typical continuous processes.

Figure I-1: Typical Continuous Processes

- Steam production
- Chemical reactions
- Separations
- Waste treatment
- Distillation

The definition of continuous operation from the *ISA Dictionary* adds to our understanding. It reads as follows: “a process that operates on the basis of continuous flow, as opposed to batch, intermittent or sequenced operations.”

As the amount of information needed to define the process increases, the documents must become more specialized, allowing for the efficient grouping of details. The piping design group develops and maintains their line lists; the control system design group does the same with their Instrument Indexes.

Although both lists are keyed to a general supervisory document in some simple way, the lists themselves are extremely detailed and lengthy, containing information of value to specialists but not necessarily important to others.

General information that defines a process is maintained in a form that is both simple and easily read, but without all of the detailed information needed by a specialist. An example of a general supervisory document is a Piping and Instrumentation Diagram (P&ID). The general document serves as the key to the more detailed documents. Information presentation and storage thus become more efficient. The overall picture and shared information of use to most people are on the general document. Information of use to specialists to flesh out the design is maintained on the detailed documents.

The documents that describe modern industrial processes, like most technical work, assume some level of understanding on the reader's part. The documents use a schematic, symbol-based “language” that may resemble Mayan hieroglyphics to those unfamiliar with the process nomenclature. The symbols, however, provide a wealth of information to those trained to translate them.

Both tradition and standards govern the presentation of these symbols on a document. Indeed, the very existence of some types of documents may seem

odd unless the observer understands their intended function. Like any living language, the symbols and their applications are being improved constantly to meet new challenges.

If you have recently entered the profession, this book will train you to read, understand, and apply the symbols and documents used to define a modern process control system. For more experienced professionals, it will offer insights into using the symbols and documents effectively, including explanations for their use. It will present variations that the authors have seen in the use of symbols and documents, and will point out some pitfalls to avoid.

To better understand process design documentation today, in this book we will look at how and when documents are developed, who develops them, why they are developed, and how they are used. The types of documents we will discuss include Process Flow Diagrams, Piping and Instrumentation Diagrams, Instrument Lists or Indexes, Specification Forms, Binary Logic Systems, Installation Details, Location Plans and Loop Diagrams. We also will investigate how these documents can be used to best advantage during plant construction and operation.

The authors are strong proponents of honoring and using standards, including industry standards developed by the International Society of Automation (ISA) and other organizations, as well as plant standards developed especially for and by staff at a specific location. However, we are not zealots. The documentation must fulfill a need and must not present information simply because someone perceives that it is called for by some standard. That said, you should understand that industry standards are almost always more “experienced” than you are. They have been developed, reviewed, and time tested. You should not deviate from any standard unless you have carefully considered all the ramifications of doing so, and have obtained permission to do so from a recognized authority.

The authors know of one large corporation that does not use Loop Diagrams. They have been able to meet their maintenance, configuration, construction, and purchasing requirements with some very creative use of instrument databases. However, they arrived at the stage where they felt confident changing their usual document set after carefully considering and testing some assumptions. They reviewed the proposed document set with all concerned parties, including their design and construction contractors and their own management, before committing to using databases in lieu of Loop Diagrams. That being said, the information they maintain and present in their databases is the very same information contained in a Loop Diagram, without the graphical representation. This is a critical point: the retention and control of the data is still the primary consideration; only the format they chose to present the information was less traditional. Control system documents have to “work” to be

effective. Plant design and operations personnel using them must have confidence that the information shown is accurate and up-to-date. A facility might be operating unsafely if there is no culture or system in place for recording changes on the affected documents. If this pipe no longer connects to that piece of equipment, is that associated relief valve still protecting what it should? If not, you might have code compliance issues, not to mention a potential safety hazard. And the best control system in the world will be unable to maintain the process temperature if there is insufficient coolant due to undocumented tie-ins that have depleted the available cooling water.

Changes or upgrades to your facility need to be based on the reality of what is actually installed. If documents are not kept accurate and up-to-date, future work at your facility will be extraordinarily and needlessly expensive. The lack of accurate, current documentation can actually kill a project that otherwise would be economically viable, due to the requirement for and cost of verification. The designer or the construction contractor will have to verify the current condition of the process before implementing changes. An effective change must be made based upon what you really have rather than on what you had or, worse, what you think you have.

The modern industrial facility can be chaotic at times. However, plant and project personnel must be able to communicate easily. An industry-recognized language facilitates that communication. Design projects are difficult enough in today's economic environment without the additional work-hour burden of developing unique instrumentation symbols to define systems when a more recognized and understood system is already available in ISA-5.1. And, believe us; some control system designer, technician, or pseudo expert in your design firm right now may be doing just that. The authors also want to point out that industry standards allow you to make variations in the content of the documentation to suit your specific requirements. ISA-5.1 contains both mandatory and non-mandatory statements. The developers of ISA-5.1 hope this will enhance the strengths and lessen the weaknesses of previous issues of the standard.

The industry standards discussed in this book have been tested over time, and they work. This book will explain how and why they work; it is up to you to apply this knowledge. Of course, the documentation you use and its content must stand the “customer” test. They must be of value to the user; they must be useful! A perfectly executed Loop Diagram with all the features outlined in ISA-5.4-1991 *Instrument Loop Diagrams* is of little value if no one finds the information useful.

The following eight document types—discussed in detail in this book—have been used successfully as a typical set of documents for many years, even back in the Dark Ages of manual drafting on linen or Mylar and the ammonia smell of blueprints.

Process Flow Diagram

The Process Flow Diagram (PFD) defines the major elements of the process schematically. It shows what and how much of each product the plant will make, the quantities and types of raw materials necessary to make the products, what by-products are produced, the critical process conditions—pressures, temperatures, and flows—necessary to make the product, and the major piping and equipment necessary. For a very simple PFD, see Chapter 1, Figure 1-1. The Process Flow Diagram (PFD) is the starting point for designing any process plant. It is the macroscopic, schematic view of the major features of a process; it is the “talking document” for managers, planners and the specialists of a process design team. The control system design group has little involvement in developing the PFD due to its macroscopic nature; however, the PFD may be quite useful to them later when developing operator interface screens on the shared display screens of the control system. Shared display is defined in ISA-5.1 as the operator interface device, a video, light-emitting diode, liquid crystal, or other display unit, used to display process control information from a number of sources at the command of the operator, often used to describe the visual features of a distributed control system, programmable logic controller, or other microprocessor or mainframe computer-based system.

PFDs are used to develop the project scope; they may also be used to document and maintain overall material and energy balances. For any specific project, PFDs are normally issued for the purpose of gathering comment and review. After questions and clarifications are resolved, the general scope is essentially established, and the P&IDs are then started along with the detailed scoping, estimating and design processes.

Piping and Instrumentation Diagram

The Piping and Instrumentation Diagram (P&ID) is the master design document for a process. Using symbols and word descriptions it defines the equipment, piping, instrumentation and indeed, the control system. It is also the key to other documents. For example, instrument tag numbers are shown on a P&ID. The instrument tag number is the key to finding additional information about any specific device on many other documents. The same is true for (pipe)line and equipment numbers. For a P&ID, see Chapter 2, Figure 2-21.

Developing P&IDs is a very interactive process. Specialists designing electrical, control systems, vessels, mechanical equipment and piping, and even civil and structural designers for some processes, all provide input into their development. Each specialist group puts information on the drawing in a standardized way, adding details as they become available. Properly used, the P&ID is the primary coordination document for design, the premier training tool for operations and records the history of the process design of any facility.

We will discuss symbols and tag numbers in greater detail in Chapter 2. Briefly, a symbol defines the type of instrument, and the instrument tag number identifies the device. An instrument tag number consists of a few letters that describe the function of the device, plus a combination of a number and letters that uniquely identify it. There will be more discussion on this later.

See Figure I-2 for an example of an instrument that might be shown on a P&ID. The circle shows a field-mounted instrument located on a pipe. The “PG” further describes the device as a pressure indicator or gauge. In this instance, sequential numbering is used. Since the gauge is the first of its type on the P&ID, the instrument number “1” is added. The next pressure gauge in this numbering system would have the tag number “PG-2”. Some tag numbers are much more complex. See Figure I-3 for a very complex tag number: “10-PDAL-01A-1A1.” The prefixes and suffixes further define the location of the instrument and are used to maintain the uniqueness of the loop number.

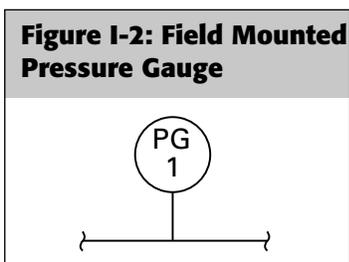


Figure I-3: Typical Instrument Identification/Tag Number - 10-PDAL-01A-1A1

	10	-	P	D	A	L	-	01	A	-	1	A1	Instrument Identification/Tag Number
												A1	Additional Tag Number Suffixes
											1	1	First Tag Number Suffix
			-									-	Recommended Punctuation
									A			A	Loop Number Suffix
								01				01	Loop Identification Number numerals
								-				-	Optional Punctuation
						L						L	Function Modifier letter
					A							A	Function Identification letter
					A	L						AL	Succeeding Letters
				D								D	Variable Modifier letter (if required)
			P									P	Measured/Initiating Variable letter
			P	D	A	L						PDAL	Function Identification letters
			-									-	Optional Punctuation
	10											10	Loop Number Prefix

From ANSI/ISA-5.1-2009

Instrument List or Index

The Instrument List or Instrument Index is a list of the data related to a facility’s control system components and, possibly, their functions. Instrument Indexes are organized using the alphanumeric tag numbers of the control system devices. They reference the various documents that contain the information needed to define the total installation. Instrument Indexes are discussed in Chapter 3. The terms list and index are essentially interchangeable.

The general term database is also used. It has many definitions in the *ISA Dictionary*. The most simple is: any body of information.

The control systems design group personnel place tag numbers on the P&ID and enter them into the Instrument List or database for tracking. This is done for control purposes because, on a large project, there may be many P&IDs—perhaps one hundred or more—plus thousands of tag-marked devices. Since each device serves a specific function, all devices' status must be tracked until they are installed during construction, their operation has been verified during commissioning, and the plant has been accepted by the owner. Furthermore, each device must be uniquely tracked so its configuration and measurement or control range are known, and many facilities capture the devices' maintenance history as well.

Specification Forms

Specification Forms (or Instrument Data Sheets) define each tag-numbered instrument with sufficient detail that a supplier can quote and eventually furnish the device. For a typical Specification Form, see Chapter 4, Figures 4-4, 4-5 and 4-6. More importantly, the Specification Form retains the critical information needed by control system technicians, such as the manufacturer, model number, range, power requirements and other features needed to define the device for maintenance.

After tag numbers are entered on the Instrument Index or List, the control system design group starts a Specification Form for each tag-marked item. Developing these Specification Forms can be a major part of the control system design group's effort. Specification Forms must be completed to secure bids from suitable suppliers, to purchase the items from the successful bidders, and to generate a permanent record of what was purchased.

Binary Logic Systems

There usually is some on-off or binary or discrete control in a continuous process plant control system. Discrete control is defined in the *ISA Dictionary* as on-off control. P&ID's are excellent documents to define continuous control systems. Other methods are needed to define on/off control. ISA-5.1 and Chapter 6 include descriptions of many of these as does ANSI/ISA-5.06.01-2007 *Functional Requirements Documentation for Control Software Applications*.

As the design progresses, the need to define on-off control will become evident. For instance, on a pulp and paper mill project, it may be necessary to isolate a pump discharge to prevent pulp stock from dewatering in the pipe if the pump is shut down. An on-off valve is added to provide the isolation, but it is necessary

to document why that device was added and what it is supposed to do. Since this on-off control may affect many design groups, it is important to define it as early and as accurately as possible.

Loop Diagrams

A Loop Diagram is a schematic representation of a control loop, which in its idealized form is comprised of a sensing element (often called a transmitter), a control component (perhaps part of a shared display, shared control system), and a final control element (usually a control valve or a variable speed drive on a motor). It depicts the process connections, the instrumentation interconnection, connections to the power sources, and the signal transmission methods, whether pneumatic, electronic, digital or a combination thereof. For a typical Loop Diagram see Chapter 7, Figure 7-7.

Finally, when all connection details are known and electrical design has progressed to the point that wiring connection points are known, the control systems design group can develop Loop Diagrams. These diagrams show all the information needed to install and check out a loop. Because these diagrams may repeat information that the piping and electrical design teams included on their drawings, it is critically important that the control systems design group coordinates closely with other disciplines.

Installation Details

Installation Details are used to show how the instruments are interconnected and connected to the process. They are also a primary coordination tool between disciplines. The details provide the means used to mount and support the devices and the specific requirements for properly connecting them to the process. Installation Details are discussed in Chapter 8.

The control systems design group develops Installation Details based on the specific requirements of the devices it has specified, along with any facility owner-driven requirements. The installation requirements needed for good operation and control are established by the instrument suppliers, by various industry groups and by the owners themselves. These requirements are then documented in the Installation Details. These details may be developed for the project, for the specific site, or possibly by the owner's corporate entity.

Location Plans

Location Plans are orthographic views of the facility or process area, drawn to scale, showing the locations of field mounted transmitters and control valves.

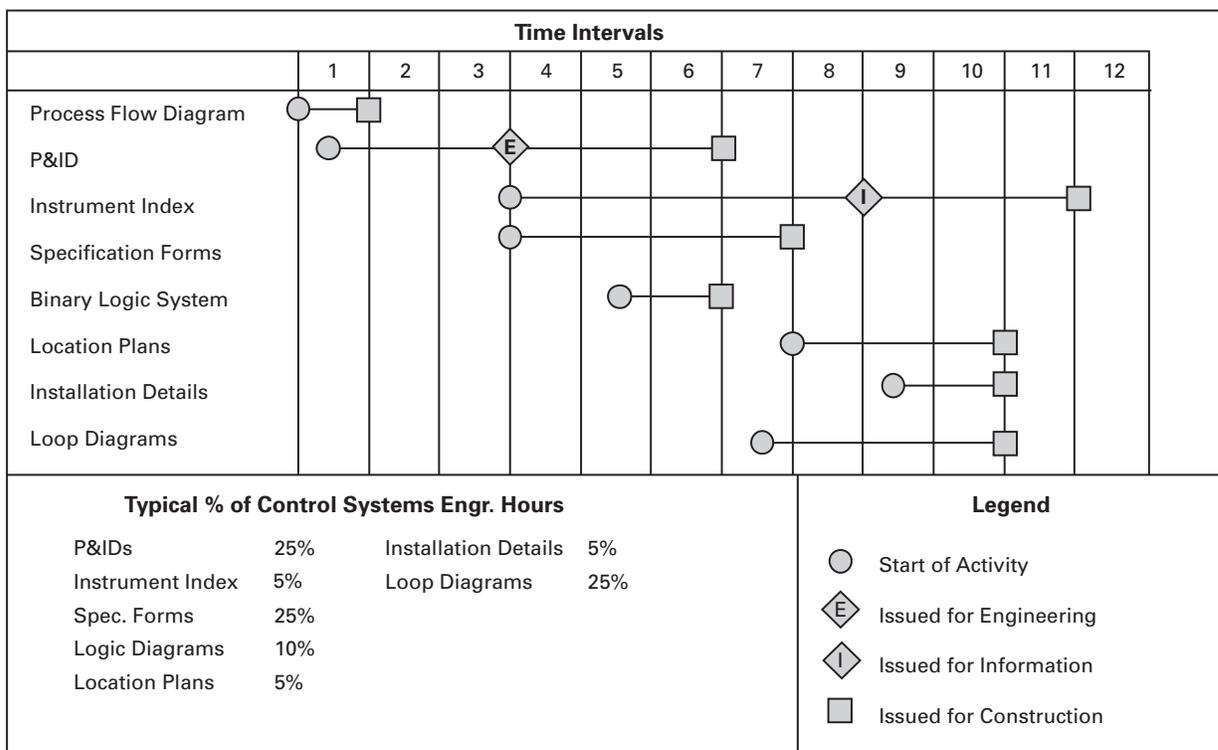
They often show other control system hardware including marshaling panels, termination racks, local control panels, junction boxes, instrument racks, instrument air piping or tubing and perhaps power panels and motor control centers. Location Plans are discussed in Chapter 8.

At the same time, the plant layout has also progressed, so the control system design group can begin placing instrument locations on the Location Plans. These drawings are most often used to assist the construction contractor in locating the instruments, but they can also be useful for operations and maintenance because they show where instruments are installed in the completed plant.

Logical Sequence of Document Development

These eight document types are developed sequentially as the project progresses and as the relevant information become available. See Figure I-4, Control System Drawing Schedule which illustrates typical sequential document development.

Figure I-4: Control System Drawing Schedule



Summary

In this introduction we have briefly described the documents that are included in the control systems set of deliverables and the sequence of their development. In the following chapters we will add more detail to describe the documents, how they can be used effectively, and how industry standards can assist.

Note: Many illustrations in this book were originally developed for various ISA training courses, ISA standards, and other ISA publications. The origins of some illustrations are noted adjacent to the figures. Some of the illustrations were revised for clarity and consistency.