

1

The Project

1.1 Introduction

- **Project** – A project is a temporary activity whose purpose is to create a product or service. Projects usually involve a sequence of tasks with definite start and end points. These points are bounded by time, resources, and end results [1].
- **Project engineering** – There are two facets to project engineering: (1) Engineering activities associated with designing and constructing a manufacturing or processing facility. (2) Engineering activities related to a specific objective, such as solving a problem or developing a product [2].

For our purposes, an engineering design project encompasses delivering engineering services, documents, and components sufficient to meet customer objectives. In short, it is a means to an end, in existence for a short time and a specific purpose. For a project to exist, there must be a perceived need and an expectation that the need can be met with a reasonable investment. The customer must weigh the risks against the rewards and conclude that the project is worthwhile. This risk/reward assessment is sometimes more of an art than a science.

Every project involves some level of risk:

All pilots take chances from time to time, but knowing—not guessing—about what you can risk is often the critical difference between getting away with it and drilling a fifty-foot hole in Mother Earth.

—test pilot Chuck Yeager, 1985. [3]

The effects of mishandling risk in process engineering projects can range from financial impacts to catastrophic equipment or public safety events. Beyond the economic ramifications of a poor estimate, which are bad enough, the potential risk to process operators and even the public at large can be extensive. Therefore, a well-conceived process of preliminary evaluation and project risk management is necessary. This evaluation begins with a thorough understanding of the issues. As General Yeager stated, the key is to know, not guess. Risk management has three components—assessing, planning, and managing risk—that will affect the project timeline, scope, and budget [4].

The keys to project risk management are knowledge, experience, and forethought. Each project team member must have a thorough understanding of the issues. What is the project? What are some outside influences on how the project will be executed? How will the project flow from inception to implementation? What are the typical products and services to expect from an E&I service provider? Who are the players/stakeholders?

This chapter attempts to answer these questions by discussing the following major topics:

- **Project planning** – Define the project. What type of project is it, deterministic or probabilistic? Lump sum or time and materials (T&M)?
- **Contracts and their effects on the project structure** – What are some of the most common contract types?
- **Project flow for a controls project** – Who are the players, and what are their interrelationships? What deliverables can be expected from each? How can their efforts best be orchestrated? What is meant by the term front-end loading (FEL)? Two organizations are discussed:
 - The owner (buyer) and the owner’s engineer (OE)
 - The seller, which is made up of the following organizations:
 - Electrical and instrumentation engineering and design (E&I)
 - Control systems integrator (CSI)
 - Control panel fabricator (CPF)
- **Integrated control systems (ICSs)** – What are some of the benefits of combining service sets into an integrated whole? What should an owner expect from such a company or group of teamed companies? What advantages does a solutions-based approach provide as opposed to a services-based approach?

1.2 Project Planning

Projects are conceived when the owner of a process identifies a need. Something is impacting production in some way, or possibly there is a safety concern on the plant floor. A project champion is selected who will develop a project charter—we’ll call this person the project manager (PM) for this phase of the project. This PM could be on the owner’s staff or a third party hired to shepherd the project through the various decision gates that must be traversed to justify a project.

1.2.1 Project Management Overview

The Project Management Institute (PMI) publishes *A Guide to the Project Management Body of Knowledge* (PMBOK® Guide) [5] that does a great job of laying out the basics of project management. The information in Figure 1-1 is based on the information in Table 1-4 in the sixth edition of PMBOK.

The commentaries in Part 1 lean heavily on the PMI model, adapting the model to an industrial automation project.

1.2.2 The Project Charter

When a project is conceived, it must be developed, packaged, and approved. The output of that process is the project charter. The owner’s PM is tasked with developing it, which can be considered a small project. Stakeholders will be polled to make sure all the factors and risks are identified and quantified. Project objectives will be articulated, and considerations such as safety, cost, schedule, production impacts during implementation, and a myriad of other effects will be considered. A budgetary estimate may be sought from a potential supplier, and an overall project budget and schedule will be developed. The project charter is then presented to the stakeholders, and a decision is made to proceed.

PMI MODEL		PROCESS GROUPS				
		INITIATE	PLAN	EXECUTE	MONITOR & CONTROL	CLOSE
PROJECT MANAGEMENT ARENAS	INTEGRATION	DEVELOP PROJECT CHARTER	DEVELOP PROJECT MANAGEMENT PLAN	DIRECT AND MANAGE PROJECT	MONITOR & CONTROL; PERFORM CHANGE CTRL	CLOSE PROJECT OR PHASE
	SCOPE		DEFINE SCOPE; DEVELOP WBS		VALIDATE & CONTROL SCOPE	
	SCHEDULE		DEFINE ACTIVITIES, DURATIONS, SEQUENCES		CONTROL SCHEDULE	
	COST		DETERMINE BUDGET		CONTROL COSTS	
	QUALITY		PLAN QUALITY MGMT	MANAGE QUALITY	CONTROL QUALITY	
	RESOURCES		ESTIMATE RESOURCE NEEDS	ACQUIRE RESOURCES; DEVELOP & MANAGE TEAM	CONTROL RESOURCES	
	COMMUNICATIONS		PLAN COMMS MANAGEMENT	MANAGE COMMS	MONITOR COMMS	
	RISK		IDENTIFY & ANALYZE RISKS; PLAN RESPONSES	IMPLEMENT RISK RESPONSES	MONITOR RISKS	
	PROCUREMENT		PLAN PROCUREMENTS	CONDUCT PROCUREMENTS	CONTROL PROCUREMENTS	
	STAKEHOLDERS	IDENTIFY STAKEHOLDERS	PLAN STAKEHOLDER ENGAGEMENTS	MANAGE STAKEHOLDER ENGAGEMENTS	MONITOR STAKEHOLDER ENGAGEMENTS	

Figure 1-1 PMI project management model.

1.2.3 The Bid Package/Request for Proposal (RFP)

The responsibility for a properly planned project is shared between the buyer and the seller. Initially, the buyer is responsible for identifying or precertifying qualified bidders. This precertification process is sometimes facilitated by publishing an RFP. The project can be advertised, and sources sought and evaluated. For some small projects, the RFP will contain all the elements of the bid package and will be used as the bid package. Most larger projects provide an RFP that includes a synopsis of the project that is simply used to prequalify bidders. The prequalified bidders are then provided with the bid package.

The bid package (Figure 1-2) is a key element in the success or failure of a project. The buyer's success or failure to articulate what they want the project to accomplish can lead to a tight bid response in which all the bidders bid on the same deliverables or a dispersed response that could reflect the fact that the bidders' interpretations varied. The goal is to have all the bidders bid on the desired scope and to force them to respond in a way that the buyer can adequately assess and compare them. The bid package typically contains the following:

- The *project specification* provides information related to the design package content: how the work products are to be formatted, what site and industry standards are applicable, and so on. For example, the buyer may have guidelines on how to number wires or want the drawing borders to appear a certain way. Much of the project specification is site-specific, usually not written to be specific to a particular project, but it describes how any project should be done for that site or that buyer. Project specifications are generally written once and published many times, with attachments that are specific to the project at hand.

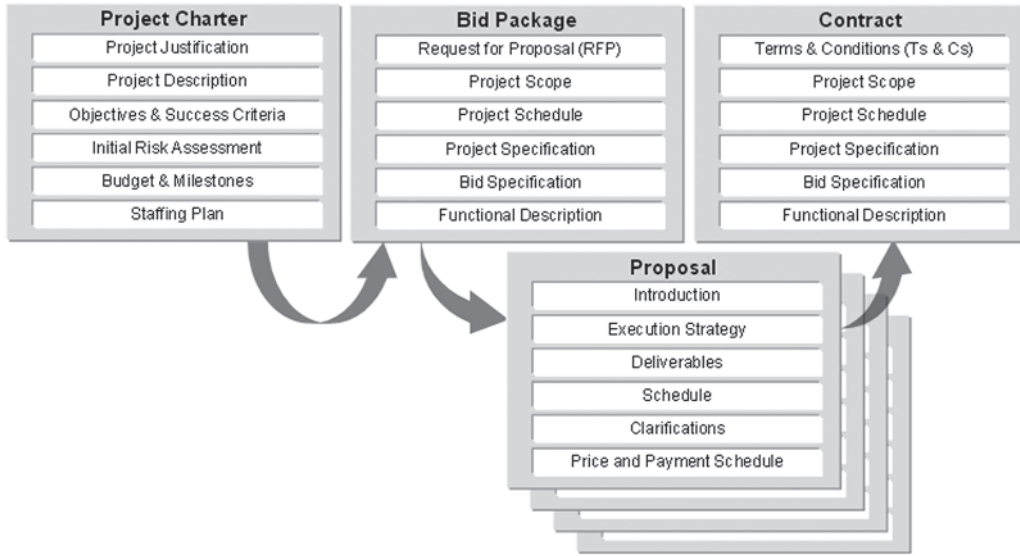


Figure 1-2 Flow from project charter to contract.

- The *control system specification* is a section of the RFP that describes the buyer's requirements specific to the control system. In competitive bid situations, the buyer must receive all bids in the same format to facilitate comparison. Proposals received that do not meet the requirements risk being eliminated from consideration. Refer to Part 2 for more information on this topic.
- The *project scope of work (SOW)* is a section of the RFP that describes the work to be done, which areas of the plant are affected, and so on.
- The *project milestone schedule* is a section of the RFP that provides target dates of particular interest to the bidder developing the proposal. This section typically discusses any applicable schedule-based incentives or penalties, such as liquidated damages (LDs). LDs are often assessed based on a late implementation, which could cost the owner profits or market share. Sometimes a project's value is in being first to market.
- The *functional description* is often a separate document referenced by the RFP that augments the SOW by providing operational detail, primarily for the instrument engineer and systems integrator. The functional description explains the controls issues relative to the SOW that the controls engineer must know.

1.2.4 Proposal Prep

After the bid package is released, project planning responsibility passes to the prospective seller analyzing the bid package and developing the execution plan. The execution plan is where the seller begins to list deliverables and assign the resources needed to satisfy the schedule component of the RFP. All of this rolls up into a project budget. The proposal document that summarizes all the information developed is then produced.

The best proposals fully comply with the requirements outlined in the RFP and are organized to align with the requirements outlined in the bid package. The proposal should also provide an honest assessment of capabilities, particularly regarding the schedule. Given the resources available, can the seller meet the buyer's schedule requirements? If not, the seller should indicate that

they will not be met. However, it is always best to find a way to meet the RFP requirements. The following are some of the key attributes of a proposal:

- The *Introduction section*, sometimes called the executive summary, provides a brief (paragraph or two) summary of the project requirements and the proposal content, sometimes even to the point of including high-level pricing and schedule information. This section may also contain information about the seller, its history, and any key points that particularly qualify them for this project. The buyer's senior management will often read only this section, look at the price, and decide.
- The *Execution Strategy section* provides a detailed list of products and services that are included in the price. This section may also describe the methods, resources, and tools or techniques that may differentiate one supplier from another. The purpose of this section is to give the buyer comfort that the seller knows their business and will execute the project in a manner that will result in it being successful.
- The *Deliverables List section* provides a list of all the documents that will be produced and equipment that will be delivered. This list will often be incorporated into the contract and then managed/monitored by the buyer when determining contract compliance by the seller.
- The *Schedule section* provides the schedule this supplier thinks it can meet. The seller's recommended schedule can differ from the schedule provided in the RFP, either less or more aggressive, based on the resources available to the seller. Any differences between the schedule provided in the RFP and the schedule in the proposal should be highlighted and discussed in the proposal.
- The *Clarifications section* primarily states exclusions, though any ambiguous inclusions can also be listed in this section.
- The *Price and Payment Terms section* provides the price, broken out as required in the RFP between labor, expenses, and materials, and describes how invoicing will occur. The seller often provides a set of recommended payment milestones that align with key moments in the life of the project. Values are placed on milestones that enable the seller to maintain a somewhat neutral cash flow across the life of the project. The buyer often retains profit on a project until after all the project requirements have been met. The invoicing schedule is frequently refined before the contract is signed.

For prospective sellers, defining the project begins with analyzing the buyer/customer and evaluating the customer's ability to articulate what they really want to achieve. Sometimes, this analysis is difficult if the project is with a new customer. The seller tends to assume that customers are effectively communicating their desires. This may or may not be true. A customer can be counted on to understand their own production processes, but the ability to clearly communicate their needs may be lacking. Only after working closely with the customer will the seller really know whether that is the case, thus making initial projects riskier than subsequent ones. This is one more reason to make every effort to generate repeat business, as the seller's cost of breaking in new customers is significant.

As a result, the seller must gain an understanding of the customer's true objectives, both stated and implied. The seller must then work with the customer to reduce the number of implied objectives by having the customer revise the bid package or issue written clarifications. Only by getting the bid package revised will the seller be assured that all parties will bid on the same SOW. Then, the seller must reduce those often complex, vaguely stated goals to a series of well-defined, simplified lists of products and services that their staff can execute in a predictable, cost-effective manner. The seller must then build a labor, materials, and expenses estimate that will satisfy the bid package and still turn a profit.

1.2.5 Bid Package Review/Contract Award

After the seller submits the proposal, responsibility passes back to the buyer, who evaluates all the proposals received and selects a winner. This is a valuable moment for the owner/buyer to assess the efficacy of the bid package. Responses that differ widely indicate a potential problem with the requirements being too vague or conflicting. This sometimes necessitates a revision cycle where clarifications are provided, and bidders reassess and resubmit.

If any party fails to execute their due diligence, the project is at risk. As the owner's level of sophistication and ability to communicate their needs increase, so does the likelihood that they will get the desired results. To that end, it helps if the owner knows as much about how each service provider operates as possible (one of the reasons for this book). For the service provider, it is key to be able to discriminate between what the owner is asking for and what they really want.

Regardless of the owner's abilities to plan and communicate, the bid package is, at best, an approximation of their wishes. The owner should collaborate with the service provider(s) during the proposal cycle to further define the project scope and, by extension, reduce the financial and physical risks inherent in the project. In this respect, everyone's interests are in complete alignment.

After the proposal is submitted, the bidders depend on the owner to execute due diligence and ensure that every prospective seller has satisfied the stipulations of the bid package.

Note: The owner has no legal responsibility to be thorough. The entire contents of the proposal can be ignored. The owner may award simply based on price or any other criteria and totally ignore the remainder of the proposal. The contract is the key document.

The contract is generated by the owner and may contain language that conflicts with aspects of the winning proposal. The contract will include the price and any other parameters that the owner deems important. However, it may not contain assumptions, exclusions, or other elements provided in the winning proposal. When the contract is issued to the seller, it is wholly the seller's responsibility to review the terms and conditions provided, as the contract is the legally binding document to be signed by both parties, not the proposal. The seller may request that the proposal be included as an attachment to the contract. In that way, issues listed as clarifications become part of the contract.

Note: If the seller plans to omit or modify items the owner has requested in the RFP, project specification, or any other document presented for proposal development, the proposal must take explicit exception to those areas of noncompliance. *Silence implies compliance.*

1.2.6 Project Setup and Execution

After being awarded the contract, the seller should reorganize the information to make it easier for internal organizations to digest. The bid package and project proposal become the basis for a new internal document called the project execution plan (PEP). The PEP will restate the project in terms that are most useful to the seller's execution team(s), providing amplification where necessary. The PEP should define relationships and dependencies between internal organizations and provide general guidance to the team relative to tools and techniques important to the success of the project. Key elements should be clearly communicated; nothing important should be left to chance.

Fortunately, while project objectives, strategies, and outcomes may vary widely, most industrial project lifecycles are similar in structure and flow. A process is begun that is, for the most part, predictable from one project to the next.

The owner has a predictable process to follow to start the bid process. The service provider has a predictable process to follow to prepare a bid. Engineering disciplines have predictable processes

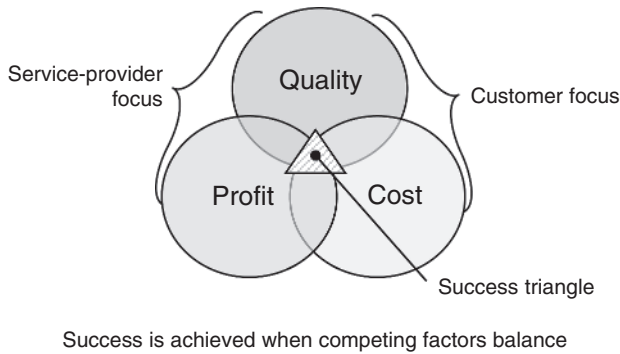


Figure 1-3 Success triangle.

to follow in generating their work products. These processes are sometimes adjusted to meet unexpected or unusual conditions. But for the most part, the engineering process that takes an idea from conception to implementation is well-defined and consistent from project to project.

The content of the project plans is wildly variable, but the planning processes and structures are predictable.

Given the deterministic nature of the project management process, it would be easy to assume that the interrelationships between the customer and service provider would be predictable from one project to the next. This is far from the case. Human nature is involved, further complicating an already complex situation. In addition, external pressures, such as financial conditions in the marketplace, constraints on resources, and other variables, may force changes in strategy from project to project, thereby imposing compromises and more complexities. Thus, it is necessary to establish contractual relationships that expose the risks and set commensurate penalties and rewards. These risk/reward relationships must be fully considered when setting up the project.

1.2.7 Project Planning Summary

Project plans make or break a project. The trick for the customer is to find service providers who understand these processes and can adapt them to specific circumstances. For the service provider, having customers who understand the design process streamlines everything. It is in everyone's interest to foster tight communications and thereby expand the success triangle (Figure 1-3), which is formed at the point where the goods delivered meet the customer's cost and quality expectations while still enabling the service provider to make a fair profit and maintain their reputation for good quality work.

The type of contract in use is a major factor that affects project plans. The following section explains the various contract types and how they affect the project execution strategy. Is the project time-driven or cost-driven? Is the project fixed-cost or cost-plus? What is the customer/service provider relationship?

1.3 Contracts and Their Effects on Project Structure

The *structure* of a project has a great bearing on how the project is executed. This is because each member organization of the project team (customer and service provider) defines *success* from its

own unique perspective, as viewed through the prism of the project parameters. From the owner's point of view, the project is successful when the desired end is achieved within the time allotted and/or the funds allocated. This is likely to be a narrower interpretation than that of the service provider, who is also interested in making a profit and maintaining a reputation. As we have seen, a truly successful project is one in which the customer and the service provider are satisfied with the outcome. For this to occur, a zone of success (the success triangle) must be created that is as large as possible (Figure 1-3).

Staying within this comfort zone is sometimes a little tricky, and it helps to understand the physics involved. The “physics” of a project is defined by the forces that drive and constrain it. The driving force(s) behind a project are the things that compel an owner to act. Project drivers can be market-based, safety-based, regulation-based, convenience-based, or any combination of these. Project constraints are those things that limit what can be done. The interplay between these forces must be managed within the context of the contract.

1.3.1 Drivers and Constraints

Time (schedule) and resources (cost) are two parameters that impose limits on the design process. Time can mean either duration or intensity. Duration is measured by calendar units (days, weeks, months); intensity is measured by labor units (e.g., labor hours, labor weeks). In this context, the term *time-driven* implies that the project is constrained by the calendar. The term *cost-driven* indicates that the project is constrained by the level of labor intensity (in labor hours) plus materials and expenses. A third constraint—content (quality)—subjugates the schedule and cost to achieve a specific end. A performance specification might define a desired outcome but might not specify an associated project cost or schedule.

Usually, the mix of these constraints (and potentially a host of others) influences major performance goals that might be set for a project. A time-driven project, for example, might provide a bonus or some other incentive to the service provider for meeting the schedule and impose a financial penalty if the quality targets are not met. In such a project, the ability to control cost is inhibited, as the service provider may be forced to pay overtime premiums, hire additional personnel, or hurry the design, thereby risking rework. The cost control mechanism, in this case, is the short project duration, which tends to limit the amount that can be effectively spent. On the other hand, a cost-driven project might provide an incentive related to meeting project cost and quality targets while subjugating the schedule, which becomes flexible and can be adjusted for optimum efficiency.

Any of these project types can get the job done (Figure 1-4), but the management protocols are very different, as the characteristics of each type are somewhat mutually exclusive. If calendar time is compressed, there will likely be an increased cost per unit of time. If the calendar is not an issue, then expenditures can be better managed and minimized, provided the project is properly managed. The characteristics of these project types can be applied to any of the project structures listed in this chapter.

The contractual relationship between the customer and the service provider (engineer or constructor) requires a clear definition. When an equipment vendor provides a quote, they are bound by it and must provide the materials or services for the price offered in the quote—even if their suppliers subsequently raise their prices. The same concept applies to a service provider. For the service provider, the act of submitting a proposal constitutes initiating the contracting process. If the customer accepts the proposal and both sign the contract, the service provider is legally bound

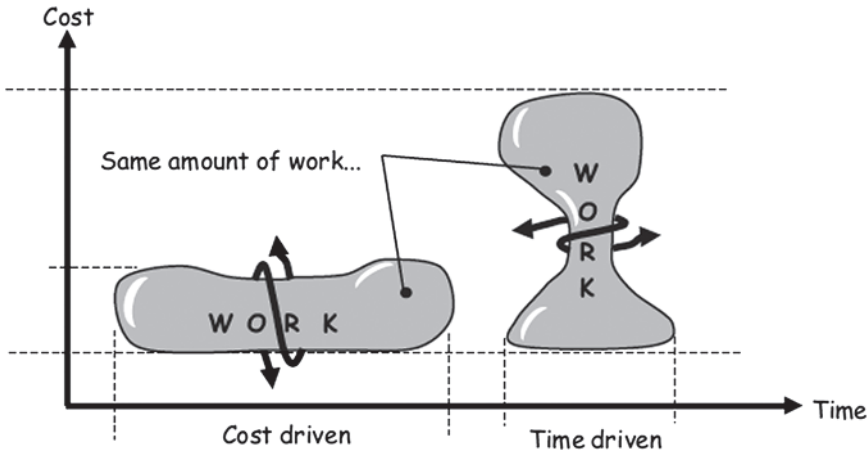


Figure 1-4 Effects of constraints on project structure.

Potential Risk / Reward Analysis				
Contract Type	(Seller) Profit	(Shared) Quality	(Buyer) Cost	Project Constraint
T&M	1 / 1	0 / *	3 / #	Content
	1 / 1	2 / *	2 / #	Schedule
T&M, NTE	2 / 1	0 / *	1 / #	Content
	3 / 1	2 / *	1 / #	Schedule
Lump Sum	1 / 3	0 / *	3 / #	Content
	3 / 3	2 / *	2 / #	Schedule

* High quality is the reward for all parties in all cases.
 # Low cost is the reward in all cases for the Buyer.
 () Indicates concerned party: Seller, or Buyer.

Figure 1-5 Risk-to-reward analysis by project type.

to execute the contract, and the customer is legally bound to honor it. The following are some of the most common types of contracts:

- Time and materials (T&M), also referred to as cost plus
- Time and material, not-to-exceed (T&M, NTE)
- Lump sum (also, fixed price)

Each contract type strikes a different balance of risk/reward for each participant, as noted in the following commentary.

Figure 1-5 depicts the relative risk/reward factors of several of the most common types of contracts. Each contract type is analyzed with respect to the project constraints and rated on a scale of 0 to 3 as follows:

- 0: None
- 1: Minimal
- 2: Moderate
- 3: Maximum

Therefore, a risk-to-reward ratio of 1:3 would indicate the condition has minimal risk with maximum reward ... a very desirable state indeed for the concerned party.

1.3.2 Contract Types: Time and Materials (T&M)/Cost-Plus (CP) Contract

With respect to contract types, the terms *cost-plus* and *time and materials* are interchangeable. These contracts guarantee a fixed, negotiated profit margin for the seller. In return, the buyer may retain a large measure of control over the project content and the seller's method of execution. The parameters defined by the contract are unit rates—not project price—plus expenses. The unit rate can be applied to the various employees' hourly billing rates or to negotiated rates based on employee classification (e.g., engineer, programmer, designer, clerk, etc.). These unit rates are valid over the life of the contract, which can extend into the future until the SOW is satisfied. Some contracts stipulate an incremental yearly increase in rates. This benefits the seller, guaranteeing a small profit, regardless of the project constraints. If the seller completes the task below budget, the buyer realizes a windfall. But if the project exceeds budget, the buyer is obligated to pay for the services rendered.

Invoicing typically occurs at regular monthly intervals rather than at predesignated milestones. Travel expenses include such things as hotels, gasoline, airfare, car rental fees, parking fees, and food and are generally reimbursed at cost plus a prenegotiated administrative markup. Likewise, any materials will be provided at a negotiated markup. The seller often agrees to full disclosure so the buyer can audit to ensure compliance with the multipliers. For auditing purposes, the buyer usually expects to see labor charges on a weekly or monthly basis, along with the itemized list of expenses and materials. The seller may also be asked to provide a document describing the work accomplished during the time frame in question. The rights and responsibilities of the seller with respect to reporting labor charges and expenses must be clearly defined in the contract.

Refer to Figure 1-5. If the T&M constraint is *content*, the buyer in a cost-plus scenario will eventually get what they want (Quality: 0; no risk), but with a very real risk of high cost (Cost: 3; high risk). In this scenario, the seller may need to work iteratively until the buyer is satisfied with the result. The seller has no profit risk, but the seller's potential reward is a small multiplier against their rate, so profit is predefined and generally small. But if a *schedule* is defined as a constraint, the risk to quality rises to moderate levels with a corresponding drop in the risk of cost overruns from high to moderate because the seller has no time to apply an infinite amount of resources. Note that cost is not a constraint factor in this type of contract, even though the buyer always has a budget that was approved internally. The buyer's internal budget has no legal bearing on this type of contract. Though it is in the seller's best interest to know the buyer's target and to try to work within it to obtain repeat business, the seller is not contractually obligated to do so.

The buyer benefits in this arrangement by retaining a large measure of control during the life of the project, even to the point of having the service provider rip out work and start over if that is desired. The seller's profit anxiety is greatly relieved, making it easier to accommodate buyer preferences and thus maintain the long-term relationship. This tends to foster a *team* atmosphere between the buyer and the seller, as opposed to the fixed-cost (lump-sum) project that sometimes fosters a contentious relationship, as many sellers lowball the bids to get the job and then rely on change orders to stay solvent.

1.3.3 Contract Types: The Time and Material/Not-to-Exceed Contract (T&M/NTE)

The cost-plus and T&M scenarios discussed previously place most of the budgetary risk squarely on the shoulders of the buyer. In those cases, the buyer is obligated to pay the seller for expenditures plus profit, regardless of whether the project is under or over budget. The not-to-exceed stipulation reverses this by adding additional constraints in the buyer's favor. In this case, the buyer is protected

from a cost overrun by virtue of a spending cap. As reflected in Figure 1-5, the seller's potential reward remains modest, as in the straight T&M contract. However, the seller's profit risk quickly climbs to high levels as the NTE constraint is approached. High risk/minimum reward for the seller makes this configuration their least favorite type of project. It increases the seller's intensity and focus and decreases their desire to work with the buyer to satisfy buyer preferences. Thus, the buyer loses some control over how the project is executed, and the likelihood of disagreements between the two organizations increases.

The seller is responsible for reporting impending overruns and attempting to negotiate contract extensions as the limit is approached. The buyer may not agree to participate in these negotiations, but the seller is still obligated to fulfill the contract requirements. The exception to this is the scope added by the buyer; a proportionate addition to the spending cap should be negotiated immediately when the scope is added. See Section 3.2.4 for more information on change management.

1.3.4 Contract Types: Lump-Sum (Fixed-Price) Contract

The terms *lump sum* and *fixed price* are interchangeable. In the lump-sum contract, the parameters defined by the contract are a fixed project price for a fixed set of deliverables. The fixed-price contract minimizes the risk of cost overrun for the buyer because the price is negotiated before the services are rendered. Further, the buyer usually signs a contract only after a bidding process in which several potential sellers compete for the contract by providing their lowest bids. The buyer can either accept the lowest bid or analyze the bids to determine the lowest reasonable bid that will save the most money while retaining a sense of comfort that the seller can execute the terms of the contract.

The profit risk to the seller depends on whether the service or product is deterministic or probabilistic. Suppose the product is widgets, for which little or no new research and development is needed. In that case, the product is deterministic, and presumably, the seller knows exactly how many resources and what funds are required for production. If the project involves making retrofit modifications to an existing facility in which drawings and/or software listings are out of date, the project is deemed probabilistic, and the risk is increased. One way for the seller to mitigate their risk, and perhaps maximize their reward, is to add a contingency to the bid. Contingency is a factor used to cover normal design development issues that are hard to quantify. If the level of uncertainty is low, then the level of contingency can be low. If not, the contingency should be commensurately higher. Finding the proper amount of contingency that reflects the balance between the level of uncertainty that exists and the level of risk that is deemed acceptable is something of an art.

Contingency levels can also reflect the seller's motivation to win the project. Sometimes, the seller may need the work badly and be willing to forgo profit in order to retain staff, leading them to reduce the contingency and take on more risk. Conversely, if the seller's staff is busy, it might lead them to raise the contingency to reflect the problems inherent in overworking their staff or hiring and training new staff members. In either case, if the project is executed with contingency unspent, it becomes profit.

The seller's profit is at risk depending on the contingent scenarios described above. However, the possibility of reward is also high due to the possibility of retaining the contingency (profit: high risk/high reward).

Invoicing is generally done based on delivery milestones. From the buyer's standpoint, auditing is minimized, as their audits are typically limited to the number of deliverables issued, and the seller is rarely obligated to provide backup data to validate their invoices. The products and services being delivered are validation enough.

A fixed-price (lump-sum) project offers the buyer several benefits, the foremost of which is an enhanced ability to allocate resources. The buyer can set aside project funds (plus a safety buffer—their own contingency) with a high level of confidence that additional funds will not be required. This works to the buyer's advantage in planning other projects. The buyer gains these benefits but, compared to the cost-plus contract, loses much control over how the project is executed. To submit fixed-price bids, bidders generally work at their own expense to clearly define the set of deliverables and the methods they expect to employ to meet the buyer's defined SOW. The buyer cannot control these methods except as specified in the RFP.

If properly managed, a fixed-price project can be the most efficient and effective format for both organizations. The buyer knows the cost from the beginning, and the seller can make a higher profit if a better execution method or lower-cost materials are found that still meet requirements. However, the seller must be ever vigilant in managing scope creep. Once the buyer accepts a bid, the seller is not obligated to adjust the deliverables or methods. If the buyer makes a request that is out of bounds with respect to the SOW, the seller has the right—and obligation—to refuse the request until the buyer approves an engineering change order (see Section 3.2.4), which might also trigger renegotiating the price. This defensive posture on the seller's part can lead to a fractious relationship with the buyer if a previously agreed-upon change control method is not employed.

1.3.5 Project Structures: The Turnkey Project

Turnkey: *Of, pertaining to, or resulting from an arrangement under which a private contractor designs and constructs a project, building, etc., for sale when completely ready for occupancy or operation....turnkey contract.*¹

In the context of a controls project, a turnkey project is governed by a fixed-price contract. The customer wants to have the final product show up with minimal to no participation on their part. Once the project is awarded, the seller's only obligation is to meet the specifications and schedule. Once the project is awarded, the customer's input drops to virtually nil with respect to how the project is executed. Projects that provide self-contained equipment that is shipped from the factory fully functioning (a "skid") are examples of turnkey projects. The customer merely mounts the skid somewhere in their facility, hooks up the utilities, and makes any necessary process connections, and the system is fully operational. The cost and profit for all of the ICS-related services are embedded in the price of the skid.

1.3.6 Project Structures: The EPC Project

EPC is an acronym for *engineering, procurement, and construction*. An EPC project is one in which the buyer designates a contractor as a single point of contact. This contractor is referred to as the *prime* and is the only project participant directly paid by the buyer. The prime must obtain bids, award subcontracts, and provide oversight as necessary to coordinate all subcontractor activities. The prime bears full responsibility for the success of the project, assuming all liability from the customer's standpoint. To maintain a reasonable risk/reward ratio, the prime can be expected to have a higher profit target than would typically be the case. EPC projects may be governed by a lump-sum, T&M, or T&M NTE contract, or a combination of each.

¹ turnkey. <http://Dictionary.com>, accessed November 22, 2023, <http://dictionary.reference.com/browse/turnkey>.

1.3.7 Project Structures: The Retrofit and Greenfield Projects

A *retrofit* project is one in which an existing process facility is being modified. Retrofit projects can be difficult to quantify on the front end, thus lending themselves more often to the T&M contract or a derivative thereof. A *greenfield* project is more suited for a lump-sum contract because nothing material exists. With everything being new, it is easier to define the project design basis. The exception to that statement is a research and development project, which has no established precursor.

1.3.8 Project Structures: The Hybrid Project

Any project can, and most large ones do, exhibit several of the characteristics just described. For example, if the SOW is well-defined, the engineering, procurement, and construction portions of the project might be done on a lump-sum basis, while unknowns about final operational tweaking might drive start-up and commissioning to be handled under a separate T&M agreement. On the same project, pre-engineered turnkey subsystems, such as package boilers and water treatment systems, could arrive and be installed.

1.4 The Customer/Service Provider Relationship

I spent most of my career as a consultant, executing capital projects for others. They had no reason to call me again once the original project was complete. But most of my customers have been repeat customers. Over the years, I've realized something obvious: People like to work with people they trust. It's also about technical prowess, to some degree, but I'm convinced it's more about interpersonal relationships. Each party must feel that the other, while wanting to win themselves, at least does not want the other party to lose. The contractual configurations described above are frameworks that define the environment within which a relationship may be built. Both sides may be honorable and have good intentions. Yet, if one is not fully aware of that environment, they may misunderstand the actions of the other or even accidentally do harm.

These relationships begin to be built in the proposal phase. For example, as a service provider, is your customer sophisticated, and is the project well-defined and funded? If so, you may be able to minimize your contingency. If not, you may feel compelled to inflate your price to the razor's edge of what you think the customer can afford in order to cover your potential risk. If the latter is the case, it would be best to let your customer know that your contingencies, in your opinion, are too high. You may need the extra funds to survive, which is not good for you, or you may make an unseemly profit, which is not good for the customer. Either the customer must refine the RFP, or the project would be best executed as a T&M. This is a good conversation to have, as it lets customers know you have their interests at heart, as well as your own.

If the customer is unable or unwilling to refine the RFP and is uncomfortable with a straight T&M, then perhaps you can use a hybrid scheme that breaks the project into two segments. The first, smaller segment is the investigation phase done under a T&M/NTE type of contract. This phase typically consumes about 10% of the anticipated overall project cost and benefits everyone as it eliminates the major unknowns. The second phase, detailed design, can then be executed as a lump-sum project. As a service provider, the T&M/NTE arrangement is usually the last thing you want to do, as it places all the advantage on the customer's side of the ledger. But in this case, it works for you because of the limited scope and the fact that the effort will likely lead directly to a larger project.

After the project is awarded, PMs from each organization need to understand the communications strategies that should be employed in various situations, both externally, between organizations, and internally. An honest and forthright dialogue should be established in which good news is carefully disseminated only after being fully vetted, and bad news is brought out for discussion as early as possible. As the service provider, the last thing you want to do is surprise your customer with a change order that has accumulated over time. It is much better to bring it up and discuss it, even before you can fully quantify the impact.

The following soft skills are important in developing a trusting relationship:

- **Be on time.** – Respect your customer’s schedule. If the meeting is at a new location, scout it in advance so you know where it is and how much time to allow for transit.
- **Be prepared.** – Mentally go through the meeting in advance. Try to anticipate questions that may arise, options that may be requested, and so on.
- **Be trustworthy.** – If you say you will do it, do it. Don’t make excuses. An old Navy chief used to say, “Don’t bring me excuses; bring me reasons!” The difference between a reason and an excuse is subtle, but you know it when you see it. Generally, reasons should be accompanied by mitigation strategies. Another phrase, “Don’t bring me problems without solutions!” also applies here. Your credibility is on the line, which reaches far beyond the exigencies of the current project.
- **Be forthright with bad news.** – Withholding bad news does not enable others to comment and help develop mitigation strategies. Mature, professional project management accepts the fact that negative events sometimes occur that affect the budget and/or schedule. Once the team is notified, it can take responsibility for mitigation.
- **Be careful with good news.** – Before broadcasting good news, double-check it, triple-check it. Taking good news back to neutral can make it feel like bad news. It is best to let the situation develop unless properly qualified and vetted. However, being too cautious can also be bad. Coming in grossly under budget on a T&M project can be bad news if the customer misses a window in which the funds could have been used for other things.
- **Be empathetic.** – If possible, learn what you can about your customer’s or coworker’s situation at work and home. The human condition affects each of us, and as background problems wax and wane, a person’s professional performance and attitudes can be affected. Having a trusting relationship sometimes requires us to adapt what we do to help the other party succeed. The ability to do this effectively has, perhaps, the most impact on developing a long-term relationship. A customer once called me at 2 a.m., after I had made a long drive home in the snow, because he was concerned that I wouldn’t make it. After that, there was nothing I wouldn’t do for that customer.

1.5 Project Flow for a Controls Project

A project may involve many engineering disciplines and organizations. This book focuses on the controls aspects of a project, which limits the discussion to electrical, instrumentation and controls, systems integration, and panel fabrication and their interfaces with other disciplines.

No matter what style of project—retrofit, greenfield, turnkey, or EPC—most industrial projects are similar in their development. There are at least two ways to describe project steps: FEL levels and phases.

1.5.1 Front-End Loading (FEL)

A properly executed project begins with a good assessment process, which starts with the owner. The owner begins with an idea, assesses its feasibility and likely cost, finds partners to help implement it, and then lives with the results. From beginning to end, the project is managed and controlled by the owner. The level of control the owner retains during design and implementation depends on the type of contract described previously. But, in the end, the owner must live with the results.

FEL is a widespread school of thought that helps the owner manage the project from conception through design. The details vary somewhat in how it's implemented, but in general, the FEL process is a sequence of stage gates that provide stakeholders with several opportunities to assess feasibility and risk. Each stage is essentially a new project with a budget, goals, and a schedule. As the stages progress, funding can be allocated for the next stage or the project can be killed before additional funds are expended. The Construction Industry Institute (CII) defines the stage gates shown in Figure 1-6 as follows:

Note: PDRI stands for Project Definition Rating Index, a tool that measures the degree of scope development.

- **FEL 0 – Feasibility** – The initial phase in which the scope is identified and generally described. Feasibility is evaluated, options are considered, and a likely project cost is derived.
- **FEL 1 – Proof of concept** – More detail is provided, the scope is refined, plans are developed, and cost projections are more fully developed. A hazard and operability study (HAZOP) should be performed at this point, and safety integrity levels (SILs) should be assessed for all process areas.

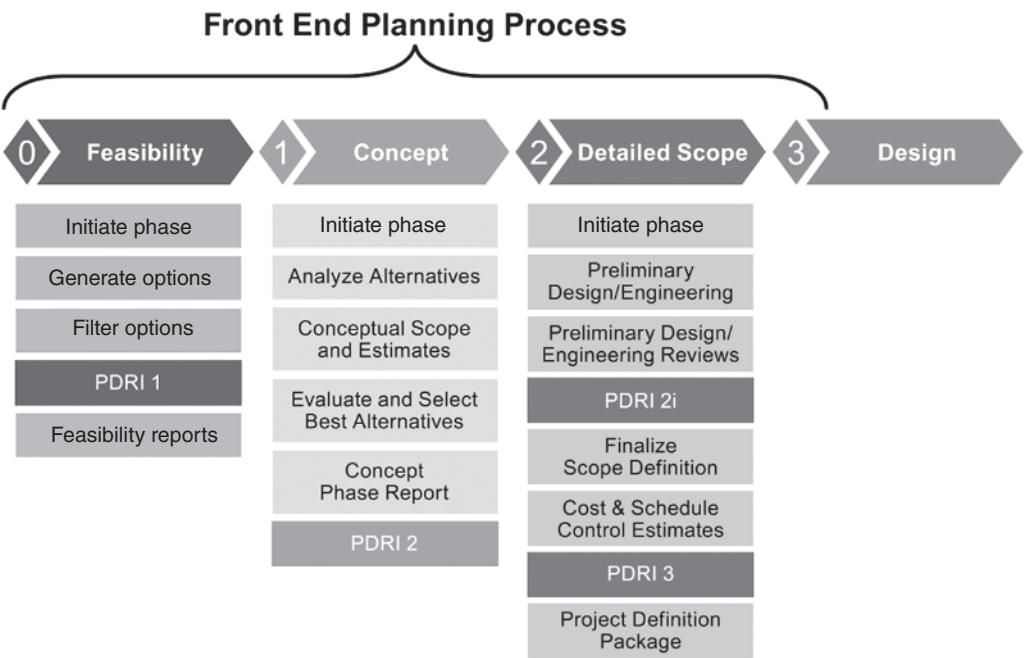


Figure 1-6 Front-end planning process from the *CII Best Practices Guide: Improving Project Performance*, version 5.0. *Source:* Reprinted with permission of the Construction Industry Institute, The University of Texas at Austin, © 2022.

- **FEL 2 – Detailed scope** – Overall project goals are established, risks are assessed and mitigated, preliminary designs are developed and approved, and a design budget is provided to a tight margin.
- **FEL 3 – Detail design** – Engineering packages are developed, issued, and approved; a construction bid package is produced and bids are sought; implementation plans are created; and a constructor is selected.
- **Project implementation** – This phase includes construction and all activities through commissioning.

According to CII [6], the cost of implementing a robust FEL process is 2% to 5% of the project's total installed cost, depending on the type and complexity of the project.

For the discussion in this section, the project is a capital project with multiple contracted organizations, but the steps and concepts discussed are scalable and also apply to smaller projects. The owner must provide guidance and oversight throughout, as successive organizations come online at the appropriate times (Figure 1-7). As each subsequent organization becomes involved, that organization should perform many of the same FEL investigative steps that the owner went through in their own self-interest.

1.5.2 Design Phases

FEL is an owner's process for managing a project. From an engineering contractor's perspective, projects are managed in phases. At least four phases are identifiable (Figure 1-7).

- Phase 1 spans FEL 1 and FEL 2 and covers the project award through preliminary engineering.
- Phase 2 aligns with FEL 3 and covers the entire detail design process.
- Phase 3 is testing and deployment.
- Phase 4 is post-deployment activities.

Figure 1-8 shows a thumbnail sketch of a typical project as the involvement intensity of participants ebbs and flows over time. Figures 1-7 and 1-8 are related as they link to the time frames shown, *Times 1 to 24*.

- **Times 1 to 4** – A project generally begins with the OE developing a project charter and getting approval to begin an investigation. Plant Operations lays out the needs and develops the requirements. The OE develops a business case for the project and proceeds through the FEL 1 and FEL 2 gates to gain initial project funding. This includes prequalifying a set of prospective bidders, preparing and issuing bid packages, and reviewing bids.
- **Times 5 to 6** – FEL 3 begins with awarding the contracts to the E&I, the CSI, and the CPF. (Note: This assumes the contract is an EPC in which one PO will be issued to an ICS provider. Otherwise, the various awards can be staged as deliverables are prepared, enabling the creation of more complete and focused bid packages.) During this time, the winning E&I team develops its upper-tier deliverables and presents them for review and approval. This 30% design review meeting (DRM)² is a gate to allow the detail design to commence.
- **Times 7 to 9** – Phase 2 begins after the owner has approved the 30% upper-tier E&I package. The CSI team uses the E&I 30% package as its design basis and starts preparing its own

² 30%, 50%, 90%, and 100% are arbitrary but common designators that indicate the approximate completion percentages for a project at the four key stages. Another set of common designators is 10%, 50%, 90%, and 100%.

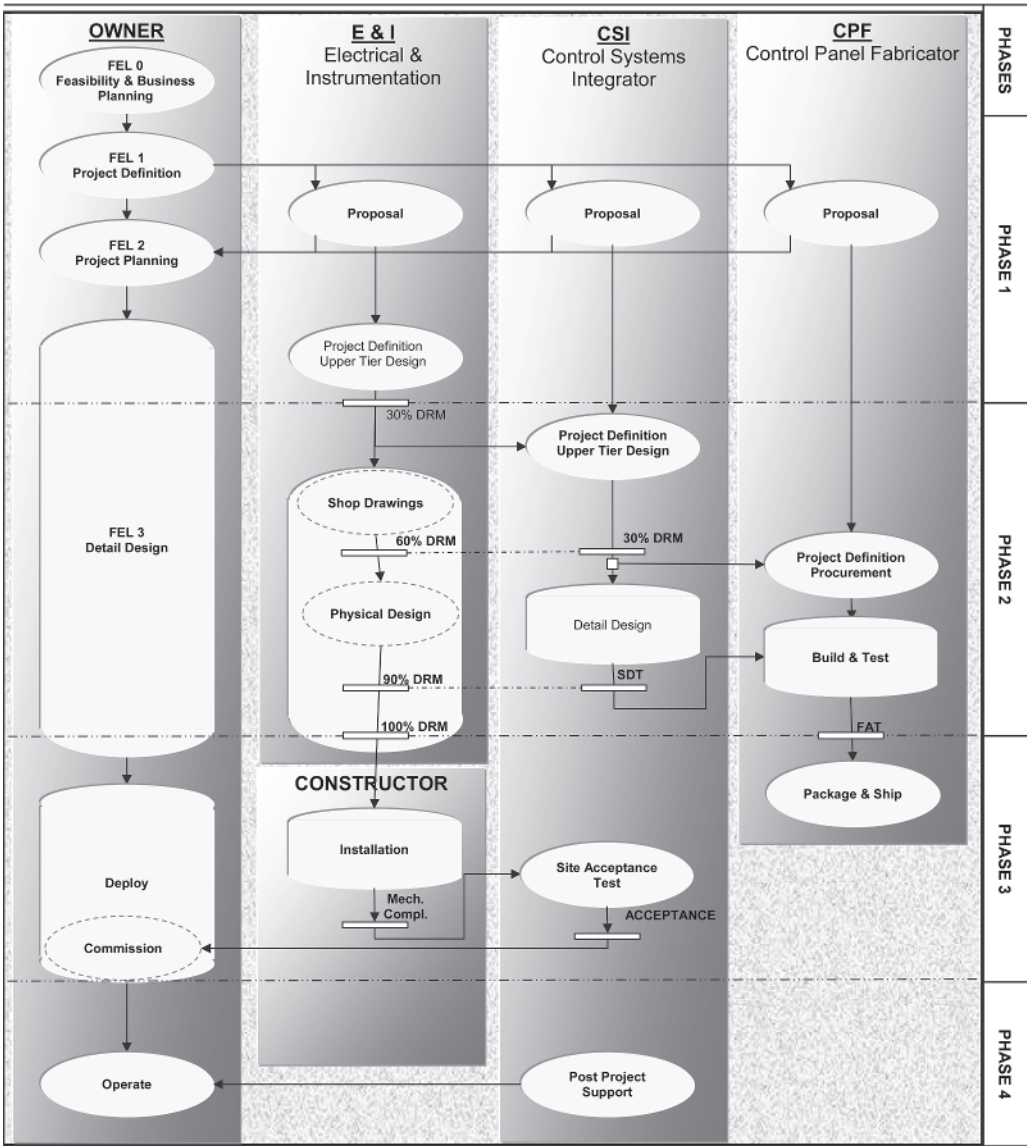


Figure 1-7 Typical ICS project lifecycle.

upper-tier design package, which will lead to its 30% DRM. The E&I team begins preparing the shop drawings that will activate the panel fabricator. When the shop drawings and bill of materials (BOM) are complete (100%), a 60% DRM is held in which the customer review and approval occur. At or about the same time, the CSI team will issue its upper-tier 30% design package for approval. It's best to coordinate the two teams' design reviews because the output of one can affect the other.

- Time 10** – After the owner approves the 60% package for fabrication, the E&I team issues shop panel drawings for fabrication (IFF), and the CPF team begins its project planning and procurement processes and executes its build tasks. The CSI team is fully involved in software

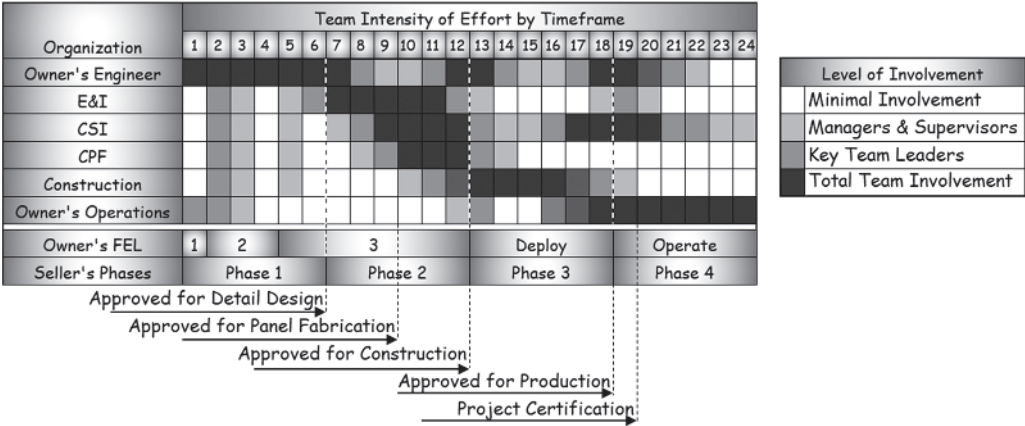


Figure 1-8 Control system project flow by involvement intensity versus time.

- development at this point. The E&I team begins physical design activities unrelated to panel fabrication (i.e., cable/conduit schedules, floor plans, installation details, etc.).
- **Time 11** – The CSI team prepares its test plan and performs any interim lab testing it deems necessary. The E&I team prepares its 90% review package for the DRM, a comprehensive review of the entire project. Coinciding with the 90% DRM, or in the same time frame, the CSI team demonstrates that its software complies with the requirements outlined in the control narrative and functional specification. This is often done in a lab environment using simulation, and the key elements of the software are demonstrated in a software demonstration test (SDT). After the SDT is approved, the CSI team releases any lab equipment to the CPF, and the CPF installs the last equipment items and applies the final touches to the panels in preparation for the factory acceptance test (FAT).
 - **Time 12** – After the 90% DRM and the SDT, both the CSI and E&I teams incorporate comments and accumulated redlines and prepare for the 100% DRM and the FAT, which are often held at about the same time. This is the culmination of all the design efforts and concludes the FEL process. On completing these events, all the control system equipment can be shipped to the site. The OE prepares a construction bid package and awards the construction contract.
 - **Time 13–18** – The deployment stage generally begins with a construction kickoff meeting in which the E&I team orients the constructor to the design package. The E&I’s effort intensity declines rapidly to supplying phone support services as needed. By Time 17, the constructor will begin to turn systems over. Mechanical completion³ of a subsystem triggers the CSI team, who will often lead the site acceptance tests (SATs), system by system. The SAT fully exercises the control system to the highest degree possible without being in full production. Every instrument will be verified to be operational, every motor bumped, and rotation verified. The SAT may include moving inert materials, testing control loops, verifying interlocks, and so on. After confirming that all systems are operating to specification, the owner signs off on the SAT and starts the commissioning run that will culminate in full production. Time 18 is where the owner’s Operations team executes the commissioning procedure with CSI team support. The constructor transitions to a support role during this time.

³ Mechanical completion can be defined several ways. In this context, it implies that all mechanical and electrical components have been verified to be correctly installed, power is applied, and the grounds are checked.

- **Time 19** – In Phase 4, the OE is engaged in closing loopholes and ensuring the project documentation is finalized. Each of the other engineering participants starts Phase 4 by finalizing their documentation, incorporating redlines that may have accumulated during Phase 3.
- **Time 20–24** – After Time 19, all documentation will have been finalized and certified “as-built.” Any performance tests will have been executed, and the project will be certified as complete. Final billing will then occur. The systems integrator shifts plant operations to support (Times 23 and 24), after which a separate general services contract may be negotiated to provide long-term support.

Of all the phases of a project, Phase 1 is the most important. It is where the owner defines their needs, and the seller digests that information and develops the plans and upper-tier documents that will form the design basis. Most projects fail because of a lack of planning or not effectively communicating the plan to the execution team. Projects in which the owner follows a rigorous FEL process that eliminates unknowns in Phase 1 have a much greater chance of success than those that do not.

These next sections look at each organization and provide a detailed view of associated considerations and tasks. Deliverables are described in general terms; more specific examples are provided in Part 3 of this book. It should be noted that the dividing lines between some project phases are fuzzy at best. But this is a good approximation of how a typical project flows. We start with the owner.

1.5.3 The Owner's Project

As previously discussed, a project is a temporary activity with a purpose. For the owner, it begins with a need, usually related to a production concern or a profit motive, coupled with the availability of a good market window. It ends with the need met or an intentional abort if due diligence dictates. Many projects are started and subsequently aborted as the evaluation process evolves to reveal insurmountable problems. On the other hand, projects that are not properly vetted may go on to fail, as those insurmountable problems are not identified until too late. Several hurdles should be crossed internally before funding appropriations can be made responsibly, materials procured, and new employees or consultants hired. Figure 1-9 provides a representative sampling of some of the activities the owner or OE performs during the project lifecycle.

1.5.3.1 Owner's FEL 0: Business Planning Stage

Business planning for the owner usually comes down to evaluating the feasibility and estimating the cost and potential return on investment, considering anticipated initial capital outlays, and estimating lifecycle costs. Projects typically fall into several broad categories:

- **New construction projects** – Large-scale automation projects usually occur when a new plant is built. The control system in a new “greenfield” project is usually a vanishingly small portion of the total project cost, perhaps as small as 3%. This results in the control system aspect of the project receiving scant notice from the capital project planners because the bulk of the project cost is in construction. The control system is almost treated as a commodity in this scenario, as various controls manufacturers are consulted and evaluated as they compete to be included in the discussion.
- **Production-driven retrofits** – In this type of project, existing control systems are expanded to take on new production lines or modified as production processes are optimized. Justification for the change is strictly production-related, with the cost/benefit analysis heavily tilted toward limiting expenses and minimizing production impacts.

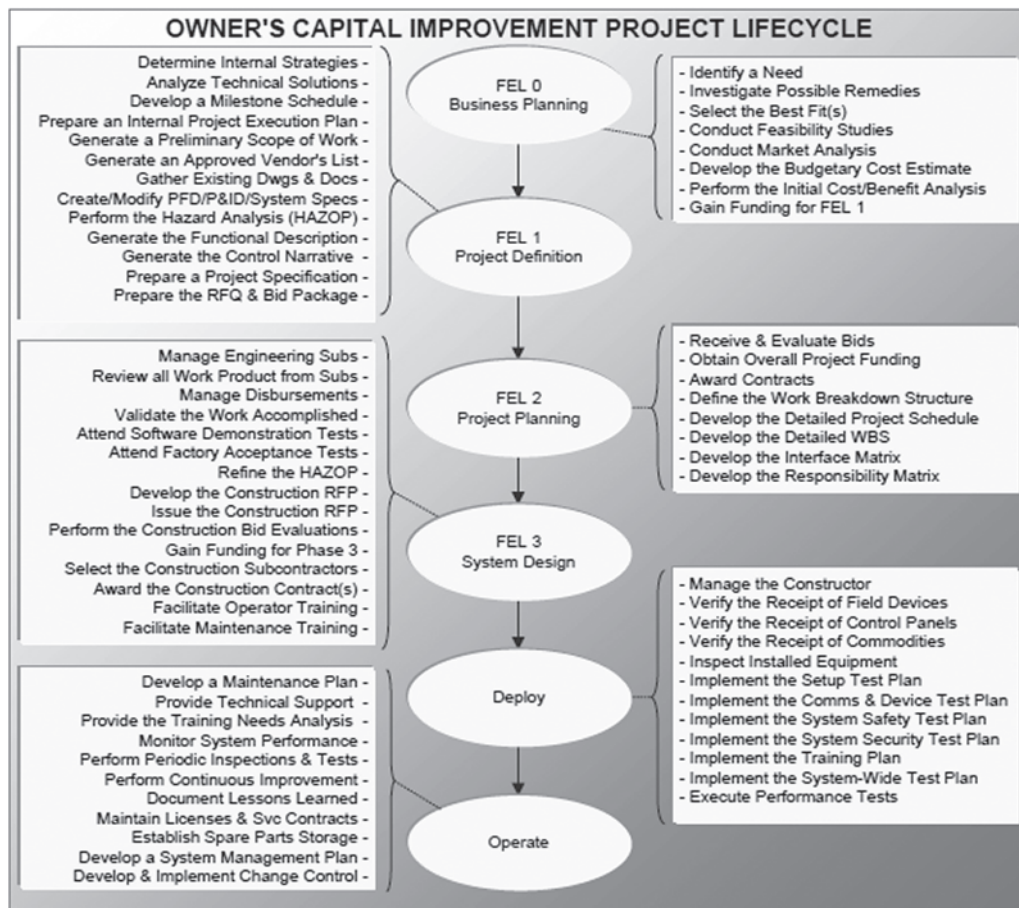


Figure 1-9 Owner's capital improvement project lifecycle.

- Control system maintenance reliability upgrades** – Projects that modernize portions of an existing control system with a newer generation of components that do the same thing as the old ones, but with added reliability, fall into this category. The upgrade can be software, hardware, or both and can involve some reengineering as newer, perhaps smaller equipment form factors (e.g., physical attributes) are deployed.
- Control system capability upgrades** – Projects that modernize portions of an existing control system with a newer generation of components and/or software that does things better fall into this category. Some of the more effective projects, at least in terms of the cost/benefit ratio, replace the older operator interface while leaving the aging programmable logic controller (PLC) or distributed control system (DCS) and input/output (I/O) modules in place. Doing this tends to make the plant easier to operate and thus more reliable while giving management more oversight tools, data historian capacity, reports, web-based tools, real-time business data, and so on.
- Control system replacement projects** – It is difficult to justify replacing an existing control system. This project is usually a last resort when maintenance issues and system failures begin to impact production. Most system manufacturers will rise to the occasion and offer enticements for the customer to upgrade the system, like low-cost engineering solutions or patch after patch. Replacement projects occur only after a great deal of effort to avoid the action has yielded negative results.

During this period, the owner's activities include developing a preliminary process flow diagram (PFD), a heat and material balance (HMB), and a study of the economics. Whatever drives the project will drive the business plan and set the constraints. After the range of remedies has been reduced to a manageable number, a best-fit analysis reduces the number of possibilities further. A rough idea of the likely project cost and schedule is developed. Then, a feasibility study and market analysis yield the hard data needed to make a final decision before appropriating additional funding to proceed to FEL 1.

1.5.3.2 Owner's FEL 1: Project Definition Stage

At FEL 1, enough hurdles have been passed to indicate that pursuing a project might be worthwhile. A small investment will have been approved and funds appropriated to take the next step: define the project better and prepare to release information to obtain bids. One of the first issues for the owner is to designate an OE—in-house or hired under contract—to shepherd the project through the preliminary stages and possibly manage the entire project. The OE investigates the range of technical solutions proposed in FEL 0 and further validates them. The OE begins to develop a preliminary SOW and a PEP for the owner's organization(s) that describe who and what must be prepared to contribute to the project. Upper-tier documents, such as piping and instrumentation diagrams (P&IDs), equipment arrangements, single lines, physical arrangements, and the like, are collected or produced to become part of a bid package that describes the project. Line lists, I/O lists, motor lists, and other lists are developed. A preliminary HAZOP may be done at this point to ensure the bid package is complete and pertinent standards and procedures are gathered. Safety instrumented systems (SISs) evaluations are performed, and SILs are defined for each process area. See Section 6.8 for more information on SISs and SILs.

A written functional description is produced and vetted, and a control narrative is written for the project specification. An SOW and a project specification are developed and folded into an RFP. After preparation, the bid package is released.

Many of these FEL 1-generated documents are described further in Chapter 3. Often, these upper-tier design basis documents are either out of date or must be created, and the owner hires an engineering firm to perform an engineering study that will complete the feasibility assessment and produce the documents needed to form a design basis. Sometimes, the firm hired to create the design basis is precluded from bidding on the final detailed design, as there could be a perceived conflict of interest, but this is usually not a restriction except for some government contracts.

1.5.3.3 Owner's FEL 2: Project Planning Stage

While bidders are responding to the RFP released at FEL 2, the OE continues to validate the design concept. The OE usually interacts with the prospective engineering service providers to help them prepare their bids, answers questions, provides site walkdowns (if appropriate), and facilitates information flow. This can be a huge undertaking on large projects with multiple engineering and construction companies covering many disciplines. The OE can also work on milestone schedules and prepare contracts. When the bids are received, the owner and OE spend time and effort evaluating and responding to each bid.

Assuming some of the bids meet the financial and schedule requirements, the owner will be able to get funding to proceed with the detailed design phase (Phase 2), make selections, and award contracts. PMs and other skilled personnel may need to be hired. A new OE may even be selected for the execution phase.

It is always a good idea to start meeting with the contractors early to ensure they understand their roles and responsibilities. At this point, it is a good idea to develop a responsibility matrix that takes

each task line item on the left side and each participating organization across the top, and lists roles and responsibilities in each cell. This is a living document that can greatly enhance communication between parties. Contractors should be encouraged to provide input into this matrix throughout the project.

1.5.3.4 Owner's FEL 3: System Design Stage

The design phases start when the first contract is awarded. Kickoff meetings are held, and design begins. Other contracts may be in various stages of progress, so the owner and OE may have activities across FEL boundaries for a time. If the project is larger than the controls group, then the OE may be dealing with mechanical, civil/structural, and/or process engineering disciplines in addition to the controls-related disciplines discussed in this chapter. Those other disciplines are on board first, and their work products feed into the controls-focused activities.

From the controls perspective, the E&I contractor will be the first on board, generally with the electrical facet leading the instrumentation facet. The electrical discipline includes facilities, lighting, and other segments in addition to the process controls elements, such as motors and variable-frequency drives. Hence, those portions of the electrical repertoire are already in progress. The controls work products of the E&I team go toward refining a control specification that will be used to finalize the scope for the systems integrator. Likewise, the CSI's work product will feed back into the E&I contractor's workflow and the scope that will be released for the CPF. At this point, the owner also begins to deal with invoices and progress payments.

As factory subassemblies are completed, the OE is well advised to travel to the various locations and observe as the FAT is executed. In most cases, FAT procedures must be provided in advance so the owner can vet them before execution.

In addition to managing contracts, the OE is also working toward Phase 3. Many of the steps taken during FEL 2 must be repeated in selecting a construction partner for the project. Work products are taken from various entities to build a construction specification. Construction work packages are generated and organized by the work breakdown structure (WBS) or other criteria to help the prospective constructor organize the work.

It should be noted that the constructor is probably already known at this point and may already be under contract based on a budgetary price. The owner may already have experience with a local construction company, and the project could already have been tentatively awarded with the proviso that the constructor's bid can be refined as more information becomes available. This is the difference between a budgetary estimate, made with sketchy information and heavy contingency, and a definitive estimate based on adequate, detailed information with minimal contingency.

1.5.3.5 Owner's Phase 3: Deployment

Phase 3 activities begin for the OE when materials begin arriving on-site and/or when the constructor's team starts to mobilize, whichever comes first. Preliminaries such as site preparation, underground work, and infrastructure-related work often begin long before the ICS services engineering and construction support organizations arrive. The OE is responsible for understanding materials availability and managing the construction schedule. The constructor is usually responsible for receiving materials and warehousing them, but the OE closely monitors those activities, clearing obstacles and ensuring the constructor properly manages the flow of materials.

As the construction packages (drawings, etc.) are released from the engineering disciplines, the OE is generally tasked with making sure they are complete and that individual documents are properly dated and signed off. The OE is also usually responsible for supervising the constructor as the work progresses. However, sometimes, a construction manager is hired to manage the constructor

and track all the materials, drawings, and checkout documents that will be delivered or produced during this event. The deployment phase includes the following major steps:

- 1) **Installation** – Buildings are erected, equipment is installed and wired.
- 2) **Verification** – After the wiring is complete, the construction team performs QA audits to ensure that the equipment has been installed per the drawings and point-to-point continuity checks to ensure the wiring is connected properly. These tests are done with the power off.
- 3) **Leak checks/pressure checks** – Vessels and pipes are pressurized to check for leaks.
- 4) **Electrical checkout (e.g., loop checks, bump, and stroke)** – Power is applied to the equipment. Valves are activated (stroked), and limit switches are adjusted. Motors are briefly energized (bumped) to confirm the proper direction of rotation. Pressures and temperatures are simulated to verify proper input and display.
- 5) **Site acceptance tests** – Subsystems are checked for proper operations and sequencing. These checks are usually done “dry” and “cold,” meaning without process materials flowing and at ambient temperature.
- 6) **Operator and maintenance training** – Plant Operations and technical support teams are trained on the systems. Off-site training to obtain background information on equipment and on-site training to gain operational insight are the norm.
- 7) **Start-up** – Subsystems begin to be brought online under full-load conditions; for example, steam is generated, raw materials are handled and processed, and Operations personnel begin to operate sections of the facility.
- 8) **Commissioning** – All systems go into full production with Operations personnel in charge. The project team begins to recede into the background as Plant Operations and Maintenance groups take ownership.

1.5.3.6 Owner's Phase 4: Support

After commissioning, the Operations department operates the facility. The OE assumes a support role, remaining on the scene until the plant is in full operation and Plant Operations and support personnel are capable of autonomous operation. During this time, lingering issues are addressed, such as collecting and archiving finalized documentation from contractors and subcontractors. Production testing is ongoing as production rates and product quality are checked against the original design criteria. Final turnover is accepted, and the project team disbands. Ongoing service agreements are negotiated and activated. Warranties are monitored.

1.5.3.7 Owner's Project Deliverables

The owner (or OE) is responsible for generating several engineering products that other project participants need. In some cases, these products are started by the owner and finished by contractors. Other deliverables listed in this section may not be owner-generated but are still required as design input for the controls design process and should be closely monitored by the owner. Some of the key items from the perspective of the process, instrumentation and controls (I&C), piping/mechanical, and electrical discipline groups are as follows.

1.5.3.7.1 Process Flow Diagram (PFD) The owner typically provides the PFD. It is a simplified schematic of the system's mechanical configuration. For example, a tank is piped to a pump that is piped to another tank. Very little detail is provided regarding tank or pipe sizes, and virtually none of the instrumentation is depicted. The PFD becomes the basis for the HMB sheet and the P&ID.

1.5.3.7.2 Heat and Material Balance (HMB) Sheet The owner or OE generally produces the HMB sheet, which is not provided to others until they sign a nondisclosure agreement; the list of valid users is short. The HMB is typically considered “classified,” as highly sensitive, confidential, or even secret information is presented. Graphically similar to a PFD, the HMB contains additional details concerning the physics of the project. The drawing shows major equipment items and the piping that connects them. Heat loads, flow rates, and energy expenditures are calculated and charted in the document. Raw materials that are expected to be processed are shown as well.

1.5.3.7.3 Piping and Instrumentation Diagram (P&ID) The P&ID is started early in the engineering process, originating directly from the PFD. The owner or OE typically starts the P&ID. However, once the contracting engineer is selected, P&ID ownership passes to them. Maintaining the P&ID is primarily the responsibility of the seller’s Process Engineering or Mechanical Engineering department; however, responsibility is shared by the Electrical and Instrumentation departments as well. It is a working document that is continually updated throughout the life of the project as a new understanding of the process develops. It provides piping detail in the form of pipe sizes and specifications and shows piping features such as expansion joints, flex hoses, blind flanges, and rupture disks. It provides instrument information in the form of instrument “bubbles” with assigned functional tag numbers to indicate level transmitters, flow switches, and the like. It indicates operability (see Section 1.5.3.7.7) by showing hand switches, indicator lights, gauges, tank-level sight glasses, and annunciator points, among other items. It also indicates major control logic elements by showing interconnected control system functions and interlocks. The P&ID is the primary medium used to communicate cross-discipline information between the electrical, mechanical, I&C, and control systems integration groups.

1.5.3.7.4 Equipment Arrangement Drawings The mechanical and civil engineering groups—usually the OE or contract engineers—produce the equipment arrangement drawings. The basis of these drawings is the civil/structural drawings. The equipment arrangement drawings become the basis for the detailed piping arrangement drawings (piping orthographies) and, ultimately, the instrument area plans.

1.5.3.7.5 Equipment Specifications The seller’s mechanical engineering group generally specifies process equipment. They, or the process engineering group, will specify vessels; heating, ventilation, and air-conditioning systems; blowers; heat exchangers; and so on.

1.5.3.7.6 Piping Drawings Once the equipment arrangement drawings are done, the mechanical engineering group begins generating three-dimensional isometric drawings (isos) for each piping section and two-dimensional orthographic drawings (orthos) showing floor plans and elevation views of the major equipment items, large-bore pipe, and in-line instrumentation. The interplay between the isometric drawings and the orthographic drawings continues iteratively until both sets are complete.

Access routes, building code requirements, weight considerations, and other pertinent information must be considered as the drawings are generated. Instruments that must be piped in-line are depicted, so the instrument engineer must be prepared to provide the flange-to-flange dimensions of in-line instruments.

1.5.3.7.7 Hazard and Operability Study (HAZOP) After the production process is defined to a fairly high degree and the HMBs are developed, the envisioned system should be analyzed for hazards

and operability. The HAZOP is sometimes a component of a process hazard analysis (PHA) produced by the process engineers. The HAZOP is typically an FEL 3 activity that must be done after the P&IDs, HMBs, and control narrative draft are complete and is usually the responsibility of the owner or OE. Operability concerns relate to the bottom line by streamlining the process or optimizing procedures. Safety issues that should be analyzed begin when the raw materials are brought to the site. Handling and storage procedures should be discussed and implemented. Hazards to personnel, the environment, and equipment should be analyzed for each area of the plant and each type of material used and created as part of the process. Finally, the final product production and distribution should be analyzed.

The HAZOP provides a structure for analyzing each element of the process facility. This structure is in the form of a checklist that presents a series of process states. Each state listed is a desired state. The series of states listed in *HAZOP and HAZAN: Identifying and Assessing Process Industry Hazards* [7] by Trevor Kletz is as follows:

If, for example, you are analyzing pressure changes in a vessel:

- None: What happens if the pressure falls to zero?
- More of: What happens if the pressure rises?
- Less of: What happens if the pressure falls?
- Part of: What if the pressure changes when the agitator is off?
- More than (or as well as): What if the pressure drops but the temperature rises?
- Other than: What other concerns are there relative to pressure changes?

Each of these questions should be asked, and each team member should be allowed to provide input. Each question and response should be recorded, along with any defined remedial action and operator responses needed.

The HAZOP is a structured brainstorming session. Freewheeling discussion of the topics should be encouraged within the boundaries set by the facilitator. The HAZOP should be all-encompassing and thorough. The time spent will be more than recouped by the resulting improvements. To gain the most benefit from the HAZOP, the analysis should be a team effort that includes representatives from every department affected by the project. Finally, the owner's management must commit to a reasonable attempt to implement the suggestions; otherwise, the whole thing is a waste of time.

1.5.4 The E&I Seller's Project

A four-phase project model applies to the control system E&I contractor just as it does to the owner and other participants (Figure 1-10). The E&I contractor must evaluate the owner's RFP and decide whether to invest in a proposal effort to pursue the project. Figure 1-10 is an overview of a typical controls project from the E&I perspective.

1.5.4.1 E&I Seller Phase 1a: Business Planning

Business planning for the E&I engineering contractor (seller) involves asking a few questions: Do we have the expertise to meet this specification? Do we have the workforce to execute it? Does this customer have a history of difficult projects, or do they work as a team with their contractors? Do they pay their bills? Have they done their due diligence? Do we have a strategic interest in pursuing this project, even if it is marginal in several areas?

If the answer to most of those questions is yes, then the prospective contractor will likely invest in the bid process and generate a response to the RFP. The contractor will appropriate internal funds for travel expenses and workforce to conduct a proper investigation and build a proposal. Part of

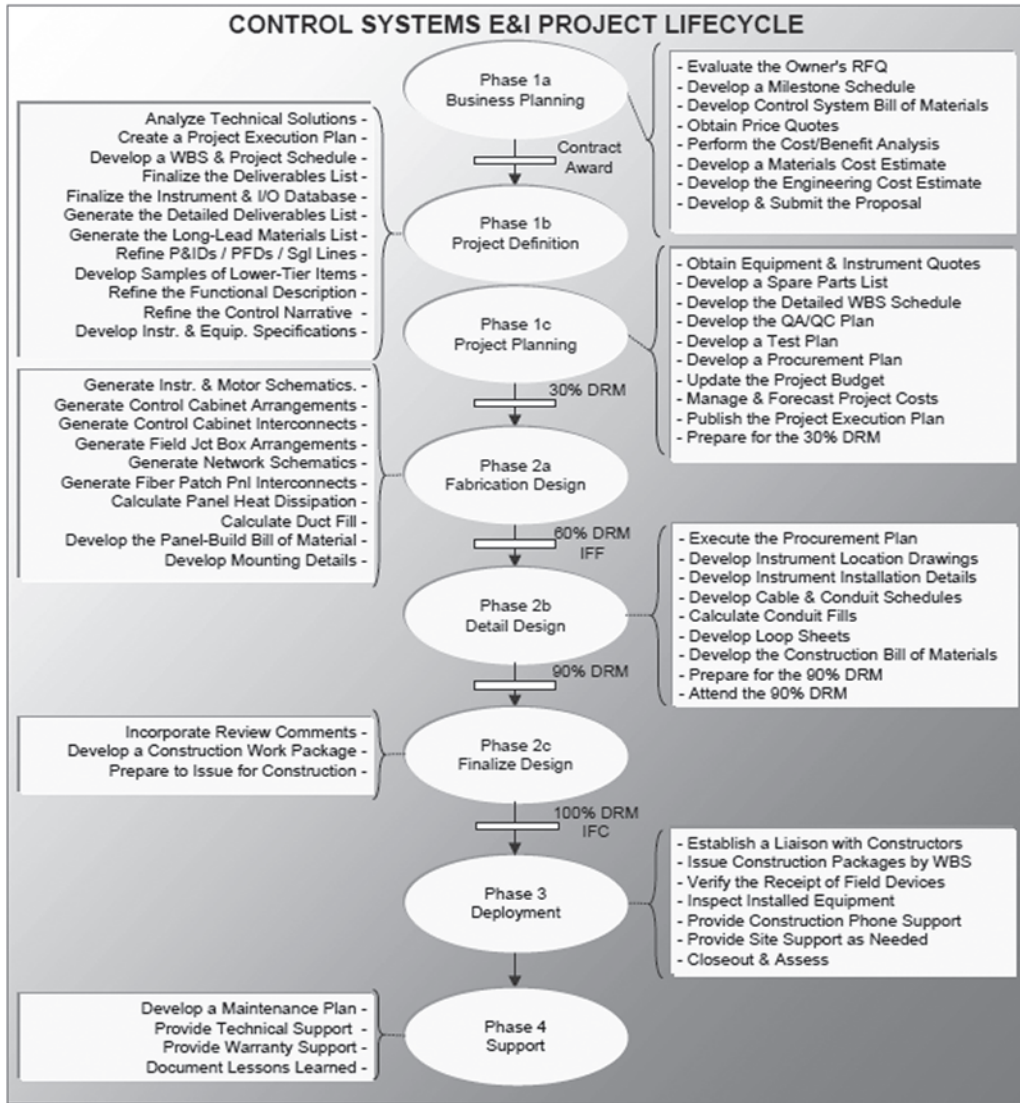


Figure 1-10 E&I seller's project lifecycle.

this process will be to obtain budgetary estimates from materials vendors that can be rolled into an overall project materials price.

Building a competitive proposal can be something of an art. Funds spent at this point are at risk. If you lose the project, the costs are lost. If you win the project, and you were able to include some or all the proposal prep costs in the project price, you may recover them. However, adding that cost to your bid makes you less competitive. This is a decision matrix that each bidder must navigate.

After the proposal is submitted to the buyer, an evaluation period ensues during which the buyer may ask the seller for clarification or modification of the seller's proposal. If the proposal is accepted, the seller may receive a notice to proceed (NTP), which is a verbal or written commitment that a contract is being finalized and that any preliminary expenditures will be honored. If the time between the NTP and contract finalization is expected to draw out, a memorandum

of understanding (MOU) can be written to bridge the gap. The MOU typically sets aside a fund for expenditures made during this time that will be deducted from the contractual budget. The purpose is to limit expenditures during this interim period. It is a legally binding document signed by all parties.

1.5.4.2 E&I Seller Phase 1b: Project Definition

After the contract is awarded, the E&I contractor begins to set up the project and dedicate staff and resources. A PM is then assigned. The PM interprets the RFP, the HAZOP, and other key design inputs and develops a WBS and PEP. The PM then works with the owner to schedule a kickoff meeting, usually at the project site, to get the key participants in each organization together for an intense review of the project and a site walkdown. This meeting and subsequent walkdown are key, as they give the contractor's team an opportunity to meet their respective counterparts in the owner's organization, conduct interviews, and validate the assertions outlined in the RFP. Flaws or omissions in the RFP should be exposed and dealt with immediately. In extreme cases, the contractor could elect to withdraw from the project at this point, with only a minimal impact on their reputation and either their or the owner's bottom line. If the choice is between backing out early and failing later, the former option is preferable, regardless of the fallout.

Another top priority should be to eliminate any assumptions in the proposal and to refine the project schedule further. Document issuance and change management procedures should be clearly defined. Upper-tier deliverables, such as the I/O List, Drawing List, Instrument List, network block diagram, and so on, should be produced either from scratch or by further refining documents provided by the owner during the bid process. A checklist of some of the key tasks to be accomplished at this point is shown in Figure 1-10.

After completing this stage, the contractor and the owner should thoroughly understand the potential problems and risks inherent in the project, and strategies should be developed to mitigate them. Both organizations should gain confidence that the task is doable, and the personnel should start to align themselves with the project goals. The product design should be sufficiently developed to enable the owner to begin negotiating with potential systems integration contractors.

The following are some of the key activities in this stage:

1.5.4.2.1 Work Breakdown Structure (WBS) The WBS breaks down the major tasks and assigns predecessors/successors and resources to add granularity to the project. It is recommended that each WBS line item should be limited to something under 200 hours in size, optimally about 120 hours.

1.5.4.2.2 Deliverables List The Deliverables List is a key management tool that provides a comprehensive list of products that will be handed over to the customer. Sometimes, the customer has a Master Submittals Log (MSL) that lists all the packages they expect to receive during the project. Each deliverable must be assigned an MSL package number, and usually, packages will be issued individually, each package under a separate transmittal.

1.5.4.2.3 Procurement Plan A Procurement Plan (Figure 1-11) should list each item to be procured, its required-by date, the vendor name, the vendor's quote number and date, its budgeted

Vendor / Quoted	Manuf. / Part#	Item	Part# / Description	Qty	PO#	MANAGE PROCUREMENT				Ship Date	Receive Date	Receive Qty	Rec By (init)	Storage Location	Comments
						Original Budget	Unit \$	\$	Actual Cost						
		1	HP Desktop Computers, Precision 3240 Compact who Date: 10/20/05 2:58PM / 10/20/05	2	PO4007635	SL465.57	\$ 2,031.14	\$ 1,268.18	\$ 2,516.36	\$ 2,655.18					
		2	CREDIT/RETURN qty 1 of Precision 3240 Compact	1	PO4007635										

Figure 1-11 Procurement register.

price, the actual price, the purchase order number it was procured under, the ship date, the receive date, who it will be received by, the receipt inspection verification, the current disposition, and the storage location.

Typical procurements for the E&I team include instruments and instrument fittings. For the most part, motors and valves will be procured by the mechanical engineering team, whose activities are outside the scope of this book. Occasionally, valves fall under the purview of the instrumentation team. Motors are usually procured with the pumps.

1.5.4.2.4 QA/QC Plan A quality management plan describes how each deliverable will be validated and the processes to be followed, including the corrective action processes. Chapter 12 covers quality control in more depth.

1.5.4.2.5 Project Execution Plan (PEP) The PEP is an internal document that is the design team's interpreted scope. It takes the Deliverables List and describes how each deliverable will be created, what tools to use, what software to use, how calculations will be done, and how all of this will be stored and distributed. Budgets are detailed for each subgroup on the team, the project master schedule is broken down into its various components, and milestones pertinent to the team's execution strategy are added. For more information on the PEP, see Chapters 3 and 10.

1.5.4.3 E&I Seller Phase 1c: Project Planning

Still, in Phase 1, the project team takes the upper-tier deliverables and analyzes them to develop a detailed project plan that includes all aspects of the project. After most of the tasks are identified and the Deliverables List is completed, it will be possible to complete the planning stage by developing a detailed project schedule and PEP. At this point, it is a good idea to revisit the HAZOP to consider new information developed since the original iteration and, if changes are not required, to reaffirm the current course of action. Internal test and oversight procedures should be revisited and adapted to the project plan. Additional staffing requirements should be defined as the project team expands beyond the senior planners to the rank and file. Training and orientation should be considered for new project team members as the scope of effort widens.

Note: E&I implies electrical and instrumentation. While we recognize that the Electrical department covers lighting, receptacles, and other categories, for the purposes of this book, the "E" component is primarily focused on motors and other equipment that directly impact the process.

Upper-tier documents (specifications and drawings) should be completed to 100%, knowing that minor edits may be required as the project progresses. But, given what the team knows, it should prepare the P&IDs, I/O List, and other key deliverables to be 100% complete.

The following is a brief on many of the common project plans that should be created at this time.

1.5.4.3.1 P&ID The P&ID is started very early in the engineering process by the owner or OE, and it flows directly out of the PFD. It is usually owned by the Mechanical Engineering or Process Engineering department and is started well ahead of the E&I department's involvement. E&I's responsibilities include reviewing and marking the P&ID to reflect the control schema properly. It is a working document that is continually updated as new understandings of the process develop. In addition to mechanical information, it provides instrument bubbles that point out level transmitters, flow switches, and the like. It illustrates operability by showing hand switches, indicator lights, gauges, tank-level sight glasses, and annunciator points, among other items. It also indicates major control logic elements by showing interconnected automation system functions and interlocks. Most of this detail is layered on during E&I Phase 1. For more on the P&ID, see Section 10.5.1.

1.5.4.3.2 Deliverables List Deliverables management is very important, and it can be time-consuming. Hundreds of documents might be newly generated. Hundreds more might be ordered from the customer to be modified. Managing the documents and tracking their active revision and disposition can be a major undertaking, one that can be supported by creating and maintaining a document list. The document list is often a design deliverable on project completion and is used as a tool for tracking progress.

1.5.4.3.3 I/O List (I/O Configuration and Partitioning) The I/O List is a list of I/O points organized around the characteristics of the control system. The P&IDs are generally organized intuitively, and it is usually a good idea to pattern the I/O structure the same way. Properly partitioning the I/O is important to give the system a measure of fault tolerance. Partitioning rules should be established early in the design process; the following are good examples:

- Assign I/O for redundant pumps, motors, and other equipment items to different I/O modules to prevent one I/O module's failure from killing both devices.
- Avoid splitting related I/O across multiple racks if possible.
- Include some percentage of ready-spares I/O that are already loaded in the I/O racks, preferably one or two I/O points per I/O card.
- Critical subsystems should be associated with their own central processing unit (CPU), or the system should have some fault tolerance, such as redundant CPUs.

1.5.4.3.4 Instrument List An Instrument List is key to a properly managed design process. If developed early and updated regularly during the design process, this list can be a very useful design tool and a tremendous aid during the design check. Each item the instrument design team touches should appear as a record in this list. It can be tied to the I/O list as described in Part 2. The list should contain records of all the instruments to be touched by the project, wired or unwired, new or legacy.

1.5.4.3.5 Instrument Specifications Assuming the availability of support information, such as pump specifications, equipment specifications, P&IDs, and an instrument database, instrument specifications must be produced as early in the design phase as possible. It is preferred that they are at a high level of completion at the 30% DRM so that issues can be discussed with the owner at that point. Instrument specifications must be finished early in Phase 2. They must be completed before the instrument elementaries (i.e., schematic diagrams) or installation details can be finalized because these depend on specific model configurations.

ISA-TR20.00.01-2007, *Specification Forms for Process Measurement and Control Instruments*, contains a wide selection of forms that can be used as a starting point.

1.5.4.3.6 30% DRM The goal of Phase 1 is to remove all the unknowns. The results are displayed for discussion in the 30% DRM. This is an important milestone in which the owner can review the project and make any necessary course corrections. Upper-tier documents generated in Phase 1b and the project plans developed in Phase 1c are reviewed and confirmed to be suitable to use as the design basis for the detailed design phase, Phase 2. Assumptions are verified, and risks are mitigated. A key consideration at this juncture is identifying any procurements that will take a long time to complete. Any long-lead items should be presented in this meeting and be approved for immediate procurement.

This is also a point at which any surprise findings should be discussed. As the design team processes the upper-tier deliverables and refines its project plans, discrepancies and potential conflicts

often arise that could impact the scope, schedule, or budget. This is the time to get those things out in the open. Findings that increase the seller's budget should be discussed. The buyer may have viable mitigation strategies that negate the issue. If the seller proceeds with this unresolved, the buyer may balk later at providing recompense.

Note: The term DRM implies a meeting. This can be a meeting in which all parties convene and go over the deliverables. More often, this is a sequence of events in which the package is issued, and the OE and other stakeholders have a contract-defined time frame to review the documents and provide feedback.

1.5.4.4 E&I Seller Phase 2a: Fabrication Design

For the E&I contractor, Phase 2 activities are split into two general categories that can be executed at the same time or in sequence. Fabrication deliverables can impact the detail design deliverables, so there are advantages to doing them in sequence, provided the project schedule has enough float available to accommodate that. PLC schematics are a common denominator that is needed for both evolutions, so while they are not considered to be strictly fabrication documents, they should be started as early as possible. Fabrication design deliverables are all related to supporting the panel shop and freeing the shop to begin work.

The following are some of the key deliverables that will be generated during the fabrication design phase.

1.5.4.4.1 Instrument Elementary Wiring Diagrams (Schematics) Instrument elementary wiring diagrams (sometimes also called schematics) are nonphysical in that distances and physical location information are minimized. For example, instrument elementary wiring information is presented as a complete electrical circuit, not as a particular physical cabinet or field device. This type of drawing differs from the interconnection wiring drawing in that the interconnection drawing shows the complete wiring for a particular device or physical area. The primary audience for these versatile documents includes engineers, operators, and installers. The level of detail provided on an instrument elementary diagram could minimize the need to create interconnection wiring diagrams. For more on schematics, see Section 6.4.

1.5.4.4.2 Panel Arrangements The panel arrangement drawing is a fabrication drawing that consists of a BOM and a component arrangement. There are several different types of panels:

- Marshalling panels are typically large enclosures that house controllers and associated hardware, such as I/O racks, and provide a place to mate field cables to control system cables. Generally, field I/Os are not organized in a way that is convenient for mass termination into the control system. Field cables are oriented toward floor locations, while I/O cables are oriented toward I/O module groupings. A marshalling panel provides a place to cross-connect the cabling systems and perform any necessary circuit protection and power distribution activities.
- Control panels house electronic equipment and sometimes have controls (e.g., switches and lights) on the front panel. This type of panel arrangement provides the interior panel arrangement and possibly a hole-punch guide for the panel front.
- Field junction boxes are panels that house wiring interconnection components, such as terminals and sometimes relays and fuses. Usually, these boxes are simply “breakout” boxes in which multiconductor cables are broken out into single-pair cables.

For more information on panel arrangements, see Chapters 10 and 11.

1.5.4.4.3 Interconnection Wiring Diagrams Unlike elementary wiring schematics that present complete electrical circuits as concisely as possible, often splitting control elements into different drawings, the interconnection wiring diagram focuses on single equipment elements and shows all the interconnections to that device. Showing complete circuits is secondary to showing all the terminations on a device. The primary audience here is the installer. Cables are shown entering and leaving the enclosure. Any internal wiring is shown in total. A wiring diagram is generally produced for every marshalling panel, field junction box, control panel, relay panel, or any other enclosure where wiring must be terminated. For more on wiring diagrams, see Section 6.6.

1.5.4.4.4 Instrument Specifications The instrument specifications should be 100% complete by the 60% DRM or issued independently in advance if they can be finished earlier. These documents affect all design activities that follow.

Note: In order to specify the instruments, hazardous area classifications must be known. The owner typically provides these guidelines or area maps, or if the project is a greenfield build, guidelines would be generated from the HAZOP.

1.5.4.4.5 60% DRM The 60% DRM is a stage gate and hold point that gives the owner the opportunity to see what is about to be built in the panel shop. Panel arrangements, wiring diagrams, and BOMs are presented for review and approval. Exiting this gate, the panel fabricator begins the project with an authorization to procure parts and start fabricating.

Note: The 60% DRM often coincides with the CSI 30% DRM, in which the CSI team presents its software development project plan.

1.5.4.5 E&I Seller Phase 2b: Detail Design

The second primary evolution ongoing during Phase 2 is what we call *detail design*. This category contains all the deliverables not required for fabrication. This includes floor plans, installation details, cable and conduit schedules, and other deliverables needed to properly install the field equipment and communicate the location and mounting methodologies to the constructor. It also includes deliverables such as loop sheets and other deliverables that are more aimed at plant maintenance than installation.

As factory subassemblies are completed for vendor-provided equipment and skids, the OE may ask the E&I contractor to act as an agent and to travel to the various locations and observe as the FATs are executed. This service could be included in the proposal or added under a change order.

The following are the primary deliverables generated during the fabrication design phase.

1.5.4.5.1 Cable and Conduit Schedules Cable schedules link a cable to a path that includes the source, destination, cable type, outside diameter (OD), and conduit/tray routing.

Conduit and tray schedules provide path information, from/to, and link up with the cable schedule to provide fill calculations. For more information on conduit fill calculations, see Figures 2-47 and 2-48 in Section 6.6.1.3.

1.5.4.5.2 Instrument Installation Details Instrument installation details are drawings (or sketches) that provide hookup information for the installer. They include pictorial representations of the components in their proper relationships to each other and a BOM chart that describes such things as part and item numbers. Installation details usually have multiple uses (i.e., they are generic drawings). For example, there might be several control valves in different parts of the plant that are to be installed the same way. One installation detail will suffice for all, provided there is a cross-reference

between the instrument and its installation detail. For this, the instrument database is a good tool. It is also a good idea to put that information on the instrument specification as a note. There are usually three categories of such details for each installation: mechanical connections, electrical connections, and mounting.

- **Mechanical installation details**

The mechanical installation detail shows a device, its tubing or piping connections, and the connection fittings. For example, the instrument air hookup to a control valve will require flanges, gaskets, and bolts, which are called out in the details.

- **Electrical installation details**

The electrical installation detail provides information relating to the conduit connections. All conduit fittings, such as condulets and flex hoses, are described, but only within about a 2-foot envelope around the instrument. The instrument location plan takes care of material outside that envelope.

- **Mounting installation details**

Mounting information, such as instrument pipe-stand fabrication, mounting bracket fabrication, and other mounting particulars, is described here.

For more information on installation details, see Section 12.2.2.

1.5.4.5.3 Mechanical and Mounting BOM After the mechanical and mounting installation details are created and assigned to each instrument, a mechanical BOM can be produced. This BOM lists all items needed for an instrument's mechanical installation. This includes all tubing, tube fittings, brackets, clamps, and mounting hardware necessary to connect the instrument to the process. All materials called for by the mechanical details are compiled into a single BOM. The BOM is then submitted to purchasing, where it is broken into packages by vendor and issued for purchase.

1.5.4.5.4 Electrical BOM After the electrical installation details are created and assigned to each instrument, an electrical BOM can be produced. This BOM lists all items needed for the instrument's electrical installation. This includes all conduits, conduit fittings, flex fittings, and drain plugs. All materials called for by the electrical details are compiled into a single BOM. The BOM is then submitted to purchasing, where it is broken into packages by vendor and issued for purchase.

1.5.4.5.5 Floor Plans There are several types of plan drawings in an engineering design package:

- **Site plans**

The Phase 1 study typically includes a site plan for physical orientation. It is sometimes just a sketch showing the intended future location for equipment, junction boxes, and so on. Formal site plans, as engineering deliverables, are considered products of the structural engineering group (if the plan is of a building) or the civil engineering group (if the plan is of a yard area). The E&I group can use these drawings as references to generate underground conduit plans, instrument location plans, or other products.

- **Process area floor plans**

These plans, sometimes called instrument location plans, are construction-related E&I deliverables that are rarely maintained past construction. They provide general information about instrument placement on the process floor, the conduit and/or tubing that must be extended to those instruments, and any support equipment, such as field junction boxes and air header connections. The drawings can be scale drawings showing the exact location of the instruments, or

they might be diagrams depicting each instrument near its expected location. These drawings can be done in two steps if the schedule demands it; though, ideally, the bulk of the work should happen after creating the elementaries and somewhat parallel to creating wiring diagrams (inter-connection drawings). The initial setup of the floor plan drawings for the process area can occur as soon as the equipment arrangements are essentially complete. The setup function would then happen in parallel to producing the orthographic piping drawings. But, due to the conduit sizing and contents information needed, it may not be possible to finish the floor plans until after the elementaries (or loop sheets) and subsequent wiring diagrams are completed. For more information on the floor plan, see Chapter 12.

1.5.4.5.6 Control Room and I/O Termination Room Arrangements The control room and I/O termination room (I/O room) drawings are closely interrelated. The control room design must be settled before the I/O room design. Sometimes, PLC or DCS equipment racks are physically in the control room, with the marshalling panels in an adjacent I/O spreading room. Sometimes, all the control system hardware is in the I/O room. Frequently, the deciding factor for placement is the availability of environmental control in the I/O room. If that room is not air-conditioned, sophisticated hardware might be located in the control room. Another consideration is the availability of space. Control rooms and I/O rooms are some of the most expensive rooms in the plant in terms of cost per square foot.

1.5.4.5.7 Loop Diagrams Loop diagrams (commonly referred to as *loop sheets*) are schematics that tend to be done late in the design phase because they incorporate detailed wiring information. Doing them too early will likely put the designer into a continual review cycle as new information becomes available. The loop sheet combines elements of the schematic and the connection diagram in that all the connections to a device are shown on one drawing, plus complete circuits are shown to the degree possible. This drawing also provides insight into how the device is controlled, with perhaps a SAMA-type⁴ functional diagramming presentation, especially in power plants. Its focus is entirely on a control loop. A pressure transmitter measuring pressure in a pipe is shown connected to the basic process control system, some detail is provided regarding the software functionality, and the output is shown to the associated control valve controlling the pressure. All electrical, mechanical, and pneumatic connections are depicted on the loop sheet. These documents tend to be very rich in information, even providing pointers to the instrument and valve specifications in some cases. These documents are aimed at plant maintenance. Section 12.2.4 discusses loop sheets in more detail. For additional information on loop sheets, refer to ISA-5.4-1991, *Instrument Loop Diagrams*.

1.5.4.5.8 90% DRM The E&I team should present a package that it deems to be 100% complete and ready to issue in this meeting. The timing of this meeting can often be synchronized with the CSI team's SDT, but that is not required.

1.5.4.6 E&I Seller Phase 2c: Finalize Design

The timing is often short between the 90% and the 100% DRM. This time frame is dedicated to incorporating any final comments from the owner or OE that accrued during testing and then packaging the design into a format that is easy for the constructor to decipher. Often, a construction package is prepared, which will be presented during the construction kickoff meeting.

⁴ The Scientific Apparatus Makers Association (SAMA) no longer exists as an organization, but the SAMA functional diagramming symbols have been incorporated into ANSI/ISA-5.1, *Instrumentation and Control—Symbols and Identification*, since the 2009 revision.

1.5.4.7 100% DRM

This is generally not a meeting, per se, but a milestone at which the design package is issued for construction (IFC). This submittal must follow the FAT performed by the panel fabricator and the subsequent staging site demonstration test (SSDT), as any redlines that accrue during those tests must be incorporated into the IFC package.

1.5.4.8 E&I Seller Phase 3: Deployment

Phase 3 activities begin for the E&I contractor when the construction contractor starts organizing their work. Construction work packages help facilitate this process, and the E&I contractor generally repackages their deliverable sets into drawing and document bundles organized by WBS. BOMs for commodities, such as cable, conduit, and fiber, and wiring components, such as terminals, relays, and fuses, are turned over to the constructor, who reviews them, augments them as necessary, and orders the materials. Engineered items, such as motors, instruments, and analyzers, will have already been ordered by the E&I contractor or the OE, depending on where that responsibility rests contractually.

At this stage in the project, the E&I contractor can begin staffing down as the bulk of their work is complete. A small team may be required to remain on-site to inspect the installation. During this period, the E&I contractor's primary roles are construction oversight and technical support.

1.5.4.9 E&I Seller Phase 4: Support

After commissioning, the E&I contractor must consolidate the design package and issue it for the record. Construction teams generally do not install exactly per the original drawing set, either from being poorly disciplined, from not following the drawings, or due to problems with the design package they must overcome. In either case, the final drawing set must reflect the as-built condition of the facility. The E&I contractor must collect all the marked-up drawings used during installation and formally incorporate the modifications. This could entail additional site walkdowns, interviews, and investigations.

Some of the documents are legal records, and inaccuracies may be punishable by fines or jail time.

1.5.5 The Control Systems Integrator's (CSI's) Project

According to the Control Systems Integrators Association (CSIA) [8], a CSI is defined as follows:

A control systems integrator is an independent (or an independent profit/loss division) value-added engineering organization that focuses on industrial control systems, manufacturing execution systems, and plant automation that requires application knowledge and technical expertise for sales, design, implementation, installation, commissioning, and support.

Most CSI service providers retain some independence in terms of what equipment and/or software they recommend for a customer. Preferences will exist based on relationships or perhaps utility, but if an owner has a preference, most CSIs will accommodate them.

Systems integrators include PLC programmers, human-machine interface (HMI) developers, network designers, data communications specialists, information systems specialists, cybersecurity specialists, and personnel with other skills, all primarily focused on hardware and software that collect, manipulate, and distribute accurate, pertinent data in a secure, timely manner.

In the industrial realm, there are two primary subspecialties within the spectrum of systems integration: process automation and machine automation. The two are related in approach and

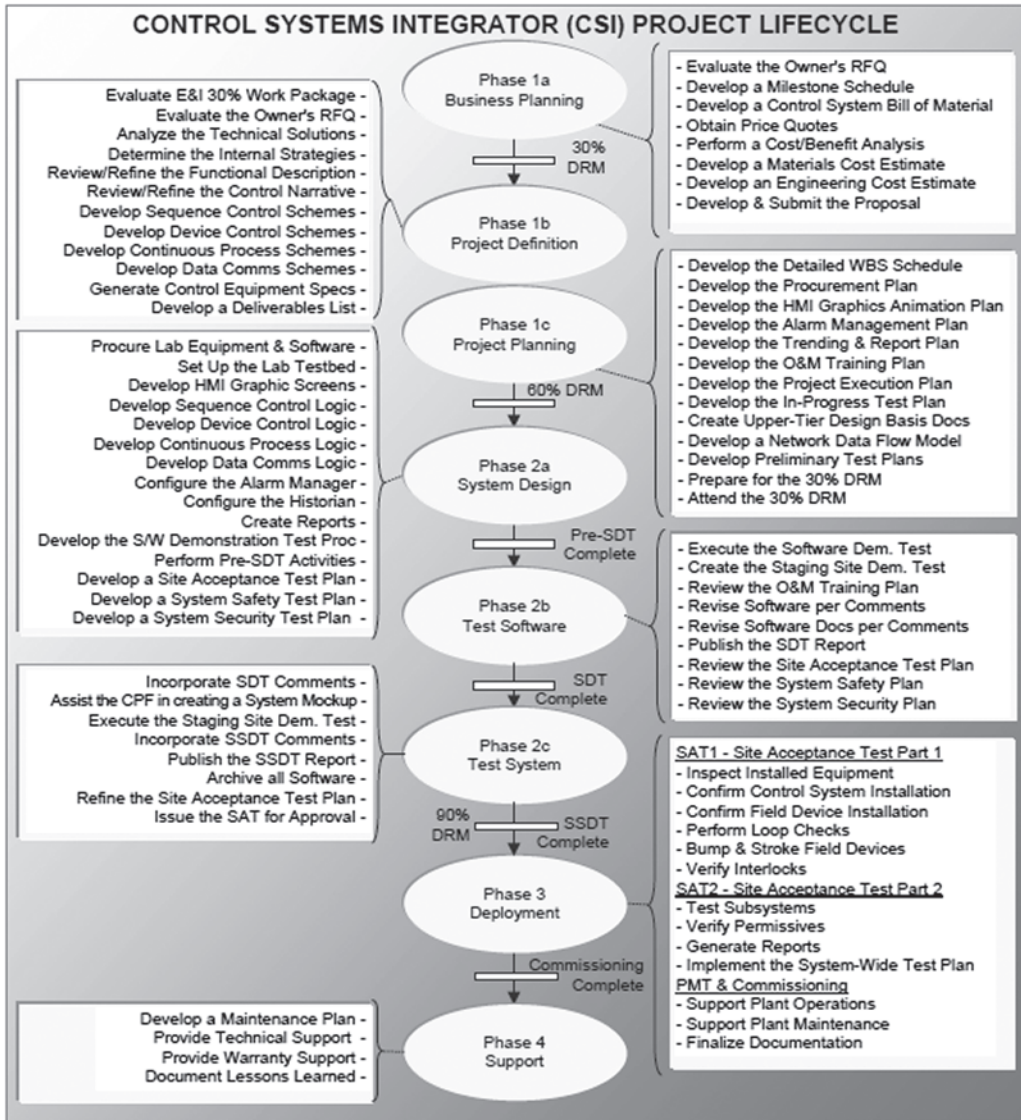


Figure 1-12 CSI seller's project lifecycle.

project structure but differ in terms of associated equipment, software development techniques, customer expectations, and other areas related to execution.

This book is focused on process automation. This chapter looks at the CSI team using the same four-phase project model employed by the E&I team. Figure 1-12 shows an overview of a typical process automation project from the CSI's perspective.

1.5.5.1 CSI Seller Phase 1a: Business Planning

Business planning for the CSI is like that of the E&I contractor, asking many of the same questions. Ideally, the CSI bid will be generated after the 30% DRM of the E&I team. But, in the case of the ICS model we are discussing, the CSI proposal will be submitted at the same time as the E&I proposal.

It makes sense to treat this CSI bid as budgetary because findings during the Phase 1 process of the E&I team can affect the scope.

The CSI must ask questions that are like the E&I questions: Do we have the expertise to meet this specification? Do we have the workforce to execute it? Does this customer have a history of difficult projects, or do they work as a team with their contractors? Do they pay their bills? Have they done their due diligence? Do we have a strategic interest in pursuing this project, even if it is marginal in several areas?

Positive answers to these questions will likely result in bid preparation.

1.5.5.2 CSI Seller Phase 1b: Project Definition

The CSI team is activated when the contract is awarded to them. But it makes sense for the team to delay starting execution until the I&C team submits its 30% package for review. Findings during the preliminary engineering phase of the E&I team can affect the CSI scope.

The CSI team evaluates the bid package and any E&I team findings to ensure it has all the information it will need to develop a winning strategy. In some cases, this may require field trips, walkdowns, and investigations. At this point, it is a good idea to revisit the HAZOP to consider new information developed since the original iteration and, if changes are required, to raise the issue to the owner. Upper-tier documents, such as the P&ID and I/O List, should be finalized by all parties during this time frame.

Using information developed during the E&I design process and the other means described above, the CSI team devises control schemes for major control elements. These control schemes include the operability and functional aspects of each type of control device, such as on-off devices, sequences, and alarms, along with other control and data acquisition topics. Typical examples may be produced and simulated for review and comment by Plant Operations and the OE to ensure that the result will be acceptable. Templates generated and tested will be used throughout the project, enabling the CSI team to plan the remainder of the project in detail.

Also at this time, the CSI team reviews and confirms the viability of the I/O partitioning work done by the E&I as part of the I/O List generation activity, which enables finalizing the PLC or DCS hardware configuration.

Finally, the Deliverables List should be fully developed. A fully instantiated Deliverables List is critical to managing the project going forward.

1.5.5.3 CSI Seller Phase 1c: Project Planning (Develop a Software Development Plan)

After most of the tasks are identified and the Deliverables List is completed, the CSI team can confidently plan its project. Key design inputs, decisions, agreements, and applicable standards should be collected and disseminated to the design team. Coalescing all this information into an overall guidance document is key to making sure the entire team is informed and has ready access to this key information. This overarching collection of standards, procedures, and work instructions is known as a *software development plan* (SDP).

The SDP is a quality management tool that is specific to the project at hand. Color schemes, animation plans, graphics content, and other features vary from one project or customer to the next. Workshops that engage the customer in these key decisions and document their preferences are advisable so that the buyer and each design team member are fully informed. An SDP should address the following areas.

1.5.5.3.1 Applicable Standards Standards and work instructions that apply to the project should be collected and listed. These can be internal company standards, industry and national/governmental

(i.e., NEC, OSHA, EPA,⁵ etc.) standards, and/or flow downs from the buyer. It's a good idea to provide copies of the standards as attachments, as the standards can be revised, and the versions of the standards enforced are the versions that are active at the time of the work. This also makes it easy for the team to access the information.

1.5.5.3.2 Resource Plan Staffing requirements should be defined as the CSI project team expands beyond the senior planners to the rank and file. Training and orientation should be considered for new project team members as the scope of effort widens.

1.5.5.3.3 WBS and Project Schedule The WBS breaks down the major tasks and assigns predecessors/successors and resources to add granularity to the project. It is recommended that each WBS line item be limited to something under 200 hours in size, optimally about 120 hours. A detailed project schedule should then be created.

1.5.5.3.4 Procurement Plan The procurement plan for the CSI team can be broken into two major classifications: (1) Lab equipment, software and just enough hardware to establish the lab supervisory control and data acquisition (SCADA) system and (2) everything else, including I/O racks and all other equipment. The first procurement activity will occur very early in the project, after the 30% hold point, and the second will occur after the 60% hold point. The second procurement activity is sometimes delegated to the panel fabricator, as it can be procured and installed without affecting software development and testing.

1.5.5.3.5 Simulation Plan Simulation is important throughout the design phase, up to and including the SDT. Interim testing of the software requires some level of simulation, making this an important topic to cover. The cheapest approach to simulation is loop-back simulation, which is discussed in Section 8.3.2, but simulation software packages that include process simulation can also be purchased.

1.5.5.3.6 HMI Graphics Animation Plan This should include the number of pages, navigation strategies, static color schemes, and animation strategies for color, flash, visibility, and remote messaging.

Note: HMI and GUI (graphical user interface) are two terms for the same thing.

The following standards are recommended for HMI development:

- ANSI/ISA-101.01-2015, *Human Machine Interfaces for Process Automation Systems*
- ISA-5.5-1985, *Graphic Symbols for Process Displays*
- ISA-TR101.02-2019, *HMI Usability and Performance*

1.5.5.3.7 Alarm Management Plan Alarm rationalization begins here. Which analog alarms should be activated, and which will become nuisance alarms? What priorities should be assigned? What actions should the operator take when an alarm occurs? What automatic actions should the software initiate? What remote messages should be transmitted, and how?

The following standards apply to alarm management:

- ANSI/ISA-18.2-2016, *Management of Alarm Systems for the Process Industries*
- ISA-TR18.2.1-2018, *Alarm Philosophy*

⁵ NEC (*National Electrical Code*), OSHA (Occupational Safety and Health Administration), and EPA (Environmental Protection Agency).

- ISA-TR18.2.2-2016, *Alarm Identification and Rationalization*
- ISA-TR18.2.3-2024, *Basic Alarm Design*
- ISA-TR18.2.4-2012, *Enhanced and Advanced Alarm Methods*
- ISA-TR18.2.5-2022, *Alarm System Monitoring, Assessment, and Auditing*

1.5.5.3.8 Trending and Report Plan When preparing a trending and report plan, these questions must be answered: Which analog and discrete signals should be configured into the historian? What should their sample rates be? How should they be displayed? Which should be on static graphics, and which should be available for custom trends? What reports will be needed, and how often are they produced? How will they be generated, hard copy or digital? Are custom reports envisioned or can they be hard-coded?

The following standard is recommended:

- ANSI/ISA-TR77.70.01-2010 (R2015), *Tracking and Reporting of Instrument and Control Data*

1.5.5.3.9 HMI Screen Hierarchy and Navigation Plan The HMI screen hierarchy and navigation plan is a document that describes the graphic screens that are envisioned for the project and the navigation rules that will be followed. An intuitive navigation plan employs a multi-tier design, starting with process overviews and ending with control pop-up overlays. A possible hierarchy could include the following screen classifications and hierarchical levels:

- **Master System Overview (Tier 1)** – One screen for at-a-glance project status and screen navigation
- **Process Area Overviews (Tier 2)** – One screen for the at-a-glance status of each WBS area
- **Subsystem Overviews (Tier 2)** – One or more screens for an at-a-glance status of each subsystem
- **Historical Trends Overview (Tier 2)** – One screen for trends navigation
- **Reports Overview (Tier 2)** – One screen for report selection
- **Control Pop-up Overlays (Tier 3)** – One overlay for each end device (e.g., a valve, motor, variable-frequency drive, conveyor, machine, etc.)
- **Historical Trend Screens (Tier 3)** – One per process control scheme
- **Report Screens (Tier 3)** – One screen per report

Navigation is usually facilitated horizontally within a particular tier and vertically between overview tiers.

1.5.5.3.10 Data Security Plan (Cybersecurity, Data Integrity) Cybersecurity and data integrity are topics that are surging in importance as the demand for real-time information grows. The need for instant access to critical performance and market data drives the integration team toward more open architectures and, thus, more risk exposure. A data security plan should address the following topics:

- Physical security
- User rights and privileges
- Authentication (passwords, biometrics, etc.)
- Virus countermeasures
- Digital signatures and certificates
- Intrusion prevention and detection
- Forensics

The ISA/IEC 62443 series of standards provides guidance for establishing cybersecurity. ISA-TR62443-2-3-2015, *Security for Industrial Automation and Control Systems*, applies specifically to this topic.

1.5.5.3.11 System Safety Response, Archival and Disaster Recovery Plan Catastrophic events, such as control room fires, acts of sabotage, or natural disasters, can cause major upsets that could take months to recover from. Procedures should be developed and processes established to reduce the upset and provide a reasonable opportunity for restoring operation in a timely, organized manner.

1.5.5.3.12 Training Plan Operators and maintenance personnel will require in-depth training prior to commissioning. In addition, periodic refresher training should be considered. Training materials could include the following:

- Operations and maintenance manual(s)
- Practical exercises
- A training testbed
- Others

1.5.5.3.13 Network Single-Line Diagram The network single-line diagram is an upper-tier drawing that shows the major control system components and the various data networks that interconnect them. This type of drawing does not show detailed connections but focuses more on the equipment, with general interconnection information. Though this convention is somewhat fluid and could change depending on the division of labor agreed upon for a particular project, for this discussion, detailed wiring interconnections for fiber and copper are provided under the E&I set of deliverables.

1.5.5.3.14 Software Documentation Strategy Control logic diagrams and control narratives may be provided to the CSI as part of the design basis. Or the integration team may be given only a narrative and must generate their own project documentation. Either way, as software development progresses, the documentation will probably need to be modified, as it is generally only an approximation of the moves that must be made in the program. Logic diagrams are one means of communicating control logic; control detail sheets are another. We provide examples of both in Part 3. The SDP should lay out a strategy that is appropriate for the project.

1.5.5.3.15 Operations and Maintenance (O&M) Training Plan The answers to the following questions will be the focus of the O&M training plan: What will be included in the operations and maintenance manuals? Will a training manual be produced? Who will teach the courses? Where will they be held? What equipment will be required? How many classes are needed? What content should be included? How will training be documented? Will the courses be recorded? How many attendees can attend each course? What kind of handouts are needed?

1.5.5.3.16 PEP The PEP is an internal document that represents the design team's interpreted scope based on the Deliverables List. The team describes how each deliverable will be created, what tools to use, what software to use, how calculations will be done, and how all of this will be stored and distributed. Budgets are detailed for each subgroup on the team, the project master schedule is broken down into its various components, and pertinent milestones are added to the team's execution strategy.

1.5.5.3.17 Interim Test Plan This plan describes the iterative testing that will be ongoing throughout the software development process. It will establish hold points at key points in the project at which software fragments will be tested before propagation. Software can often be “objectized,” in which a typical function is written and propagated many times with slight modifications. It’s advantageous to identify those fragments in advance and fully validate them before they are propagated. This minimizes the risk of bug propagation.

1.5.5.3.18 Upper-Tier Design Basis Documents Every control object in the project should be identified and documented. It’s best to do this documentation in advance, as the documentation can be used to guide the workflow. Operating in reverse can be difficult, and poorly documented projects often result, as money tends to get tight at the end of projects. It is much better to spend the documentation funding early and let that guide the work. Chapter 7 of this book describes control detail sheets, which are one way to address this need. Device control, process functions, sequences, and communications links are all examples of the types of control elements that should be documented and considered upper-tier.

1.5.5.3.19 Preliminary Network Data Flow Diagram A data flow diagram is a block diagram that shows data flow paths and details the type of data being transmitted. It is very similar in format to a power distribution block diagram. Each pathway should be defined according to the type of information, its cybersecurity impact, the frequency of transmission, and the system’s response should it be interrupted. This document can be started now, but it can only be finished after the software development is complete.

1.5.5.3.20 Preliminary Test Plans A list of test plans should be created that describes each test to be executed and the requirements the test plan must satisfy.

1.5.5.3.21 Prepare for and Attend the 30% DRM The CSI 30% DRM should coincide with the E&I 60% DRM if possible. The two teams should collaborate leading up to the meeting to ensure they are in sync. Findings in one area can affect the scope of the other. After these two meetings are concluded and everything is approved, fabrication and software development can commence.

1.5.5.4 CSI Seller Phase 2a: System Design

In Phase 2, the CSI assembles any lab test beds and/or simulation mockups deemed necessary to write the software and perform the requisite in-progress testing. For this narrative, the SCADA system includes the HMI and the process controller (PLC or DCS), recognizing that in some cases, the HMI and process controller are combined into one software package. Systems engineers begin writing software and configuring screens based on previously developed and vetted templates. Simulation strategies are implemented, Ethernet switches are configured, variable-frequency drives are programmed and tested, networks are temporarily wired, and throughputs are baselined (i.e., analyzed during ideal conditions).

Note: Simulation techniques are covered in detail in Part 2. At a minimum, loop-back simulation should be used to allow incremental testing and facilitate the formal test scenarios that come later.

As the project develops, the CSI seller will create an SDT procedure that will be issued and reviewed/approved by the owner or OE. The procedure should be written in a cause-and-effect format in which the operator initiates an action at the HMI, and the system reacts. Software utilities, such as the alarm manager and the historian, will be configured, and operations reports will be designed.

A pre-SDT should be executed in advance of the formal test. This pre-SDT will find any major problems with the test procedure or the SCADA system that would negatively impact the formal SDT that the customer will witness. The major activities that take place during this time are listed here.

1.5.5.4.1 PLC/DCS Programming Control software can be developed remotely and downloaded to the controller. Multiple programmers can work at the same time in different sections of the program and then have their work merged at a later time. The programming effort should not begin until the logic diagrams and/or control detail sheets are in an advanced state of readiness.

1.5.5.4.2 HMI Programming Visualization software is usually developed on the platform on which it will reside. For that reason, mockups are frequently built using the actual control elements that will be installed later in the plant. It is possible to write the software elsewhere and then import it onto the platform of choice, which is the normal method for retrofits. But, whenever possible, it is best to develop the software on the same equipment that it will be used on later.

1.5.5.4.3 Server Setup Services There can be several groups of servers on a project. SCADA servers serve up data from the PLC or DCS to visualization equipment. Thin client servers, for example, may take data from the SCADA servers and serve that data up to the thin client workstations or dumb terminals. A historical data server may sit on the network and pull data from the SCADA database. Regardless of the actual configuration, all the servers must be configured, and the setup must be stored for later retrieval. They also require software licenses, sometimes multiple layers of them.

1.5.5.4.4 Network Configuration Ethernet switches, routers, and data diodes must all be configured and tested.

1.5.5.5 CSI Seller Phase 2b: Test Software (Execute the SDT)

The formal SDT is usually done in the lab and is based on simulated field devices. The goal is to demonstrate the software's capabilities to the fullest extent possible. The test procedure should take the test team through each device, each process control function, each sequence, and each interlock and demonstrate proper operation as compared to the requirements documentation. Performing this highly detailed test at this point will reduce the need for extended field tests and save time and money later.

1.5.5.6 CSI Seller Phase 2c: Test System (Execute the SSDT)

The goal of SSDT is to establish performance baselines that can be compared to identical tests performed on-site with everything in situ and verify the configuration. Gross differences could imply installation problems, grounding issues, or other impediments that must be investigated. The SSDT is usually done in the fab shop and is scheduled for after the shop's internal panel QA processes are complete. However, the test can be done at any staging site, such as a warehouse or other open area that can be secured.

This test is done with the entire control system fully mocked up with temporary network and power connections between panels and between network elements. Each I/O point can be simulated by injecting signals, shorting contacts, or other means. As an I/O point is exercised, the correct HMI graphic should animate. This validates the I/O mapping between the SCADA system and the I/O modules. Also, time delays can be recorded between when an action is requested at the HMI

and when effects are noted at the I/O module or other device. This will enable addressing lags or throughput issues in the shop.

Note: If it's possible to get the key operators off-site and into the shop, that is an excellent time to perform superuser operator training. The shop is a quiet environment, and simulation is active so the operators can run through scenarios and gain familiarity with system operation.

1.5.5.7 CSI Seller Phase 3: Deployment

The CSI is the key player in deploying the control system. The CSI works closely with the OE, with construction, and with Plant Operations to confirm proper installation and to test the software.

1.5.5.7.1 Construction Support The CSI will provide guidance on an as-needed basis to the construction team as they install the controls equipment.

1.5.5.7.2 SAT Part 1 Part 1 of the SAT procedure verifies that all the components attached to the network have been installed correctly and wired. One of the constructor's responsibilities is to achieve mechanical completion, which entails not only installing the equipment but also wiring continuity, power-up, and operational checks. After a subsystem has been verified as installed by the constructor, it is "turned over" to the CSI team, which collaborates with the constructor to execute the SAT. Systems are powered up and exercised to stimulate the control system. The CSI team leads this validation effort, requesting actions to be taken in the field and monitoring the SCADA system to ensure the system responds as desired. This includes various tests such as loop checks for instruments, bump and stroke tests for motors and valves, interlock response tests, and numerous other tests that can be performed on one device at a time.

1.5.5.7.3 SAT Part 2 Part 2 of the SAT procedure looks at subsystems. A set of conveyor belts may be sequenced on and off, a tank may be filled with water and emptied, a subsystem may be started and stopped, and so on, gradually adding subsystems until all have been tested to the fullest degree possible without producing product. In some cases, preliminary tuning can occur in this phase. The SAT procedure is most often developed and led by the CSI, though Operations begins to take on a bigger role as the subsystems start to be exercised.

1.5.5.7.4 Operator and Maintenance Training Operators and maintenance staff will receive formal training during this time. The CSI will execute the training plan devised earlier.

1.5.5.7.5 Post-Modification Test These tests are executed by Plant Operations personnel. They can be performed "dry," with simulated process conditions, or "wet," with raw materials flowing, moving, and/or heating/cooling. The CSI team begins to assume a supporting role at this stage.

1.5.5.7.6 Commissioning Commissioning begins when raw materials are fed into the production process to make resale products. At this point, the CSI starts to step into the shadows. Plant Operations generally drafts the commissioning procedure and oversees its implementation. The CSI team provides support. The E&I and the CSI teams begin incorporating any redlines accumulated through the installation and checkout phases. Once the product is being generated, commissioning is complete, and the project is essentially complete except for warranty services that will carry into Phase 4.

1.5.5.8 CSI Seller Phase 4: Support

After commissioning, the CSI's work continues, migrating toward plant support as opposed to project support. Additional troubleshooting support may be needed, along with software upgrades and patch installation. Service contracts come into play at this point, as the CSI may need to remain available to support the plant for tasks such as warranty-related repairs during the warranty period.

1.5.6 The Control Panel Fabricator's (CPF's) Project

The same four-phase project model applies to the control panel fabricator (CPF). Figure 1-13 is an overview of a typical controls project from the CPF's perspective.

1.5.6.1 CPF Seller Phase 1a: Business Planning

Business planning for the CPF is like that of the E&I contractor; many of the same questions must be answered. Ideally, the CPF bid will be generated after the 60% DRM of the E&I team and the 30%

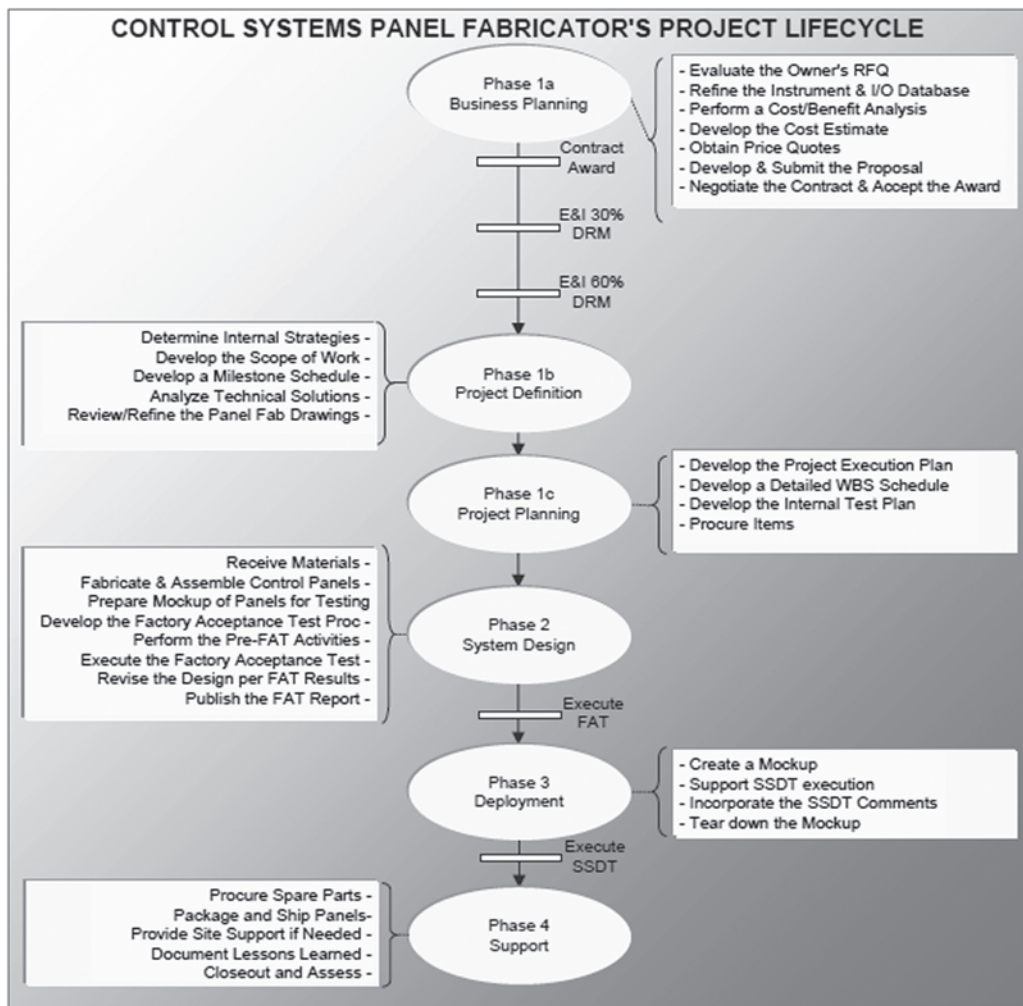


Figure 1-13 Sample CPF seller's project sequence.

DRM of the CSI team. But, in the case of the ICS model we are discussing, the CPF proposal will be submitted at the same time as the E&I proposal. It makes sense to treat this CPF bid as budgetary because findings during the Phase 1 process of the E&I team can affect the scope.

Some of the questions that must be answered in this phase include these: Do we have the expertise to meet this specification? Do we have the workforce to execute it? Does this customer have a history of being difficult with projects or of working as a team with their contractors? Do they pay their bills? Have they done their due diligence? Do we have a strategic interest in pursuing this project, even if it is marginal in several areas?

Positive answers to these questions will likely result in bid preparation.

1.5.6.2 CPF Seller Phase 1b: Project Definition

After the project has been awarded and the E&I team issues its 60% package, the FAB contractor may begin to set up the project by dedicating staff and resources. The contractor interprets the RFP and the design package and develops an SOW and a PEP. Using BOMs produced during the E&I design process, the FAB team begins to procure materials and organize the shop floor to accommodate the project.

1.5.6.3 CPF Seller Phase 1c: Project Planning

Project planning for the FAB team revolves around scheduling. It is important to orchestrate materials procurement and flow so that materials arrive when needed, not too soon, clogging up the production floor, and not too late, interrupting production processes. The FAT should be planned here in anticipation of visiting customers.

1.5.6.4 CPF Seller Phase 2: System Design

In Phase 2, materials are procured and received, and panel fabrication, assembly, and internal panel wiring occur. Internal testing (pre-FAT) activities are done prior to executing the formal FAT. FAT procedures are typically inside the boundary limits of the panels and include three steps:

- 1) **Verify the physical installation.** Were the components installed where the drawings depicted them? Is the BOM accurate, or did the fabricator have to make substitutions due to unavailable components or other reasons? Are the labels positioned correctly and properly spelled?
- 2) **Check the wiring connections.** Are the wires properly terminated point-to-point? Is continuity confirmed? Are the connections tight? Are the wires properly labeled and sized? Are ground connections confirmed?
- 3) **Perform power-up voltage checks.** Are the voltages per expectations? Does the equipment energize?

When the FATs are completed, each panel has been validated individually and confirmed to be fully populated, wired, and tested.

1.5.6.5 CPF Seller Phase 3: Deployment

For the panel fabricator, deployment involves creating the mockup for the SSDT, which usually occurs in the shop. The fabricator's team installs the temporary patch cabling and fibers necessary to power the entire system and demonstrate the system's function. This can mean setting up a temporary control console with loose equipment that is not in the cabinets the fabricator has designed. The fabricator's technicians will likely participate in the SSDT, injecting signals and performing other tasks as led by the CSI team.

After concluding the SSDT, the mockup will be torn down and the panels crated for shipment.

1.5.6.6 CPF Seller Phase 4: Support

Post-project support effort by the fabricator is minimal, including shipping the panels and closing out the project. Questions sometimes arise from the plant when the equipment arrives, but there is seldom a need for the CPF team to be involved with on-site activities.

1.6 Integrated Control Solutions

The previous sections discussed the participants in a control systems project as if they were separate entities. A review of the project stages reveals that each group must perform many of the same steps in the early stages if they follow prudent FEL-based guidelines. This repetition between groups generates waste. The owner may be able to construct EPC scenarios that enable them to issue a single purchase order for all these services by designating a prime contractor to manage the others. However, if the participants are all in different companies, the overall cost and complexity of the project may not be reduced, even though the owner's project management aspect may be simplified by reducing the number of purchase orders to issue and invoices to process. On the contrary, adding management layers to the contractors' normal set of services may increase project cost, and passing the responsibility for managing the interfaces between contracting companies to a third party may also increase risk.

A new type of company that addresses these issues is emerging, providing all the key engineering, systems integration, and panel fabrication services as an integral aspect of their operation. These companies, sometimes called *control solutions providers* (CSPs), provide ICS products and services. The great benefit of these companies is the effect of prenegotiated interfaces between the CPF, the E&I engineer, and the CSI. Some of the immediate benefits are:

- A single PM can be appointed (instead of three).
- The E&I design product can be tailored to the panel fabrication shop's needs and capabilities.
- Scheduling can be streamlined.
 - The E&I designer can specify materials that are already on the fabricator's shelf.
 - The integrator can get involved earlier in the process, assisting the E&I designer with an initial system (Instrument and I/O List) database design and partitioning.
- Proposal costs can be minimized, resulting in lower project costs as one bidder, instead of three, builds proposal recovery costs into their bid.
- Closer, more informal ties among the three internal organizations enable problem resolution to occur below the owner's radar, thus reducing their oversight workload.

The benefits extend beyond the design and fabrication stage. In Phase 3, when the system integrators are in the lead, they can draw from an instrument design knowledge base that is internal to their own company, knowing that all participants have the same success motivation. E&I personnel can be called on to augment the CSI in site support, troubleshooting, and construction liaison. FAB personnel can be called on to make field adjustments in the panels. Overall, a better, simpler, and more flexible workflow can be achieved.

In closing, every design project is different. Yet, the design engineer's approach to a new project should not change. The same initial questions should be asked every time: What is the structure of the project? What are the customer's expectations, and how will they measure success? How much risk is it wise to assume?

Once those questions have been answered and the design environment is known, the specific content of the design package can be resolved. The mix of products and services can change from

project to project, and the design team must be able to adapt to the evolving needs. If the team has a good feel for all the deliverables that may be offered, modifying the package by deleting deliverables will have little effect on the design process. In contrast, adding deliverables that are new to the team could have a great impact, upsetting the workflow. Therefore, it is in the best interest of all concerned to have all team members fully aware of the full range of products and services and their interrelationships.

References

The dates and editions for standards and other references in this chapter are current as of publication. The reader is encouraged to check for later revisions or editions.

- 1 G. W. Cockrell, *Practical Project Management: Learning to Manage the Professional*. Research Triangle Park, NC: ISA (The Instrumentation, Systems, and Automation Society), 2001.
- 2 Instrument Society of America, *ISA Comprehensive Dictionary of Measurement & Control*, 3rd ed. Research Triangle Park, NC: ISA, 1995.
- 3 G. C. Yeager and L. Janos, *Yeager: An Autobiography*. New York: Bantam Books, 1985.
- 4 G. Courter and A. Marquis, *Mastering Microsoft Project 2000*. Alameda: Sybex Inc., 2000.
- 5 Project Management Institute (PMI), *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*, 6th ed. Newtown Square, PA: PMI, 2017.
- 6 Construction Industry Institute, *CII Best Practices Guide: Improving Project Performance*, Version 5.0. Austin, TX: CII (Construction Industry Institute), 2022.
- 7 T. Kletz, *HAZOP and HAZAN: Identifying and Assessing Process Industry Hazards*, 4th ed. Philadelphia: Taylor & Francis, 1999.
- 8 Control Systems Integrator's Association, *CSIA Guide to Control System Specification and System Integrator Selection*, vol. 1, REV(00). Exton, PA: CSIA, 2000.