Achieving Success in the Commissioning and Startup of Capital Projects: Implementing Critical Success Factors

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Research Team 312, Best Practices for Commissioning and Startup

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Contents

Executive Summary

This implementation resource provides key guidance on how project teams can help ensure success in capital project commissioning and startup. The document is intended to complement or supplement the prior recommendations and learnings from Research Team (RT) 121, Planning for Startup. CII established RT 312, Best Practices for Commissioning and Startup, to identify the best practices for commissioning and startup (CSU) that define, achieve, and maintain owner operational performance. Through surveys and interviews with CSU experts from CII member companies, the research team identified 16 critical success factors (CSFs) and then validated them through analysis of project performance and external expert feedback.

The introduction of this publication gives an overview of the research purpose and objectives, scope limitations, and research methodology. Chapter 2 presents CSU terminology, CSU phases/milestones, and CSU organizational functions. Chapter 3 defines the 16 CSFs, and discusses their recommended timing, how frequently the industry accomplishes them, barriers to their accomplishment, and their links to project safety and quality. Chapter 4 links the CSFs to the work process model presented in Implementation Resource (IR) 121-2, *Planning for Startup*. Chapter 5 presents a reproducible user-friendly checklist of the CSFs and innovative commissioning technologies. Chapter 6 compares the CSU performance of 26 actual projects to their levels of CSF implementation, providing validation of the CSFs, along with additional insights into both CSU performance and key indicators of CSF achievement. In Chapter 7, four case studies examine four CSU failures, highlighting missing links to critical success factors. Chapter 8 describes five innovative commissioning technologies investigated by the research team. The concluding chapter presents key take-aways from the study. The appendix provides additional ideas on how to advance CSU practice.

1

Introduction

Purpose and Objectives

Successful capital project investment depends on successful project commissioning and startup. RT 121, Best Practices for Commissioning and Startup, defined commissioning and startup (CSU) success in terms of eight different component metrics: 1) product quality; 2) product quantity (or production rate); 3) startup schedule performance; 4) startup safety performance; 5) startup environmental performance; 6) operations team performance; 7) impact of startup on operations; and 8) level of startup effort required.

Yet industry benchmarking data indicate that commissioning/startup performance often falls far short of expectations and that CSU planning and execution efforts are often deficient. Thus, industry is in need of effective guidance on planning and implementing project commissioning and startup. Certainly, organizations should consider how new technologies can leverage the efforts of CSU team members.

The purpose of this research was to understand effective management approaches and new technologies for successful commissioning and startup of capital projects. Specific objectives of the research included the following:

1. Broaden the understanding of key terms pertaining to commissioning/startup/initial operations.
2. Identify critical success factors (CSFs) for step-wise advancement of CSU planning and execution.
3. Understand the current extent of industry accomplishment of the identified CSFs and identify relevant barriers to their successful achievement.
4. Analyze project CSU performance relative to degree of CSF implementation, and thereby determine the relative contribution of CSFs to actual commissioning performance.
5. Understand how the CSFs link to the activities contained in the process model presented in IR 121-2, *Planning for Startup*.
6. Identify innovative technologies for optimizing CSU performance.

Facility owners/operators are the primary intended beneficiaries of this research, especially in the industrial sector. Capital project team members involved in the planning and implementation of facility CSU (representing both contractors and owners) will also benefit from the results.

Scope Limitations

This study focused on commissioning, startup, and preparation for initial operations of industrial facilities, such as petro-chemical, power, water/waste-water treatment, and nuclear plants, among others. In addition, most of the findings are also applicable to systems-intensive building and infrastructure projects, such as pharmaceutical, hospital, and airport projects. Facility operations considerations are limited to relevant issues and opportunities prior to and during operational ramp-up periods, and up to and including final plant performance testing. Steady-state plant operations issues that arise after final performance testing are outside the scope of this study. The scope included best industry practices for commissioning/startup/initial operations that should be performed in all project phases. Some additions and modifications to IR 121-2 have been included in this study, but a comprehensive update/revision of that planning document was outside the scope of this study.

Research Methodology

Figure 1 shows that the RT 312 research methodology involved a mix of literature review, research team model-development, surveys of industry commissioning experts, and several approaches to validation of the team findings. The research team focused on establishing CSU CSFs, starting from an initial listing of 139 potential factors. Industrial commissioning experts then were asked to draw on their experience to estimate the relative contribution of these potential factors to CSU success. With these expert CSF ratings in hand, the research team was able to determine the timing of CSF implementation (within the project context), identify the CSF indicators (or tell-tales) of achievement, assess the frequency of CSF achievement (industry benchmarking), and identify the barriers to implementation for the less frequently achieved CSFs. The team was also able to link the CSFs to the IR 121-2 activity flowcharts and to conduct four detailed commissioning failure mini-case studies, highlighting failures to achieve the CSFs, and links between CSFs and project quality and safety.

The research team then conducted brainstorming sessions, discussions, and analysis to determine indicators of CSF achievement. Research Report (RR) 312-11, *Identification and Implementation of Critical Success Factors in the Commissioning and Startup of Capital Projects*, provides a full account of the reserach methodology, including details about the literature review, data collection and analysis methods, characterization of data sources, and details on the validation.) Lastly the team developed the CSF indicators checklist tool.

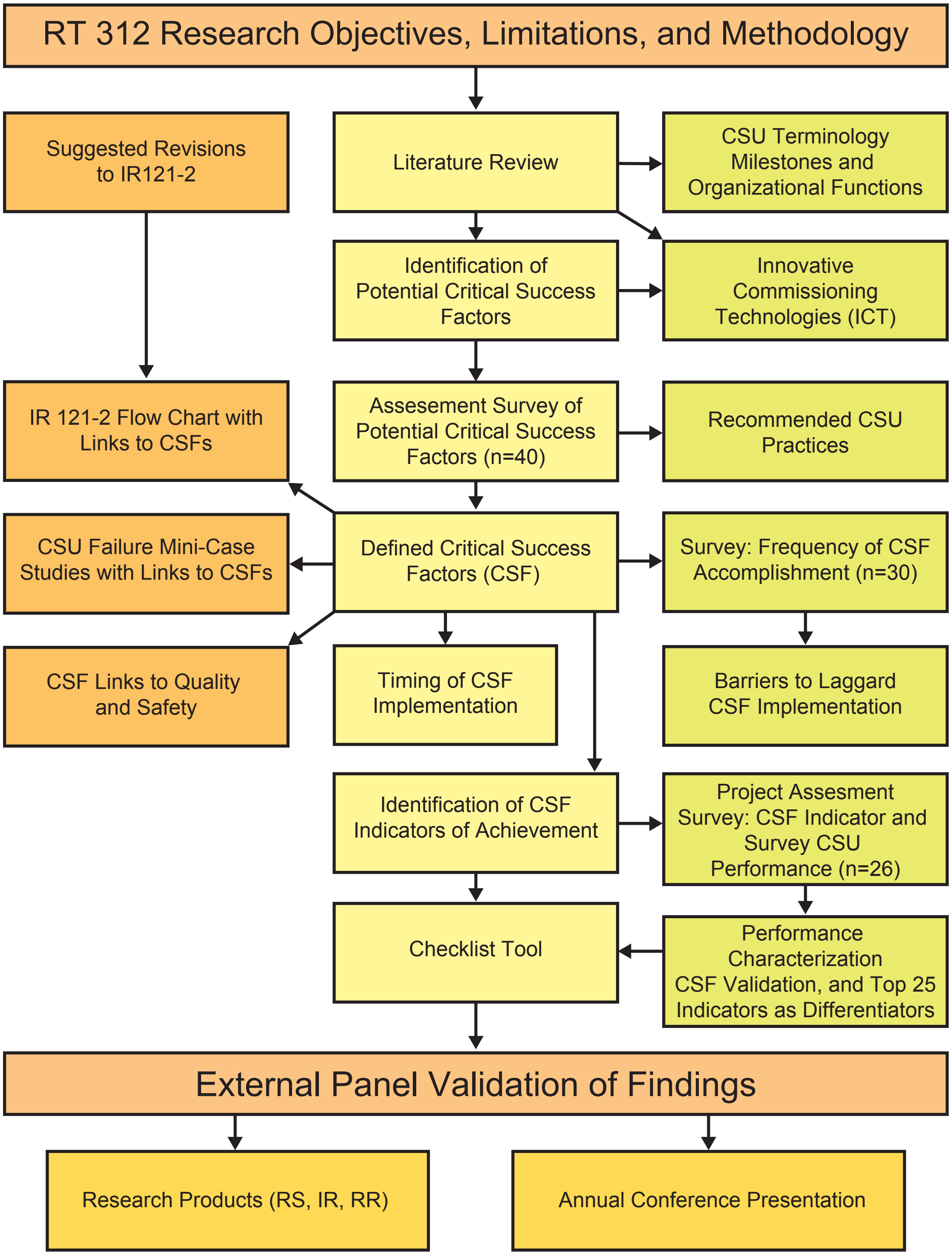

Figure 1. RT 312 Research Methodology

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Commissioning and Startup Terminology and Structures

From the beginning, the research team recognized that better industry alignment on CSU terminology and CSU management system structures would provide a needed foundation upon which to establish or extend CSU best practices. CSU terminology can vary from company to company and across industry sectors; and, because this is particularly true of the terms pre-commissioning and commissioning, RT 312 clarified them with consensus distinctions. (See Table 1.) CSU phase and milestone labels and relationships also vary and, thus, warranted clarification and alignment. (See Figure 2.)

Table 1. Terminology: Pre-commissioning versus Commissioning

Pre-commissioning (Component-level)	**Commissioning** (Multi-component Integration and System-level)
Scope Description Activities	
• Activities are usually post-mechanical completion (at the component level) but prior to energization and any feedstock introduction. • Activities may or may not be the responsibility of the construction contractor. • Concludes with a ready-for-commissioning certificate for each system. • Rotating equipment: bump for, rotation guards, installed, rotation check, motor bumps, alignment checks, and uncoupled checks	• All construction is complete and verified prior to initiation of commissioning (but post- construction handover). • Energization of equipment starts the commissioning process • Actions immediately prior to startup • Activities are most often the client's responsibility. • Concludes with a ready-for-startup certificate for each system.

Table 1. Terminology: Pre-commissioning versus Commissioning *(Continued)*

Pre-commissioning (Component-level)	**Commissioning** (Multi-component Integration and System-level)
Key Conclusions	
• Line-vessel cleaning; initial leak checks; non-operating checks, inspections, testing, cleaning, flushing, blowing, drying, adjusting; cold aligning of equipment, piping, instrumentation, electrical systems, cold alignment checks, spring hanger settings, and some equipment tests • Mechanical equipment, wiring checks for installation accuracy; point-to-point continuity checks • Mechanical function tests • Construction rework, as required • All verification tests to ensure equipment is fabricated, installed, cleaned, and tested in accordance with the design • All tests/inspections required prior to any dynamic testing • Function checks accomplished with discipline-specific check-sheets • Power-off checks of equipment, piping, and electrical cable • Non-operating adjustments performed before system turnover • “First fill” (e.g., lubricants, and utility fluids); loading of catalysts, desiccants, polishers, and other fluids	• All energized and/or dynamic tests that verify that each system or subsystem is fabricated, installed, cleaned, and tested in accordance with the design intentions, and that systems are ready for startup • Chemical cleaning and steam blowing • Final leak checking and air freeing; leak and tightness testing • Instrument loop calibration • Checkout of PLC and emergency shutdown system; testing of all safety functions; testing of control functions • Refractory dry-out • Rotating equipment run-in; coupled testing of rotation equipment • Circulation with temporary fluids • Testing of utilities • Testing of control functions and installation of final valve trim

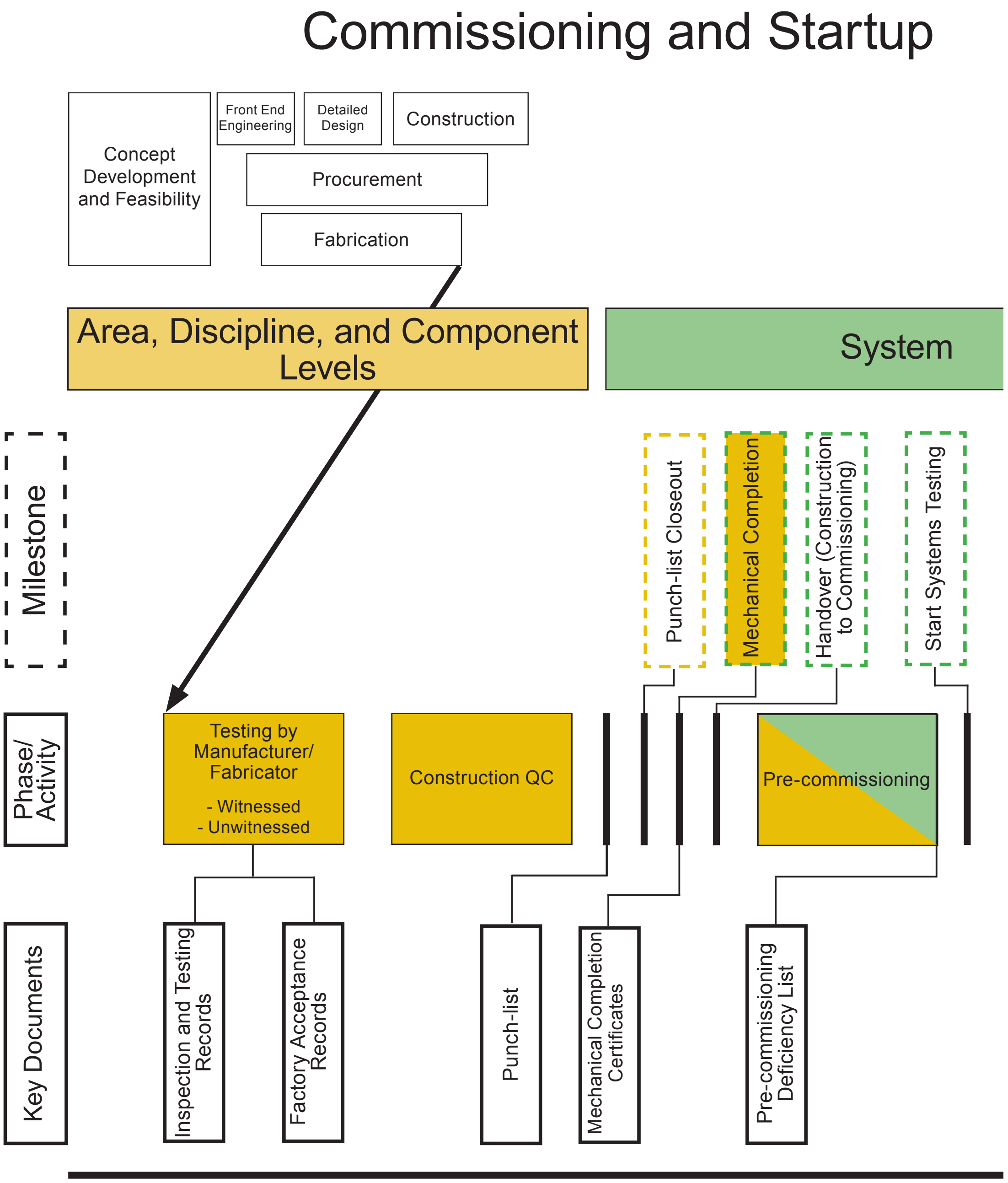

Figure 2. CSU Phases and Milestones

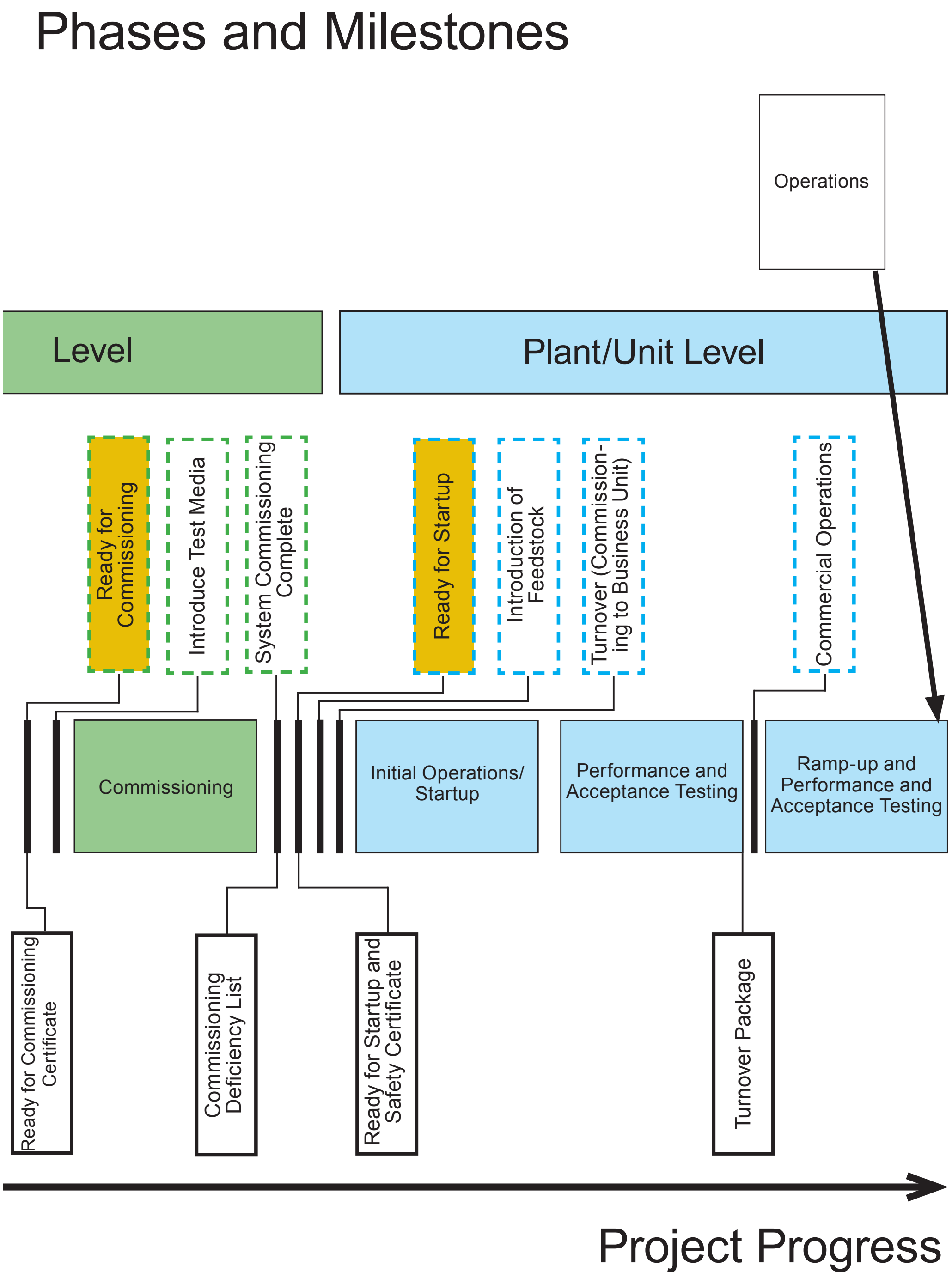

Figure 2. CSU Phases and Milestones

The research team also believed it would help to determine who is typically involved (in some way) in CSU activities. Figure 3 matches these activities to their organizational functions. While the team did not further explore detailed organizational dimensions of CSU, this listing of functions provided a useful basis for subsequent discussions and research developments.

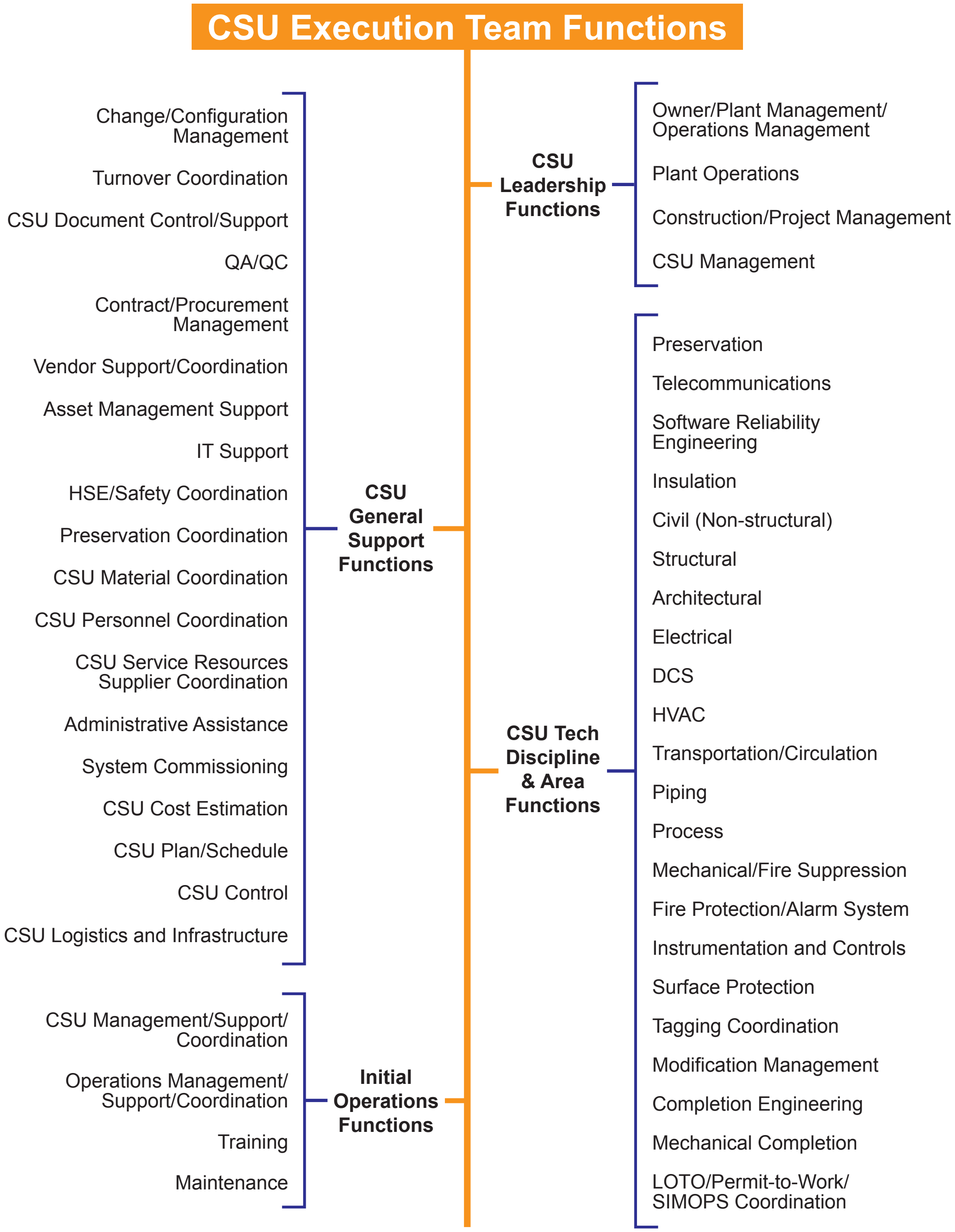

Figure 3. CSU Organizational Functions

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CSU Critical Success Factors and Implementation

Critical Success Factors for Commissioning/Startup

As mentioned in the previous chapter, the research team isolated 16 CSU critical success factors (CSFs) from an initial list of 139 potential factors. Table 2 presents the CSFs, numbered in order of sequence of implementation on projects, with succinct CSF labels and descriptions. At a high level, these factors focus on leadership, team alignment, integration, collaboration, capability, success criteria, interface management, recognition of value drivers, planning, funding for planning, CSU systems-focus, support tools, and information.

Table 2. Critical Success Factors for Commissioning/Startup

Critical Success Factor	Description
1. CSU Value Recognition	Establish the business case (including CSU staffing plan) for effective CSU leadership. Recognize the value added from successful CSU (e.g., the value of one day of successful operations). Avoid being “dollar foolish”: the owner and all contractors must buy into (and be aligned on) the economics of effective planning, and the investment required.
2. Critical Interfaces on Brownfield Projects	For brownfield projects identify early-on all critical interfaces with existing plant facilities and plant operational approaches. Examples include isolation design, system controls, worker access, permitting, and interim operations, among others.
3. Adequate Funding for CSU	Project funding for CSU must be adequate, budgeted up-front, and preserved. The common threat from failure to do so is a lack of enough operators, which causes subsequent delays in the CSU progress.
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	The project and CSU will benefit substantially from getting early alignment among CSU, operations, project management, engineering, construction, and other key stakeholder representatives on the key issues of CSU terminology, CSU success drivers, and CSU strategies. Lack of such alignment may pose a threat to CSU success. Sustained alignment between these entities can only be achieved with effective collaboration throughout the life of the project.
5. CSU Leadership Continuity	Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.

Table 2. Critical Success Factors for Commissioning/Startup *(Continued)*

Critical Success Factor	Description
6. System Milestone Acceptance Criteria and Deliverables	Establish specific detailed systems/subsystems acceptance criteria and associated deliverables for each major milestone: mechanical completion, turnover, pre-commissioning, commissioning, and handover. All project parties should understand these expectations.
7. CSU Systems Engineering during FEED	CSU systems Engineering during FEED is the activity of defining CSU systems within a facility. As the design of facilities has a major impact on how they are fabricated, tested, integrated, and started up, effective FEED design efforts can reduce commissioning and startup challenges. Preliminary P&IDs are key documents for this effort.
8. Recognition of CSU Sequence Drivers	The planned sequence of commissioning should be coordinated with construction planners and based on such considerations as construction sequence, plant operations philosophy, ramp-up objectives, plant controls automation objectives, HAZOP awareness, modularization scope, clean-build procedures, sequence of flushing, sequence of leak/hydro testing, preservation steps, system tagging, and sequence of loop checks, among other issues.
9. Detailed CSU Execution Plan	CSU success requires timely and thorough execution planning, which integrates project planning with CSU planning. Execution plans should address the appropriate skill mix necessary in both CSU craft and CSU management. Plant operations must be an effective contributor to this planning effort, and common challenges that must be addressed (in the plan) include Operations staff availability, continuity, authority, breadth of experience, and timeliness of input.
10. Systems-focus in Detailed Design	A systems-focus during design, involving CSU and operations, will raise awareness of how systems will be handed over, tested, and started up. With this approach more design attention will be given to such issues as high/low point drains, removable spools for critical inline equipment, critical isolation points, LOTO requirements/supports, and access for operations and maintenance.
11. CSU Check-sheets, Procedures, and Tools	Ensure component/system functional checkouts include adequate check-sheet criteria, detailed system commissioning procedures, and certifications. Application of innovative CSU technologies will enhance implementation.
12. CSU Team Capability	CSU team has a good understanding of the operations performance metrics-oriented requirements and the CSU activities and deliverables needed to obtain those results.

Table 2. Critical Success Factors for Commissioning/Startup *(Continued)*

Critical Success Factor	Description
13. Integrated Construction/CSU Schedule	A fully integrated construction/pre-commissioning/commissioning schedule is critical to achieving CSU objectives. This schedule should integrate all checks, tests, and approval milestones for each component and all systems, and show development of supportive documentation. CSU acceleration effects from delayed construction are to be avoided.
14. Accurate As-built Information	Accurate as-built drawings and asset database are needed to ensure effective planning, implementation, and closeout of CSU activities.
15. Transition to Systems-based Management	Plan to transition from construction progress tracking on an area basis to a systems-completion basis so that construction forces may be most effectively redirected as needed. Involve CSU staff in construction planning at approximately 60-80 percent system construction complete (for each single major system) in order to help mitigate construction punch list items (with particular early focus on utility systems).
16. Collaborative Approach to Construction-CSU Turnover	CSU managers should work collaboratively with construction managers in managing construction completion and systems turnover. Proactive communications are needed to minimize construction-CSU conflicts.

Timing of CSF Implementation

Proper timing of implementation is key to the effectiveness of each CSF. Figure 4 illustrates the recommended timing of CSF implementation. Three of the 16 CSFs should be fully achieved prior to the initiation of detailed design, and nine of them should be fully achieved prior to the initiation of construction. Many practitioners that recognize these success factors might be surprised at the recommended timing of their implementation. A key finding of this research is that project teams should not delay their implementation of the CSFs.

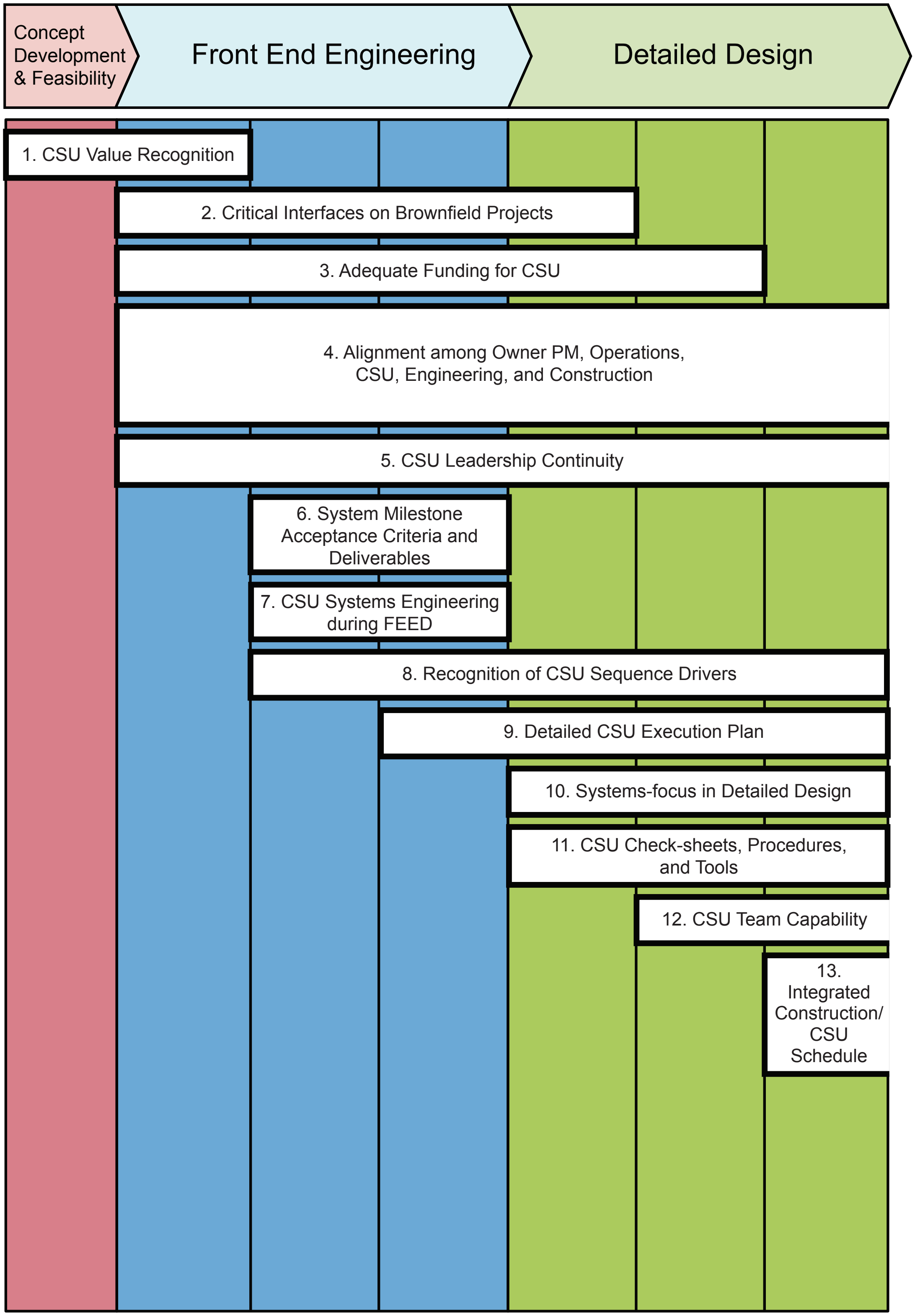

Figure 4. Timing of CSF Implementation

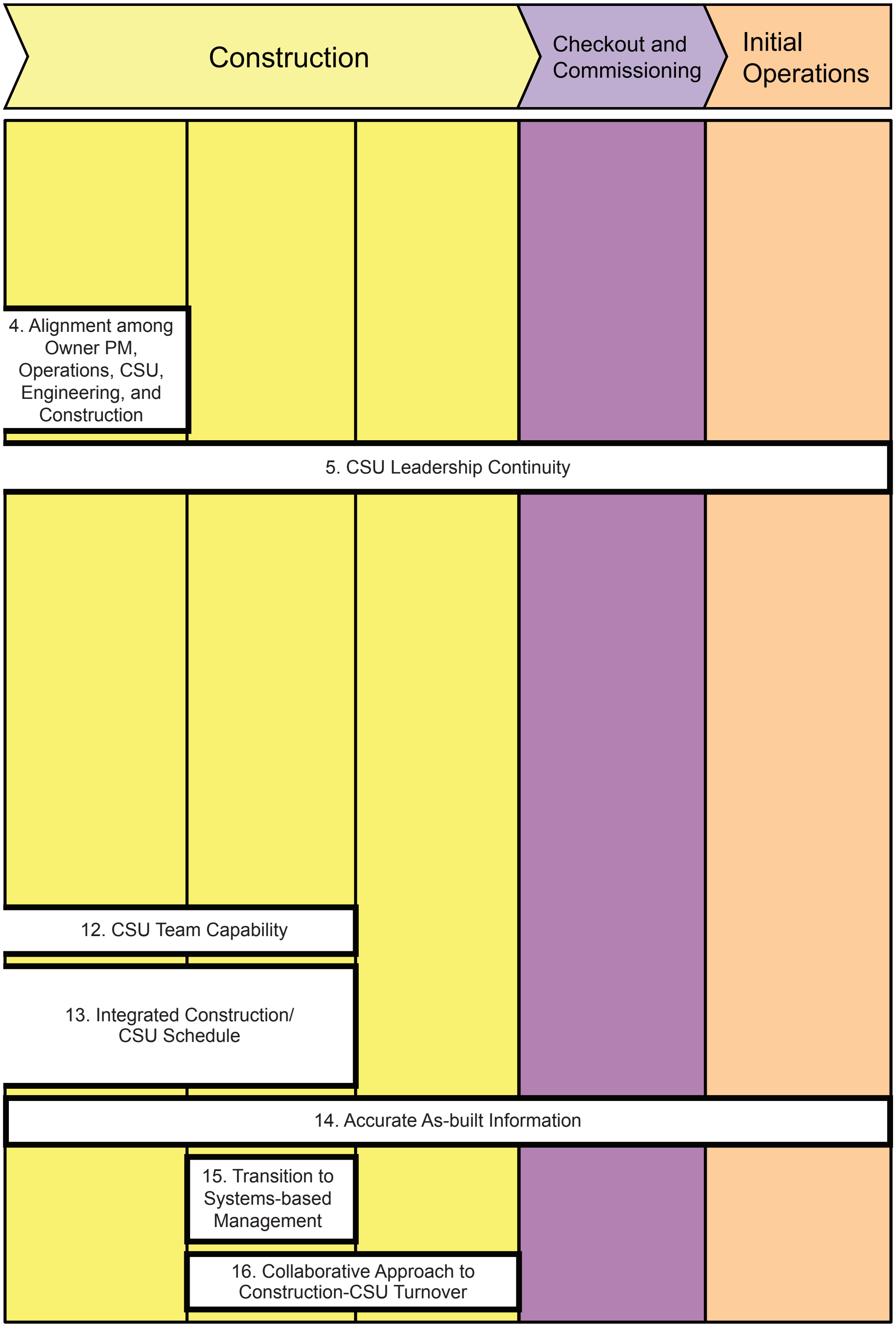

Figure 4. Timing of CSF Implementation

CSF Frequency of Achievement

The research team sought to determine to what extent project teams are currently implementing or accomplishing the CSU critical success factors. To do this, the team surveyed 30 CSU managers on the relative frequency or accomplishment of the CSFs on their projects, and gathered project characteristics from 26 actual projects, noting any CSF indicators of achievement. (See Chapter 6 for more on this project characteristic data.)

A comparison of the analyses of these data indicated that the following CSFs were the least frequently achieved:

1. System Milestone Acceptance Criteria and Deliverables
2. CSU Value Recognition
3. Adequate Funding for CSU
4. CSU Systems Engineering during Front End Engineering Design (FEED)
5. Systems-focus in Detailed Design
6. CSU Leadership Continuity.

This finding shows that more than a third of all CSFs are challenging to implement. To provide further insight into these challenges, the team examined implementation barriers to these six CSFs.

Barriers to the Implementation of Less Frequently Accomplished CSFs

The research team brainstormed a large number of potential barriers to CSF achievement and refined the list down to those considered most significant. (See Table 3.) Practitioners should first be aware of these barriers and then confront and mitigate them at the earliest opportunity.

Table 3. Barriers to Less Frequently Accomplished CSFs

Critical Success Factor	Barrier to Achieve CSFs
1. CSU Value Recognition	1. Too little focus on “doing the right things” (investing in CSU)
	2. Many stakeholders and project managers do not understand the value proposition; they are “penny-wise and pound-foolish.”
	3. Project managers are stuck in old paradigms.
	4. Difficulty quantifying relationship between CSU resourcing/planning and the benefits of effective CSU.
3. Adequate Funding for CSU	1. Funding is not proportionate to project complexity and size.
	2. Failure to recognize fully the value of successful CSU.
	3. Project funding stress due to construction overruns
	4. Overly simplistic estimating methods (percentage of TIC)
	5. Failure to include funding for specialty SMEs needed and/or specialty training needed
5. CSU Leadership Continuity	1. Lengthy duration of projects, from project planning to end of startup
	2. HR effects and difficulty in achieving continuity: routine promotions, retirements, and job changes
	3. Lack of appreciation for the importance and impact of leadership continuity
	4. No established training/mentoring program for CSU team members
	5. Lack of early-phase project funding leading to the delayed establishment of the CSU team
6. System Milestone Acceptance Criteria and Deliverables	1. Lack of systems definition during FEED
	2. CSU planning team not established during FEED
	3. CSU is not involved in execution contract development, so it may not be included in the contractual scope of work.
	4. Lack of timely involvement of operations in establishing acceptance criteria
	5. Challenges in keeping the acceptance criteria current, due to design/scope changes

Table 3. Barriers to Less Frequently Accomplished CSFs (Continued)

Critical Success Factor	Barrier to Achieve CSFs
7. CSU System Engineering during FEED	1. The "It's too early" paradigm ("We don't have enough information")
	2. Lack of understanding of the importance of early systemization and needed planning resources
	3. No CSU visibility, compared to constructability and other best practices
	4. Lack of a champion at this time
	5. Failure to effectively transfer CSU knowledge to engineering personnel
10. System-focus in Detailed Design	1. Late engineering deliverables tend to push this into construction
	2. Lack of continuity in engineering resources and contractors
	3. Package units that lack system definition; poor associated assumptions
	4. Lack of a champion at this time
	5. Failure to transfer CSU knowledge effectively to engineering personnel

Indicators of CSF Achievement

The 16 CSU critical success factors provide meaningful insight and substantial guidance for project teams seeking high levels of CSU performance. Follow-through efforts by management should pertain to CSF implementation and periodic assessment of actual CSF achievement. To support this recognition and assessment of CSF implementation, RT 312 formulated 45 CSF achievement indicators. These tell-tales offer strong evidence of actual CSF achievement. Table 4 matches them with their associated CSFs. The research indicated that 30 of the 45 indicators are excellent differentiators between CSU success and failure. Project teams will find these indicators to be particularly informative in their assessments of actual CSU preparedness. (See Chapter 6 for a detailed discussion of the 30 indicators.)

Table 4. Indicators of CSF Achievement

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
1. CSU Value Recognition	1.1 CSU manager is on the project organizational chart at the start of front end engineering.	✓
	1.2 Prior to the start of front end engineering, approved CSU budget and schedule are in hand for CSU planning work.	
	1.3 Project leadership is very familiar with the venture value that would be lost from a one-day delay in startup of operations.	
2. Critical Interfaces on Brownfield Projects	2.1 Project team has identified all tie-ins and individual shut-downs by 30-percent detailed design complete; and these have been integrated into the construction-CSU integrated schedule.	✓
	2.2 All construction-CSU physical access constraints due to brownfield conditions have been identified by 30-percent detailed design complete.	
	2.3 System boundaries and isolations are developed with full understanding of brownfield operations/controls conditions.	
	2.4 All project team members understand site permitting requirements.	
3. Adequate Funding for CSU	3.1 By the end of front end engineering, the CSU budget has been derived from knowledge of CSU strategy and scope of work, and if needed CSU resources, not simply a percentage of TIC.	✓
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	4.1 The CSU philosophy/strategy/execution plan has been reviewed/approved by all stakeholders, and signatures are affixed.	✓
	4.2 Repeated confirmation of alignment is achieved.	✓
	4.3 Critical CSU input has been acquired for engineering design reviews, engineered equipment purchases, construction sequencing, and schedules.	✓
	4.4 Several CSU joint meetings were held in which all stakeholders were present. These were initiated early and were repeated throughout planning, design, and construction phases.	

Table 4. Indicators of CSF Achievement *(Continued)*

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
5. CSU Leadership Continuity	5.1 A CSU manager was assigned at the start of front end engineering and remained with the project through to initial operations.	✓
	5.2 The qualifications and the planned tenure of the CSU manager were well-defined by early front end engineering.	✓
6. System Milestone Acceptance Criteria and Deliverables	6.1 System acceptance criteria were incorporated into the contract with the execution contractor.	✓
	6.2 System/subsystem acceptance criteria were well documented prior to bid document submission, and key parties were aligned on the criteria by the end of front end engineering.	
7. CSU System Engineering during FEED	7.1 Formal CSU design review has occurred by the end of front end engineering.	✓
	7.2 By the end of front end engineering, system (and module) boundaries are identified on P&IDs and electrical one-line diagrams.	
	7.3 CSU manager was accountable for leading the team through the systemization process, involving operations, maintenance, and CSU resources.	
	7.4 Preliminary CSU sequence was defined by end of front end engineering.	
8. Recognition of CSU Sequence Drivers	8.1 A methodical approach was used to develop the project's CSU sequence (including all system, subsystems and related dependencies), with formal recognition of all critical sequences and was finalized by end of detailed design.	✓
	8.2 The formulation of CSU sequence was completed by the end of detailed design and took into consideration timely completion of life-safety and process safety systems, control systems, utility systems, and process systems, among others.	✓

Table 4. Indicators of CSF Achievement *(Continued)*

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
9. Detailed CSU Execution Plan	9.1 A CSU-specific execution plan (including at a minimum CSU objectives, strategies, schedule, and roles and responsibilities) was developed and reviewed/approved by CSU stakeholders by end of detailed design.	✓
	9.2 The CSU execution plan was integrated into the overall project execution plan and had evident linkages to other project functions (e.g., engineering, construction, operations, maintenance, quality, and HSE)	✓
	9.3 Operations provided input into the preparation of the detailed CSU execution plan.	✓
10. System-focus in Detailed Design	10.1 Finalization of CSU sequence, depicting all systems, subsystems, and associated dependencies.	✓
	10.2 Commissioning test procedures were completed by the end of detailed design.	✓
	10.3 Construction and pre-commissioning check-sheets were finalized by the end of detailed design.	
	10.4 Identification and finalization of CSU system and subsystem boundaries on P&IDs, one-lines, and controls architecture.	
11. Definition of CSU Check-sheets, Procedures, and Tools	11.1 A complete set of construction/QC and commissioning check-sheets has been defined, reviewed, and approved by key project functions (e.g., construction, commissioning, operations, and quality) and loaded into a CSU management system prior to construction.	✓
	11.2 A complete set of construction/QC and commissioning test procedures has been defined, reviewed, and approved by key project functions (construction, commissioning, operations, and quality) and loaded into a CSU management system prior to construction and/or module fabrication.	✓
	11.3 If an asset management solution was used, then an equipment diagnostic alerts utilization plan was in place prior to construction.	

Table 4. Indicators of CSF Achievement *(Continued)*

Critical Success Factor	CSF Indicators of Achievement	Top 30 Indicator
12. CSU Team Capability	12.1 Project operational objectives were well documented and well understood among CSU team members.	✓
	12.2 CSU team members understood the links between their actions and the technical metrics for project success.	✓
	12.3 CSU progress was regularly assessed with management metrics.	✓
13. Integrated Construction/ CSU Schedule	13.1 Project schedule included system logic interdependencies and turnover milestones prior to 30-percent construction complete.	✓
14. Accurate As-built Information	14.1 A master set of asset drawings was readily available and document control procedures were effective, from construction through final facility turnover.	✓
	14.2 An asset information plan has been defined, reviewed, and approved by the end of detailed design.	✓
	14.3 A detailed as-built plan has been defined, reviewed, and approved by the end of detailed design, and was referenced within the project execution plan.	✓
15. Transition to Systems-based Management	15.1 Possession of a construction and commissioning integrated schedule by the 30-percent construction complete milestone.	✓
	15.2 Tracking of system completion with the use of check-sheets during construction.	✓
	15.3 Formalized system-level walk-down and punch list management, led by CSU team.	✓
16. Collaborative Approach to Construction-CSU Turnover	16.1 Joint meetings, involving both CM and CSU managers, were conducted starting around 50-percent construction complete.	✓
	16.2 Joint CSU system walk-downs were conducted, involving both CM CSU managers.	
	16.3 Short-term scheduling priorities (at both construction area and system/subsystem levels) were established with input from both CM and CSU managers.	

CSF Support of Quality and Safety

The research team examined each CSF for any linkages to project quality and safety, with a focus on how failure to implement the CSF could threaten quality and safety performance. (See Table 5.)

Table 5. CSF Links to Quality and Safety

Critical Success Factor	Safety and Quality Linkage	Threats to Safety and Quality Due to CSF Failure
1. CSU Value Recognition	Recognition of the positive effects of a successful CSU helps to reinforce quality-driven results	Lack of justified investment and resources threaten safety and quality.
2. Critical Interfaces on Brownfield Projects	Identification of critical interfaces ensures continued operation of the facility systems/ subsystems, while maintaining CSU goals and milestones	Unrecognized brownfield hazards are substantial.
3. Adequate Funding for CSU	Adequate funding must be allocated and planned for during the early project stages. Delays, missed milestones, and lack of operators during CSU are common results of lack of funding, which then can have a negative impact on quality.	Lack of justified investment and resources threaten safety and quality.
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	Early and sustained alignment by CSU stakeholders to establish strategies, drivers, responsibilities, and other key issues helps to maintain the highest-quality CSU, through constant reiteration of goals, CSU status, potential hurdles, and collaboration strategies for success.	Lack of alignment on CSU priorities, commitments, and follow-through threaten both safety and quality.
5. CSU Leadership Continuity	Continuous and consistent CSU leadership throughout the project helps to ensure the proper level of quality be maintained, from the planning stages of CSU through facility handover.	Lack of CSU staff continuity challenges safety and quality leadership.
6. System Milestone Acceptance Criteria and Deliverables	Detailed system milestone acceptance criteria establish the quality standard expected, prior to system handover. This is detailed through milestones and deliverables required for mechanical completion, turnover, pre-commissioning, commissioning, and handover.	Acceptance verification is incomplete, leading to safety and quality risks.

Table 5. CSF Links to Quality and Safety (Continued)

Critical Success Factor	Safety and Quality Linkage	Threats to Safety and Quality Due to CSF Failure
7. CSU System Engineering during FEED	Proper definition of CSU systems within a facility and recognition of the need to consider these systems during front end engineering can reduce CSU difficulties and increase quality of overall CSU plan.	Poorly isolated systems lead to rework and hazards.
8. Recognition of CSU Sequence Drivers	Recognizing and identifying the key actions for maintaining the planned CSU sequences maintains quality throughout CSU.	Out-of-sequence turnovers threaten safety and quality.
9. Detailed CSU Execution Plan	A detailed plan, that includes responsibilities of personnel, ensures that roles are clearly defined and that each CSU activity has a responsible party and meets the highest quality.	Lack of planning threatens safety and quality.
10. System-focus in Detailed Design	A focus on systems during the design phase, in addition to a focus on equipment and individual components, has the advantage of increasing awareness of systems and how they ultimately will be handed over from CSU to operations.	Poorly integrated systems lead to rework and hazards.
11. Definition of CSU Check-sheets, Procedures, and Tools	Assurances that component/system checkouts include adequate criteria and procedures prior to handover.	Lack of check-sheets and procedures threaten safety and quality.
12. CSU Team Capability	A knowledgeable and experienced CSU team ensures the highest quality CSU through a thorough and comprehensive understanding of operations performance requirements, CSU activities, and project deliverables.	Safety and quality risks result from lack of capability.
13. Integrated Construction/ CSU Schedule	A CSU schedule is integral to achieving critical milestones and objectives. Quality is enhanced by the establishment of specific dates for CSU progress, along with the incorporation of quality checks, tests, and system/component milestones.	An unintegrated schedule leads to schedule errors, accelerations, and short cuts, which threaten safety and quality.

Table 5. CSF Links to Quality and Safety *(Continued)*

Critical Success Factor	Safety and Quality Linkage	Threats to Safety and Quality Due to CSF Failure
14. Accurate As-built Information	Accurate as-built information from the construction phase, helps CSU staff plan, implement, and close out CSU activities.	Inaccurate or missing as-built information can threaten safety and quality.
15. Transition to Systems-based Management	Transitioning from area-based construction progress tracking to systems-completion tracking helps to redirect resources effectively and efficiently, ensuring that construction packages are completed prior to commencement of CSU.	Inefficient transitions lead to shortcuts in safety and quality.
16. Collaborative Approach to Construction-CSU Turnover	A collaborative approach between CSU managers and construction managers helps minimize conflicts, allows for a more efficient CSU, and eliminates gaps in construction completion and system turnover.	A non-collaborative approach is inefficient and incomplete, and raises risk levels.

Other Recommended CSU Practices

As mentioned in Chapter 1, the research team isolated the 16 CSFs from among 139 potential success factors, and conducted a survey of CSU industry experts. The survey results indicated that the CSFs would have the greatest impact on CSU performance. However, the survey also showed that the next 29 potential factors could also have a substantial positive effect on CSU. Thus, the team tabulated these “other recommended CSU practices.” (See the appendix for a listing of these other practices.) The full listing of all 139 potential factors may be found in Research Report 312-11, *Identification and Implementation of Critical Success Factors in the Commissioning and Startup of Capital Projects*.

4

Linkages between CSFs and Planning for Startup Model

Another key research finding was the determination of the linkages between the 16 CSU critical success factors and the existing IR 121-2 activity flowcharts, which were modeled in the late 1990s. RT 312 was motivated to identify these linkages for several reasons:

- The research products of RT 121 and RT 312 better serve industry if they provide a clear, cohesive path-forward approach.
- Two entirely standalone disconnected models of industry best practice would run the risk of incompatibility, incongruity, and conflict.
- Understanding the linkages between the two best-practice models could serve as a form of cross-check of the CSFs with regard to frame of reference and industry relevance.

Figure 5 below illustrates how the 16 critical success factors should be integrated within the IR 121-2 phase/activity flow charts. Since this older model was established by CII as an industry best practice, any future updates to IR 121-2 should take these recommendations into account.

The CSU Planning Model

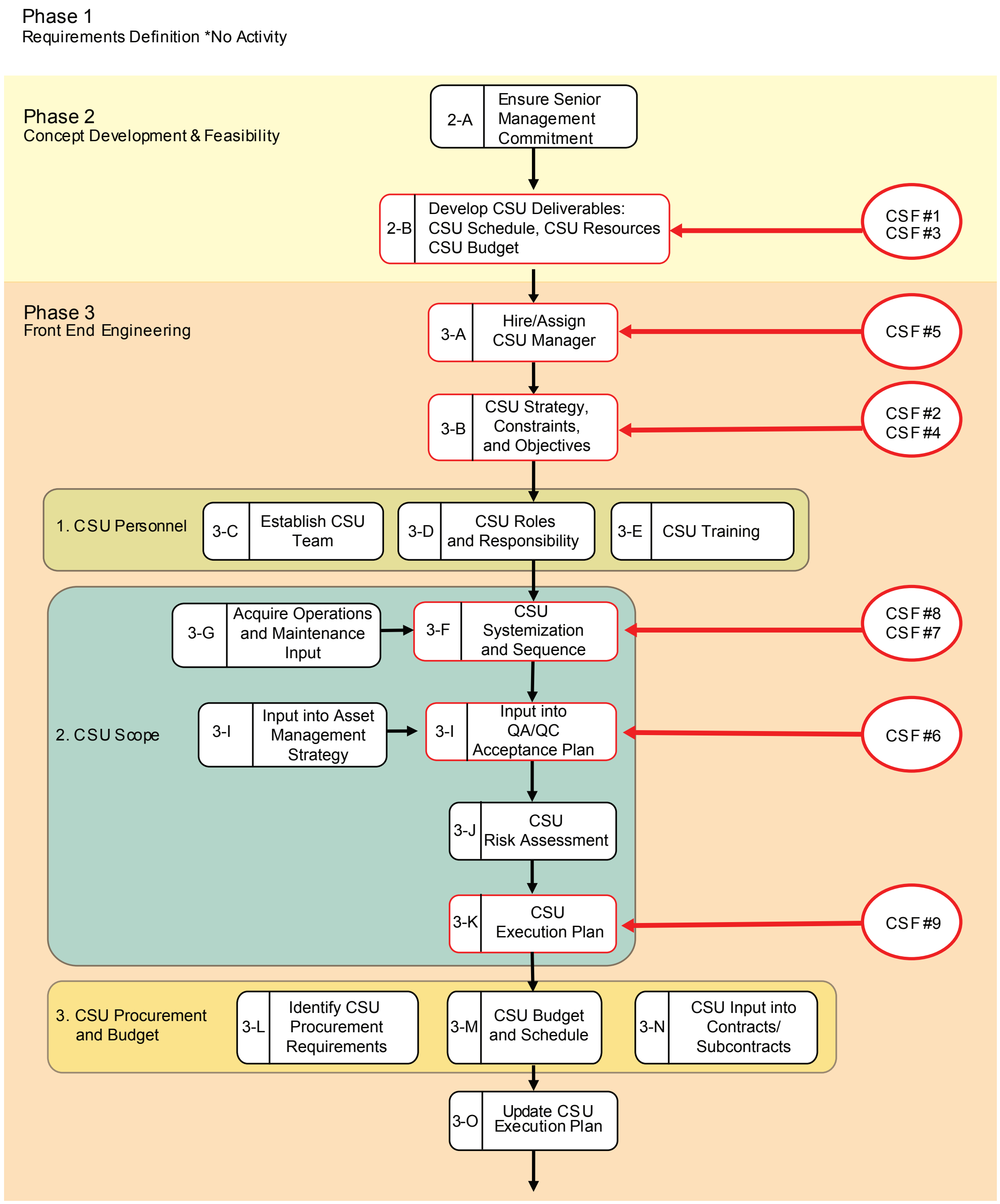

Figure 5. Linkages between CSFs and Planning for Startup Model

The CSU Planning Model

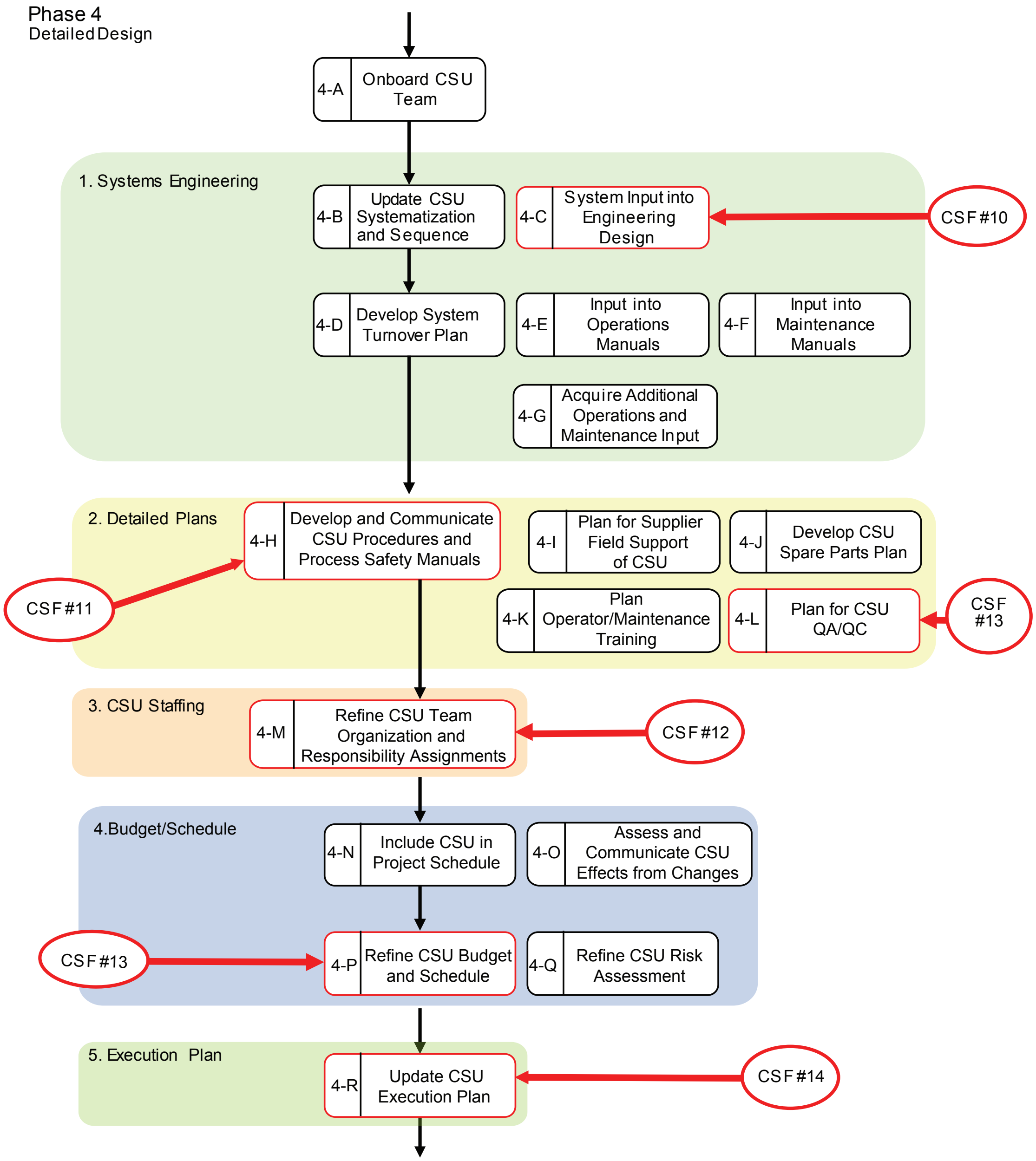

Figure 5. Linkages between CSFs and Planning for Startup Model *(Continued)*

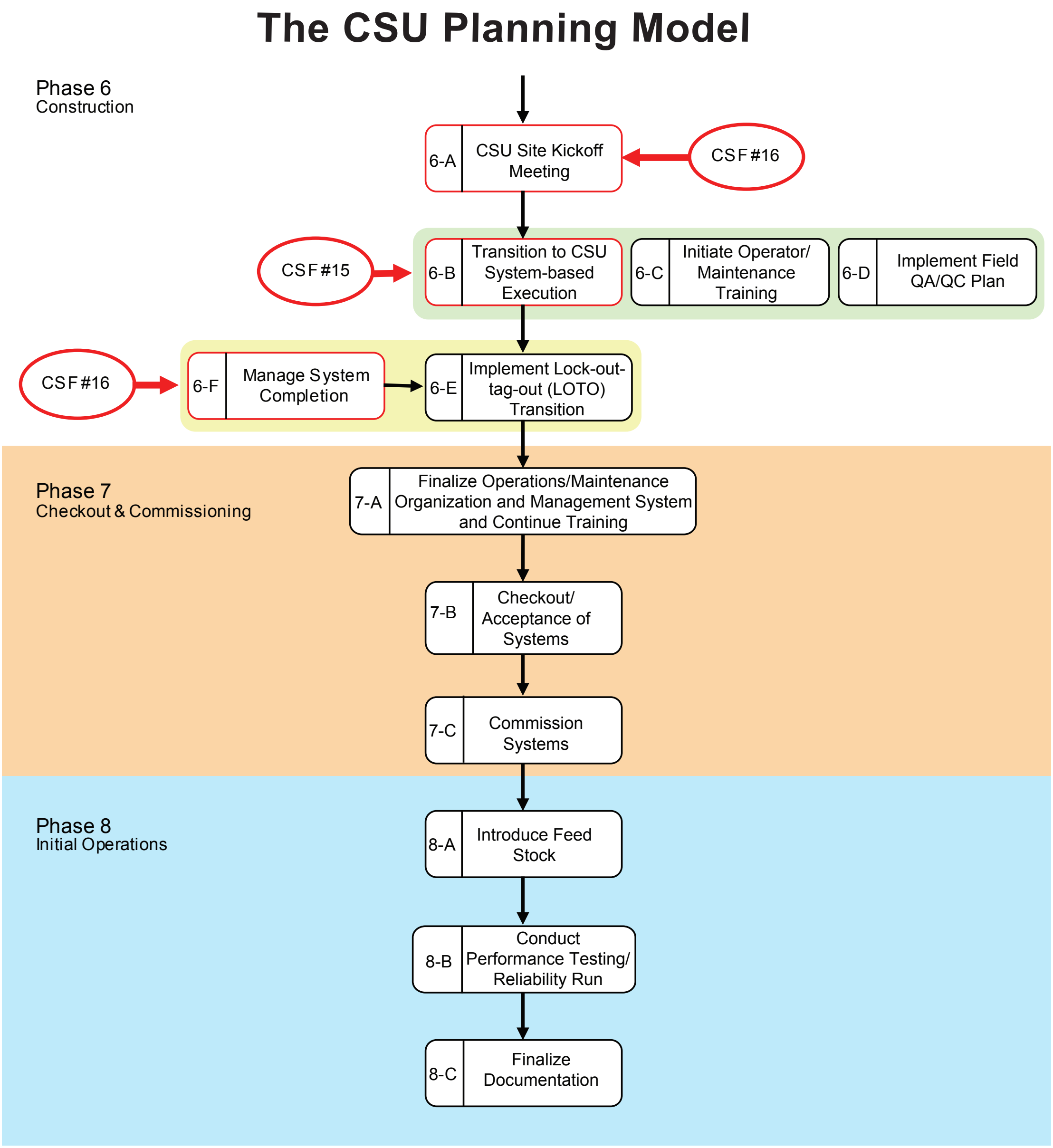

Figure 5. Linkages between CSFs and Planning for Startup Model *(Continued)*

5

CSU Critical Success Factor Checklist

To support increased industry awareness and implementation of the CSU critical success factors, RT 312 devised a simple two-page checklist tool, based on key study findings. (See Table 6.) This tool conveys four types of information:

- critical success factors
- most influential indicators of CSF achievement (top 30)
- timing of implementation of CSFs
- innovative commissioning tools and their timing of application.

Practitioners are encouraged to copy and widely distribute the checklist and the CSF Implementation Timing chart shown above in Figure 4. (This chart is included on a poster that comes with the hard-copy version of this implementation resource and is also available as an electronic download.)

Table 6. CSU Critical Success Factor Checklist

Critical Success Factor	Indicators of CSF Achievement	✓
1. CSU Value Recognition	1.1 CSU manager is on the project organizational chart at the start of front end engineering.	
2. Critical Interfaces on Brownfield Projects	2.1 Project team has identified all tie-ins and individual shut-downs by 30-percent detailed design complete, and these have been integrated into the construction-CSU integrated schedule.	
3. Adequate Funding for CSU	3.1 By the end of front end engineering, the CSU budget has been derived from knowledge of CSU strategy and scope of work, and needed CSU resources, not simply a percentage of TIC.	
4. Alignment among Owner PM, Operations, CSU, Engineering, and Construction	4.1 The CSU philosophy/strategy/execution plan has been reviewed/approved by all stakeholders and signatures are affixed.	
	4.2 Repeated confirmation of alignment is achieved.	
	4.3 Critical CSU input has been acquired for engineering design reviews, engineered equipment purchases, construction sequencing and schedules.	
5. CSU Leadership Continuity	5.1 A CSU manager was assigned at the start of front end engineering and remained with the project through to initial operations.	
	5.2 The qualifications and the planned tenure of the CSU manager are well defined by early front end engineering.	
6. System Milestone Acceptance Criteria and Deliverables	6.1 System acceptance criteria are incorporated into the contract with the execute contractor.	
7. CSU Systems Engineering during FEED	7.1 Formal CSU design review has occurred by the end of front end engineering.	
8. Recognition of CSU Sequence Drivers	8.1 A methodical approach was used to develop the project's CSU sequence (including all system, subsystems and related dependencies), with formal recognition of all critical sequences and was finalized by end of detailed design.	
	8.2 The formulation of CSU sequence was completed by the end of detailed design and took into consideration timely completion of life-safety and process-safety systems, control systems, utility systems, and process systems, among others.	
9. Detailed CSU Execution Plan	9.1 A CSU-specific execution plan (including at a minimum CSU objectives, strategies, schedule, and roles and responsibilities) was developed and reviewed/approved by CSU stakeholders by end of detailed design.	
	9.2 The CSU execution plan is integrated into the overall project execution plan and has evident linkages to other project functions (engineering, construction, operations, maintenance, quality, and HSE, among others.).	
	9.3 Operations fully participated in the preparation of the detailed CSU execution plan.	

Table 6. CSU Critical Success Factor Checklist *(Continued)*

Critical Success Factor	Indicators of CSF Achievement	✓
10. Systems-focus in Detailed Design	10.1 Finalization of CSU sequence, depicting all systems, subsystems, and associated dependencies.	
	10.2 Commissioning test procedures are completed by the end of detailed design.	
11. CSU Check-sheets, Procedures, and Tools	11.1 A complete set of construction/QC and commissioning check-sheets has been defined, reviewed, and approved by key project functions (construction, commissioning, operations, and quality) and loaded into a CSU management system prior to construction.	
	11.2 A complete set of construction/QC and commissioning test procedures has been defined, reviewed, and approved by key project functions (construction, commissioning, operations, and quality) and loaded into a CSU management system prior to construction.	
12. CSU Team Capability	12.1 Project operational objectives are well documented and well understood among CSU team members.	
	12.2 CSU team members understand the links between their actions and the technical metrics for project success.	
	12.3 CSU progress is regularly assessed with management metrics.	
13. Integrated Construction/ CSU Schedule	13.1 Project schedule includes system logic inter-dependencies and turnover milestones prior to 30-percent construction complete	
14. Accurate As-built Information	14.1 A master set of asset drawings is readily available and document control procedures are effective from construction through to final facility turnover.	
	14.2 A detailed as-built plan has been defined, reviewed and approved by the end of detailed design and is referenced within the project execution plan.	
	14.3 An asset information plan has been defined, reviewed, and approved by the end of detailed design.	
15. Transition to Systems-based Management	15.1 Possession of construction and commissioning integrated schedule by the 30-percent construction complete milestone.	
	15.2 Tracking of system completion with the use of check-sheets during construction.	
	15.3 Formalized system-level walk-down and punch list management, led by CSU team.	
16. Collaborative Approach to Construction-CSU Turnover	16.1 Joint meetings, involving both CM and CSU manager, are conducted starting around 50-percent construction complete.	

6

Comparison of Commissioning Successes and Failures

The research team sought to determine whether and how much the 16 CSU critical success factors actually enhanced or contributed to CSU performance. The team did this by analyzing real project CSU performance and associated CSF implementation efforts. This effort involved surveying CSU managers to collect data on 26 projects with both successful and unsuccessful CSU efforts. Table 7 provides an overview of the variety of projects examined in this analysis. The projects are diverse in nature, with a wide variety of location types, responsible lead organizations for CSU, sizes/complexities, and industry sectors/sub-sectors.

To validate the effectiveness of the CSFs, the team obtained CSU performance data, using the CSU performance assessment model recommended in IR 121-2. This approach measures each of eight CSU performance criteria on a five-point scale, for a maximum score of 40 points. To assess CSF implementation, the team used the 45 indicators of CSF achievement described in Chapter 3 (worded so as to elicit simple "Yes/No" responses).

Table 7. Data Sample: Project Characteristics

#	Project Characteristic		Sub-characteristic	N	%
1	**Project Location**		Domestic U.S.	20	76.9
2			Remote/Frontier International	3	11.5
3			Other International	3	11.5
4	**CSU Execution Responsibility**		Contractor	14	53.9
5			Owner	12	46.2
6	**Number of CSU/ Operating Systems**		Maximum	872	—
7			Average	88	—
8			Median	30.5	—
9			Minimum	4	—
10	**Project Total Installed Cost**		<$25 million	7	26.9
11			$25 million – $100 million	5	19.2
12			$100 million – $500 million	5	19.2
13			$500 million – $1 billion	4	15.4
14			>$1 billion	5	19.2
15	**Industry Sector**	**Heavy Industrial Sector**	Chemical	2	7.7
16			Power	10	38.5
17			Oil/Petroleum	3	11.5
18			Other	2	7.7
19		**Light Industrial Sector**	Water	2	7.7
20			Wastewater	1	3.9
21		**Pharmaceutical/ Healthcare/ Laboratory Sector**	Clinic	1	3.9
22			Pharmaceutical Manufacturing	1	3.9
23			Research Laboratory	3	11.5
24		**Other Sector**	–	1	3.9
25	**Total Number of Projects**		–	**26**	**100%**

From among the 26 projects, 15 were adjudged “more successful” (with >30 out of 40 maximum CSU performance points), and 11 of the projects were deemed “Less successful” (with <30 out of 40 points). An examination of how the more successful projects differed from the less successful projects relative to the 45 indicators of CSF achievement showed that 25 of the 45 indicators may serve as very effective differentiators, or leading indicators, in foretelling CSU success. These 25 indicators are associated with 13 of the 16 CSFs. Interestingly, the remaining three CSFs have relatively high proportions of “Yes” responses, regardless of the level of CSU performance. This indicates a level of consensus on their importance to CSU performance. Thus, overall, the project data offered significant validation of the 16 CSFs, and also provided valuable insight into meaningful leading indicators of CSU performance.

7

Learnings from Commissioning Failures: Mini-Case Study Summaries

Studying past CSU failures can provide additional insight into how to prevent their causes in the future and, thereby, ensure CSU success. To promote this continuous improvement process, the research team documented and analyzed four mini-case studies. The sections below summarize each case study, listing which critical success factors were not achieved or were achieved too late on the project studied. (See Appendix B for in-depth case study descriptions, each organized into six sections:

1. Project Description
2. Project and CSU-related Performance and Outcome
3. CSU-related Problems, Opportunities, and Contributing Factors
4. Impact of CSU Failure
5. Lessons Learned
6. Links to Critical Success Factors.

Scored on the 40-point CSU success scale presented in Chapter 6, the four failure case studies ranged between 13 and 27 points (with 30 points differentiating the more successful CSUs from the less successful ones). The team found that two of the commonly neglected CSFs were problematic for all four projects studied:

1. CSF 4 – Alignment among Owner PM, Operations, CSU, Engineering, and Construction
2. CSF 11 – CSU Check-sheets, Procedures, and Tools.

Three of the four case studies also had difficulty with an additional three CSFs:

1. CSF 9 – Detailed CSU Execution Plan
2. CSF 12 – CSU Team Capability
3. CSF 13 – Integrated Construction/CSU Schedule.

As with the six laggard CSFs presented in Chapter 3, these five CSFs also warrant special attention.

Case Study A: Plant X Energy Center

Project Sector: Heavy Industrial–Power

Project Size (TIC): $1 million

Approximate Number of CSU Systems: 20

Project Type: Brownfield

CSU Failure Description

Coal-fire steam plant with boiler feed pump turbine experiencing uncontrolled over-speed, resulting in significant damage to the turbine and surrounding equipment.

Impact of CSU Failure

This failure resulted in damage to turbine and surrounding equipment, threat to safety of personnel, and loss of schedule while turbine was replaced. Costs were $1.5 million in repair components and an additional $7.5 million in lost profit from potential sales.

CSFs Not Achieved or Achieved Too Late

CSF 1 – CSU Value Recognition

Commissioning and startup were not properly recognized, with the CSU team not being properly staffed and with management disregarding advice from the controls provider to have properly trained personnel as part of the CSU team.

CSF 4 – Alignment among Owner Project Manager, Operations, CSU, Engineering, and Construction

It became evident that, across project stakeholders, little knowledge was being shared about the startup. This lack of alignment led to failed oversight during instrumentation tuning and created an environment in which communication was difficult. Also pressure to meet the schedule meant that decisions were rushed.

CSF 8 – Recognition of CSU Sequence Drivers

Because the project team did not understand the primary sequences and procedures for startup, it established an improper protocol and the wrong startup sequencing. This, in turn, led to pump failure.

CSF 9 – Detailed CSU Execution Plan

The project team neglected to perform proper execution planning, largely due to inadequate oversight and lack of communication. No one had defined any set procedures, and the startup planning did not allot enough schedule days. This lack of planning caused improper sequencing on the project.

CSF 10 – Systems-focus in Detailed Design

The DCS controls did not operate as intended, failing to incorporate automatic changes experienced in the field.

CSF 11 – CSU Check-sheets, Procedures, and Tools

There was a lack of clear procedure during testing of the controls. Furthermore, improper sequencing and startup of additional equipment were allowed to proceed without the proper milestones being met.

CSF 12 – CSU Team Capability

The CSU team did not have experienced personnel familiar with the feed pump turbine and controls. Also, although the controls provider recommended that a mechanical engineer be on site, this expertise was not included on the CSU team.

CSF 13 – Integrated Construction/CSU Schedule

With the outage schedule being lessened, the CSU schedule felt more pressure to get the feed pump turbine up and operational. Performing a sound startup and achieving all objectives required the proper allocation of time.

CSF 16 – Collaborative Approach to Construction-CSU Turnover

Collaboration should have been a top priority as the outage schedule was reduced. Increased communication could have ensured that proper protocols were followed prior to startup of the feed pumps.

Case Study B: Urban Water Pumping Station

Project Sector: Heavy Industrial–Water

Project Size (TIC): $25 million

Approximate Number of CSU Systems: 5

Project Type: Brownfield

CSU Failure Description

Potable water pumping station upgrade with replacement of three 48-inch butterfly valves. A false alarm caused an emergency shutdown of one active valve, while the other two valves were out of service. This resulted in the rupture of a 96-inch water line and rerouting of water in a major metropolitan area.

Impact of CSU Failure

This failure resulted in the rerouting of water and loss of service to a major urban center, and a possible threat to worker safety. The project schedule was also severely delayed.

CSFs Not Achieved or Achieved Too Late

CSF 2 – Critical Interfaces on Brownfield Projects

All brownfield projects require a complete and thorough understanding of the existing facility operations and equipment. Knowledge of interim operations, emergency protocols, and upstream/downstream impacts would have helped in this startup.

CSF 4 – Alignment among Owner Project Manager, Operations, CSU, Engineering, and Construction

Early project alignment and planning were not accomplished. All stakeholders, including maintenance staff, were not involved in early CSU planning, and alignment was ineffective for the stakeholders that were involved. The assumption at the start of the project was that the retrofit was simple and did not require much technical expertise or input. The mechanical and process engineers were not involved in the CSU planning and team. Alignment of these parties and their goals could have prevented some of the outcomes of this startup.

CSF 5 – CSU Leadership Continuity

The CSU team was also incomplete, without a single, continuous startup manager to oversee CSU on the contractor’s side. Requirements and qualifications for this manager were not defined on this project.

CSF 11 – CSU Check-sheets, Procedures, and Tools

A lack of access to specification data and the absence of check-sheets during startup were contributing factors to this failure. Functional checkouts were not performed prior to the installation of the actuators.

CSF 12 – CSU Team Capability

The CSU team had a limited understanding of the original operating parameters of the existing equipment and plant. No one on the team solicited any expert knowledge from the plant operators during planning for startup, and unfamiliarity with the system led to the failure.

Case Study C: Project Y Downstream Chemical Plant

Project Sector: Heavy Industrial–Chemical

Project Size (TIC): $750 million

Approximate Number of CSU Systems: 75

Project Type: Greenfield

CSU Failure Description

A downstream new chemical plant with over 2000 I/Os, 200 control valves, and 600 transmitters, on which CSU was delayed due to a lack of training and no loop troubleshooting.

Impact of CSU Failure

Significant loss of production and associated cash flow (tens of millions of dollars); extra time and cost were required to achieve required product quality; loss of contractor's substantial early startup bonus.

CSFs Not Achieved or Achieved Too Late

CSF 1 – CSU Value Recognition

No member of the CSU team, including the CSU manager, recognized the CSU value or knew the procedures (or best practices and CSFs) that would help achieve a bonus-level CSU performance. As a result, the project suffered penalties due to delayed handover. Affordable CSU team training applied early, along with the use of a few supplier certified SMEs at the site, could have saved millions of dollars.

CSF 3 – Adequate Funding for CSU

The budget for CSU lacked the necessary funding for a successful startup. Funding was insufficient both for maintaining the CSU team and training operators. A small amount of funding for a proper startup could have saved the millions of dollars in revenue that was lost due to delayed plant operations.

CSF 4 – Alignment among Owner Project Manager, Operations, CSU, Engineering, and Construction

The project team did not accomplish early project phase alignment and planning, nor did it properly develop training or obtain key resources. Key issues, drivers, and strategies were also not identified early in the project. The CSU team involvement was minimized until too late in the project, and without effective collaboration. Also the owner made far more process changes than originally planned, diverging from the initial intention to replicate the existing plant.

Project management was also not aligned with its new operating plant staff. Thus, operations and project management experienced many clashes, delays in schedule, creation of excess costs, as well as increased risk. An understanding of TICC (total installed and commissioned costs) is crucial to the CSU goal of making the owner's saleable product available at the promised date, grade, and quality.

CSF 6 – System Milestone Acceptance Criteria and Deliverables

Milestone acceptance criteria were vague and left gaps in the set-up and testing specifications. Milestone dates for completion and the required deliverables were also ill-defined. The EPC did not understand these expectations well enough prior to CSU.

CSF 8 – Recognition of CSU Sequence Drivers

Critical interfaces to the existing plant were not well-planned, and experienced operator resources were not scheduled when needed. Key CSU sequences and sequence drivers were not recognized or even defined during planning. The project team also failed to communicate these drivers.

CSF 9 – Detailed CSU Execution Plan

Execution planning was conducted too late or not at all. The proper skill mix in CSU craft and management was not provided for in the planning that did take place, and it lacked any contribution from the plant operators. There was also no established plan for the massive amount of training needed on instrumentation and the new security system.

CSF 11 – CSU Check-sheets, Procedures, and Tools

System functional checkouts were not performed for the security system. The criteria lacked the scope, breadth, and depth to achieve a fully functional system.

CSF 12 – CSU Team Capability

Because the CSU team lacked the understanding and knowledge of the multitude of CSU systems, it did not possess the expertise needed to identify potential problems and concerns prior to CSU; nor did it even grasp the need to incorporate SMEs.

CSF 13 – Integrated Construction/CSU Schedule

The integrated construction/CSU schedule was developed late, did not emphasize collaboration, and failed to share the operations performance metrics and project guarantees with the key CSU team members.

CSF 14 – Accurate As-built Information

Lacking adequate training of CSU team members, clearer roles and requirements, and the presence of SMEs, the team did not properly load the asset management database. The self-documenting as-built drawing tool was only partially utilized and partially correct. Neither the CSU team nor the operators were able to get the full benefit of as-built information.

CSF 16 – Collaborative Approach to Construction-CSU Turnover

In its beginning stages, the project lacked a collaborative approach to CSU. The CSU team was brought on too late to work effectively on system handover with the construction team. Conflict arose when systems were not ready and after training proved to be ineffective.

Case Study D: Power Generating Facility; Ammonia Forwarding Line

Project Sector: Heavy Industrial–Power

Project Size (TIC): $100 million

Approximate Number of CSU Systems: 40

Project Type: Brownfield

CSU Failure Description

A power generating facility with a failure of a union coupling on a selective catalytic reduction ammonia forwarding line. On this project, an incorrect coupling caused a leak in the line, which resulted in a release of high concentrations of ammonia. A properly welded union had to be installed.

Impact of CSU Failure

Significant safety and environmental threats to workers and the local community.

CSFs Not Achieved or Achieved Too Late

CSF 2 – Critical Interfaces on Brownfield Projects

Properly communicated existing plant protocols and procedures would have revealed the mistake of using threaded union couplings on pressurized ammonia lines. Operator education and a more thorough understanding of the system could have prevented the failure.

CSF 4 – Alignment among Owner Project Manager, Operations, CSU, Engineering, and Construction

Lack of alignment between engineering, construction, and operations led to an information gap that ultimately caused the ammonia leak. The lack of collaboration during the engineering and construction phases ultimately posed safety and environmental risks during initial operations on this brownfield project.

CSF 9 – Detailed CSU Execution Plan

Plant operations should have been more thoroughly involved during construction and should have reviewed system startup procedures. Input should have been provided during the construction phase and CSU. CSU staff needed to have a more thorough understanding of operations and of the need for specialized milestone acceptance criteria.

CSF 11 – CSU Check-sheets, Procedures, and Tools

Functional checkouts for the ammonia forwarding line were inadequate, and check-sheet and detailed system commissioning procedures were ill-defined. Testing of the ammonia line should have been more stringent than a standard leak test, and was not defined for the CSU or construction team.

CSF 13 – Integrated Construction/CSU Schedule

The proper checks and tests should have been established in the construction/CSU schedule. Approval and acceptance milestones for the unit forwarding line should have been established prior to system startup and initial operations. Development of supportive documentation, including proper test protocols, should have been listed as a requirement prior to system acceptance.

CSF 14 – Accurate As-built Information

Inaccurate as-builts of the union connection installed during construction caused the faulty union to be overlooked during CSU. Due to insulation, the team could not perform a visual inspection, and, thus, needed accurate as-builts. It was only after the leak occurred that the team discovered the union had been incorrectly installed.

8

Innovative CSU Technologies

Another key finding from this research was the identification and characterization of five innovative commissioning and startup technologies. Each of these technologies facilitates CSU information management in ways that can significantly leverage the effectiveness of CSU team efforts. More specifically, the benefits from the technologies include more effective management of systems complexity, improvement of systems organization and scheduling, component functionality problem prevention, error reduction through data automation, and more effective and efficient training. Table 8 provides an overview of the five technologies.

Table 8. Innovative CSU Technologies

Technology	Objective	Benefit to CSU	Timing
A. Smart P&IDs	Enhance CSU planning and execution by enabling automated analysis/manipulation of CSU systems/components and associated properties/attributes of piping and instrumentation systems.	Allows for complete and accurate piping and instrumentation diagrams to be generated, modified, managed, and improved through 2D and 3D CAD files in a single, shared database. Helpful for early understanding of CSU systems/subsystems/components, and their related interactions. Complete system components and component attributes are easily accessible to CSU personnel during planning and startup and allow enable understanding of system integrations and relationships.	Implemented at the commencement of front end engineering through the initial phases of detailed design.
B. BIM Design Models/ 3D Models	Support CSU by providing spatial models, component system membership, operations functions, maintenance functions, component functionality characteristics, and asset data management.	Delivers complete, accurate, and connected digital information on 2D- and 3D-based models over the project life cycle. Assists in tracking safety, quality, and commissioning processes by minimizing error-prone procedures, providing coordinated and consistent links to information and promotion of collaboration among CSU Team.	Initiated at the commencement of front end engineering and continued through to initial operations.
C. Asset Data Management/ Wireless Instrumentation	Provide CSU personnel more pervasive and useful plant measurement data (both wired and wireless), while reducing overall installed and commissioned costs.	Enables easy creation and updating of a common database with which to better manage instrumentation/control devices. Gives access to assets in real time, with simplified, easily configured devices. Automated processes and diagnostics speed up commissioning, eliminating human interaction and speeding up startup.	Implemented in early phases of front end engineering and continued through to initial operations.

Table 8. Innovative CSU Technologies *(Continued)*

Technology	Objective	Benefit to CSU	Timing
D. Simulation-based Virtual Commissioning and Operator Training	Deploy simulators for virtual commissioning and training for main DCS, PLC, and SCADA systems.	Simulates systems for detailed tests in life-like environments, enabling extensive engineering checkout and virtual commissioning of equipment, machines, and processes. These simulated environments also allow for training of operators prior to CSU and initial operations. Cost savings and shortened startup schedule are among the many benefits.	Applied at the start of detailed design and continued through completion of checkout and commissioning.
E. Completion Management System	Use software to track CSU system and equipment statuses for more efficient CSU performance. This tracking allows for understanding of current status and progress of CSU system completion.	Allows for the remote collection of field data, through mobile technologies and cloud-based systems. Consolidates data on all systems into a single and updated database. Manageable, reliable, and consistent documentation creates an auditable trail and helps reduce error. Reduced project costs through reduced startup, handover, and improved efficiencies.	Initiated in the early stages of detailed design and continued through completion of checkout and commissioning.

Many of the benefits of technology application are keyed to its timing. Based on in-depth research team discussions, the recommendations in Figure 9 address the timing of application of the five technologies across the various project phases. Appendix C provides a full description of each technology, under the following 10 headings:

1. Technology Objective
2. Functionality of Technology
3. Benefits to CSU
4. Project Phase Implemented
5. Providers or Suppliers
6. Current Technology Maturity
7. Implementation Challenges
8. Key Terms
9. Success Stories
10. References.

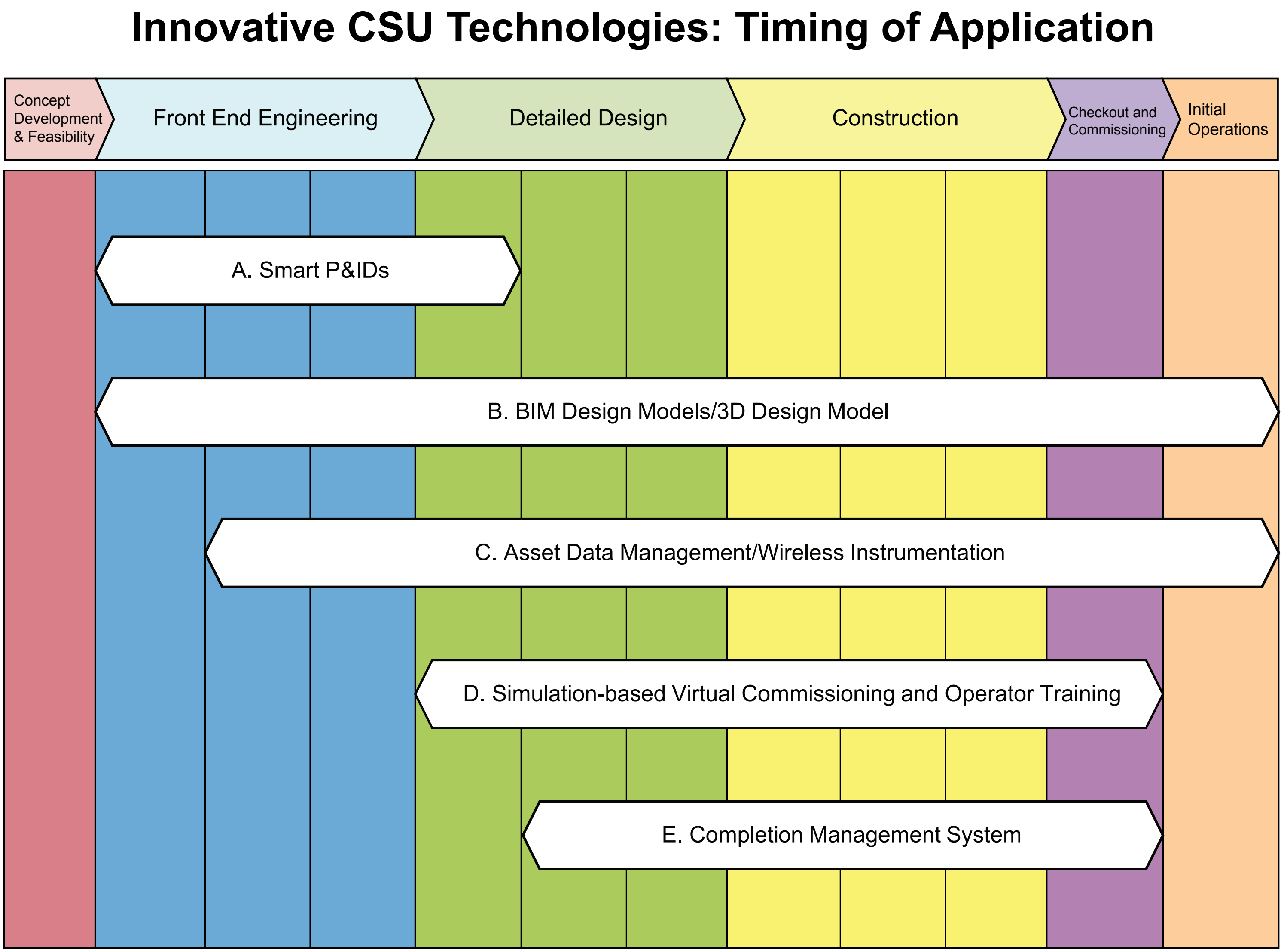

Figure 7. Timing of Application of Technologies

9

Conclusions and Recommendations

Conclusions

Proper commissioning and startup is a requirement for the success of any capital project venture. Yet such success remains elusive for many projects, particularly large ones. RT 312 focused on how to achieve CSU success, rigorously establishing and validating 16 critical success factors. Project teams (and their clients) should benefit substantially from applying team effort to accomplish these CSFs.

Recommendations

Based on the learnings from this research, commissioning managers—and more importantly, project managers—should do the following:

- Ensure that the importance of commissioning and startup is recognized among all key project participants, and that greater focus is put on CSU planning and execution.
- Work diligently and collaboratively to achieve all 16 of the critical success factors, ensuring their initiation early in the planning and design phases of the project.
- Be particularly attentive to the “laggard” CSFs that appear particularly challenging for industry. It will be helpful to become aware of the barriers to their implementation identified in this research.
- Make use of the indicators of CSF achievement identified in this research. The team found that 30 of these indicators are statistically significant differentiators between more and less successful project startups, and can serve as effective leading indicators.
- Consider application of the five innovative commissioning technologies identified in this research. These can further leverage the efforts of CSU execution teams.
- Aggressively seek out lessons-learned from past CSU failures and share these with project and CSU managers. The four mini-case studies provided in this implementation resource are a good place to start.
- Become aware of and effectively exploit the full suite of learnings and features provided in this implementation resource.

Appendix A:

Other Recommended CSU Practices

Recommended CSU Practice
1. Ready-to-start Commissioning Confirm that ready-to-start-commissioning includes the readiness of the physical plant and of the people.
2. Level of CSU Staff Support CSU staff support should match the needs/challenges of the commissioning/startup itself. This applies to both owner and contractor(s) staff. Drivers of greater staff support include the following: number of units; number of systems; scope of project; division of responsibilities; use of local content; level of experience; familiarity with process technology; complexity of controls/level of automation; and productivity rates needed versus expected; among other consideration.
3. Systems Completion Database Establish and maintain a systems completion database, ensuring that all changes in engineering data are reflected in the system.
4. FAT Requirements FAT requirements and timing should be fully addressed in the owner's RFP.
5. CSU Team Communication Plan Establish an owner-contractor-contractor communication plan for the CSU effort. Key features should include a single point of CSU contact for each contractor, planned interface management (meetings), and planned document sharing, among others.
6. Integration of Operations into CSU Integrate the operations team into commissioning.
7. CSU Document Control Document control during CSU is critical and requires a defined discipline throughout CSU, with adequate support resources.
8. Punch-list Management Procedure/Protocol Punch-list management procedure/protocol should incorporate different priority categories, stipulate ownership assignment, and be integrated into the change management system.
9. Engineering Leadership Continuity Continuity of engineering leadership's support of CSU is needed from detailed design through construction, and through CSU.
10. System-specific CSU Procedures CSU detailed procedures (in contrast to general CSU procedures) should be system-specific and reviewed periodically for accuracy and completeness.
11. Vendor Data Supportive of CSU Timely acquisition/processing of vendor data is necessary to ensure compatibility with quality and CSU requirements (including instrument and equipment data sheets).
12. Deliverables to Support Process Safety Identify and schedule the development of all vendor and engineering deliverables that are needed to maintain process safety through operating and maintenance procedures to support associated operator training.

13. CSU System Lead Individual Capabilities
Each CSU system lead plays a critical role that should be adequately skilled in all facets of the system type.

14. CSU Requirements and Responsibilities in Bidding Documents
Ensure that CSU requirements and responsibilities are included in all appropriate bidding documents. Omissions are too common in the buildings sector, among others.

15. Detailed Specification of Performance Testing
As a deliverable from detailed design, spell out detailed specifications of final performance testing methods, metrics, and time-targets. Assignment of post-test repair work scope should be included in appropriate contract agreements.

16. Control System Program Field-testing
Control systems programs need to be field-tested under robust real-world conditions, with abundant input from operations personnel.

17. Contractor Involvement during CSU
Require construction contractor(s) to provide adequate, appropriate supports during CSU, such as commissioning deficiency list work, scaffolding, flushing/leak testing, line/equipment/instrument reinstatement, among others.

18. CSU Schedule Risks and Contingency
CSU planners should be very aware of CSU schedule “upset factors” such as construction delays, turnover delays (including documentation delays), access problems (e.g., obstructive scaffolding), equipment failures (e.g., sticking valves, faulty instrumentation, pump bearing failures, pump alignment problems, and vibration issues); inadequate spare parts; unreliability in design; lack of equipment cleanliness; and overly optimistic estimates of durations; among others. As a contingency plan for the CSU risk-based schedule, build in float time for construction delays.

19. Key Project Characteristics and Conditions
It is very important that CSU planners and managers understand key project characteristics and conditions, especially the risks that are unique to the project and to CSU success.

20. Availability of Supplier Equipment Procedures
Equipment-specific equipment installation/CSU/operating procedures from suppliers should be developed/acquired early for integration into the overall CSU plan. Too often, these surface too late and contain surprises with respect to work scope, sequence, resources, training, and warranty.

21. Specification of System Requirements
The design engineer should formulate explicit written requirements by system, including identification of all supporting design documents for a single system.

22. Safety Threats and Mitigation Strategies
Identify safety threats and control/mitigation strategies for locales/times at which adjacent facility operations are concurrent with adjacent construction or CSU activity.

23. CSU and Constructability
Constructability planning should include timely consideration of CSU-related issues: safety, schedule, responsibility, access, systems isolation, and special CSU issues or opportunities with modularization.

24. FAT Test Parameters and Equipment
Ensure that FAT tests are conducted with the proper test parameters and test equipment, to prevent the need for re-testing or failure at project site.

25. Timely Completion of Supporting Projects
Ensure timely completion of CSU support infrastructure and other supporting projects for necessary utilities, materials handling, logistics, and other project functions. The project’s integrated schedule should indicate key related milestones for these projects.

26. Effective Permit with SIMOPS

Effective management of work permits is needed, given SIMOPs (simultaneous operations). The objectives are to avoid any SIMOPS control room bottlenecks, promote early applications, and achieve 48-hour turnaround on approvals of permit applications. The effort should entail a collaborative assessment of work permit applications involving operations, control room, and CSU planners, along with a review of 4-, 3-, 2-, and 1-week look-ahead schedules of CSU activity.

27. CSU Organization Chart

The CSU manager should report directly to the project manager, not to the construction manager or operations manager.

28. Simulation and Control Systems

Full-scale bench-testing of controls systems through simulation software that models all operating conditions can help in the timely identification of systems bugs and elicit timely client feedback.

29. Involvement of Safety, Environmental And Permitting Planners

Ensure the timely and knowledgeable involvement of safety, environmental, and permitting planners in the planning and execution of CSU.

Appendix B:

Descriptions of Innovative CSU Technologies

Smart P&IDs

Technology Objective

Smart P&IDs can enhance CSU planning and execution by enabling automated analysis/manipulation of CSU systems/components and the associated properties/attributes of piping and instrumentation systems. This technology provides an overview of the P&ID functionality at the entire facility and stores it in a single shared database. It also allows for an understanding of P&ID systems and their integrated relationships prior to and during the CSU process.

Functionality of Technology

This technology allows for complete and accurate piping and instrumentation diagrams to be generated, modified, managed, and improved through 2D CAD and 3D CAD modeling that is compatible with most CAD software packages. System components are tagged and annotated with applicable attributes and consolidated into a single database (graphical and non-graphical). This annotated data can be consolidated and merged with existing data (e.g., BIM modeling data) for coordinated access by CSU personnel.

Benefits to CSU

Smart P&ID models can establish an early understanding of CSU systems/subsystems/components and their related interactions. Complete system components and component attributes are easily accessible to CSU personnel during planning and startup, and allow for an understanding of system integrations and inter-relationships. The technology helps maintain accurate information during evolving designs and deviations in the field. It also allows for a systemization/isolation and controls model that can examine systems in a standalone environment. The technology can also shorten the commissioning and startup timeline by providing accurate as-built and in-field conditions.

Project Phase Implemented

Smart P&IDs are initiated during early front end engineering and continue into detailed design, with necessary updates through construction and checkout and commissioning. Smart P&ID data are integrated and imported to central databases prior to CSU. Information from a P&ID can later be utilized by the facility owner during operations.

Providers or Suppliers (listed alphabetically)

- Autodesk – AutoCAD P&ID
- Bentley – AutoPlant P&ID V8i & OpenPlant Power PID
- Intergraph – SmartPlant P&ID

Current Technology Maturity

Multiple software packages are available from three major suppliers and have been implemented globally on a wide range of projects in the past decade. Products can be integrated with common CAD software (e.g., AutoCAD and Microstation) and other existing software (e.g., Excel). However, multi-vendor integration still remains a challenge.

Implementation Challenges

Beginning with front end engineering and continuing through detailed design and as-builts, the main challenge is to ensure that data are accurate and current. Also, the set-up of system/subsystem identification coding is crucial. Changes must be incorporated to reflect up-to-date and accurate information. Some cross-platform integrations may be required to ensure that data have been transferred to the CSU database properly.

Key Terms

- **Drafting Engine** – CAD-based software that is used to represent P&ID systems in 2D and 3D representations. It can be integrated into existing database systems for easy accessibility.
- **System/Component Attributes** – The library of descriptors for individual and system components, such as line size, material, design rules, identifier tags, and symbols. Attributes are stored and accessible in the shared database.

Success Stories

Plant Radcliffe Project – Kemper County, Mississippi

- $2.8 billion clean-coal power generation plant, generating 582 MW and reducing carbon dioxide emissions 65 percent from traditional coal-fired plants
- Created fully integrated and managed environment, which enabled efficient access to over 300,000 design and engineering discipline data assets and over 75,000 vendor assets.
- CSU team saved over 36,000 work hours in the CSU phase, equivalent to $2 million.
- Ichthys LNG Project – Australia

- Joint venture to produce 8.4 million tons of LNG annually off the coast of Western Australia, with an operational life of 40 years
- Utilized databases to consolidate, cross-reference, and link all data and documents through a single portal.
- The traditional handover of information was adjusted from tremendous batched handovers of data to a progressive delivery at regular intervals during construction. This gave operational staff access to data well before plant operations, resulting in smoother commissioning and startup.

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BIM Design Model/3D Design Model

Technology Objective

BIM and 3D design models support CSU by providing spatial models, component system membership, operations functions, maintenance functions, component functionality characteristics, and asset data management, all on a uniform digital platform.

Functionality of Technology

This technology delivers complete, accurate, and connected digital information on 2D- and 3D-based models over the project life cycle. It is accessible on a wide array of platforms, including laptops, smart phones, and tablet PCs, as well as online and cloud-based databases. Standardized and electronic check lists, punch lists, operations data, and analytical reporting are made available project-wide, prior to and during CSU. Equipment and systems are tagged with specific bar codes or other identifiers, allowing for in-field lookup of related information and documents. This technology enables the following:

- direct CSU functions supported by BIM/3D modeling systems
- automated and accessible test reports, punchlists, and other documents
- list of procedures and protocol
- access to equipment and systems data sheets, manuals, and warranties
- reporting capabilities and quality documentation
- issues and conflict resolutions
- systems completion processes.

Benefits to CSU

This technology supports the tracking of safety, quality, and commissioning processes, by minimizing error-prone procedures, providing coordinated and consistent links to information and documentation, and promoting collaboration among the interconnected teams and systems critical to CSU operations. Its mobility in the field allows for speed and accuracy in the decision-making process, whether the user is disconnected or using a web browser. It can also lead to improved and efficient handover to CSU by incorporating models and documents developed during construction into a single digital asset.

Models built and maintained during construction can help personnel during CSU quickly bring facilities into operational status, while reducing costs and delays. These models and electronically-organized data can later facilitate the owner's long-term facility operations by consolidating useable deliverables (e.g., O&M manuals and maintenance schedules), rapidly transferring data, and lowering operational startup costs.

Project Phase Implemented

This technology is initiated in front end engineering and continues throughout the project, into initial operations phases of the facility. Early smart P&IDs may be used as part of the data foundation upon which the BIM model is further developed.

Providers or Suppliers (listed alphabetically)

- Autodesk – Revit, BIM 360, & Navisworks
- Bentley – ConstrucSim & Facilities v8i
- Innovaya – Innovaya Visual BIM
- Onuma – Onuma System
- Solibri – Model Checker
- Tekla – BIMsight

Current Technology Maturity

Though BIM use has primarily been focused on the design and construction phases of buildings, it has recently been seen as beneficial to CSU for capital projects, with continuously expanding capabilities and functionalities. BIM software use is well-established in the buildings sector.

Implementation Challenges

Effective use of BIM requires the participation of the design/construction team, beginning well before CSU commences. Frequent participation and accurate input from vendors and suppliers are also integral to success. Because data input can be very sizeable, accurate and up-to-date information is essential.

Key Terms

- **AIA E202 BIM Level of Development Standard** – This standard establishes responsible authors for each element of the model at each project phase. It also defines the extent to which the model may be used by later users, including contractors and owners. It further helps to maintain interoperability across platforms and promotes consistent and uniform standards and formats.
- **BIM Execution Plan** – A detailed and comprehensive plan that helps to define the BIM goals and application, execution procedures, responsible parties for information content at each level, and the required support for successful BIM development. A well-developed BIM execution plan ensures communication and stimulates project team planning during all phases.

- **Construction Operations Building Information Exchange (COBie)** – Common and major data exchange for the publication of facility data for use during facility maintenance. Collects important data points such as equipment lists, checklists, O&M manuals, warranties, and spare parts lists, among others.
- **Industry Foundation Classes** – A major data exchange and commonly-used collaboration format for projects utilizing BIM. The IFC model specification is an open-source, platform-neutral file format available for use.

Success Stories

Medical School – CoGen Facility, Boston, Massachusetts

- Expansion of power co-generation facility to support growth; included new 7.5 MW gas-fired turbine, 4,000 ton electric chiller unit, and capacity of 3.5 million SF for 24-7 access.
- The owner saved on schedule and costs by using information provided in an orderly and accessible fashion—not just "piles of paper or CDs."
- Facilities can be started up more quickly by digital data delivery, and it is easy to locate O&M manuals, product data, and operation procedures.

Health Complex – San Antonio, Texas

- New hospital tower with supporting infrastructure. BIM was implemented for field commissioning.
- Facility went from expecting to need four to six months for startup to being able to start up in four days, with data available in a structured manner.
- The owner is now exploring a three-year plan to model all existing facilities.

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Asset Data Management with Diagnostics/Wireless Instrumentation

Technology Objective

Manufacturing processes, energy, environmental, and employee safety control/monitoring “points” are increasing in number and becoming increasingly wireless. This technology provides CSU personnel with more available and useful device performance data, and is thereby helping to reduce overall commissioned costs.

Functionality of Technology

This technology offers increased and earlier awareness of issues or concerns with in-field devices and associated conditions. The information it provides enables the CSU team to avoid or correct such issues quickly. The wireless approach allows for easy inclusion of additional monitor points, with reduced material requirements and reduced module weights.

The technology also enables easy creation and updating of the asset database, for better management of instrumentation/control devices. The technology automatically associates/updates user-defined parameters for individual (or grouped) assets and allows for restoration of asset data to previous points in time. Configurable data views allow users to organize, filter, and group information to improve asset management/operations decision-making.

The technology also offers an ability to track and view asset change history at the parameter and device levels. Wireless instrumentation has the ability to self-calibrate and auto-report device/system status and performance data, which offers significant benefits for more efficient and reliable CSU performance. Some wireless suppliers also provide wireless device diagnostics pass-throughs, which can further reduce CSU duration by eliminating much troubleshooting.

Benefits to CSU

Safer and more efficiently executed CSU and operations are the key benefits of this technology. The technology provides access to assets in real time, with easily configurable devices. Automated processes and diagnostics speed up commissioning, eliminating many requirements for human operator interaction. Predictive diagnostics serve to reduce operational risk. Implementation experience provides evidence of approximately 50-percent reduction in field device configuration and commissioning, and 30-percent reduction in facility startup. After 30 minutes to one hour per device for set-up/calibration, devices are ready for immediate use, with alerts being resolved, if any appear.

For modular projects, an asset management solution (with device database manager and diagnostics) allows the modularization yard to establish device alerts quickly and ship modules with higher levels of commissioning completion. Wireless measurement points are easily started up, primarily due to auto-meshing of the devices to the wireless gateways. This allows the CSU process to commence sooner.

There are no requirements for hard-wired conduits to wireless monitoring devices, resulting in 40-60 percent less time for installation, compared with hard-wired monitoring points. The wireless approach results in significant schedule savings and reduces the volume of instrumentation drawings as well as the costs of material and labor. For example, installation time is approximately 15 minutes per wireless point and 30 minutes per wireless gateway.

Project Phase Implemented

Accommodations for wireless monitoring and asset data management should be planned for during the detailed design phase.

Providers or Suppliers (listed alphabetically)

- ABB
- Emerson
- Siemens
- Yokogawa
- There are several other major automation suppliers, with over 100 device manufacturers having released IEC 62591-compliant wireless devices.

Current Technology Maturity

First implemented in 2000, this technology now involves more than five million asset management system- or diagnostics-based installed devices, both on shore and off shore. Wireless devices have been IEC 62591 globally certified for more than eight years. Over 25,000 gateways and over one million wireless devices are in place today in every industry around the world.

Implementation Challenges

The development of new commissioning, startup, and maintenance practices is necessary to obtain the maximum potential of asset management tools. These new approaches and methodologies are crucial to achieving faster and more effective results, which may require new skill sets and/or a pool of new SMEs. Some wireless solutions are not IEC 62591 globally certified and may have issues connecting to standard gateways, resulting in diagnostics not being able to port fully through gateways to CSU personnel. Data collection is not as big a hurdle as proper analysis and application of the information for improving commissioning and startup results.

Key Terms

- **Asset Management Software (AMS)** – Software and associated self-diagnostic tools designed to aid in the installation, checkout, commissioning, and startup phases. The software, with real-time diagnostics digitally embedded in field devices and rotating equipment, provides proactive, predictive, and preventative information and capabilities, to significantly improve CSU, while also reducing risk and safety concerns. Equipment served should include both wired and wirelessly connected assets of all types.
- **Device and Equipment Portal** – The ability to tag, reference, and/or point-and-click on devices in the facility for immediate access to a device. This access means obtaining a device's current set-up and calibration, reported diagnostic health, and automatic issue-solving recommendations (generated from its intelligent database tools).
- **Device Manager** – A flexible CRT and/or tablet-based human interface software tool that allows the user to add device tags, calibration information, and tracking information, and to print out/electronically transfer as-built documentation. The device manager is able to communicate in real time with other associated tools after the facility is operational, as well as provide information for device alerts and other critical device issues. A secure, remote-access-hardened capability is an option for both wired and wireless devices.
- **Diagnostics, Alerts, and Measurements** – Several dozen individual parameters per device can be communicated through wired and wireless instruments. Examples include weak or lost air supply, low power module alerts, or excessive speed alerts.
- **Gateway(s)** – Gateways wirelessly connect up to 100 wireless field devices and pass both measurements and device diagnostics to distributed control systems and asset management monitors/tablets.
- **Mobile Worker Screens** – Wireless tools/hardened safe tablets to investigate diagnostics and calibrate field devices and rotating equipment
- **Operating Equipment** – Operating equipment that is particularly appropriate for integration with asset management systems and wireless diagnostics includes motors, pumps, gearboxes, generators, turbines, control valves, compressors, boilers, fans, transmitters, and analyzers.

- **Predictive and Proactive Diagnostics** – Equipment diagnostics technologies include set-up analysis, protection analysis, vibration analysis, oil analysis, and infrared analysis, among others. A combination of multi-variable information from devices strategically regressed can offer more intelligent status information. For example, a bearing temperature profile showing a dropping tank level indicates that the motor and pump set will fall in one of several modes: “Very Soon” indicates that it requires attention immediately; “Soon” means that it will require attention within the next one or two months; and “Proceed As Planned” shows that it should be repaired during next scheduled shutdown.

Success Stories

Chemical Plant

- With 100 field control valves and transmitters, staff decided to utilize AMS software, databases, and mobile worker CRTs in lieu of older technology. Device set-up time was reduced from the 90 minutes per conventional device down to 15-30 minutes per device, with documentation available immediately. This implementation also increased worker safety, since no personnel were required in high or dangerous locations.

Large Oil Field Development Project

- Plant startup was two weeks sooner than if conventional technologies had been used.
- Project utilized wireless devices on approximately 15 percent of its monitoring points, with the opportunity for quicker startup and accommodation of last-minute changes by the process engineers. Average savings of $2,000 per device, with over 600 devices, for a total savings of $1.2 million.
- A chief engineer with 37 years of experience stated that it was the smoothest startup he had witnessed, with an estimated two to three months of schedule savings. He planned to increase wireless devices from 15-30 percent on upcoming projects.

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Simulation-based Virtual Commissioning and Operator Training

Technology Objective

This technology enables virtual execution (through simulation) of commissioning and operator training for the main distributed control system (DCS), programmable logic controllers (PLCs), and supervisory control and data acquisition (SCADA) systems.

Functionality of Technology

This technology allows plant control systems to be tested in life-like environments, permitting extensive engineering checkout and virtual commissioning of equipment, machines, and processes. By means of virtual commissioning, PLC and robot programs may be tested in preparation for implementation and can help ascertain the time needed for commissioning. For this purpose, a simulation model of the actual site is created, which is connected directly to PLCs, allowing for testing of the interface between the PLCs and the DCS. This simulated environment also allows for operators to be trained prior to CSU and initial operations, while providing a virtual, hands-on experience. The systems can be modeled in a 3D environment, allowing for detailed tests by design engineers prior to implementation.

Benefits to CSU

The benefits of a virtual system tool for testing and training purposes include the following:

- Cost savings through reduced startup time and elimination of potential conflicts. Minimal investment (compared to overall CSU budget) to establish a simulation-based commissioning and training program.
- Earlier and more thorough operator understanding of facilities and systems, with early hands-on interaction, and the added benefit of design engineers being able to test their systems prior to implementation. This reduces reengineering efforts, identifies conflict prior to construction, and reduces downtime and risk during integrations.
- Shortened training program, less time away from facility, and quicker achieved startup, with some commissioning times being reduced by 20-50 percent. Minimized use of resources and minimum-wear lifespan of the plant during commissioning and startup, with maximized production profit through high availability from initial startup.
- Allows for complete and accurate simulation of the control systems, enabling modifications to the control logic prior to commissioning, which can eliminate costly delays in commissioning. Ability to test and validate the human-machine interface of the operating systems prior to startup.

- Testing of the DCS and PLCs prior to the implementation phase, with earlier refinement of the DCS library of function blocks.
- Ability to create a standalone and safe simulation environment for systems commissioning feedback, with future operators using this tool to visualize the equipment, operations procedures, and fault management as if in real time.
- The simulation system is based on the real experience of operators and engineers in the field, and thus provides a realistic, hands-on field experience.
- Reduces the risk and need to train on real, in-use systems and equipment, which may not be available or appropriate for training purposes.

Project Phase Implemented

Plans to implement virtual commissioning and operator training should be undertaken at the outset of detailed design. Training simulation itself should occur during construction.

Providers or Suppliers (listed alphabetically)

- Emerson – Ovation Simulation Solutions
- Rockwell Automation – Allen-Bradley
- Siemens – SIMIT & Tecnomatix® Plant Simulation
- TRAX
- WinMOD (Germany)
- Xcelgo – Experior

Current Technology Maturity

Commercial simulation software has been successfully applied on a wide range of projects since the late 1990s.

Implementation Challenges

Procedures to implement system capabilities in simulators and DCS emulators depend greatly on how the emulators are implemented. Thorough analysis of the internal data structure is necessary to be able to determine the correct strategic approaches to simulation. Accuracy of the simulation models is crucial, with changes in system and control logic requiring extensive assurance checks.

Success Stories

LNG Facility – Norway

- Production began three weeks ahead of schedule as a result of the central role played by simulation software in the testing and startup phases of the project.
- Use of the simulator facility provided good safety routines in the process, as well as significant savings in the startup period of the facility.

Repowering Project – New York

- This project utilized virtual simulators and commissioning software to train operators on plant processes and controls.
- This plant was safely and efficiently started up, reducing the commissioning time from four months to one month.

Nuclear Power Plant

- The plant was upgraded to a more modernized control system, but demanded reduced downtime due to software debugging and operator familiarization. Simulator technology was used in order to train plant operators and validate the control system software prior to implementation.
- Commissioning time for the new control system was shortened by three weeks due to operator familiarity and confidence developed on the simulator.
- Subsequent annual outages were shortened, yielding an additional two days of full-load generation per year.
- Several million dollars in increased revenue due to shorter commissioning and reduced outages.

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Completion Management System

Technology Objective

This software can track CSU system and equipment progress/status for more efficient CSU performance. The technology allows for an understanding of current status and progress of CSU system completion, along with automation of equipment- or system-testing records and product data, including initial run data and punch-list items.

Functionality of Technology

The technology makes use of tablet and mobile PCs to manage and maintain crucial system and equipment records throughout the life of the project. It allows for progress tracking by percent complete per system (i.e., system stats), physical progress, or punch-list items progress. CMS also allows the user to obtain real-time data in the field (e.g., product data, punch-lists, startup tests, or safety documentation) throughout the CSU process, through the use of barcodes and field-level entry. These tools work best when built off existing Smart P&IDs or redlines, and linked to the asset management database, allowing downloads for frequent and fast downloads (in real time). With this approach, tablet PCs can serve as test equipment to verify system readiness. The CMS can also be combined with existing 2D and 3D BIM software, and thus provide a valuable link to design models.

Benefits to CSU

The technology allows for the remote field-collection of data, through the use of mobile technologies and cloud-based systems. It consolidates data on all systems into a single and updated database. It helps establish consistent documents and forms across all project systems, allowing for one-time data entry and real-time updates. Manageable, reliable, and consistent documentation creates an auditable trail and helps reduce error. Realizes reduced project costs through reduced startup, handover, and improved efficiencies.

Project Phase Implemented

Should be planned for during detailed design, and implemented starting in the construction phase and through CSU completion. Upload of system documentation to occur during installation and testing phases, with updates, as required, through commissioning.

Providers or Suppliers (listed alphabetically)

- Autodesk – BIM 360 Field
- Complan (Norway) – WinPCS
- Epic Management Resources – EPICom
- Gate – GCS
- Intergraph – SP Completions
- Omega (Norway) – PIMS
- Orion Group (UK) – Orbit (OCCMS)
- QEDi/AMEC (UK) – GoCompletions (GoC)

Current Technology Maturity

Some suppliers have had the software in use since the 1980s, and it has been used on hundreds of capital projects ranging in value from $100 million to $40 billion. Other existing software has been in use for at least ten years and has been implemented on a wide range of global projects.

Implementation Challenges

The uploading of data and proper assignment of data to system components may require manual and labor-intensive efforts initially, if the system is not fully automated.

Key Terms

- **Barcode Scanning** – Ability of a CMS to read a unique identifier (barcode or similar identifier) printed on a paper document, and then record the document and update its status within the database.
- **Briefcasing** – Ability of a CMS to permit documents/check records to be downloaded or “checked out” while an internet connection is available, completed without an internet connection, and then updated once the connection is re-established.
- **Legend Laser Scanning** – Ability of a CMS to digest a laser scan of an area (3D) or of a drawing (2D) and then insert a “hot spot” or “tag hyperlinking” into that file or document to link to other documents or database information.
- **Paperless –** Refers to the ability of a CMS to record, report, and produce all completion dossiers in a fully electronic environment.
- **Preservation –** Ability of a CMS to track and report preservation records/documents.

Success Stories

LNG Facility (WinPCS) – Papua New Guinea

- $20.5 billion liquefied natural gas (LNG) project, constituting the single largest resource investment in Papua, New Guinea, with over nine trillion cubic feet of natural gas expected to be produced over the facility's lifespan.
- The first shipment of LNG cargo shipped six months ahead of schedule as a result of early commissioning. Completion of commissioning activities and the first LNG production ensured that the project remained on target for its first LNG cargo.

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Research Team 312, Best Practices for Commissioning and Startup

Daniel W. Barrett, ConocoPhillips
Mark Bennett, Black & Veatch
Jin Ouk Choi, The University of Texas at Austin
Jonah Collins, Southern Company
Tony Ermovick, U.S. Department of Energy
Paul Foster, Alstom Power, Inc.
Quint Hebert, ConocoPhillips
Ron Johnson, Lauren Engineers & Constructors, Inc.
Edward McDaniel, CH2M
Dale Millsap, The Williams Companies, Inc.
Rob Murray, Irving Oil Limited
Brian Nordmann, Emerson Process Management
* Jim O’Connor, The University of Texas at Austin
* Tom Pierie, Ameren Corporation – Missouri
Mauricio Rodriguez, Smithsonian Institution
Michael B. Rugh, Technip North America
Elizabeth Shaw, ArcelorMittal
Matt Sikstrom, Ontario Power Generation, Inc.
Mitchell Suchyta, Barton Malow
Joel Tremblay, Chevron
Matthew Winkler, The University of Texas at Austin

* Principal authors

Editor: Jacqueline Thomas

Construction Industry Institute
The University of Texas at Austin
3925 W. Braker Lane (R4500)
Austin, Texas 78759-5316

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