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Critical Success Factors in Commissioning and Start-up of Capital Projects

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Critical Success Factors in Commissioning and Start-up of Capital Projects

by

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Thesis

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Dedication

This thesis is dedicated to my family who throughout the years has been a constant source of encouragement, enthusiasm, and inspiration. Words would not be sufficient to express the gratitude I feel to have you all as part of my life.

First, I want to thank my parents, John and Alberta, who provided me with the firmest of foundations from which to grow. Your faith, positive attitude, and devotion have inspired in me the same qualities that will last a lifetime. To your credit, I will always remember who I am.

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Abstract

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Commissioning and start-up (CSU) is the critical last phase of a capital project. CSU must be accomplished before a facility can initiate initial operations and begin meeting commercial objectives. Actions necessary for successful CSU are often not well planned or executed, resulting in poor CSU performance. Recognizing this significant shortfall, Construction Industry Institute's (CII) Research Team 312 was organized to conduct a study to determine critical activities necessary to increase the likelihood of successful CSU performance on capital projects.

Utilizing input from CSU experts, objective data collection, and subsequent data analysis, 16 Critical Success Factors (CSFs) were identified through this research. These factors focus on the themes of leadership, team alignment, management methods, planning techniques, and support tools, among others. Each factor is specific and unique in their required actions and implementation recommendations. These CSFs all reinforce the concept of earlier planning and alignment of CSU on capital projects.

Further elements developed include, CSF's support of safety and quality, indicators for CSF achievement, timing of CSF implementation, and current frequency of CSF achievement. Data from 26 actual projects was collected to determine the CSF's impacts on CSU performance. Through this analysis, all CSFs and many of their associated indicators were validated and shown to be true differentiators in CSU performance. Other findings include the integration of CSFs with past CSU research completed by CII, analysis of commissioning failure case studies, and alignment of industry CSU terms and CSU organizational functions. Five technologies shown to beneficially leverage efforts of CSU teams and project stakeholders were identified and fully characterized. A final development was the creation of a user-friendly checklist tool to assist CSU teams in planning and managing CSU efforts throughout all project phases.

Commissioning and start-up success is a major contributing factor in the overall success of capital projects. The case for action for an efficient and effective CSU planning process is compelling. Application and implementation of the 16 CSFs, in conjunction with other study findings, has been shown to improve project CSU performance and be a beneficial asset to project teams.

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Chapter 1: Introduction

1.1 PURPOSE AND OBJECTIVES

Commissioning and start-up (CSU) is a collection of critical activities that must be successfully accomplished in order to realize capital project investment objectives. Previous research has been conducted to fully describe commissioning & start-up success in metrics (O'Connor et. al. 1998). However, data indicates that industry efforts oftentimes fail to meet expectations. The processes and procedures that lead to effective CSU planning and execution are often deficient and lack the elements required for success. This failure to implement proper CSU practices leads to cost and schedule overruns, resulting in delayed or inefficient start-up and initial operations. More thorough and effective guidance is needed in order to successfully plan and implement project commissioning and start-up. A clear understanding of the benefits of properly implementing CSU best practices, management methods required, and advanced technologies available is needed to enhance performance.

The main purpose of this research was to better understand the management approaches and emerging technologies needed to ensure a more effective and successful commissioning and start-up of capital facilities. Six main objectives of this study were identified as follows:

1. Examination and alignment of key terms, organizational functions, and phases pertaining to commissioning/start-up/initial operations in capital projects across industry sectors.

2. Identify and fully describe critical success factors that offer significant advantages in the planning and execution of CSU.
3. Understand the industry's current extent of accomplishment or achievement of the identified critical success factors. Further explore and identify relevant barriers to their successful implementation.
4. Analyze project commissioning/start-up performance relative to the extent of Critical Success Factor (CSF) implementation. Through this analysis, achieve an understanding of the contribution and impacts the CSFs have on actual commissioning performance.
5. Link the critical success factors to the activities contained in previous CII research on the start-up phase (CII 1998).
6. Identify innovative and emerging technologies that can further improve CSU performance on capital projects.

The results of this study offer insights into how best to achieve a safe and successful CSU, allowing for successful transition into initial operations. The primary beneficiaries of this study are facility owners/operators; however, other key stakeholders, including engineers, contractors, and personnel involved in the planning and implementation of CSU, will benefit from these results as well. Though most of the findings are particularly applicable to projects in the industrial sector, the study findings can also be applied to buildings, labs, hospitals, light industrial facilities, or any project with multiple CSU systems.

1.2 SCOPE LIMITATIONS

This study focuses on commissioning and start-up, and any applicable and related activities, across all phases of a project. The primary focus is on commissioning, start-up, and preparation for initial operations of industrial facilities, such as petro-chemical, power, water/waste-water treatment, and nuclear plants, among others. In addition to these sectors, most findings are applicable to systems-intensive building and infrastructure projects, such as pharmaceutical, hospital, and airport projects. Facility operations considerations are limited to issues and opportunities of relevance prior to and during operational ramp-up periods and up to, and including, final plant performance testing. Steady-state plant operations issues that occur after final performance testing were outside the scope of this study. Some additions and modifications to CII pub. *IR 121-2* (CII 1998) have been included in the study, but a comprehensive update and revision of that planning document is outside the scope of this study.

1.3 STRUCTURE OF THESIS

This thesis is organized in the following order. Chapter 2 reviews and summarizes the available literature on commissioning and start-up. This review concentrates on pertinent terms and definitions; current practices and challenges in industry; identification of best practices, with their possible benefits; and finally review of innovative technologies. Chapter 3 presents the detailed methodology conducted to complete this research. This includes methods of industry data collection, identification of critical success factors, and emerging technologies. Chapter 4 details the terminology, phases, milestones, and team functions for alignment in industry. Chapter 5 analyzes the findings from CII’s Benchmarking dataset in relation to commissioning and start-up. Chapter 6 describes the Critical Success Factors, as well as their timing, frequency, indicators, barriers, and relation to safety and quality. Chapter 7 discusses the modifications to CII 121-2 Planning for Start-up model and the CSFs links to this modified flow chart. Chapter 8 examines four case studies and identifies primary causes and failed CSFs. Chapter 9 analyzes actual project data to assess the CSFs impacts to CSU performance. Chapter 10 identifies five Innovative Commissioning Technologies (ICT) to enhance CSU performance. In Chapter 11, a checklist tool is presented to assist project teams in improving their preparation for the start-up phase of projects. Finally, Chapter 12 delivers conclusions and recommendations for future research. The appendices contain additional information obtained from the research, including data collection tools, additional recommended practices, fully-detailed case studies, and data for project evaluations.

Chapter 2: Literature Review

2.1 OVERVIEW OF LITERATURE REVIEW

At the initiation of the research, it was necessary to conduct a review of all relevant literature pertaining to the current practices in Commissioning and Start-up (CSU). The objective of this review was to assess the current state of CSU practice across industry. This objective was accomplished by the identification of common terminology, current practices, and demonstrated best practices. In addition, past learnings from previous CII publications in relation to CSU were explored. Finally, innovative technologies currently available and used in improving CSU performance were studied.

The literature review is divided into general scopes and organized as follows:

- Literature pertinent to terms and definitions used in industry
- Current best practices and challenges in CSU practice
- Best practices and their related benefits
- Innovative commissioning technologies

The review concentrated on completed research projects, relevant industry journals and articles, conference presentations, magazine articles, and discussions with industry experts. Internal documents from the research team members' companies were also made available for review to provide insight into current CSU practices by industry practitioners. Though this report primarily concentrates on commissioning of industrial facilities, it was found beneficial to examine literature from building commissioning, as well, to determine if any relevant practices were relevant to the research objectives.

Sources from the United States and foreign countries were gathered, but only sources in English, or translated to English, were considered for review.

2.2 KEY TERMS AND DEFINITIONS

From the outset, it was determined that varying terminology is used throughout industry; however, this terminology is not consistent. One of the main objectives of this research was to align key terms used in the industry to provide a common foundation for the research. To accomplish this, a review of the varying terms and their definitions was examined. The most crucial terms were examined, providing the research team with a foundation.

Pre-Commissioning

Pre-Commissioning applies to the stages of a project in preparation for the CSU process, but items encompassed by this term vary widely. A simple definition of pre-commissioning is "testing activities prerequisite to handover of commissioning." (CH2MHill 2013). CII Pub. 121 (CII 1998) used the term "checkout" to describe pre-commissioning and defined it as "component-level testing of systems."

Pre-commissioning should include preparation and functional/mechanical testing of equipment and systems to make ready the plant for commissioning (Horsly 1998). In particular, these "activities are intended to verify that pieces of equipment, and the associated control loops, shutdown systems, utility supplies, etc., are in the required state of readiness." (API 2013). These activities are undertaken immediately following mechanical completion, but prior to energization or the introduction of feedstocks (API 2013).

Commissioning

Commissioning pertains to the testing of a plant's systems prior to initial operations (CII 1990; CII 1998). Energization of the systems occur, with dynamic testing of the systems and sub-systems functionality being performed to determine adherence to specified requirements and any adjustments or optimizations may be made(American Petroleum Institute 2013; Horsly 1998). This entire process ensures the facility is ready for start-up from a quality and safety perspective (Technip 2013). This activity is primarily executed by the Client/owner, with the Contractor transferring control either at the end of construction or pre-commissioning. (Technip 2013; Irving 2013; API 2013). At the conclusion of Commissioning, the facility is given a Ready for Start-up certificate, and initial operations are allowed to begin. (API 2013).

Other Terms

Other key terms were also reviewed to further clarify and align terminology. Factory Acceptance Testing (FAT) is a witnessed or unwitnessed test that is part of the systems completion process, and is testing of individual components prior to delivery of equipment to the facility site (Technip 2013; Ameren 2013). Construction-to-CSU Turnover is considered a formal transfer or responsibility of specific equipment, piping, and instrumentation from the construction contractor to the client or owner (API 2013). Ready-for-Start-up signifies that all construction, pre-commissioning, and commissioning activities are complete and the system(s) are ready to be safely started (API 2013). Start-up as defined by CII Pub. 121-2 (CII 1998) is the “transitional phase between plant construction completion and commercial operations.”

2.3 CURRENT PRACTICES AND CHALLENGES

Commissioning is a vital phase in capital projects, but prior research and literature has been limited, with the last CII research update nearly 17 years prior. (Almasi 2012; CII 1998). Shortages of experienced and trained personnel, especially in industrial facilities has contributed to the practice of trial and error in many facilities, with costs and schedule remaining unpredictable (Almasi 2012; Cagno et. al. 2002). Development of an overall, written CSU plan, standard operating procedures, and handover processes should be thoroughly detailed, but are rarely fully completed (Almasi 2012; Lager 2012).

CSU execution has a direct economic impact, as compressed CSU schedules and faster time-to-market may result in earlier revenue and profits for owners (Leitch 2004). Some facilities are able to start up, but under perform and are not able to meet production expectations due to issues not addressed in CSU (Merrow 2011). A large percentage of projects experience both cost and schedule overruns, with high levels of planning negating some of this variance (CII 2010). However, it is oftentimes difficult to demonstrate and quantify the benefit to project teams of a successfully executed CSU, as data is not widely kept and is difficult to conduct a cost/benefit analysis (Altwies et. al. 2001).

Poor execution of CSU in industrial facilities is often poorly understood and results from poor communication and organizational dysfunction. (McDowall 2007).

These issues are rarely discussed beforehand, and can often be blamed on improper personnel, new technologies, or inadequate support during CSU (Lager 2012). The broad definitions of commissioning, and its related activities across many industries and sectors, contribute to miscommunication and resulting mistakes contribute to poor CSU performance (McDowall 2007).

Insights into the current status of CSU have been derived from project data. A database of large-scale industrial megaprojects maintained by Independent Project Analysis, Inc. indicates that over half the projects in their database had significant operability problems. Projects that continued to have technical problems into the second year after start-up were considered failed projects, meeting only 60% of planned production in the first year, and over 65% of these projects suffering from long-term issues. (Merrow 2011). Oil & Gas and Mineral megaprojects fared the worst, with over 70% of these projects being considered failures (Merrow 2011). In examining eleven large steel manufacturing facilities started up from 1995-2001, none reached design capacity within one year, and only one did so after two years. (Lager 2012).

CII Pub. 121-2 was published in 1998 with a broad model intended to assist industry professionals effectively plan and manage start-ups. However, the Planning for Start-up model was intended to be supplemented with project management practices, was geared toward a very wide audience, and lacked specific CSU scope requirements and coordination (CII 1998). CII Pub. 213-2, *Front-End Planning Toolkit*, addresses front-end planning for many types of capital projects, including the CSU planning process, but CSU is not its primary focus (CII 2014).

2.4 BEST PRACTICES AND BENEFITS

One of the primary best practices detailed in literature is the vital need for CSU goals and objectives to be planned and aligned early in the project phases. (Wilkinson 2000; McEnteggart 2012; Zerger 2011; Haasl 2006; CII 1998; CII 2014; Killcross 2012; Mukherjee 2005). Commissioning is a planned process and is introduced in the early stages to members of the construction and design team; upfront planning mitigates unexpected changes and unnecessary reviews during the course of the project (Wilkinson 2000). These goals should be written, defined, well scoped, and re-visited often (McEnteggart 2012; Zerger 2012).

A central champion for CSU or a Commissioning Authority should be named, and be present in early stages of the project, including during design and pre-award to contractor (Wilkinson 2000). The CSU Manager should "specify, schedule, and directly oversee the implementation of the procedures and practices necessary for commissioning" (Killcross 2012). In addition to this leader, a team should be assembled and documented in the organizational chart, including operations & maintenance personnel, subject matter experts (vendors, suppliers, etc.), and other qualified individuals (Hurtz 2012, Azhar et. al. 2011). Successful CSU projects obtain the necessary buy-in from all stakeholders, including owner, contractor, engineer, operations & maintenance, and CSU team, and approach commissioning in a collaborative way (Haasl 2006; Wilkinson 2000). Continuity of CSU personnel is needed to prevent loss of information and maintain stability of the CSU process (Mills et. al. 2009).

Commissioning is successful when it is considered at every stage of the project, from conceptual development to initial start-up. (Wilkinson 2000; Mills et. al. 2009). A critical element of properly executed CSU is the execution plan, documentation, and approach. A CSU plan should be written in a systematic approach and is comprehensive of the entire facility (Wilkinson 2000; Mills et. al. 2009). A 2009 study of buildings with a comprehensive approach to commissioning showed an average of double the savings in CSU, as compared to projects that were not thoroughly planned (Mills et. al. 2009). The sequencing of commissioning activities also need to be scheduled well in advance of construction completion, integrated into the overall schedule, and discussed among project leaders (PECI 2000).

Proper testing is also a critical element in commissioning and can be huge cost and schedule savings for the project. Testing should begin at the factory, be executed at the component level in the field, and then tested on a system level. (McEnteggart 2012; Zerger 2011). Adequate documentation, proper operating conditions, and acceptance criteria should be determined in the early stages and gain approval from the operating party (Zerger 2011.) Testing then transitions into operator training. Requirements for this training should be detailed, reviewed, and approved in the early phases of the project, so that training is enhanced and adequate for proper operations (Hurtz 2012). The training plan should include terminology and background; staffing plans; training materials for commissioning; operator simulator training; use of system engineers; and training of maintenance personnel, among others (IAEA 2008).

The benefits of a successful CSU are many. As mentioned previously, the economic benefits of schedule, equipment, and material reductions results in costs savings and allows for quicker operation and production. Perhaps more importantly, a well-run CSU process increases the safety of a facility. Serious harm to operators and other personnel can result should systems operate incorrectly or inefficiently (Cagno et.

al. 2012). A Hazard and Operability (HAZOP) study will be conducted to determine scenarios in the plant, and the CSU and Operations team should be involved and aware of these analyses (Killcross 2012).

The CII Value of Best Practices Report examined the CII Best Practice of Planning for Start-up and was an additional source of information on how performance is impacted by effective CSU planning. The report describes how Planning for Start-up data was collected on 77 owner-submitted projects and 24 Contractor-submitted projects, with levels of implementation (high or low) and resulting cost and schedule performances documented. For owner-submitted projects with high application of Planning for Start-up, cost and schedule growth averaged 1.7% and 1.1%, respectively. When low implementation of Planning for Start-up was observed on these projects, cost and schedule growth increased to an average of 5.7% and 9.0%, respectively. For Contractor-submitted projects, with high application of Planning for Start-up, cost growth averaged -3.4%. When these projects were shown to have low levels of Planning for Start-up implementation, the cost growth for the project was 6.9%. (CII 2010).

2.6 INNOVATIVE TECHNOLOGIES

The first category of technologies identified was the use of virtual commissioning and simulator technologies. Exploring their use in the virtual commissioning of the main Distributed Control System (DCS), it was found these simulators could determine the time needed for actual commissioning; quickly and safely test complex facilities; help in minimizing the use of resources; and, help maximize production and therefore profit at initial operations (Wullenweber et. al. 2013; Rutherford et. al. 2003). Virtual commissioning has been successfully executed in large facilities, where not only operator simulations can be done, but also virtual commissioning, including complex DCS systems (Krause 2007). These simulators provide for exposure of the systems to multiple organizational users, and reduce the learning curve when operations begin. (Rutherford et. al. 2003). These technologies were categorized under Virtual Commissioning and Simulation-Based Operator Training, as described in Chapter 10.

The next technology identified in the literature review was 3D modeling technology in particular regard to Piping and Instrumentation Diagrams (P&IDs). These 3D models provide a comprehensive model that aid in project understanding, data management, workflow automation, and data handover, to name a few (Intergraph 2013; Bentley 2013). These software platforms support multiple disciplines and allow for full integration of the plant design, instrumentation, and piping information (Intergraph 2013). The automated model has the capability to streamline information and also generate easier-to-interpret drawings and diagrams (Intergraph 2013). These technologies were categorized under Smart P&IDs in Chapter 10.

A third, and more emerging, technology is the use of Building Information Modeling (BIM). Related to 3D Design Models, it utilizes the power of mobile devices, to fully integrate the project team with conditions in the field (Autodesk 2013). The system provides more thorough means of quality control, leveraging field data instantaneously and intelligently across the entire project model (Barton Malow 2013). Utilizing the cloud and mobile devices, information can immediately be gathered or viewed in the field, reducing confusion, creating a clear chain of control, establishing consistency, and reducing schedule (Autodesk 2013). These technologies were categorized under BIM/3D Design Models in Chapter 10.

A fourth technology identified was asset data management. This technology provides a common environment to manage asset lifecycle data through the CSU phases (Intemation 2013.) The configurable data allows the user to view attributes and improve decision making in the field, view asset history, restore asset data to a previous time, and conform to industry standards (Intemation 2013). These technologies were categorized under Asset Data Management as characterized in Chapter 10.

A final technology currently utilized by industry professional is the use of a completion management system (CMS). Such a system has the capability to track the status of a multitude of complex operating systems on a project and associated tasks, activities, approvals documentation, and tasks completed or to be completed (Complan 2013). Used on a common software platform, it is designed to assist in the execution of mechanical completion, pre-commissioning, commissioning, and start-up (Omega 2013). The common database increases communication, reduces confusion, and accurately tracks progress (Orion 2014; Lucy-IMS 2013). This fully integrated process has the added benefit of helping to reduce the CSU schedule and CSU costs. These technologies were categorized under Completion Management Systems as discussed in Chapter 10.

Chapter 3: Research Methodology and Data Collection

3.1 OVERVIEW OF METHODOLOGY

Identification of **Critical Success Factors (CSF)**, which is paramount to the successful project commissioning and start-up of capital facilities, is the central element of this research. Figure 3-1 contains an overview of the study methodology utilized. The methodology figure details the steps and progression used to identify these CSFs and the corresponding products that were generated from their identification.

The overall study methodology was initiated with the formation of the research team and the definition of research objectives and limitations. A literature review and critique of CII Pub. 121-2 was conducted to best understand the current process planning for commission and start-up in industry. Potential critical success factors were then identified and screened in order to arrive at the 16 ultimate success factors. Research team input, industry expert opinion, and published literature helped to define common terminology and innovative technologies.

Once established, the 16 CSFs were analyzed to develop the following items:

- Timing of CSF Implementation across conventional project phases
- Identification of Indicators of Achievement that CSFs have been accomplished
- Frequency of CSF accomplishment to assist in industry benchmarking
- Detailing of Barriers of Achievement for those CSFs less frequently accomplished

- CSF’s relationship to the Planning for Start-up activity flowchart from CII pub. 121-2
- Four detailed commissioning failure case studies that were linked to lack of implementation of CSFs
- CSF association with quality and safety
- Development of a CSF Checklist Tool.

To validate the CSFs, 26 actual projects, of various industry project sectors, size, and CSU success, were analyzed for the extent of influence or impact of the CSFs. CSU managers assessed these projects regarding the presence of CSF Indicators of Achievement in order to determine if implementation of CSFs correlates with CSU performance. As a final step, nine external industry experts were engaged to review the research findings and provide critiques through a feedback survey. Research products were created at the completion of the research validation.

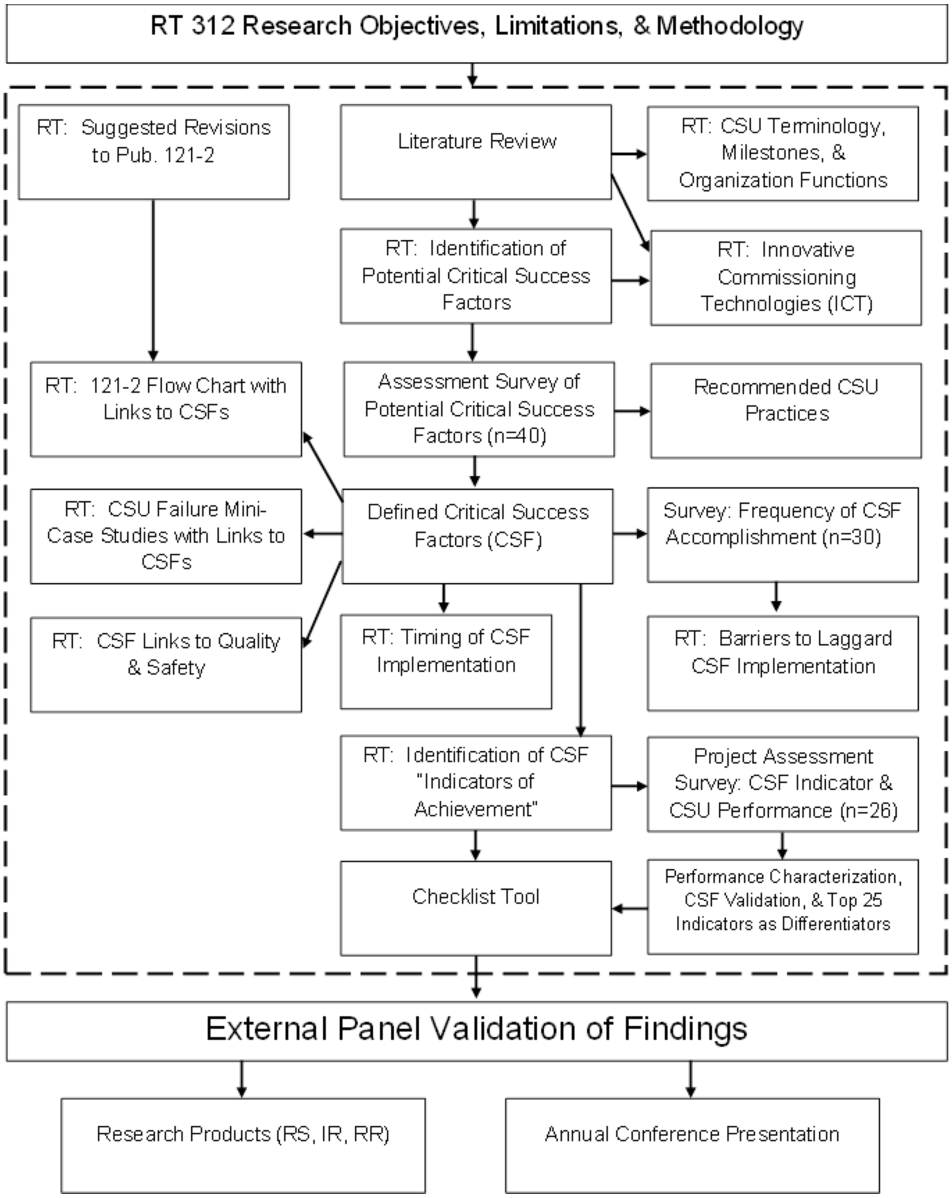


Figure 3-1: Research Methodology

3.2 RESEARCH TEAM BACKGROUND

The Research Team 312 (RT 312) was established by the Construction Industry Institute in May 2013 and was tasked with determining those best practices related to commissioning and start-up, that can lead to successful initial operations of capital projects. Data pertaining to professional experience was collected from each team member on such issues as industry experience, background, specialties, and project involvement. As shown in Table 3-1, the team was comprised of 18 members from a variety of owner, contractors, suppliers, engineers, and academia. Appendix F contains a listing of research team members and their affiliations.

Table 3-1: Research Team Characteristics

Characteristics		Job Titles	
Industry Members	18	Corporate Practices Standards Manager	1
Academics	3	Asset Managers	2
Total Years of Industry Experience	453	Project Managers	2
Average Years of Industry Experience	25.2	Commissioning Managers	7
Total Projects Commissioned and Started-up	572	Design Manager	1
Average Projects Commissioned	31.8	Construction Managers	3
Average Project Size (in $M)	$652.7	Fabricator/Supplier Managers	2
Organizations Represented		**Industry Sectors Represented**	
Owner	9	Power - Nuclear/Non-Nuclear	6
Contractor	6	Petrochemical	7
Supplier/Vendor	1	Water/Wastewater	1
Engineer	2	Pharmaceutical/Healthcare/Labs	3
Other	3	Metals Manufacturing	1

3.3 DEFINITION OF OBJECTIVES

Identification of research objectives, limitations, and planned methodology was the initial step of the research. The team sought to provide awareness of real and significant challenges to CSU, as well as beneficial opportunities and innovative solutions with which to achieve a successful CSU.

The primary purpose was better understanding of the critical elements that collectively help to ensure success in facility commissioning and start-up. A total of six objectives were initially established:

- Strengthen the understanding of terms
- Provide recommendation to CII pub. 121-2
- Examine existing CII performance assessment database to extract beneficial learnings,
- Document industry experiential knowledge and learnings to identify critical success factors, best practices, and lessons learned
- Survey industry's current extent of implementation of the identified CSFs and evaluate their impact and relevance to CSU performance.
- Identify new opportunities for leveraging new innovative technologies to enhance CSU.

These objectives were initially indicated in the research proposal and further discussed in the initial research team meetings. Objectives were periodically reviewed during the research process.

3.4 LITERATURE REVIEW

A substantial literature review was conducted after setting team objectives. Resources from libraries, the internet, and practitioners were reviewed in this step. This review allowed for the state of commissioning across multiple industries to be explored. Best practices and potential success factors were identified in various publications for review by the RT, as well as common terminology, functions, and milestones used across industry. A case for successful CSU planning and implementation was also established, by summarizing published findings on CSU performance. The impacts of poorly executed CSU were documented, in economic, safety, and quality-related terms. A review of CII Benchmarking and Performance Assessment pertaining to CSU also demonstrated the need for proper planning of start-up. Emerging and supportive technologies used in industry were also identified and researched to better understand the tools available to assist in achieving a successful CSU. The literature review is discussed in Chapter 2.

3.5 LEARNINGS FROM CII BENCHMARKING

An examination of benchmarking conducted by CII was also undertaken. Two benchmarking databases were examined to further define the state and trends of CSU within the industry. Objective data related to commissioning costs and schedule were available, as well as more subjective data in regards to project leaders' views of commissioning performance. By examining these two databases, further understanding of the actual status of CSU in industry and the factors that can potentially lead to commissioning success were further understood.

The first database is the CII General Program Dataset. The General Program is a database of nearly 400 projects. The majority of these projects are concentrated in the industrial sector. Multiple project-level data is collected, including planned and actual commissioning costs and schedule performance. A total of 162 projects contained data on commissioning costs and 247 projects included data on commissioning schedule.

The second database is the 10-10 Program Assessment. The 10-10 program collects data related to specific industries and project phases. One of the phases available for review was the commissioning phase. A total of 36 projects, ranging across multiple industry sectors, had data pertaining to commissioning and start-up. This information is collected through questionnaires that assess the project leaderships' judgement of project commissioning performance relative to multiple perceived attributes and performances.

3.6 CRITIQUE OF CII PUBLICATION 121-2

Prior CII research had been conducted in the late 1990's on the subject of planning for start-up. The research team felt compelled to understand and critique CII Pub. 121-2 *Planning for Start-up* prior to progressing its own research too far. This critique was done through an RT subcommittees over multiple meetings. From the detailed review the RT identified several recommendations, including renaming of the document to "Planning for Commissioning and Start-up;" remapping of activities within the planning model (requiring addition, removal, combination, and relocation of certain activities); and needed updates to implementation tools. However, during this critique, the team did not pursue a complete rewrite of CII Pub. 121-2. Rather, their suggested modifications are being recommended for future research.

Recommended modifications to the 121-2 *Planning for Start-up* model resulted from the review. The modified 121-2 CSU planning model was created with the original 121-2 model. Some activities are recommended for removal, and others combined or eliminated to create a modified model. The modified model maintains the original intent of the original model, but with updates and simplifications to better represent current industry best practices. A full description of the critique to 121-2 is contained in Chapter 7.

3.7 TERMINOLOGY, MILESTONES, AND FUNCTIONS

CSU terminology varies from company to company and across industry sectors. From the literature review and RT input, it was recognized that alignment on terminology, milestones, and organizational functions would further enhance the understanding of CSU. Definitions of terminology, milestones, and functions were useful in subsequent discussions and developments. Terminology confusion is particularly common with the terms pre-commissioning and commissioning. Based on RT discussions, these terms were clarified by defining their associated scopes, component activities, and notable inclusions. Common CSU milestones and their associated labels and relationships were also documented in the format of a CSU phase diagram. Finally, the RT desired to clarify CSU team functions and staff roles. A figure was produced to illustrate the various CSU-related functions. CSU terminology, milestones, and functions are discussed in Chapter 4.

3.8 INNOVATIVE TECHNOLOGIES

CSU technology tools surfaced from the literature review and RT discussions on CSFs. Tools that are intended to enhance CSU performance were identified and categorized. Details on these technologies were sourced from further literature review and information obtained from subject matter experts (SMEs). A list of 12 technologies was initially identified. Upon further examination and discussion by team, these Innovative Commissioning Technologies were condensed into five main types: Smart P&IDs, BIM Design/3D Design Models, Asset Data Management/Wireless Instrumentation, Simulation-Based Virtual Commissioning & Operator Training, and Completion Management Systems. Each of the five tools was assigned to one research team member who had experience with the technology to help draft and detail characterizations for each technology. Each innovative commissioning tool was fully detailed by identifying the tool objectives, functionality, benefit to CSU, project phase implemented, providers or suppliers, current tool maturity, implementation challenges, applicable terms, and success stories of recent successful industry implementations. As a final step, implementation of these technologies was mapped across the typical project phases, to identify when these technologies should be applied in a project. Proper timing of the application of these technologies is crucial in realizing the full benefits of the tools. This timing of application was based on RT experience and SME input. The innovative technologies are discussed in Chapter 9.

3.9 POTENTIAL CRITICAL SUCCESS FACTORS

The central focus of this research was the identification of the best practices that can help ensure CSU success. The RT named these the “Critical Success Factors” and sought industry input as to what these CSFs may be. A list of potential CSFs was generated, followed by an evaluation by CSU industry experts. The effort resulted in a listing of factors with the most significant perceived impact on CSU success.

3.9.1 Generation of PCSFs

Based upon literature reviews, brainstorming with the RT, and input from industry SMEs, leading best practices were identified as “Potential Critical Success Factors” (PCSF). The objective was to identify a large, robust number of possible success factors. The PCSFs were briefly defined and cross-checked to ensure that each factor was unique and significantly different from others. A list of 139 PCSFs resulted from this effort. Appendix B contains a listing of all 139 PCSFs generated.

3.9.2 Survey of CSF Impact Assessment

The objective of the next step was to screen the PCSFs down to a smaller listing of the most significant factors. To accomplish this screening, 40 CSU industry experts were surveyed on each PCSFs relative magnitude of impact or contribution to CSU success. The survey used in this collection effort is provided in Appendix A.

As shown on the survey, the study participants selected one of seven options for all 139 defined PCSFs. Each study participant was asked to characterize the estimated impact of the PCSF on CSU success with one of seven optional responses:

- PCSF was considered a Critical Success Factor
    - “CSF, Least Critical”

    - “ CSF, Low to Mid”
    - “CSF, Mid to High”
    - “CSF, Most Critical”
- PCSF was not considered a Critical Success Factor
    - Innovative Future Practice
    - Standard Operating Procedure
- No opinion on status of PCSF

The research team then analyzed the raw data. For each study respondent, individual PCSF scores were assigned, depending on the type of response. Points were then averaged for each PCSF based on the following metric:

- CSF, Least Critical = 0 Points
- CSF, Low to Mid = 3 Points
- CSF, Mid to High = 5 Points
- CSF, Most Critical = 7 Points

An average score was obtained by tallying up all scores based upon how all respondents ranked the PCSF. The highest score possible for a PCSF was 7.0. From this analysis, the PCSFs were ranked based upon their average score. The top 20 PCSFs were selected as consideration for CSFs. The minimum score was 5.53, placing each of these top 20 PCSFs between the “Most Critical” and “Mid to High” categories. From this list of 20, the RT was able to combine and consolidate the PCSFs and created the 16 Critical Success Factors.

3.9.3 CSF Survey Respondents

The 40 study participants included members from the RT as well as other industry CSU experts. A total of 32 respondents came from the oil & gas, utility, power, water/wastewater, and steel/metals industries. The survey participant characteristics are detailed in Table 3-2.

Table 3-2: CSF Survey Participants

Participant Characteristics	
Number of Participants	40
Total years of industry experience	816
Average years of industry experience	20.4
Organizational Characteristics	
Owners	22
Contractors	10
Suppliers/Vendors	2
Other	2
Role Characteristics	
Leader Roles	16
Support Roles	15
Other	9

3.9.4 CSFs vs. Recommended Practices

Once the CSFs were established, the RT wanted to retain the learnings associated with the other non-CSF PCSFs. From the list of PCSFs. Based on survey results, the next

40 were categorized as CSU Recommended Practices. The list was consolidated to 29 CSU Recommended Practices after team discussions. These Recommended Practices are listed in Appendix B. Twelve PCSFs were frequently assessed as Innovative Future Practices. This list helped to establish the Innovative Commissioning Technologies portion of the research.

3.10 CRITICAL SUCCESS FACTORS

The primary focus of the research team was the determination of Critical Success Factors for improvement of commissioning and start-up. Once established, the CSF definitions were refined and the CSFs were linked to various project characteristics. Timing and current frequency of implementation were established and plotted out against the project phases. To enable project-level assessment of implementation of the CSFs, indicators of achievement and barriers to implementation were developed. Finally, a checklist tool was created.

3.10.1 CSF Definition

Once the CSFs were determined, adequately descriptive definitions needed to be established for the list of 16. The list of PCSFs had only contained short descriptions to aid in narrowing down to the most critical factors. Using these descriptions as a starting point, full descriptions were created and expanded. Primary input on the detailed definitions of the CSFs came from RT brainstorming, as well as literature reviews. After multiple reviews of the descriptions by the RT, the definitions of the 16 Critical Success Factors were finalized. The CSFs are discussed in more detail in Chapter 6.

3.10.2 CSF Relationship to CII 121-2

The next step for the research team was identifying how these 16 Critical Success Factors linked with the modified activity flow chart from CII Pub. 121-2. The team examined the modified flow chart to identify linkages with the activities and CSFs. Group discussion and brainstorming were used in the initial stages. The RT was then spilt into two groups, with each group mapping the CSFs into the modified activity flow chart. Following this session, the RT compared the results and identified any disagreements. After further discussion of the results, the CSF links to each phase activity were finalized. The final modified activity flow chart, with CSF relationships, is contained in Chapter 7.

3.10.3 CSF Association with Safety and Quality

Promotion of quality and safety are vital elements of any capital project and the CSFs offer additional support of these two pursuits. Quality and safety are at risk if the CSFs are not implemented. To convey this link, the research team felt compelled to describe how the CSFs can result in quality defects and/or safety hazards. Each CSF was assigned two columns: “Safety & Quality Linkage” and “Threats to Safety & Quality due to CSF Failure.” Through RT group discussions and brainstorming, each of these two aspects was characterized for all 16 CSFs. Though the links and threats to quality and safety may appear evident, the RT desired to fully define these two dimensions for each CSF. Full description and characterization of the CSF’s link to quality and safety are contained is Chapter 6.

3.10.4 Timing of CSF Implementation

Proper timing of CSF implementation is critical to the success of that particular factor. Each CSF was examined for its relevance across six phases: Concept

Development & Feasibility, Front-End Engineering, Detailed Design, Construction, Check Out & Commissioning, and Initial Operations. The RT's primary concern was determining when each CSF can be beneficially initiated and when in the project phases each CSF should be substantially completed or achieved. These considerations resulted in a timeframe being established in which each CSF should be conducted. To make this timing determination, the RT was divided into subgroups and each group plotted the schedule of each CSF. These results were compared and an initial, integrated timing chart was created. For three subsequent meetings, the timing chart was re-examined and any modifications or edits were discussed. The RT reached a consensus and the timing of implementation chart was finalized. This chart is contained in Chapter 6.

3.10.5 Survey of Frequency of CSF Accomplishment

With the determination of the CSFs, the team desired to learn the frequency in which the CSFs are being accomplished on projects. A survey was sent to 30 CSU industry professionals to ascertain their experience-based knowledge regarding frequency of CSF implementation. The survey was designed such that each CSF was ranked on their perceived actual occurrence or frequency on projects. Five accomplishment options were established for each CSF to facilitate the ranking: rarely, occasionally, frequent, common, and don't know. Each survey participant ranked each CSF according to these criteria. A copy of this survey is contained in Appendix A and the results discussed in Chapter 6.

Once the data was collected, analysis then proceeded. The total number of affirmatives for each of the five categories was tallied for each CSF. A scoring system similar to the PCSF evaluation was applied to establish a summary metric on frequency of CSF accomplishment. The scoring for frequency of accomplishment was as follows:

- Rarely = 1 Point
- Occasionally = 3 Points
- Frequent = 5 Points
- Common = 7 Points
- Don’t Know = No consideration in the calculation

A total of 30 individuals participated in the survey to determine the CSFs Frequency of Accomplished. These survey participants’ characteristics are contained in Table 3-3.

Table 3-3: CSF Frequency of Accomplishment Survey Participants

Participant Characteristics	
Number of Participants	30
Total years of industry experience	650
Average years of industry experience	21.7
Organizational Characteristics	
Owners	18
Contractors	10
Other	2
Role Characteristics	
Leader Roles	18
Support Roles	8
Other	4

3.10.6 Barriers to Laggard CSF Implementation

Six CSFs were identified through project and survey analysis as being less commonly implemented. These CSFs were labeled as “laggard” CSFs. The RT felt it was pertinent to further explore the reasons and barriers behind their hesitant or failed implementation. A listing of barriers for each of the six laggard CSFs were developed through brainstorming and group discussions. However, the barriers needed to be confirmed with input from each team member. A survey was designed for the research team to rank each barrier and its relevance to preventing or hindering CSF accomplishment. For each of the six CSFs and their listed barriers, 18 RT members were asked to rank the top four barriers. These results were analyzed for the most relevant barriers to implementation success of the laggard CSFs. The RT examined the averages from this survey for natural separations. No set minimum average was declared for barrier relevance. Those barriers with high occurrence in the survey were confirmed by the RT as relevant and finalized as barriers to implementation. Some laggard CSFs received up to six barriers of implementation. These barriers of implementation are listed and discussed in Chapter 6.

3.10.7 Identification of CSF Indicators of Achievement

The RT developed a collection of “CSF Indicators of Achievement” to further support recognition and assessment of CSF implementation on projects. The indicators are intended to offer stronger and more apparent evidence of actual CSF achievement. These indicators of achievement, or tell-tales, were generated through RT discussions and assigned to the corresponding CSFs. A final listing of 45 Indicators of Achievement was developed. The RT reviewed the indicators in multiple meetings for edits and adjustments. During the Project Assessment Survey discussed next, these 45 indicators were validated against 26 actual projects. From these results, the top 30 Indicators for Achievement were identified. The indicators are discussed in Chapter 5.

3.11 PROJECT CSU & CSF ASSESSMENT SURVEY

With the CSFs and Indicators of Achievement defined, the RT wished to answer some critical questions regarding the CSF's actual impact on CSU performance. Actual project data was collected for this effort. The primary focus was to determine if, and to what extent, the 16 CSFs actually enhance or improve CSU performance. A secondary focus was to determine the validity of the CSFs and which Indicators of Achievement were true differentiators for CSU success. A full analysis is contained in Chapter 9.

3.11.1 Survey Tool

Twenty-six actual projects were examined, with a portion associated with CSU success and a portion associated with CSU failure. The projects examined ranged widely relative to project type, cost, location, industry, number of CSU systems, and lead CSU organization, to name a few. Specific project characteristics collected included project location, CSU responsibility, and approximate number of CSU systems, total installed costs, and industry sector. Assessment forms were sent to each CSU manager to obtain their input on the 26 selected projects. A copy of the survey form is included in Appendix A.

Each team member was asked to identify one "more successful CSU" project and one "less successful CSU" project for analysis and evaluation. A project assessment survey was prepared that elicited project information regarding both the nature of CSU performance and responses to the 45 Indicators of CSF Achievement questions.

CSU performance was scored in eight different categories:

- Product Quality Performance
- Product Quantity Performance
- CSU Schedule Performance
- CSU Safety Performance
- Environmental Performance
- Preparation of CSU Operations Team
- CSU Impact on Ongoing Operations
- Level of Effort Required by the CSU Team

These performance criteria were suggested from CII Pub. 121-2, Tool 3-A (the Planning for Start-up Implementation Resource). Each CSU performance criteria was ranked on a 1-5 point scale, depending on level of satisfaction indicated in the tool. This tool allowed for a maximum score of 40 points on commissioning performance. Each project had their sum in this category computed.

The last section of the assessment survey pertained to the CSF Indicators of Achievement. Forty-six indicators were provided, with a yes/no responses for each. Due to the yes/no option and the randomization of the order the indicators were asked, these indicators allowed for more objective analysis. Each yes answer selected was worth 1 point and each project's total sum tallied in this category.

3.11.2 Nature of Sample Projects & Respondents

A total of 26 projects were submitted by a total of 18 team members. These projects ranged in size from less than \$25 million to over \$1 Billion in Total Installed Costs. The locations of the projects were primarily in the US, with an average of 88 CSU Operating Systems per project. There were approximately equal number of projects where CSU was managed by the owner (n=12) or the contractor (n=14). Heavy industrial facilities were the primary industry examined, with some light industrial and healthcare/lab facilities also surveyed. Table 3-4 contains a complete breakdown of the project characteristics.

Table 3-4: Project CSU & CSF Assessment Survey Characteristics

Project Characteristics		Sub-Characteristics	N	%
Project Location		Domestic US	20	76.9%
		Remote/Frontier International	3	11.5%
		Other International	3	11.5%
Project Total Installed Cost		< \$25 M	7	26.9%
		\$25 M - \$100 M	5	19.2%
		\$100 M - \$500 M	5	19.2%
		\$500 M - \$1 B	4	15.4%
		> \$1 B	5	19.2%
Industry Sector	**Heavy Industrial Sector**	Chemical	2	7.7%
		Power	10	38.5%
		Oil/Petroleum	3	11.5%
		Other	2	7.7%
	Light Industrial Sector	Water	2	7.7%
		Wastewater	1	3.9%
	Pharma./Healthcare/Lab Sector	Clinic	1	3.9%
		Pharm. Manufacturing	1	3.9%
		Research Lab	3	11.5%
	Other Sector	-	1	3.9%
CSU Execution Responsibility		Contractor	14	53.9%
		Owner	12	46.2%
Number of CSU/Operating Systems		Max.	872	-
		Average	88	-
		Median	30.5	-
		Min.	4	-
Total No. of Projects			**26**	

3.11.3 Analysis Approach

With the project data in-hand, CSU Performance was evaluated and the more successful CSU projects needed to be separated from the less successful CSU projects. Examining the data with the team, a minimum score of 30 out of 40 on the commissioning performance criteria was deemed a sufficient boundary separating the more successful projects from the less successful projects. This resulted in the sample comprising 15 more successful projects and 11 less successful projects. The number of CSF indicators marked "yes" were summed for each project within these performance groups. The results for each project were then plotted on a scatter plot to examine the correlation between the implementation of CSFs and the associated level of commissioning performance.

An examination was undertaken on which CSF indicators had the strongest association with CSU performance success. Each indicator was individually examined to determine the average number of "yes's" for those projects deemed more successful and those deemed less successful. The research team classified indicators as "Top Indicators" if the difference between the "yes" averages on the more successful versus the less successful projects was more than 30%. This classification resulted in 25 Top Indicators of achievement that were clear differentiators of commissioning success.

Only one indicator, regarding incentive systems for CSU leadership, was found to more likely occur in the less successful projects than in the more successful projects. This result demonstrated that this indicator was not valid. The indicator was eliminated from the list of 45 indicators for achievement. The remaining indicators had little difference between their average levels of implementation. This signified that either both types of projects implement the indicator regularly, or both types of performers struggle to implement the indicator.

Next, the research team examined the CSFs as a whole and evaluated their use in successfully commissioned projects. The Top 25 Indicators of Achievement were present in 13 of the 16 CSFs. The remaining 3 CSFs have relatively high proportions of "yes" responses, regardless of the level of CSU performance, thereby indicating a level of consensus of their impact to CSU performance. This result helped to further validate the findings of the team and to affirm the value of both the CSFs and their associated indicators of achievement.

3.12 CASE STUDIES WITH LINKS TO CSFS

In an effort to further understand the effectiveness of the CSFs, case studies of failed start-ups were collected to identify deficient CSFs. Team members helped to identify failed projects for examination. A total of 12 failures were initially identified. Each project's team member contact was asked to identify basic project characteristics; project or CSU-related performance or outcome; CSU-related problems, opportunities, and contributing factors; impact of the CSU failure; lessons learned; and, links to the unaccomplished CSFs. Case studies for further analysis were selected based on the most compelling and insightful cases. Based on extent of description, four case studies were selected for full evaluation. Further detail was added through interviews with case study participants. The links to the CSFs identified and confirmed to complete the case studies. These case studies are presented in Chapter 8.

3.13 CHECKLIST TOOL

A checklist tool was created to assist project stakeholders in implementing the study findings. The RT strived for a simple, two-sided checklist where critical information regarding implementation of the CSFs could be conveyed. One side of the checklist tool includes the top 30 CSF indicators for achievement. Though the top 25 were indicated as differentiators, these only covered 13 of the 16 CSFs. For the remaining three CSFs, five additional indicators for achievement were selected to allow for coverage of all 16 Critical Success Factors. The CSFs and indicators are ordered numerically, which also coincides with the implementation timing of the CSFs.

On the opposite side of the tool are two graphs. The first graph is the timing of CSF implementation chart for each CSF. In the RT's opinion, proper timing of CSFs is a critical step for commissioning and start-up success. The second graph is the Innovative Commissioning Tools (ICT) timing of application graph. Group discussion by the team determined that knowledge of which phase to implement innovative technologies is vital information and has great potential to enhance CSU performance. The checklist tool can be seen in Chapter 11.

3.14 EXTERNAL PANEL VALIDATION OF FINDINGS

An external, third-party review of the study findings was desired to further confirm their validity. This effort was undertaken to identify any critical missing content or areas requiring significant correction. To facilitate this process, the research team identified nine CSU experts to independently review the findings of the team, No member of the RT was allowed to participate in the review. Each reviewer was provided a draft copy of CII Pub. 312-2 Implementation Resource, *Achieving Success in the Commissioning and Start-up of Capital Project*. This document contained a listing of CSFs, their associated indicators for achievement, CSU phase descriptions, modifications to IR 121-2 flow chart, commissioning mini-case studies, project CSU & CSF assessment findings, innovative commissioning technologies, and the implementation checklist tool.

A form was provided with which each panel member could provide input and critiques of the research team's findings, as well as general background and experience information. See Appendix A for a copy of this assessment form.

3.14.1 BACKGROUND OF REVIEWERS

A total of nine commissioning experts were used to validate and critique the research team's results. The validation panel's characteristics are described in Table 3-5.

Table 3-5: Validation Panel Survey Participants

Participant Characteristics	
Number of participants	9
Total years of industry experience	207
Average years of industry experience	23
CSUs completed	162
Average CSUs completed	18
Organizational Characteristics	
Owners	6
Contractors	2
Engineer	1
Roles and Positions	
Senior Project Specialist	General Engineer
Senior Completions Advisor	Hydroelectric Operating Supervisor
Chief of Automation & Controls Engineering	Supervisor of Transmission Engineering
Senior Project Management Consultant	Principal Engineer

3.14.2 Analysis of Feedback

The panelists' comments were collected, compiled, and organized in tabular format. A total of 62 comments were received from the nine reviewers. Panel feedback comments (and corresponding RT reaction) were categorized as seen in Table 3-6.

Table 3-6: Validation Panel Feedback Categorizations

Category	Description	No. of Comments	RT Action
1	Complimentary comment	2	No action
2	Minor spelling, wording, or grammar	7	Fix implemented
3	Comment unclear	3	No action
4	Response or fix in place	12	No action
5	Substantial comment for Graduate Research Student fix	6	Changes implemented
6	Substantial comment for Principal Investigator	2	Changes implemented
7	Substantial comment for RT to address	1	Changes implemented after RT review
8	Disagree with comment	29	No action
	Total	**62**	

3.14.3 Corrective Actions Taken

Sixteen comments required action, and nine were seen as valuable and added significant contribution to the research team's findings. Table 3-7 contains a summary of these corrective actions.

Table 3-7: Corrective Actions from Validation Panel Review

Corrective Actions Taken	No. of Comments
Minor spelling, wording, or grammar	7
Changes to wording of CSF descriptions	3
Additional reference sources	2
Changes to indicators for achievement description	3
Changes to ICT description	1
Total	**16**

3.15 RESEARCH PUBLICATIONS AND PRESENTATION

The research team concluded the study with the preparation of three publications. The Research Summary (RS), a brief overview on the findings of the team, was completed and named CII Publication RS 312-1, *Critical Success Factors for Project Commissioning and Start-up*. The Implementation Resource (IR), meant to be a resource for practitioners wishing to apply the findings of this research to improve project CSU performance, was published under CII Publication IR 312-2, *Achieving Success in the Commissioning and Start-up of Capital Project*. A research report (RR), detailing the full findings, analysis, and methodology of the team was also created and named CII Publication RR 312-11, *Identification and Implementation of Critical Success Factors in Commissioning and Start-up of Capital Projects.*

In addition, two presentations were prepared and delivered at the Construction Industry Institute's 2015 Annual Conference held in Boston, MA. The first was a plenary session and was a brief overview of the findings of the entire research and presented to the entire conference. A second presentation, promoted toward individuals most interested in the research findings, was for an Implementation Session. Strategies, methods, and technologies for proper CSF implementation were discussed, with potential consequences of failed implementation highlighted. Afterward, a panel consisting of three RT members and the principal investigator were present for a Q&A session with the conference attendees.

Chapter 4: Commissioning and Start-up Structures and Descriptions

4.1 OVERVIEW

From the initiation of this study, it was recognized that industry alignment on CSU terminology and CSU management system structures was needed. Terminology commonly used in industry was not consistent in regards to CSU, project phases and milestones, and leadership functions. This lack of consistency creates an environment of potential confusion and miscommunication. Agreement on key terms, functions, and phases would serve as a necessary foundation upon which to establish CSU best practices.

4.2 TERMINOLOGY

Terminology relevant to commissioning and start-up varies widely. The common phrases used in industry can vary from company to company and across industry sectors. This is particularly true of the terms pre-commissioning and commissioning.

The team undertook the task of clarifying and establishing consensus agreement of these terms. Scope definition relative to pre-commissioning (component level) and commissioning (system level) were identified. Also, the common key activities included during these two stages were detailed and defined. The terminology is fully detailed in Table 4-1.

4.3 PHASES & MILESTONES

The labels and relationships for CSU phases and milestones are also not consistent. This inconsistency warranted clarification and alignment. Based on the initial scope limitations of this study, the team focused on the phases and milestones between the end of construction and the commencement of initial operations.

Three primary commissioning stages were defined within this phase of the project: Area, Discipline, & Component Level; System Level; and Plant/Unit Level. As the project progresses forward through the stages, further integration and interoperability of the systems is achieved, until the facility operates as a whole unit.

Within each of these stages are milestones to be completed and included in the CSU process. The research identified multiple milestones to be achieved and categorized those by the approximate timeframe in which they should be accomplished in each stage. Also identified are the key activities and phases to be accomplished in each stage. Key documents and deliverables are also identified relative to their respective stage and approximate timeframe for completion. Clarifications of these phases and milestones are included in Figure 4-1.

4.4 TEAM FUNCTIONS & ROLES

The research team believed it would be helpful to better understand the project stakeholders and their roles in commissioning and start-up. A unified listing of team functions was deemed useful for future discussions and research development; however, detailed organizational dimensions relative to commissioning and start-up was not explored. The CSU execution team functions are broken down from an organizational perspective by leadership, general support, technical discipline, and initial operations. These are illustrated in Figure 4-2.

Table 4-1: CSU Terminology - Pre-Commissioning vs. Commissioning

	PRE-COMMISSIONING	**COMMISSIONING**
LEVEL	Component-Level	Multi-component Integration & System-Level
SCOPE DESCRIPTION: ACTIVITIES	• Activities are typically Post-Mechanical Completion (at component level) but prior to energization and introduction of any feed stocks • 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 Start-up • Activities are most often the client's responsibility • Concludes with a Ready-for-Start-up certificate for each system
KEY INCLUSIONS	1. 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 2. Mechanical equipment, wiring checks for installation accuracy; Point-to-point continuity checks 3. Mechanical function tests 4. Construction rework, as required 5. All verification tests to ensure equipment is fabricated, installed, cleaned, and tested in accordance with the design 6. All tests/inspections required prior to any dynamic testing 7. Function checks accomplished with discipline-specific check sheets 8. Power-off checks of equipment, piping, and electrical cable 9. Non-operating adjustments performed before system turnover 10. "First fill" (e.g. Lubricants, utility fluids); Loading of catalyst, desiccants, polishers, etc.	1. All energized and/or dynamic tests that constitute verification that each system or subsystem is fabricated, installed, cleaned, and tested in accordance with the design intentions, and that systems are ready for start-up 2. Chemical cleaning and steam blowing 3. Final leak checking and air freeing; Leak and tightness testing 4. Instrument loop calibration 5. Checkout of PLC and emergency shutdown system; Testing of all safety functions; Testing of control functions 6. Refractory dry-out 7. Rotating equipment run-in; Coupled testing of rotation equipment 8. Circulation with temporary fluids 9. Testing of utilities 10. Testing of control functions & installation of final valve trim

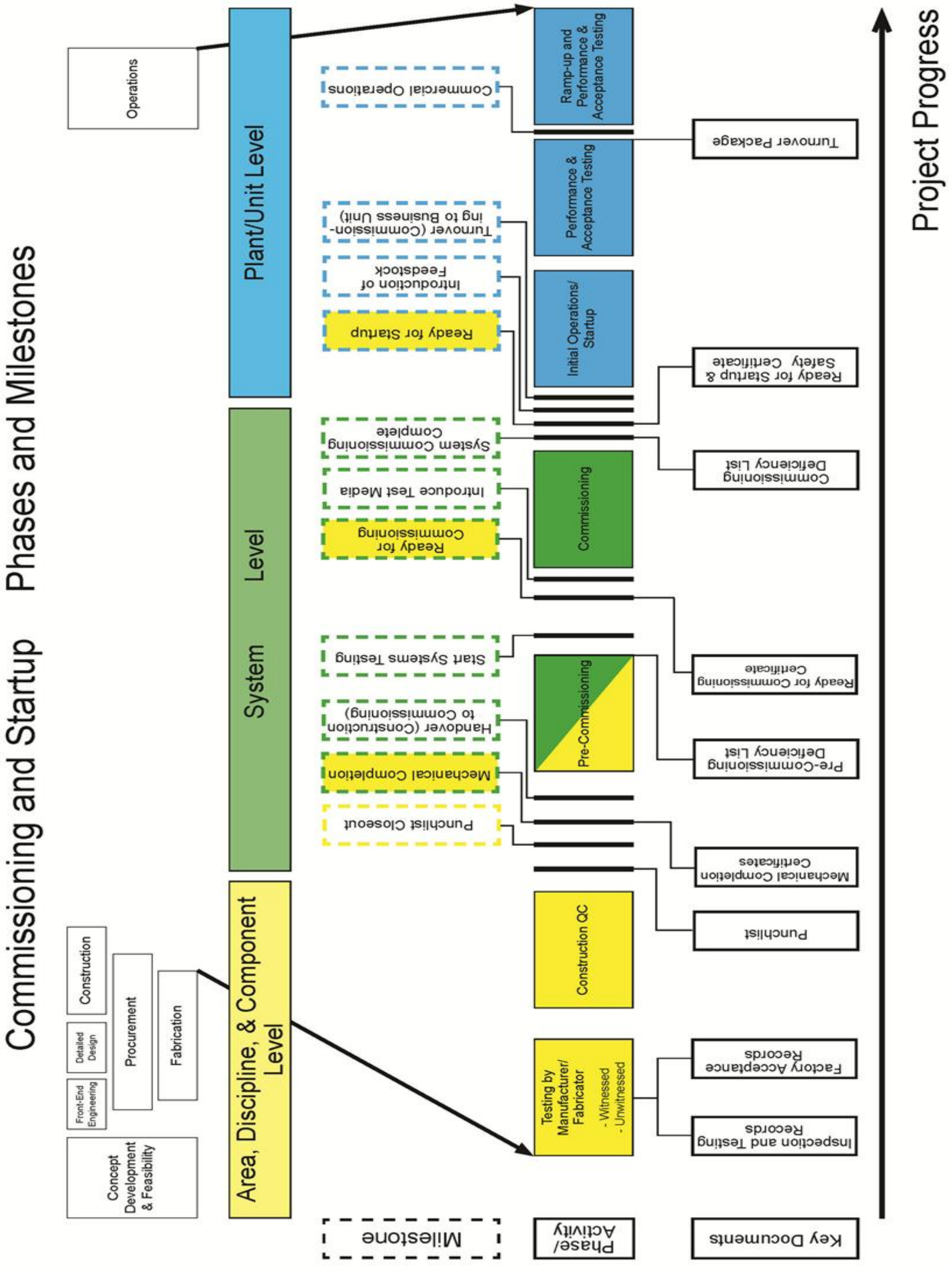


Figure 4-1: Commissioning and Start-up Phases and Milestones

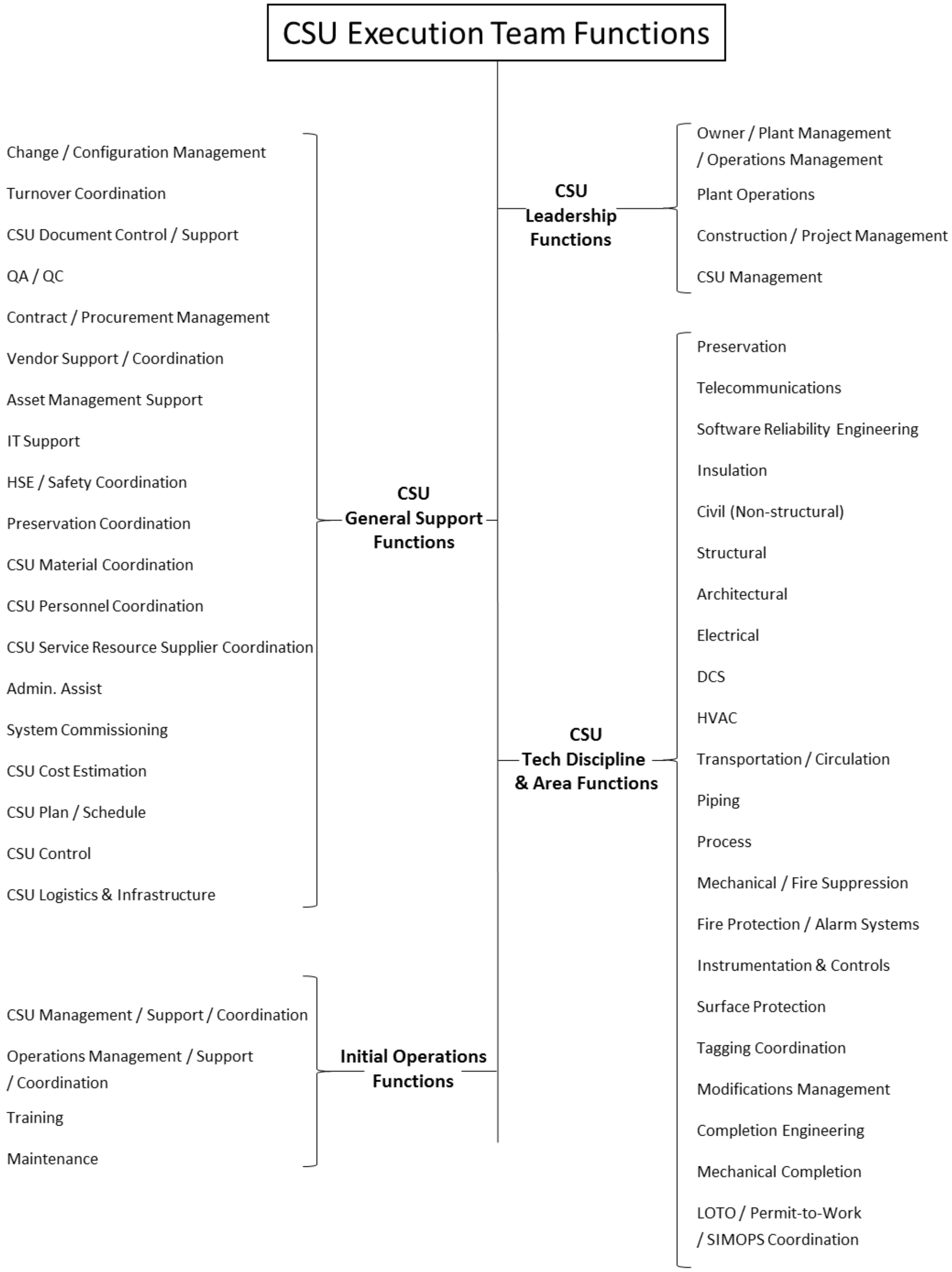


Figure 4-2: CSU Organizational Functions

Chapter 5: Learnings from CII Benchmarking

5.1 OVERVIEW

Analysis of performance of recently completed projects offers valuable insight to the current status of CSU in industry. With assistance from CII, access to their benchmarking database provided valuable project-level information. Projects with commissioning data in the database were able to be isolated, with trends and characteristics examined. The two databases examined were the CII General Program dataset and the 10-10 Program Assessment dataset.

5.2 LEARNINGS FROM CII GENERAL PROGRAM DATASET

The General Program benchmarking dataset has nearly 400 projects for which there is CSU-related data, with most being concentrated in the heavy and light industrial sectors. In addition to other project information, the data includes specific information on CSU, such as commissioning costs and commissioning schedule.

A total of 162 projects possessed complete data on commissioning costs, which included the original commissioning budget and the actual commissioning costs. From this a commissioning cost variance was able to be determined. The average project size examined was $144 million, with over 70% of the projects being allotted an initial commissioning budget of $2 million. On average, these projects had commissioning cost growth of 24%, with the highest being reported at 400%. In all, nearly 50% of projects examined overran their initial commissioning cost budget, with a third of all projects experiencing commissioning cost growths greater than 25%.

A total of 247 projects in the database had information pertaining to planning vs, actual commissioning schedule. The average planned commissioning schedule was a 158 days, with all projects averaging 192 days for actual commissioning schedule. Over 60% of the projects experienced schedule delays in the commissioning phase, with an average CSU schedule variance of 76% for all projects. CSU schedule duration overruns greater than 25% were seen in nearly half of the projects examined. Only 17% of projects were able to improve their commissioning schedule by more than 25%.

5.3 LEARNINGS FROM 10-10 PROGRAM ASSESSMENT

The 10-10 Program Assessment dataset was also a valuable source of information allowing specific project phases and specific industries to be examined. The dataset contained a total of 36 industrial, building, and infrastructure projects with CSU-related data. The survey participants had an average of 18 years' experience and were part of projects ranging from <$1M to >$450M. As was the case with the General Program dataset, CSU cost and CSU schedule overruns were seen in the 10-10 dataset, though not to the level seen previously. See Figure 5-1 and Figure 5-2 for a graph of the CSU cost and schedule performance in the 10-10 dataset.

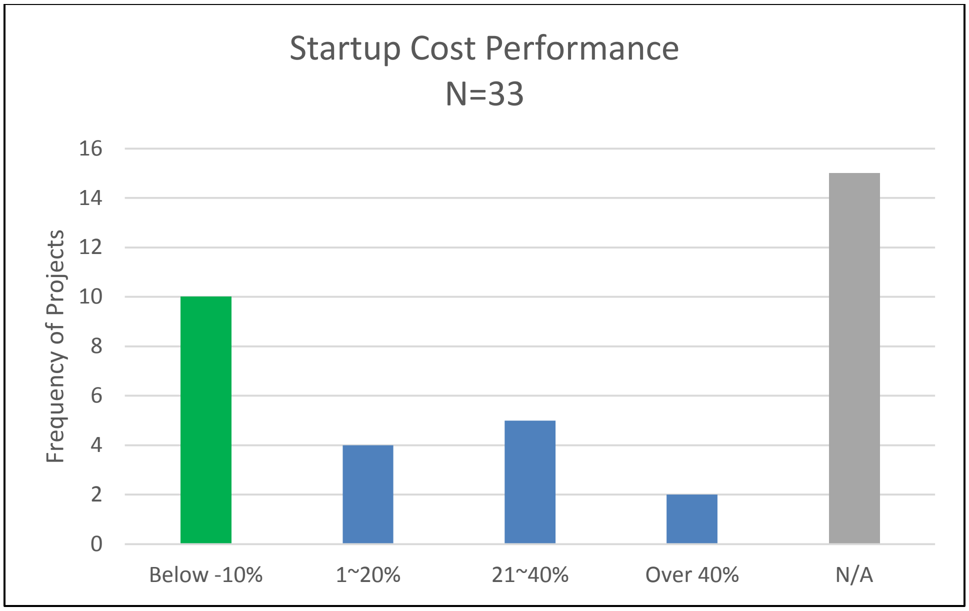


Figure 5-1: CSU Cost Performance in 10-10 Program dataset (n=33)

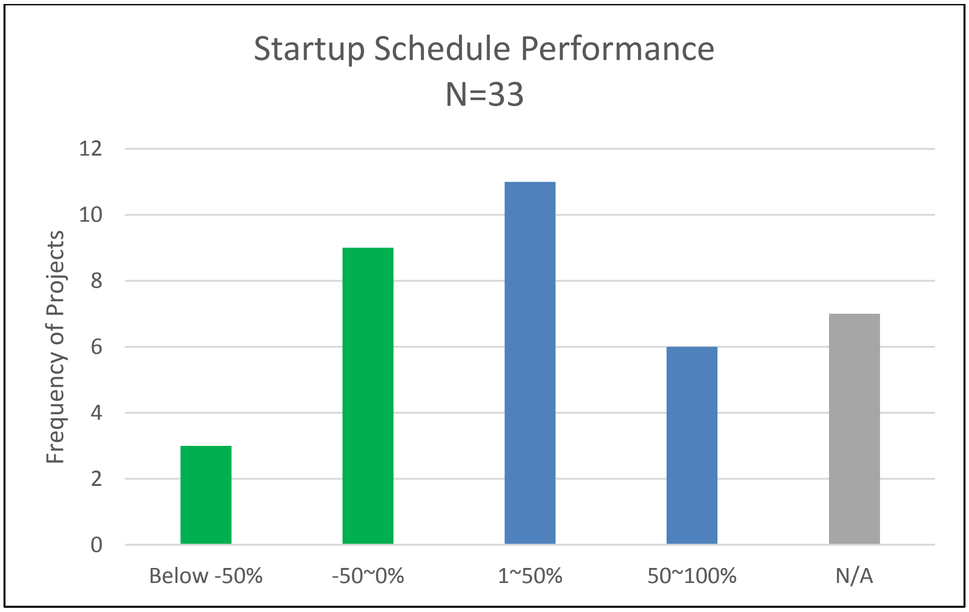


Figure 5-2: CSU Schedule Performance in 10-10 Program dataset (n=33)

Also of particular note from 10-10 dataset are some statistically significant relationships that should be highlighted and noted in support of this study in commissioning and start-up. These were gathered through the 10-10 Program questionnaire and ask that key project leaders assess and judge the impact of project characteristics and past actions. Some of the key relationships include:

- When cost of quality is monitored during start-up, CSU cost performance improves. See Figure 5-3.
- CSU schedule performance improves when the start-up management team has the information available to perform effectively. See Figure 5-4.
- When high degrees of trust and respect exist within the project teams, a positive correlation is seen for the start-up systems and processes to support project success. See Figure 5-5.
- Start-up is more likely to meet operability and quality objectives when CSU management teams have experience with similar projects/processes. See Figure 5-6.
- Start-up is more likely to meet operability and quality objectives when CSU management teams understand the client's goals and objectives. See Figure 5-7.
- Meeting operability and quality objectives is more likely when key CSU management team members have the proper authority to execute their duties. See Figure 5-8.

- Customer satisfaction with start-up deliverables is higher when CSU planning and schedule processes are effective. See Figure 5-9.
- Client satisfaction with the startup delivery and deliverable improves when all CSU stakeholders are trustworthy, transparent, and respectful. See Figure 5-10.

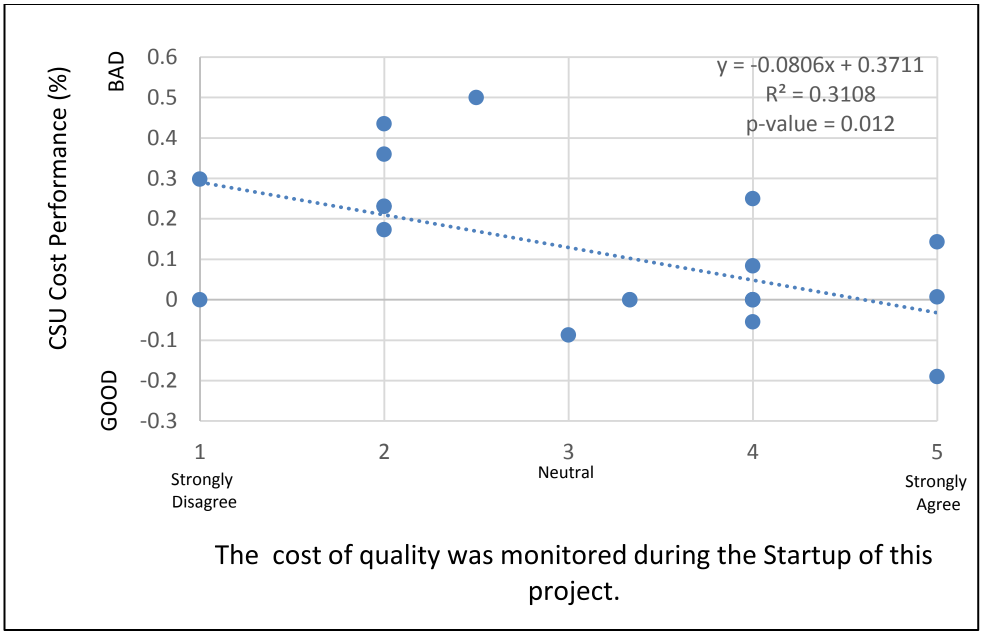


Figure 5-3: CSU Cost Performance vs Quality Cost Monitoring (n=21)

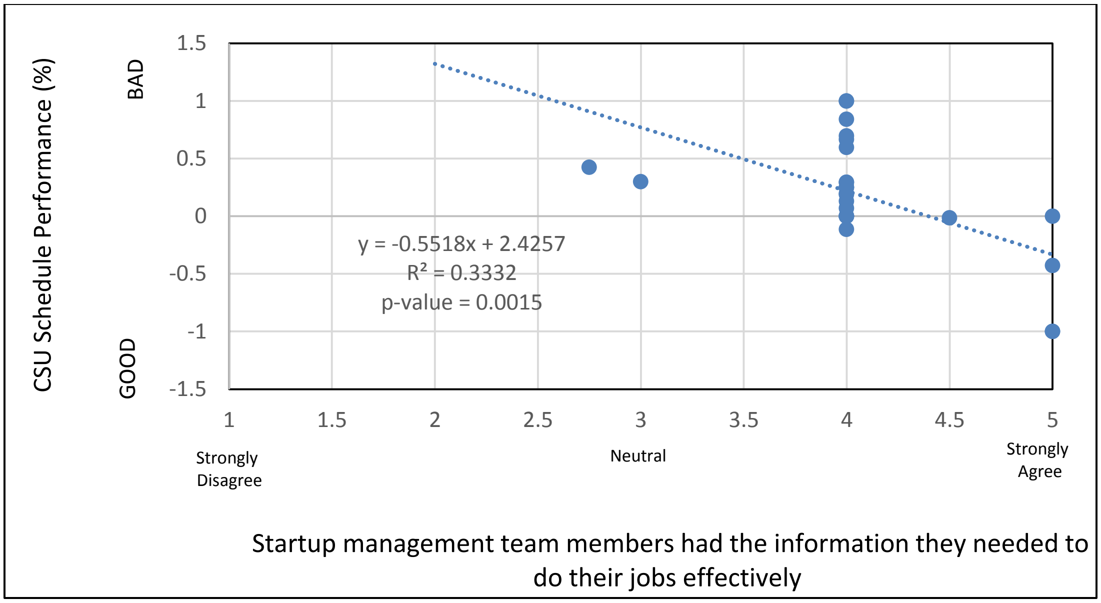


Figure 5-4: CSU Schedule Performance vs Information Available (n=28)

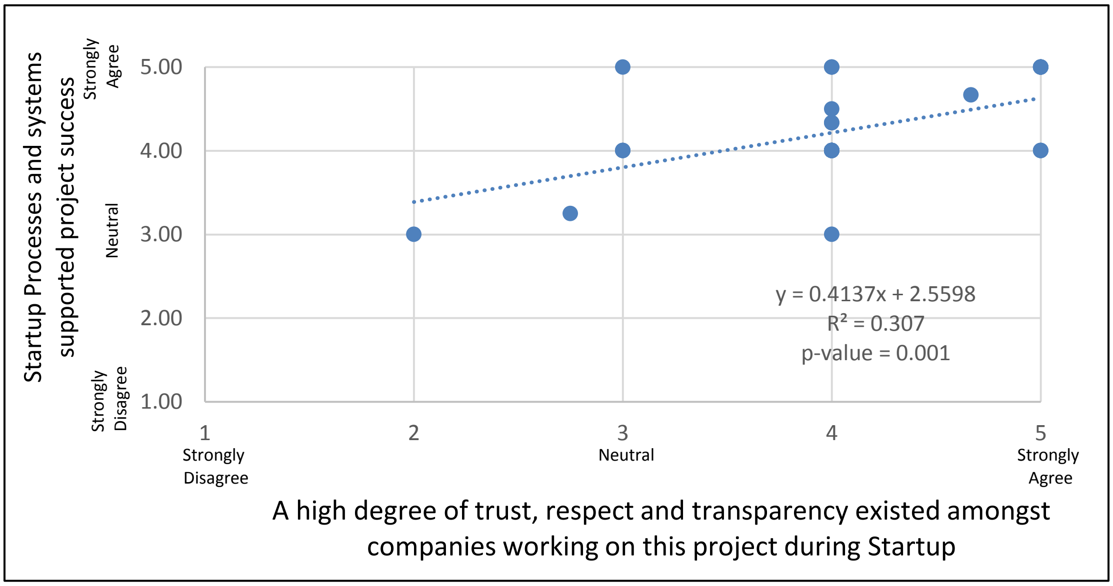


Figure 5-5: Start-up Processes in Support of Project Success vs High Degree of Trust among Project Stakeholders (n=33)

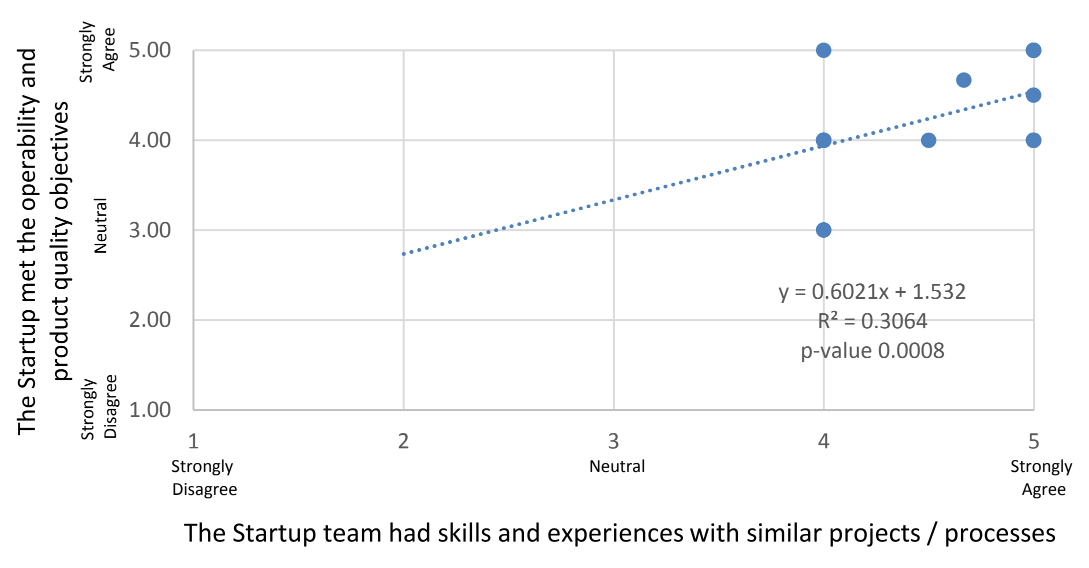


Figure 5-6: Start-up Meeting Objectives vs. Start-up Team’s Experiences (n=33)

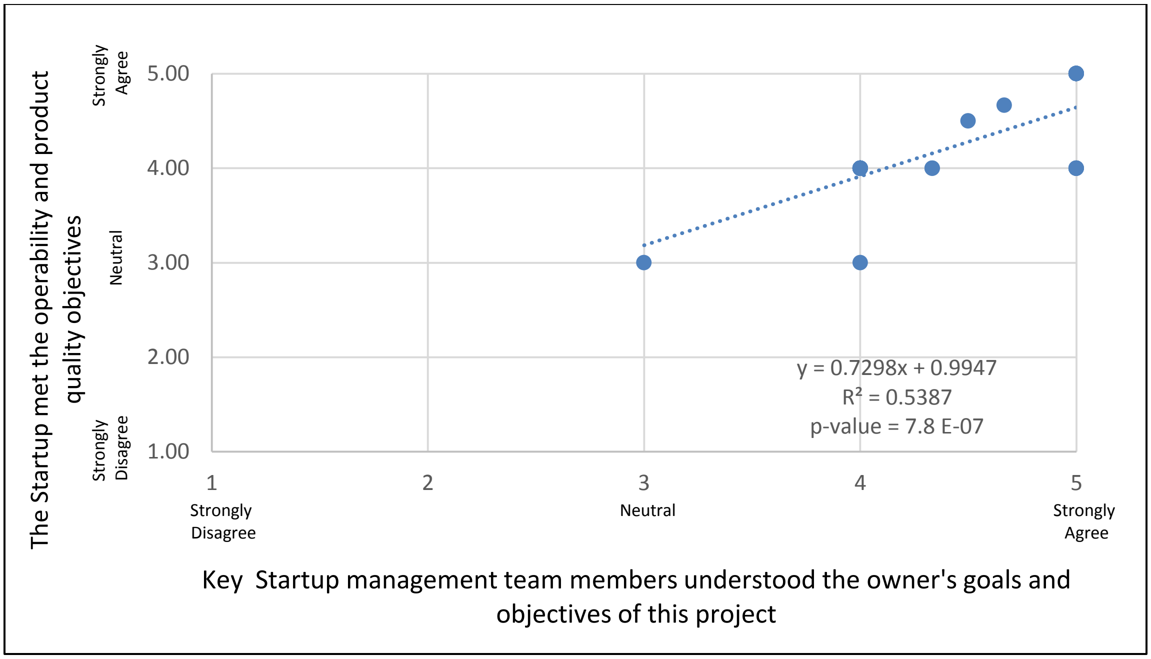


Figure 5-7: Start-up Meeting Objectives vs. Start-up Team's Understanding of Owner's Objectives (n=34)

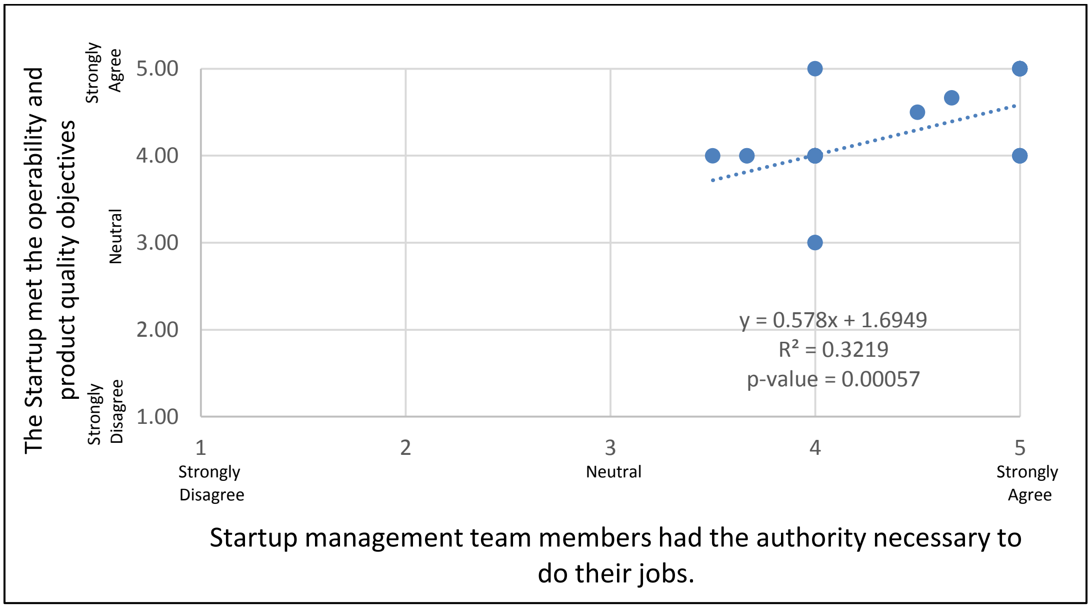


Figure 5-8: Start-up Meeting Objectives vs. Start-up Member's Authority (n=33)

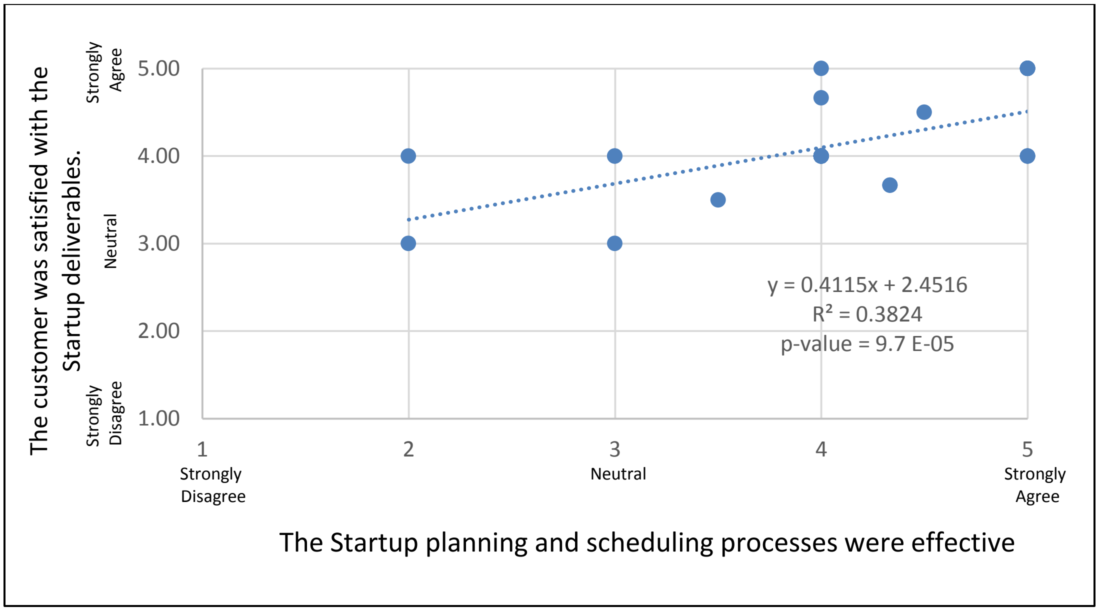


Figure 5-9: Customer Satisfaction vs. Effective CSU Processes (n=34)

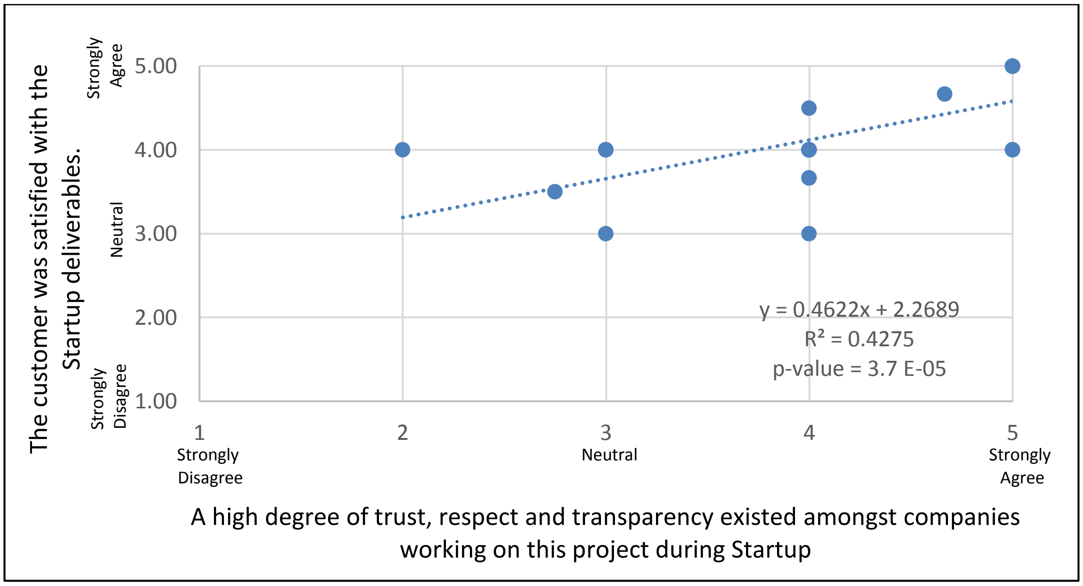


Figure 5-10: Customer Satisfaction with Deliverables vs. High Degree of Trust among Project Stakeholders (n=34)

Chapter 6: Critical Success Factors (CSF)

6.1 DESCRIPTIONS

Sixteen commissioning and start-up critical success factors (CSF) were refined from an initial listing of 139 potential factors. The 16 factors are presented below in Table 6-1, and with full descriptions in Table 6-2. The factors are numbered in order of recommended sequence of implementation on projects. When drafting the label names and descriptions of each CSF, concise and succinct wording was chosen over more expanded phrasing. These factors focus on such themes as 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 6-1: 16 Critical Success Factors for Commissioning and Start-up

CSF No.	CRITICAL SUCCESS FACTOR
CSF #1	CSU VALUE RECOGNITION
CSF #2	CRITICAL INTERFACES ON BROWNFIELD PROJECTS
CSF #3	ADEQUATE FUNDING FOR CSU
CSF #4	ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION
CSF #5	CSU LEADERSHIP CONTINUITY
CSF #6	SYSTEM MILESTONE ACCEPTANCE CRITERIA AND DELIVERABLES
CSF #7	CSU SYSTEMS ENGINEERING DURING FEED
CSF #8	RECOGNITION OF CSU SEQUENCE DRIVERS
CSF #9	DETAILED CSU EXECUTION PLAN
CSF #10	SYSTEMS-FOCUS IN DETAILED DESIGN
CSF #11	CSU CHECK-SHEETS, PROCEDURES, AND TOOLS
CSF #12	CSU TEAM CAPABILITY
CSF #13	INTEGRATED CONSTRUCTION/CSU SCHEDULE
CSF #14	ACCURATE AS-BUILT INFORMATION
CSF #15	TRANSITION TO SYSTEMS-BASED MANAGEMENT
CSF #16	COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER

Table 6-2: Critical Success Factors Descriptions

CSF No.	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 sufficiently adequate, budgeted up-front, and preserved. The common threat from failure to do so is lack of enough operators, with subsequent delays in CSU progress.
4	**ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION**	The project and CSU will benefit substantially by 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.

Table 6-2: Critical Success Factors Descriptions, cont.

CSF No.	Critical Success Factor	Description
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.
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 start-up 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.

Table 6-2: Critical Success Factors Descriptions, cont.

CSF No.	Critical Success Factor	Description
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, Lock-out, Tag-out (LOTO) requirements/supports, and access for operations and maintenance.
11	**CSU CHECK-SHEETS, PROCEDURES, AND TOOLS**	Insure 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 6-2: Critical Success Factors Descriptions, cont.

CSF No.	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 close-out 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% 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 & systems turnover. Proactive communications are needed to minimize construction-CSU conflicts.

6.2 IMPLEMENTATION SCHEDULE

Proper timing of implementation is critical to the effectiveness of an individual success factor. Figure 6-1 illustrates the recommended timing of implementation for the critical success factors across the project phases. As shown in the figure, over 80% of the CSFs are initiated prior to the start of construction. Early planning and alignment is critical in ensuring these CSFs are properly and fully achieved.

Examining the first three CSFs, initiation and completion should be achieved prior to the completion of Detailed Design. Nine of the 16 CSFs should be completed or fully achieved prior to the initiation of Construction. A key finding from this study is that project teams should not delay their implementation of the critical success factors. Only three of the CSFs should be started after commencement of construction. No CSF is recommended to commence past construction completion, with only two CSFs extending into the last phases of the project.

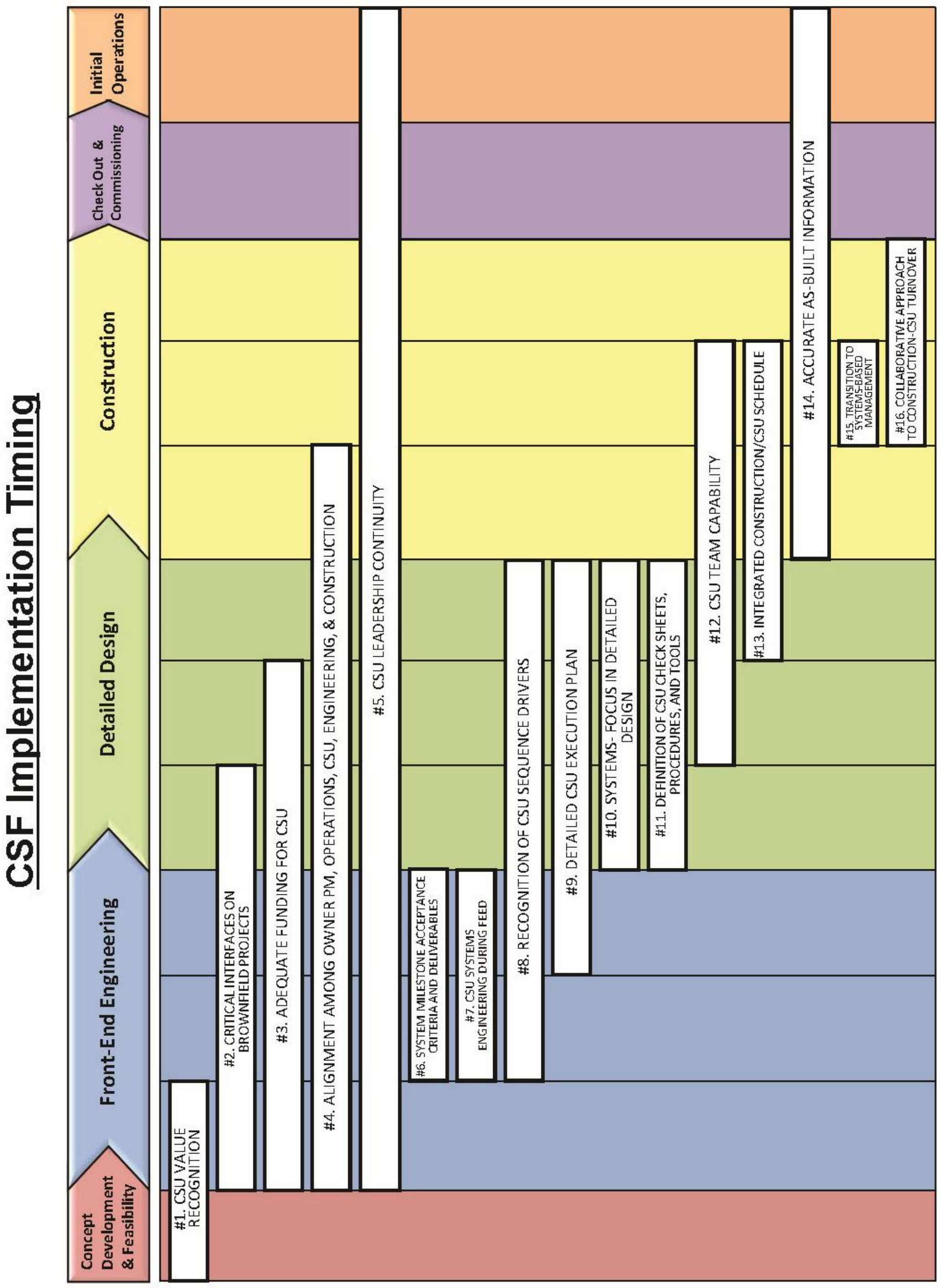


Figure 6-1: Timing of CSF Implementation

6.3 FREQUENCY OF ACHIEVEMENT

One primary question that required attention by the research team was to what extent are the CSU critical success factors being implemented or accomplished by project teams. To determine this frequency of achievement the team collected two types of data:

- 30 CSU experts were surveyed on the relative frequency of actual occurrence or accomplishment of the CSFs on their projects as detailed in Chapter 3.
- As explained further in Chapter 9, project characterization data was collected on the CSF Indicators for Achievement for 26 actual projects.

The survey of CSU experts was scored per the summary in Section 3.9.5. Each CSF received a frequency score, ranging on a scale of 0-7, based on the average score received from the five possible categories. The average frequency score obtained was 4.37. Three divisions were then made to classify these CSFs and their level of accomplishment: “Most Common”, “Frequent”, and “Occasional”. Natural breakpoints in the data were the primary means in establishing these divisions. To be classified as “Most Common”, the frequency score was established at 5.5 or higher. One CSF fell into this category. To be classified as “Frequent”, the frequency score established was between 5.5 and 4.0. A total of nine CSFs were classified in this category. Those CSFs below a frequency score of 4.0 were classified as “Occasional” and were shown to be laggards in terms of accomplishment. A total of six CSFs fell below this line. These laggard CSFs were later examined with the 26 projects of the Project Assessment Survey and are discussed further in Chapter 9.

Results from the two analyses were compared and the composite findings showed the less-frequently-achieved CSFs include the following:

- CSF #1 - CSU value recognition
- CSF #3 - Adequate funding for CSU
- CSF #5 - CSU leadership continuity
- CSF #6 - System milestone acceptance criteria and deliverables
- CSF #7 - CSU systems engineering during FEED
- CSF #10 - Systems-focus in detailed design

These six laggard CSFs constitute more than a third of all critical success factors, signifying significant challenges to implementation. To provide further insight into these challenges, barriers to CSF implementation were examined for these six CSFs.

6.4 BARRIERS TO LESS FREQUENTLY ACHIEVED CSFS

The research team brainstormed a large number of potential barriers to CSF achievement and refined the listing down to those considered most significant. These are provided below in Table 6-3. Awareness of these barriers is necessary to confront and mitigate their negative impacts at the earliest opportunity.

Table 6-3: Barriers to Less Frequently Accomplished CSFs

CSF No.	Critical Success Factor (CSF)	Barrier to Achieving CSFs	
1	CSU VALUE RECOGNITION	1	Too little focus on “doing the right things” (investing in CSU)
		2	Many stakeholders and Project Managers don’t understand the value proposition; "Penny-wise and pound-foolish"
		3	Project Managers stuck in old paradigms
		4	Difficulty in quantification of relationship between CSU resourcing/planning and the benefits from effective CSU

Table 6-3: Barriers to Less Frequently Accomplished CSFs, cont.

CSF No.	Critical Success Factor (CSF)	Barrier to Achieving CSFs	
3	ADEQUATE FUNDING FOR CSU	1	Funding not proportionate to project complexity and size
		2	Failure to adequately recognize value of successful CSU
		3	Project funding stress from construction overruns
		4	Overly simplistic estimating methods (% of Total Installed Costs)
		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 Start-up
		2	HR effects and difficulty in achieving continuity: routine promotions, retirements, and job changes
		3	Lack of appreciation for the importance of and impacts from 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 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 6-3: Barriers to Less Frequently Accomplished CSFs, cont.

CSF No.	**Critical Success Factor (CSF)**	**Barrier to Achieving CSFs**	
7	CSU SYSTEMS ENGINEERING DURING FEED	1	"It's too early" paradigm; "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
10	SYSTEMS-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 effectively transfer CSU knowledge to Engineering

6.5 INDICATORS FOR ACHIEVEMENT

The 16 commissioning and start-up critical success factors provide meaningful and substantial insight and guidance for project teams that seek high levels of CSU performance. Periodic assessment of actual CSF achievement and implementation is necessary and requires concentrated efforts by CSU leadership. To further support recognition and assessment of CSF implementation, the research team developed a collection of "indicators for CSF achievement," which are intended to offer stronger and more apparent evidence of actual CSF achievement. The listing of the 45 indicators, along with their associated CSF, is provided below in Table 6-4. As further discussed in Chapter 9, 30 of these indicators have been shown to be excellent differentiators between CSU success and failure. These indicators are particularly informative in their assessments of actual CSU preparedness for projects.

Table 6-4: Indicators for CSF Achievement

CSF No.	**Critical Success Factor (CSF)**	**CSF Indicators for Achievement** Indicators the CSF has been accomplished		**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 1-day delay in start-up of Operations.	
2	Critical Interfaces on Brownfield Projects	2.1	Project team has identified all tie-ins and individual shut-downs by 30% 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% 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.	

Table 6-4: Indicators for CSF Achievement, cont.

CSF No.	**Critical Success Factor (CSF)**	**CSF Indicators for Achievement** Indicators the CSF has been accomplished		**Top 30 Indicator**
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 % 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 held in which all stakeholders were present. These are initiated early and are repeated throughout planning, design, and construction phases.	
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.	✓
		6.2	System/sub-system acceptance criteria are well documented prior to bid document submission and key parties are aligned on the criteria by the end of Front-End Engineering.	

Table 6-4: Indicators for CSF Achievement, cont.

CSF No.	Critical Success Factor (CSF)	CSF Indicators for Achievement Indicators the CSF has been accomplished		Top 30 Indicator
7	CSU Systems 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 is accountable for leading the team through the systemization process, involving operations, maintenance, and CSU resources.	
		7.4	Preliminary CSU sequence is 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, sub-systems 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, process systems, etc.	✓

Table 6-4: Indicators for CSF Achievement, cont.

CSF No.	Critical Success Factor (CSF)	CSF Indicators for Achievement Indicators the CSF has been accomplished		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 is integrated into the overall project execution plan and has evident linkages to other project functions (engineering, construction, operations, maintenance, quality, HSE, etc.)	✓
		9.3	Operations provided input into the preparation of the detailed CSU Execution Plan.	✓
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.	✓
		10.3	Construction and pre-commissioning check sheets are 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. Construction and pre-commissioning check sheets are finalized by the end of Detailed Design.	

Table 6-4: Indicators for CSF Achievement, cont.

CSF No.	**Critical Success Factor (CSF)**	**CSF Indicators for Achievement** Indicators the CSF has been accomplished		**Top 30 Indicator**
11	CSU Checksheets, Procedures, and Tools	11.1	A complete set of construction/QC and commissioning <u>check sheets</u> 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 <u>test procedures</u> 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 is being used, then an equipment diagnostic alerts utilization plan is in place 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 CSU/Construction Schedule	13.1	Project schedule includes system logic inter-dependencies and turnover milestones prior to 30% construction complete.	✓

Table 6-4: Indicators for CSF Achievement, cont.

CSF No.	Critical Success Factor (CSF)	CSF Indicators for Achievement Indicators the CSF has been accomplished		Top 30 Indicator
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	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 is referenced within the project execution plan.	✓
15	Transition to Systems-based Management	15.1	Possession of construction and commissioning integrated schedule by the 30% 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% construction complete.	✓
		16.2	Joint CSU system walk-downs are conducted, involving both CM CSU Manager.	
		16.3	Short-term scheduling priorities (at both construction area and system/sub-system levels) are established with input from both CM and CSU Manager.	

6.6 CSF SUPPORT OF QUALITY AND SAFETY

The support of project safety and project quality are important features of the CSFs. Each CSF was examined by the research team for its linkages to these two aspects, and in particular, how failure to implement the CSF could threaten project safety and quality. These findings are presented below in Table 6-5.

Table 6-5: CSF Links to Quality and Safety

CSF No.	Critical Success Factor (CSF)	Safety & Quality Linkage	Threats to Safety & 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 & 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 stage of the project. Delays, missed milestones, and lack of operators in CSU are the common results of lack of funding, which can have a negative impact on quality.	Lack of justified investment and resources threaten Safety & Quality.

Table 6-5: CSF Links to Quality and Safety, cont.

CSF No.	Critical Success Factor (CSF)	Safety & Quality Linkage	Threats to Safety & Quality due to CSF Failure
4	ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERS, AND CONTRACTORS	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-thru threaten both Safety & Quality.
5	CSU LEADERSHIP CONTINUITY	Continuous and consistent leadership of the CSU throughout the project helps to ensure the proper level of quality is maintained from the planning stages of CSU through facility handover.	Lack of CSU staff continuity challenges Safety & Quality leadership.
6	SYSTEM MILESTONE ACCEPTANCE CRITERIA AND DELIVERABLES	A detailed system milestone acceptance criteria establishes 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 & Quality risks.
7	CSU SYSTEMS ENGINEERING DURING FRONT-END ENGINEERING	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 leads to rework and hazards.

Table 6-5: CSF Links to Quality and Safety, cont.

CSF No.	**Critical Success Factor (CSF)**	**Safety & Quality Linkage**	**Threats to Safety & Quality due to CSF Failure**
8	RECOGNITION OF CSU SEQUENCE DRIVERS	Recognizing and identifying the key actions to maintaining the planned sequences of CSU maintains quality throughout CSU.	Out of sequence turnovers threaten Safety & Quality.
9	DETAILED CSU EXECUTION PLAN	A detailed plan, that includes responsibilities of personnel, ensures roles are clearly defined and all CSU activities have a responsible party and meet the highest quality.	Lack of planning threatens Safety & Quality.
10	SYSTEMS-FOCUS IN DETAILED DESIGN	Focused on Systems during the Design phase, in addition to focus on equipment and individual components. This has the advantage of increasing awareness of systems and how they ultimately will be handed over from CSU to Operations.	Poorly integrated systems leads to rework and hazards.
11	CHECK-SHEETS, PROCEDURES, AND TECHNOLOGIES	Assurances that component/system checkouts include adequate criteria and procedures prior to handover.	Lack of check-sheets and procedures threaten Safety & 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 & Quality Risks result from lack of capability.

Table 6-5: CSF Links to Quality and Safety, cont.

CSF No.	Critical Success Factor (CSF)	Safety & Quality Linkage	Threats to Safety & Quality due to CSF Failure
13	INTEGRATED CONSTRUCTION/CSU SCHEDULE	A CSU schedule is integral to achieving critical milestones and objectives. Quality is enhanced by establishing specific dates for CSU progress, while also incorporating quality checks, tests, and system/component milestones.	Unintegrated schedule leads to schedule errors, accelerations, and short cuts, which threaten Safety & Quality.
14	ACCURATE AS-BUILT INFORMATION	Accurate as-built information from the construction phase, helps CSU staff to plan, implement, and closeout CSU activities.	Inaccurate or missing as-built information can threaten Safety & Quality.
15	TRANSITION TO SYSTEMS-BASED MANAGEMENT	Transitioning from construction progress tracking in an area, to systems-completion tracking helps to effectively redirect resources in an efficient manner to ensure construction panelists are completed prior to commencement of CSU.	Inefficient transitions lead to shortcuts in Safety & Quality.
16	COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER	A collaborative approach between CSU managers and construction managers helps to minimize conflicts, allows for a more efficient CSU, and ensure no gaps in construction completion and system turnover.	Non-collaborative approach is inefficient & incomplete, raising risk levels.

Chapter 7: Modifications to CII 121-2

7.1 RECOMMENDED MODIFICATIONS

Previous research from CII (CII 1998) argued for the importance of start-up planning. This is crucial as the industrial business environment is challenged by the some of the following characteristics:

- pressure to increase profits by reducing costs
- a need to reduce owner project staff and to increase the outsourcing of services
- demand for shorter project cycle times
- general lack of planning capabilities and supportive tools

Since that time, the industrial business environment has only become more challenging, thereby increasing the importance of commissioning and start-up planning.

CII has published two studies on commissioning and start-up which are:

1. CII, 1990. *Planning Construction Activity to Support the Start-up Process*, Publication 6-9 (CII 1990).
2. CII, 1998. *Planning for Start-up*, Implementation Resource (IR) 121-2 (CII 1998).

Pub 6-9 focused on implementing project planning in the early phases of a project to support start-up. IR 121-2 developed a *Planning for Start-up* best practice model and associated tools. Both Publication 6-9 and IR 121-2 should be viewed as dated and deficient. Nonetheless, the team concluded that significant value relative to the current study still remains in the IR121-2 publication. The research team made a commitment to identify significant modifications or updates in the 15-year-old *Planning for Start-up* document. The team recommended a limited number of specific, high-priority expansions/updates to this document. For this effort, a sub-committee of the research team was formed. In several face-to-face meetings, the sub-committee scrutinized the existing *Planning for Start-up* publication for relevancy and areas requiring update and expansion.

After an initial review of the document, it was concluded that the *Start-up Planning* model is a valuable tool for ensuring management commitment. Only minor revisions were recommended by the team. However, a major revision/update is needed to the overall Publication IR121-2, especially on activity profiles and implementation tools. Thus, the team decided to update the *Planning for Start-up* flow chart only and recommend CII to initiate a subsequent future research team to update those activity profiles and implementation tools.

Recommended modifications included:

- Change name of the document to "Planning for Commissioning and Start-up."
- Remap activities: add/remove/combine/move activities.
- Develop an electronic tool based on IR121-2.
  - The tool should track commissioning progress or mark milestones (plug-in tool; simple for the user).
- Introductions in 121 should describe CSU in the context of overall project sequence.

- Additional tools are needed (particularly for Phases 7 & 8).
- Additional details on organization and responsibilities are needed (specifically regarding commissioning manager).
- Add detailed "inputs" to each activity.
- Responsibility, Accountability, Consult, & Inform (RACI) for each activity needs to be validated/updated.
- Ensure that "Quality Gates" includes O&M approval.

7.2 MODIFIED 121-2 FLOW CHART WITH LINKS TO CSFS

The original purpose of the *Planning for Start-up* model (IR121-2) was to help the industry plan start-ups in a more thorough, effective, and efficient manner. The model was not intended to be a project management guide; rather, the activities in the model were provided to supplement basic project management practices. The original *Planning for Start-up* model was a sequence of 45 planning activities organized around eight typical project phases. Each planning activity was detailed in a one-page activity profile that presented nine fields of descriptive information. The 45 activities were complemented with 26 tools intended to facilitate the implementation of the particular start-up planning activity (CII 1998).

The Updated CSU Planning model (see Figure 7-1) maintains the same purpose as that of the original model. A major difference between the original model and updated model is the sequencing of planning activities. The team was in consensus that sequences in the original model were too complicated to understand or follow. The team updated the model into a more straightforward and simple model by re-sequencing and grouping activities.

Of the original 45 planning activities, 13 new activities were added, while removing four of the original activities, and combining another seven. These modifications are detailed below. The team also concluded that four activities in Phase 1 and 2 were too early to be implemented. These activities were moved to a later phase and included 'Ensure Sr. Management Commitment' [1-A]; 'Seek Realistic Start-up Duration Forecast' [2-A]; 'Estimated Start-up Cost' [2-B]; and 'Recognized Impact of Start-up on Economics' [2-C]. Consequently, Phase 1 was removed entirely. Phase 5 was removed as well because the team judged that procurement activities should be implemented concurrently in multiple phases, not in an independent phase. All the activities in the Procurement Phase were moved to Phase 4 and included 'Quality Suppliers for Start-up Services' [5-A]; 'Refine Start-up Spare Parts Plan & Expedite' [5-B]; and 'Implement Procurement QA/QC Plan' [5-C].

As a result, the Updated CSU Planning Model is now a sequence of 47 planning activities organized around six typical project phases. Presented below are the number of the original model's new, transferred, and removed activities, as well as a summary of the new model's CSU planning activities. See Table 7-1 for a summary of the changes made to the 121-2 model.

Removed Project Phases:

- Phase 1 - Requirements Definition & Technology Transfer
- Phase 5 – Procurement

Added activities:

- Develop 3 CSU Deliverables: CSU Schedule, CSU Resources, CSU Budget [2-B]
- Hire/Assign CSU Manager [3-A]
- Establish CSU Team [3-C]
- Input into Asset Management Strategy [3-I]
- Input into QA/QC Acceptance Plan [3-H]
- CSU Execution Plan [3-K]
- CSU Input into Contracts / Subcontracts [3-N]
- Onboard CSU Team [4-A]
- System Input into Engineering Design [4-C]
- Input into Operations Manuals [4-E]
- Input into Maintenance Manuals [4-F]
- LOTO (Lock-Out, Tag-Out) Transition [6-E]
- Manage System Completion [6-F]

Removed activities:

- CSU Incentives (IR 121 [3-G])
- Address CSU Issues in Team-Building Sessions (IR121 [4-A])
- Update CSU Execution Plan & Issue for Construction (IR121 [6-A])
- Refine CSU Integrated CPM Schedule (IR121 [6-C])

Combined activities:

- CSU Risk Assessment (IR121 [3-F] 'Assess Start-up Risk' & [2-C] 'Recognize Impact of Start-up on Economics')
- CSU Budget & Schedule (IR121 [3-I] 'Refine Start-up Budget & Schedule' & [2-A] 'Seek Realistic Start-up Duration Forecast' & [2-B] 'Estimate Start-up Cost')
- Plan for Supplier Field Support of CSU (IR121 [4-C] ‘Plan for Supplier Field Support of Startup' & [5-A] Quality Suppliers for CSU Services’)
- Refine CSU Risk Assessment (IR121 [4-I] 'Refine Start-up Risk Assessment' & [6-F] 'Finalize Start-up Risk Assessment')
- Plan for Supplier Field Support of CSU (IR121 [4-C] 'Plan for Supplier Field Support of Start-up' & [5-A] 'Qualify Suppliers for Start-up Services')
- Develop CSU Spare Parts Plan (IR121 [4-K] 'Develop Start-up Spare Parts Plan' & [5-B] 'Refine Start-up Spare Parts Plan & Expedite')
- Plan for CSU QA/QC (IR121 [4-E] 'Plan for Start-up QA/QC' & [5-C] 'Implement Procurement QA/QC Plan')

As final step, the 16 CSFs identified earlier in the research were linked to the activities detailed in the updated *Planning for Start-up* model. These linkages are shown in Figure 7-1. These links will assist project teams in identifying how the Critical Success Factors relate and coordinate to the planning model previously established by previous research. Appendix C contains figures detailing the entirety of changes made to the original 121-2 model.

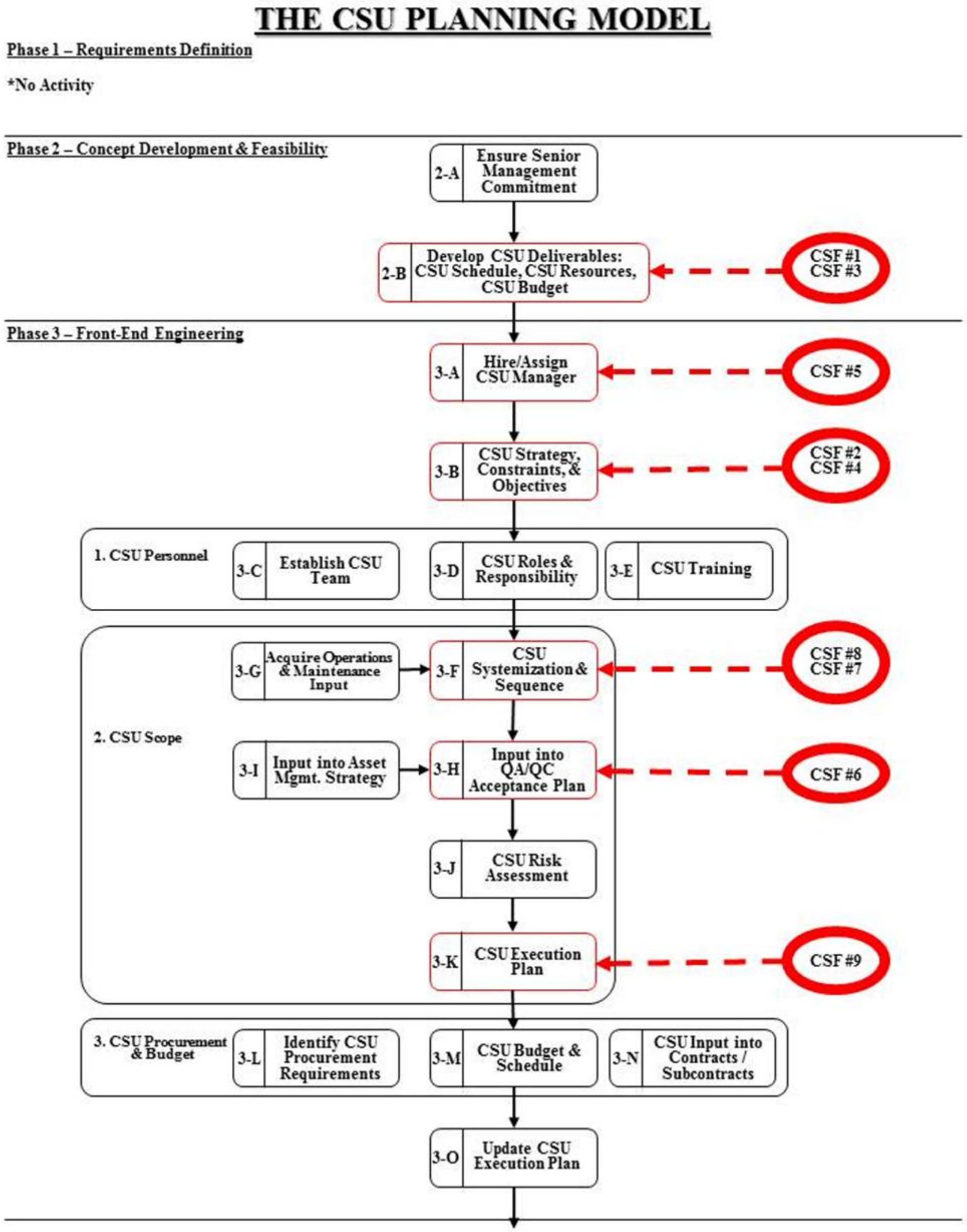
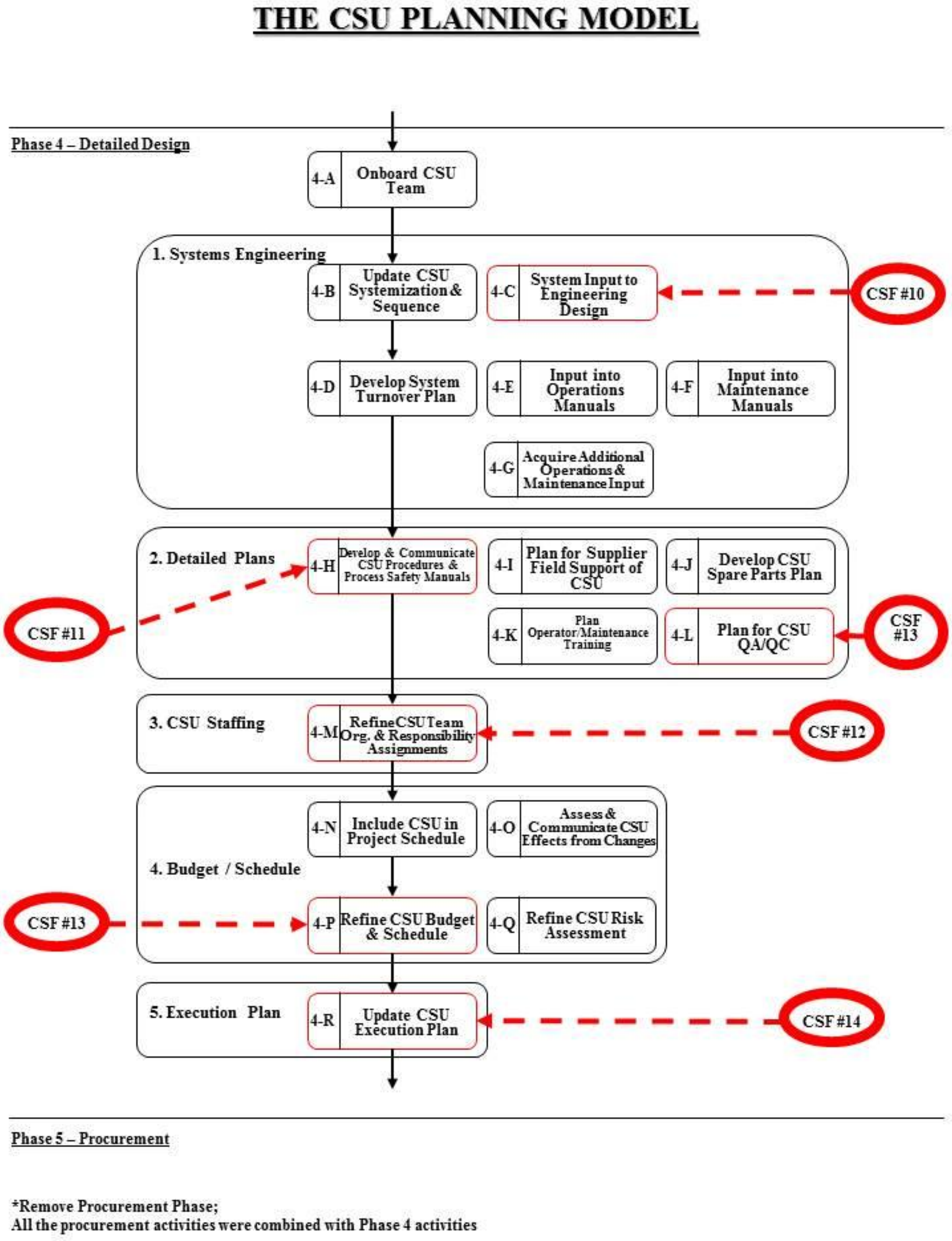


Figure 7-1: Modified *Planning for Start-up* Model with CSF Links



***Remove Procurement Phase;**
All the procurement activities were combined with Phase 4 activities

Figure 7-1: Modified *Planning for Start-up* Model with CSF Links, cont.

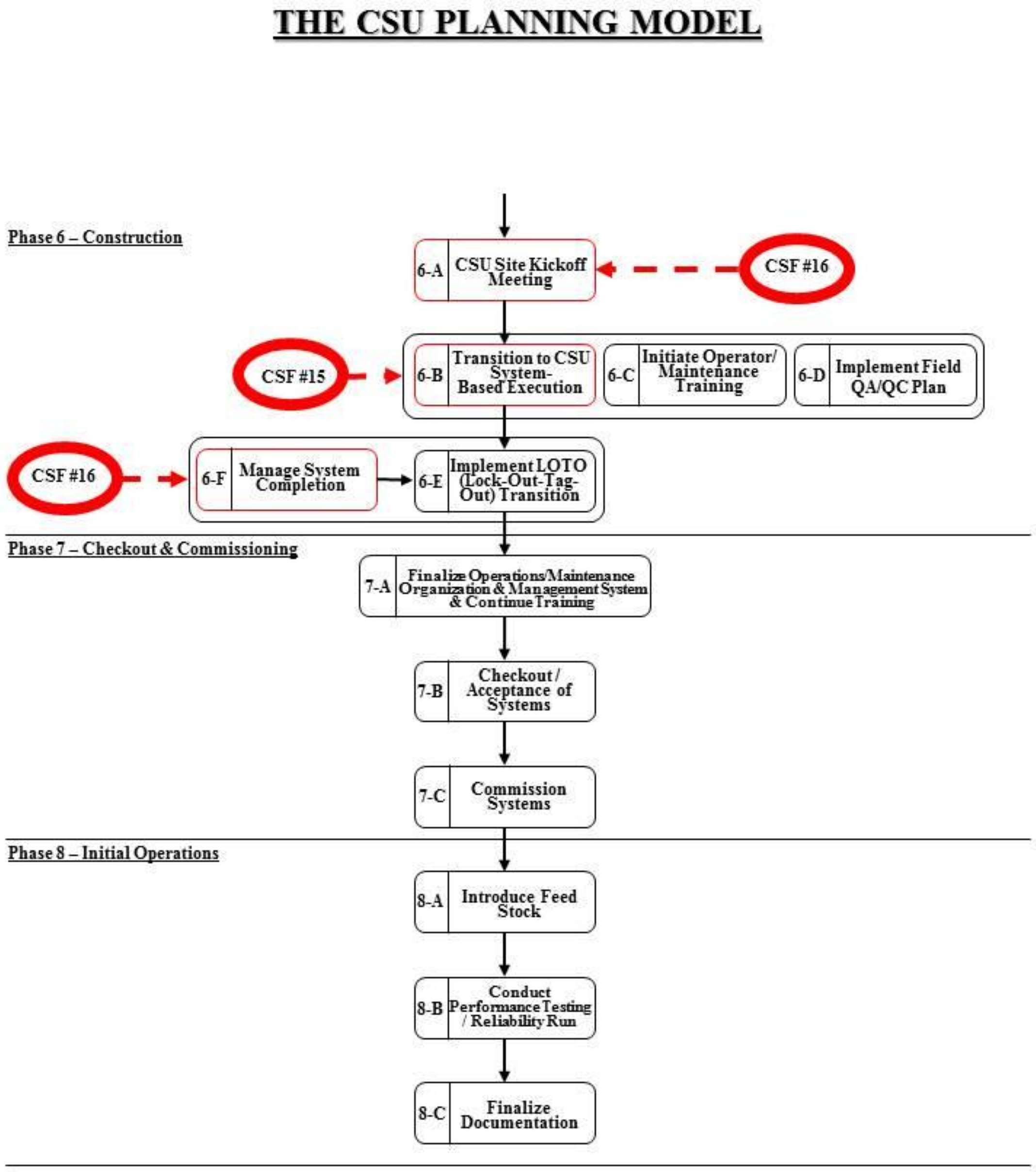


Figure 7-1: Modified *Planning for Start-up* Model with CSF Links, cont.

Table 7-1: Updated Status of 121-2 *Planning for Start-up* Model and Activities

Phase	Project Phase	Number of CSU Planning Activities						
		Original Model	New	Phase Transfer			Removed	New Model
				-	+	Combined		
1	Requirements Definition & Technology Transfer	1	0	1	0	0	0	0
2	Conceptual Development & Feasibility	3	1	3	1	0	0	2
3	Front-End Engineering	10	6	0	0	3	1	15
4	Detailed Design	15	4	0	0	4	1	18
5	Procurement	3	0	3	0	0	0	0
6	Construction	7	2	1	0	0	2	6
7	Checkout & Commissioning	3	0	0	0	0	0	3
8	Initial Operations	3	0	0	0	0	0	3
	Total	45	13	8	1	7	4	47

Chapter 8: Commissioning Failure Case Studies

8.1 INTRODUCTION

Knowledge and assessment of past CSU failures can offer additional insights into how to prevent such failures in the future, and thereby further ensure CSU success. To promote this continuous improvement process, four commissioning failure case studies were documented and analyzed. Summary-level descriptions of each case study are provided in this chapter. Identification of the critical success factors not achieved or achieved too late for each project are discussed. In-depth case study descriptions may be found in Appendix D of this document. These in-depth descriptions are organized in six sections: Project Description; Project and CSU-related Performance and Outcome; CSU-related Problems, Opportunities, and Contributing Factors; Impact of CSU Failure; Lessons Learned; and Links to CSFs.

On the 40-point CSU performance scale discussed in Chapter 3 & 9, the four failure case studies ranged between scores of 13 and 27 (with 30 points differentiating the More Successful CSUs from the Less Successful). Regarding common CSFs neglected among the case study projects, two CSFs were problematic for all four projects: CSF # 4 - Alignment Among Owner PM, Operations, CSU, Engineering, and Construction; along with CSF #11 - CSU Check-sheets, Procedures, and Tools. Three out of the four case studies also had difficulty with an additional three CSFs: CSF #13 - Integrated Construction/CSU Schedule, CSF #12 - CSU Team Capability, and CSF #9 - Detailed CSU Execution Plan. As with the six laggard CSFs presented in Chapter 6, these five CSFs also warrant special attention.

8.2 CASE STUDY A - PLANT X ENERGY CENTER

Table 8-1: Case Study A Summary

Project Sector:	Heavy Industrial - Power	**Project Size:**	$ 1 M
CSU Systems:	20	**Project Type:**	Brownfield
CSU Failure Description:	Coal-Fire Steam Plant with boiler feedpump turbine experiencing uncontrolled overspeed, resulting in significant damage to the turbine and surrounding equipment.		
Impact of CSU Failure:	Resulted in damage to turbine and surrounding equipment, threat to safety of personnel, and loss of schedule while turbine was replaced. Costs were $1.5M in repair components and an additional $7.5M in lost profit from potential sales.		

CSFs Not Achieved or Achieved Too Late

CSF #1 – CSU VALUE RECOGNITION

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

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

There was shown to be low level knowledge of the start-up across all stakeholders. This lack of alignment also led to failed oversight during the Instrumentation tuning and created an environment where high levels of communication were not achieved. Also pressure to meet the schedule created an environment where decisions were rushed.

CSF #8 – RECOGNITION OF CSU SEQUENCE DRIVERS

A lack of understanding of the primary sequences and procedures for start-up was present. Improper protocol and start-up sequencing was conducted, leading to pump failure.

CSF #9 – DETAILED CSU EXECUTION PLAN

Proper execution planning was not undertaken, with inadequate oversight and communication playing a large factor. No set procedures were defined and planning for the start-up neglected to allot enough schedule days. Proper sequencing was not followed due to a lack of planning.

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 start-up of additional equipment was allowed to proceed without proper milestones being met or achieved.

CSF #12 – CSU TEAM CAPABILITY

The CSU team did not have experienced personnel that were familiar with the feedpump turbine and controls. Also, a mechanical engineer was recommended to be on site by the controls provider, but this expertise was not included on the CSU team.

CSF #13 - INTEGRATED CONSTRUCTION/CSU SCHEDULE

The CSU schedule was feeling pressure to get the feedpump turbine up and operational, with the outage schedule being lessened. Proper allocation of time to perform a sound start-up and achieve all objectives was necessary.

CSF #16 - COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER

Collaboration should have been a top priority as the outage scheduled was reduced. Increased communication could have ensured proper protocols were met prior to start-up of the feedpumps.

8.3 CASE STUDY B - URBAN WATER PUMPING STATION

Table 8-2: Case Study B Summary

Project Sector:	Light Industrial - Water	**Project Size:**	$25 M
CSU Systems:	5	**Project Type:**	Brownfield
CSU Failure Description:	Potable water pumping station upgrade with replacement of three, 48” Butterfly Valves. A false alarm caused emergency shutdown of one active valve, while the other two valves were out of service. Resulted in rupture of 96” water line and rerouting of water in a major metropolitan area.		
Impact of CSU Failure:	Resulted in rerouting of water and loss of service to major urban center and possible threat to worker safety. Severe delays to project schedule, as well.		

CSFs Not Achieved or Achieved Too Late

CSF#2 - CRITICAL INTERFACES ON BROWNFIELD PROJECTS

A complete and thorough understanding of the existing facility operations and equipment is needed in all brownfield projects. Knowledge of interim operations, emergency protocols, and upstream/downstream impacts would have assisted in this start-up.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Early project alignment and planning was 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 a vast amount of technical expertise or input. The mechanical and process engineer 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 start-up.

CSF#5 – CSU LEADERSHIP CONTINUITY

The CSU team was also incomplete, without a single, continuous start-up manager to oversee Commissioning and Start-up on the Contractor's team. Requirements and qualifications for this manager were not defined in this project.

CSF#11 – CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

A lack of access to specification data, and the absence of check-sheets during start-up were a contributing factor to this failure. Functional checkouts were not performed prior to the installation of the actuators.

CSF #12 - CSU TEAM CAPABILITY

The CSU team was limited in the understanding of the original operating parameters of the existing equipment and plant. No expert knowledge from the plant operators was solicited during planning for start-up and unfamiliarity with the system led to the failure.

8.4 CASE STUDY C - PROJECT Y DOWNSTREAM CHEMICAL PLANT

Table 8-3: Case Study C Summary

Project Sector:	Heavy Industrial - Chemical	**Project Size**	$750 M
CSU Systems:	75	**Project Type:**	Greenfield
CSU Failure Description:	Downstream new Chemical Plant with over 2000 I/O's, 200 Control Valves, and 600 Transmitters. CSU was delayed due to lack of training and loop troubleshooting.		
Impact of CSU Failure:	Significant loss of production and associated cash flow (tens of millions of dollars); Extra time and cost required to achieve required product quality; Loss of contractor's substantial early start-up bonus.		

CSFs Not Achieved or Achieved Too Late

CSF#1 - CSU VALUE RECOGNITION

No member of the CSU team, including the CSU manager, knew the value recognition and procedures (or best practices and CSF's) to help achieve a bonus-level CSU accomplishment. As a result, the project achieved penalties due to delayed handover. Affordable CSU team training applied early and the use of a few supplier certified SME's at site, could have potentially saved millions of dollars.

CSF#3 - ADEQUATE FUNDING FOR CSU

The budget for Commissioning and Start-up lacked the necessary amounts of funding for a successful start-up. There was a lack of funding for both the CSU team and operator training. A small amount of expenditures could have potentially eliminated millions of dollars in lost revenue due to delayed plant operations.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Early project phase alignment, planning and development of training and key resources needs were not accomplished. Key issues, drivers, and strategies were not identified early in the project. The CSU team involvement was minimized until too late in project without effective collaboration. Also the owner made far more process changes that they had originally stated when what was initially indicated was a carbon copy plant to the existing plant. Project Management was also not aligned with its new Operating plant staff, and therefore Operations and Project Management had many clashes, delays in schedule, creation of excess costs, as well as an increase in risk. Understanding of TICC (Total Installed and Commissioned Costs) is crucial to the CSU mission of meeting the schedule of saleable product produced by owner at the promised date, grade and quality.

CSF#6 - SYSTEM MILESTONE ACCEPTANCE CRITERIA AND DELIVERABLES

Milestone acceptance criteria was vague and left gaps in the set up & test specifications. Milestone dates for completion and the required deliverables were ill-defined. These expectations were not well understood by the EPC prior to Commissioning and Start-up.

CSF#8 - RECOGNITION OF CSU SEQUENCE DRIVERS

Critical interfaces to the existing plant and availability of experienced operator resources when needed was not well planned. Recognition and even definition of key CSU sequences and sequence drivers was not well planned and discussed. A lack of communication of these drivers was also present.

CSF#9 - DETAILED CSU EXECUTION PLAN

Execution planning was conducted too late or not at all. The proper mix of skill in CSU craft and management was not achieved, with lack of contribution by the Plant Operators. There was no established plan for the multitude of training on instrumentation and the new security system.

CSF#11 - CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

System functional checkouts weren't performed for the security system. The criteria lacked scope, breadth, and depth to effectively achieve a functional system.

CSF #12 - CSU TEAM CAPABILITY

The CSU team lacked the understanding and knowledge of the multitude of CSU systems and did not possess the expertise to identify potential problems and concerns prior to Commissioning and Start-up, such as the need to incorporate SMEs.

CSF #13 - INTEGRATED CONSTRUCTION/CSU SCHEDULE

The Integrated Construction/CSU schedule was developed late, did not emphasize or encourage collaboration, and did not share with the key CSU team the Operations performance metrics and guarantees for the project.

CSF#14 - ACCURATE AS-BUILT INFORMATION

Without the adequate training of CSU team members, clearer roles and requirements, and the use of SME's, the asset management database was not properly loaded. The self-documenting As-Built drawings tool was only partially utilized and partially correct. The full benefit of As-Built information was not able to be utilized by the CSU team or plan operators.

CSF#16- COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER

There was a lack of a collaborative approach in regards to CSU in the beginning stages of the project. The CSU team was brought on too late to effectively work with system handover from the construction team. Conflict arose when systems weren't ready and training was ineffective.

8.5 CASE STUDY D - POWER GENERATING FACILITY

Table 8-4: Case Study D Summary

Project Sector:	Heavy Industrial - Power	**Project Size:**	\$100 M
CSU Systems:	40	**Project Type:**	Brownfield
CSU Failure Description:	Power Generating Facility with failure of a union coupling on a selective catalytic reduction ammonia forwarding line. High ammonia concentration was activated due to leakage in the line as a result of an incorrect coupling. A proper 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 flaw in using threaded union couplings on pressurized ammonia lines. Operator education and a more thorough understanding of the system could have potentially stopped the failure prior to it occurring.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Lack of alignment between Engineering, Construction, and Operations led to a gap in information that ultimately led to the ammonia leak. Collaboration was lacking during Engineering and Construction phases, which ultimately posed safety and environmental risks during Initial Operations on a brownfield project.

CSF #9 - DETAILED CSU EXECUTION PLAN

Plant operations should have been more thoroughly involved during Construction and reviewed system start-up procedures. Input should have been provided during the Construction phase and CSU. CSU staff required a more thorough understanding of operations and the need for specialized milestone acceptance criteria.

CSF#11 - CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

Functional checkouts for the Ammonia Forwarding Line were not adequate, and check sheet and detailed system commissioning procedures were ill defined. Testing of the ammonia line required more stringent tests than a standard leak test which was not defined to 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 be established prior to system start-up and initial operations. Development of supportive documentation, including proper test protocols, should have been listed for achievement 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, visual inspection could not be performed, therefore requiring reliance on accurate As-Builts. It was not discovered the union was incorrectly installed, until a leak occurred.

Chapter 9: Project CSU and CSF Assessment Findings

9.1 INTRODUCTION

With the critical success factors and indicators for CSF achievement defined, the research team collected actual project data to address the following questions:

- Are the 16 CSFs relevant to CSU performance?
- To what extent do CSFs contribute to CSU performance?
- Are the CSFs valid?
- Which indicators for CSF achievement are true differentiators between CSU success and CSU failure?

The research team sought to answer these questions by analyzing real project CSU performances and associated CSF implementation efforts. A survey of CSU managers was used to collect data on 26 projects – involving both projects with successful CSU and projects with unsuccessful CSU. Chapter 3 contains information on these project characteristics as well as methodology used. The projects are diverse in nature, involving a wide variety of project locations, responsible parties for CSU, project size and complexity, and industry sectors/sub-sectors. Appendix E contains additional support information and data used for this analysis.

9.2 COMMISSIONING PERFORMANCE OF PROJECTS

For the commissioning and start-up performance data, the team employed the CSU performance assessment model recommended in CII publication 121-2, Tool 3-A (CII 1998). This approach measures each of eight CSU criteria on a five-point scale – for a maximum score of 40 points. The CSU managers indicated how their projects performed on each of these 8 criteria. To be deemed a successful CSU, a score of 30 out of 40 was required on the commissioning performance. Appendix E contains additional data in regards to each individual projects' performance in this parameter.

9.3 CSF INDICATORS FOR ACHIEVEMENT ON PROJECTS

For the CSF implementation assessments, the team used the 45 Indicators for CSF Achievement previously described in Chapter 6 (which are worded succinctly so as to elicit simple Yes/No responses). These 45 questions were presented in randomized order and each CSU manager indicated if their project accomplished each indicator. From this data, the team was able to ascertain the indicators that were valid and those that separated themselves as true indicators for commissioning success. Appendix E contains additional data in regards to each individual projects' performance in this area.

9.4 SCATTERPLOT AND STATISTICAL FINDINGS

From the 26 projects, 15 of the projects were judged as More Successful (with > 30 out of 40 maximum CSU performance points), and 11 of the projects were judged as 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 leading indicators in predicting CSU success. These 25 indicators are associated with 13 of the 16 Critical Success Factors. The remaining three CSFs have relatively high proportions of "yes" responses, regardless of the level of CSU performance, thereby indicating a high level of consensus on their importance to CSU performance. Overall, the project data offers significant evidence of validation of the 16 critical success factors, and also offers valuable insight into meaningful leading indicators of CSU performance.

To determine the how dependent commissioning performance was to CSF implementation, a scatter plot for the projects was created (see Figure 9-1). Commissioning performance (defined by IR 121-2 Tool 3-A) is plotted on the y-axis and CSF Implementation (25 Top Indicators for Achievement) plotted on the x-axis. As a further examination, a regression analysis was performed of these results and resulted in an r-square value of 0.5758. This is interpreted as 57.58% correlation between the implementation of the Top 25 indicators for achievement and successful commissioning performance. This statistically significant relationship indicates that more than half the variation on commissioning performance can be explained by the Critical Success Factors.

The project data collected also provided some insights into specifically how the 15 More Successful project start-ups differ from the 11 Less Successful start-ups. Table 9-1 below summarizes the performance differences observed between the two project categories in the eight commissioning parameters.

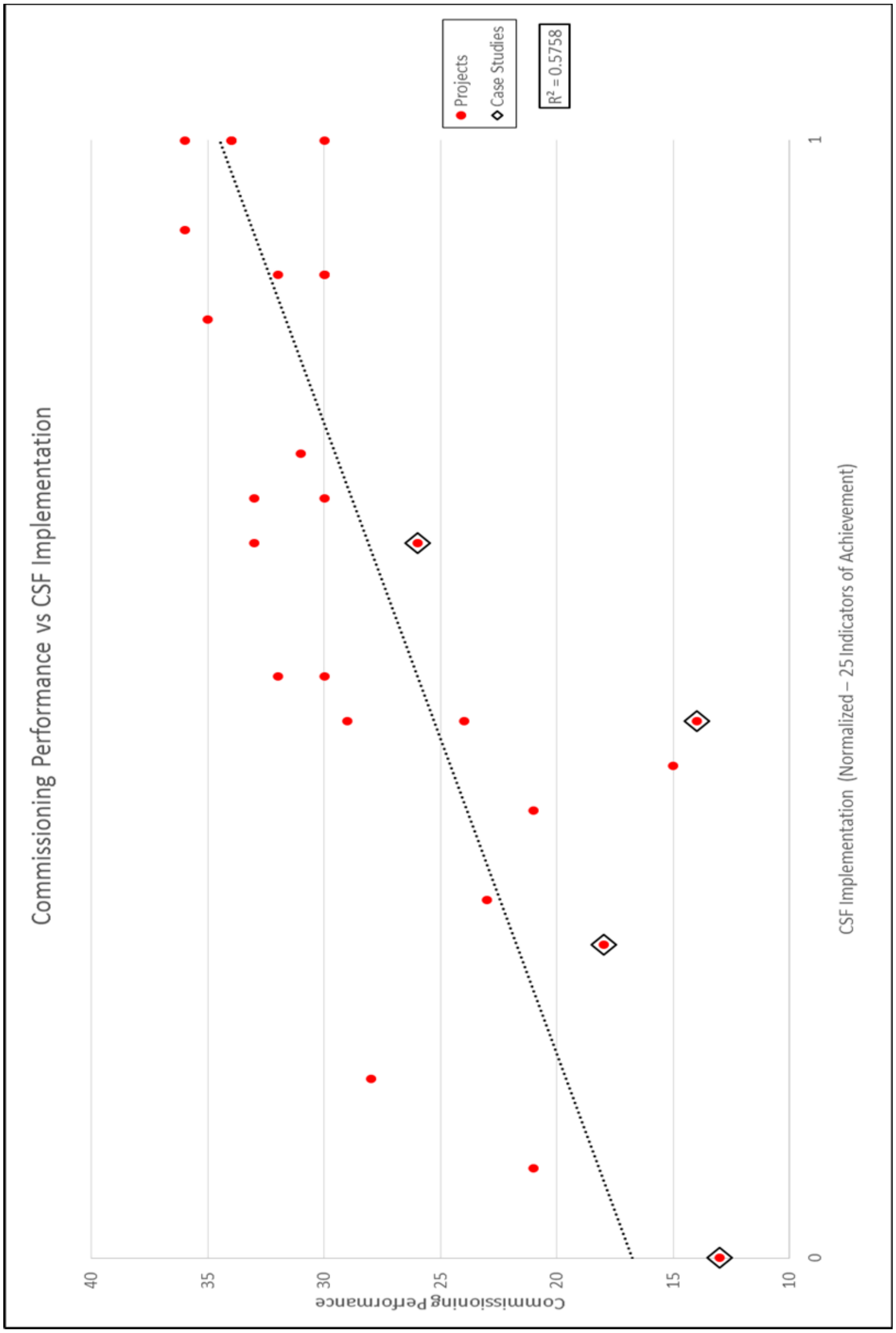


Figure 9-1: Project CSU Performance vs. CSF Achievement

Table 9-1: Performance of More vs. Less Successful Project Start-ups (n=26)

Level of Satisfaction for Criteria	**Project Sample Group**	
	Projects with MORE Successful CSU (n=15)	**Projects with LESS Successful CSU (n=11)**
MORE THAN Satisfactory	• CSU Safety Performance • CSU Environmental Performance • Product Quality • Product Quantity • CSU Schedule Performance • Operations Team Preparedness • Impact on On-going Preparations	• CSU Safety Performance • CSU Environmental Performance
Satisfactory	• Level of CSU Team Effort	• Product Quality • Product Quantity
LESS THAN Satisfactory		• CSU Schedule Performance • Operations Team Preparedness • Impact on On-going Operations • Level of CSU Team Effort

Chapter 10: Innovative CSU Technologies (ICT)

10.1 INTRODUCTION

Another key finding from this research was the identification and characterization of five innovative commissioning and start-up technologies. Each of these innovative CSU technologies (ICTs) facilitate CSU information management in ways that can significantly influence 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 10-1 provides an overview and summary of the five ICTs. Full descriptions of each technology are provided later in this chapter.

Each ICT has the following sections detailed:

- Technology Objective
- Functionality of Technology
- Benefits to CSU
- Project Phase Implemented
- Providers or Suppliers (listed alphabetically)
- Current Technology Maturity
- Implementation Challenges
- Key Terms (where relevant)
- Success Stories
- References

Table 10-1: Innovative CSU Technologies (ICT) Summary

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 start-up and allows for understanding of system integrations and relationships.	At the commencement of Front-End Engineering through the initial phases of Detailed Design.
B. BIM Design Models/ 3D Models	To 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.

Table 10-1: Innovative CSU Technologies (ICT) Summary, cont.

Technology	**Objective**	**Benefit to CSU**	**Timing**
C. Asset Data Management/ Wireless Instrumentation	Provides CSU Personnel more pervasive and useful plant measurement data (both wired and wireless), while reducing overall installed and commissioned costs.	Enables easy creation and updates of a common database with which to better manage instrumentation/ control devices. Access to assets in real-time, with simplified, easily configured devices. Automated processes and diagnostics speed up commissioning, eliminating human interaction and speeding up start-up.	Implemented in early phases of Front-End Engineering and continued through to Initial Operations.
D. Simulation-Based Virtual Commissioning & Operator Training	Simulators for virtual commissioning and training for main DCS, PLC, & SCADA systems.	The system may be simulated for detailed tests in a life-like environment, allowing for extensive engineering checkout and virtual commissioning of equipment, machines, and processes. This simulated environment also allows for operators to be trained prior to CSU and Initial Operations. Cost savings and shorted start-up schedule among the many benefits.	Applied at the start of Detailed Design and continued through completion of Checkout & Commissioning

Table 10-1: Innovative CSU Technologies (ICT) Summary, cont.

Technology	**Objective**	**Benefit to CSU**	**Timing**
E. Completion Management System	Software to track CSU system and equipment statuses for more efficient CSU performance. Allows for understanding of current status and progress of CSU system completion.	Allows for the collection and gathering of data, remotely in the field using mobile technologies and cloud-based systems. Consolidates data on all systems, in a single and updated database. Manageable, reliable, and consistent documentation creates an auditable trail and helps to reduce error. Reduced project costs through reduced start-up, handover, and improved efficiencies.	Initiated in the early stages of Detailed Design and continued through completion of Checkout & Commissioning.

10.2 TIMING RECOMMENDATIONS

Many of the benefits from this technology application are directly related to the timing of application. Based on in-depth research team discussions, Figure 10-1 illustrates the recommended timing of application for each of the identified technologies. The timing is mapped across the project phases established in the early stages of the study and also used in the timing of CSF implementation graph. The ICTs are organized by timing of initiation. BIM and Asset Data Management have the benefit of being able to be initiated early in the project, and to continue offering valuable assistance into Initial Operations. As the figure shows, all ICTs are spread across at least two project phases. Their use and proper implementation can assist in improving CSU performance.

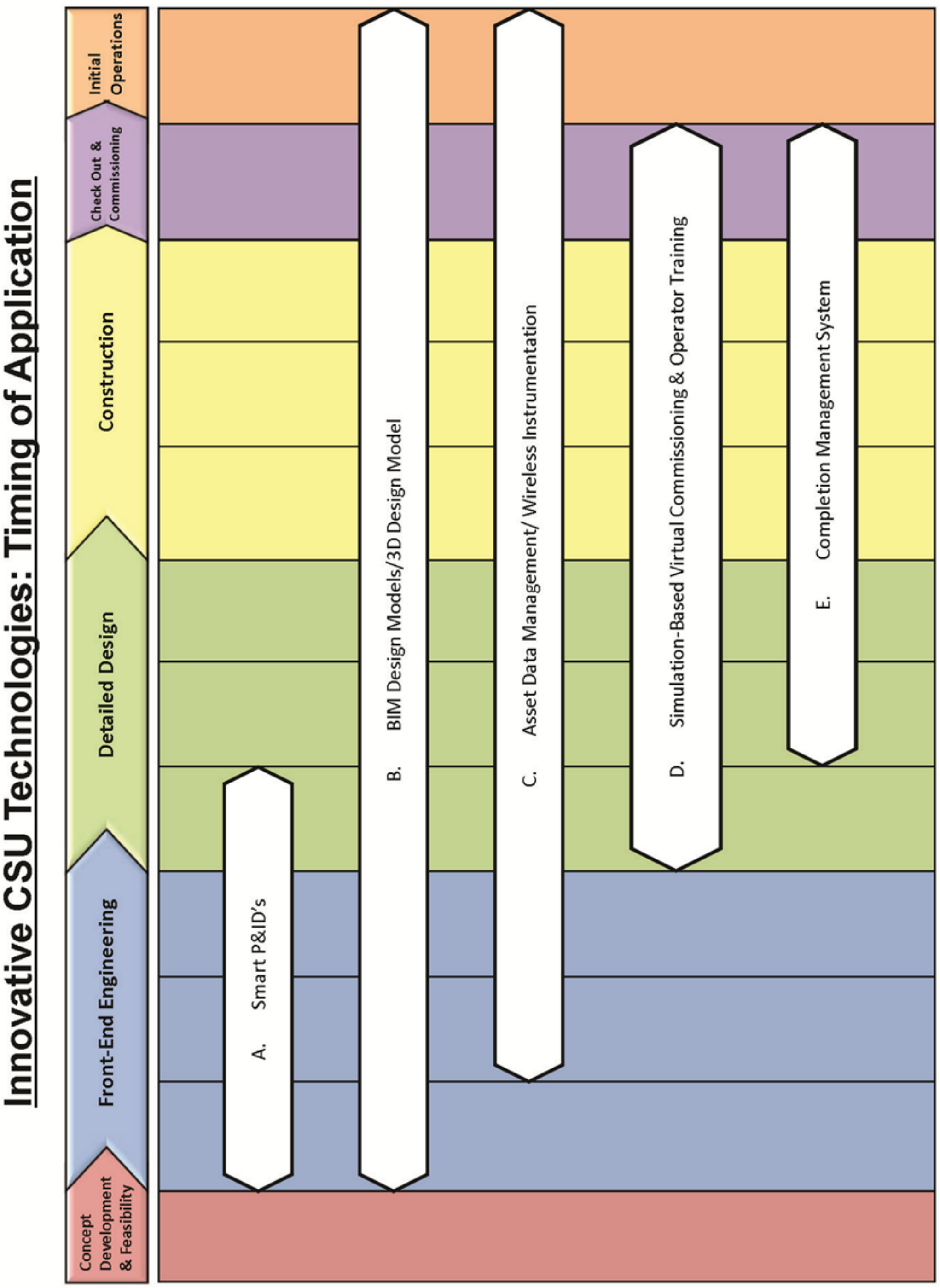


Figure 10-1: Timing of Application of ICTs

10.3 SMART P&IDS

Technology Objective

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

Functionality of Technology

Allows for complete and accurate Piping and Instrumentation Diagrams to be generated, modified, managed and improved through 2D and 3D CAD modeling 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 (BIM modeling) for coordinated access by CSU personnel.

Benefits to CSU

Smart P&ID models can be 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 start-up and allows for understanding of system integrations and relationships. The technology helps to ensure accurate information during evolving designs and deviations in the field. Also allows for a systemization/isolation and controls model to examine systems in a standalone environment. The technology also has an ability to shorten commissioning and start-up timeline by providing accurate as-built and in-field conditions.

Project Phase Implemented

Smart P&ID initiated during early Front-End Engineering and continued into Detailed Design, with necessary updates through Construction and Checkout & Commissioning. Smart P&ID data is integrated and imported to central databases prior to CSU. Information from the P&ID can later be utilized by the facility owner during operations.

Providers or Suppliers (listed alphabetically)

1. Autodesk – AutoCAD P&ID
2. Bentley – AutoPlant P&ID V8i & OpenPlant Power PID
3. Intergraph – SmartPlant P&ID

Current Technology Maturity

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

Implementation Challenges

Beginning with Front-End Engineering, through Detailed Design and As-Builts to ensure data is accurate and current. Setup of System/Sub-system 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 data has been transferred to CSU database properly.

Key Terms

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

Success Stories

Plant Radcliffe Project – Kemper County, Mississippi

- \$2.8B clean-coal power generation plant, generating 582 MW and reducing carbon dioxide emissions 65% 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.
- Start-up and Commissioning team saved over 36,000 man-hours in the CSU phase, equivalent to \$2M.

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 via a single portal

- The traditional handover of information was adjusted from tremendous handovers of data to a progressive delivery at regular intervals during construction. This allowed operational staff to have access to data well before plant operations, resulting in smoother start-up and commissioning.

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10.4 BIM/3D DESIGN MODELS

Technology Objective

To 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

Delivers complete, accurate, and connected digital information on 2D and 3D-based models over the project life cycle. 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 available project-wide prior to and during CSU. Equipment and systems tagged with specific bar codes or identification, allowing for in-field lookup of related information and documents.

Direct CSU functions supported by BIM/3D Modeling Systems

- Automated and accessible test reports, punchlists, etc….
- List of procedures and protocol
- Access to equipment and systems data sheets, manuals, warranties, etc….
- Reporting capabilities and quality documentation
- Issues and conflict resolutions
- Systems completion processes

Benefits to CSU

The technology assists in tracking safety, quality, and commissioning processes by minimizing error prone procedures, providing coordinated and consistent links to information and documentation, and promotion of collaboration among the interconnected teams and systems critical to CSU operations. Mobility in the field allows for speed and accuracy in the decision-making process while either disconnected or via web browser. The technology can lead to improved and efficient handover to CSU by linking models and documents during construction into a single digital asset.

Models built and maintained during construction can assist personnel during CSU to quickly bring facilities into operational status, while reducing costs and delays. These models and electronically-organized data can later assist the owner in long-term facility operations by consolidating useable deliverables (O&M Manuals, maintenance schedules), rapid data transfer, and lowered operation start-up costs.

Project Phase Implemented

Initiated in Front-End Engineering and continued throughout 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)

1. Autodesk – Revit, BIM 360, & Navisworks
2. Bentley - ConstrucSim & Facilities v8i
3. Innovaya - Innovaya Visual BIM
4. Onuma - Onuma System
5. Solibri - Model Checker
6. Tekla - BIMsight

Current Technology Maturity

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

Implementation Challenges

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

Key Terms

- AIA E202 BIM Level of Development Standard – Establishes responsible authors for each element of the model at each project phase. Also defines the extent at which the model may be used by later users, including contractors and owners. 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 goals and application of BIM, 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 planning of the project team in 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, spare parts lists, etc.

- Industry Foundation Classes - 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, MA

- Expansion of power Cogeneration 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
- owner able to save schedule and costs by information provided in an orderly and accessible fashion – not just "piles of paper or CD's"
- Facilities able to be started up more quickly by digital data delivery and easy locating of O&M Manuals, product data, and operation procedures.

Health Complex – San Antonio, TX

- New hospital tower with supporting infrastructure. BIM implemented for field commissioning.
- Facility went from 4-6 months for start-up to 4 days, with data available in a structured manner.
- Owner now exploring 3-year plan to model all existing facilities.

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10.5 ASSET DATA MANAGEMENT AND WIRELESS INSTRUMENTATION

Technology Objective

Manufacturing process, 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, 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. This information enables avoidance or quick correction of such issues by the CSU team. The wireless approach allows for easy inclusion of additional monitor points, with reduced material requirements and reduced module weights.

The technology enables easy creation and updating of the asset database with which to better manage instrumentation/control devices. The technology automatically associates/updates user-defined parameters for individual (or groups of) 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 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 problem trouble-shooting.

Benefits to CSU

Safer and more efficiently executed CSU and Operations are the key benefit from 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 operator human interaction. Predictive diagnostics serve to reduce operational risk. Implementation experience provides evidence of approximately 50% reduction in field device configuration and commissioning, and 30% reduction in facility start up. After 30 minutes to 1 hour per device for setup/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 quickly establish device alerts 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 conduit to wireless monitoring devices, resulting in 40-60% 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 along with material and labor costs. For example, installation time is approximately 15 min./wireless point and 30 min./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)

1. ABB
2. Emerson
3. Siemens
4. Yokogawa
5. 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 over five million asset management system-/diagnostics-based installed devices, both on- and offshore. Wireless devices have been IEC 62591-globally certified for more than eight years. Over 25,000 gateways and over 1 million wireless devices are in place today in every industry around the world.

Implementation Challenges

The development of new commissioning, start-up, and maintenance practices is necessary to obtain the maximum potential of asset management tools. These new approaches and methodologies are crucial in 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 fully port 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 start-up results.

Key Terms

- Asset Management Software (AMS) – Software and associated self-diagnostic tools designed to aid in the installation, checkout, commissioning and start-up 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 reducing risk and safety concerns. Equipment served should include both wired and wirelessly connected assets of all types.
- Device and Equipment Portal – Ability to tag, reference, and/or point-and-click on devices in the facility that immediately provides personnel access to a device, its current setup and calibration, reported diagnostic health, and issue-solving recommendations automatically being suggested from the devices intelligent database tools.
- Device Manager – A flexible CRT and/or tablet-based human interface software tool that allows one to add device tags, calibration information, tracking information, and print out/electronically transfer as-built documentation. The device manager is able to communicate in real-time to 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 via wired and wireless instruments. Some Examples include weak or lost air supply, low power module alert, or excessive speed alert.
- Gateway(s) – Wirelessly connects up to 100 wireless field devices and passes both measurements and device diagnostics to distributed control systems and asset management monitors/tablets.
- Mobile Worker Screens – Wireless tool/hardened safe tablet to investigate diagnostics and calibrate field devices and rotating equipment
- Operating Equipment – Operating equipment particularly appropriate for integration with asset management systems and wireless diagnostics include 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, bearing temperature profile along with tank level dropping indicates motor and pump set will fail in one of several modes: "Very Soon" – requires attention immediately; "Soon" – over the next 1-2 months; or "Proceed As Planned" – repair during next scheduled shut down.

Success Stories

Chemical Plant

- With 100 field control valves and transmitters, staff decided to utilize AMS software, databases, and mobile worker CRT's in lieu of older technology. Device setup time was reduced from the 90 min. per conventional device setup time down to 15-30 minutes per device, with documentation available immediately. Also increased worker safety, as no personnel were required in high or dangerous locations.

Large Oil Field Development Project

- Plant start-up was two weeks sooner than if conventional technologies had been used.
- Project utilized wireless devices on approximately 15% of their monitoring points, with the opportunity for quicker start-up and accommodation of last-minute changes by process engineers. Average savings of $2000/device, with over 600 devices, for a total savings of $1.2M.
- Chief Engineer with 37 years of experience stated it was the smoothest start-up he had witnessed, with an estimated 2-3 months of schedule savings. He planned to increase wireless devices from 15-30% on upcoming projects.

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10.6 SIMULATION-BASED VIRTUAL COMMISSIONING AND OPERATOR TRAINING

Technology Objective

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

Functionality of Technology

Plant control systems can be tested life-like environments, allowing for 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 of implementation and can assist in ascertaining the time needed for commissioning. For this purpose, a simulation model of the actual site is created, which is connected directly to PLC's, allowing for testing the interface between PLC and 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 start-up time and elimination of potential conflicts. Minimal investment to establish a simulation-based commissioning and training program compared to overall CSU budget.

- 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 start-up, with some commissioning times being reduced by 20%-50%. Minimized use of resources and minimum-wear lifespan of the plant during commissioning and start-up, with maximized production profit by ensuring high availability from initial start-up.
- Allows for complete and accurate simulation of the control systems, allowing for modifications to 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 start-up.
- Testing of DCS and PLC prior to implementation phase, with earlier refinement of the DCS's library of function blocks.
- Ability to create a standalone and safe simulation environment for systems commissioning feedback, with future operators being trained using this tool to visualize the pseudo, real-time equipment, operations procedures, and fault management.
- The simulation system is based on real experience of the operators and engineers in the field, which 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 onset of Detailed Design. Training simulation itself should occur during Construction.

Providers or Suppliers (listed alphabetically)

1. Emerson – Ovation Simulation Solutions
2. Rockwell Automation – Allen-Bradley
3. Siemens – SIMIT & Tecnomatix® Plant Simulation
4. TRAX
5. WinMOD (Germany)
6. 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 strongly on how the emulators are implemented. Thorough analysis of the internal data structure is necessary to be able to correctly decide 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 at began 3 weeks ahead of schedule due to simulation software playing a central role in testing and start-up phases of the project.
- Use of the simulator facility provided good safety routines in the process, as well as significant savings in the start-up period of the facility.

Repowering Project – New York

- Utilized virtual simulators and commissioning software to train operators on plant processes and controls
- Safe and efficient plant start-up, reducing the commissioning time from 4 months to 1 month.

Nuclear Power Plant

- 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 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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10.7 COMPLETION MANAGEMENT SYSTEMS

Technology Objective

This software can track CSU system and equipment progress/status for more efficient CSU performance. The technology allows for understanding of current status and progress of CSU system completion, along with automation of equipment/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 (system stats), physical progress, or punchlist items progress. CMS also allows the user to obtain real-time data in the field (i.e. product data, punchlists, start-up 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 to occur frequently and quickly (in real-time). With this approach, tablet PCs can serve as test equipment to verify system readiness. CMS can also be combined with existing 2D and 3D BIM software, providing a valuable link to design models.

Benefits to CSU

The technology allows for the collection and gathering of data, remotely in the field using mobile technologies and cloud-based systems. It consolidates data on all systems, in 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 to reduce error. Reduced project costs through reduced start-up, handover, and improved efficiencies.

Project Phase Implemented

Should be planned for during Detailed Design and implemented in Construction phase until CSU completion. Upload of system documentation to occur during installation and testing phases, with updates as required through commissioning.

Providers or Suppliers (listed alphabetically)

1. Autodesk – BIM 360 Field
2. Complan (Norway) - WinPCS
3. Epic Management Resources – EPICom
4. Gate – GCS
5. Intergraph – SP Completions
6. Omega (Norway) – PIMS
7. Orion Group (UK) – Orbit (OCCMS)
8. QEDi/AMEC (UK) – GoCompletions (GoC)

Current Technology Maturity

Some suppliers have had the software in use since the 1980's and has been used on hundreds of capital projects ranging in price from \$100M to \$40B. 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

Upload of data and proper assignment 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) printed on a paper document, then record the document and update its status within the database.
- Briefcasing – In the table below, refers to the 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 "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 – Refers to the ability of a CMS to track and report preservation records/documents.

Success Stories

LNG Facility – Papua New Guinea

- $20.5B Liquefied Natural Gas (LNG) project, constituting the single largest resources investment in Papua New Guinea, with over 9 trillion cubic feet of natural gas expected to be produced over the facility's lifespan.

- 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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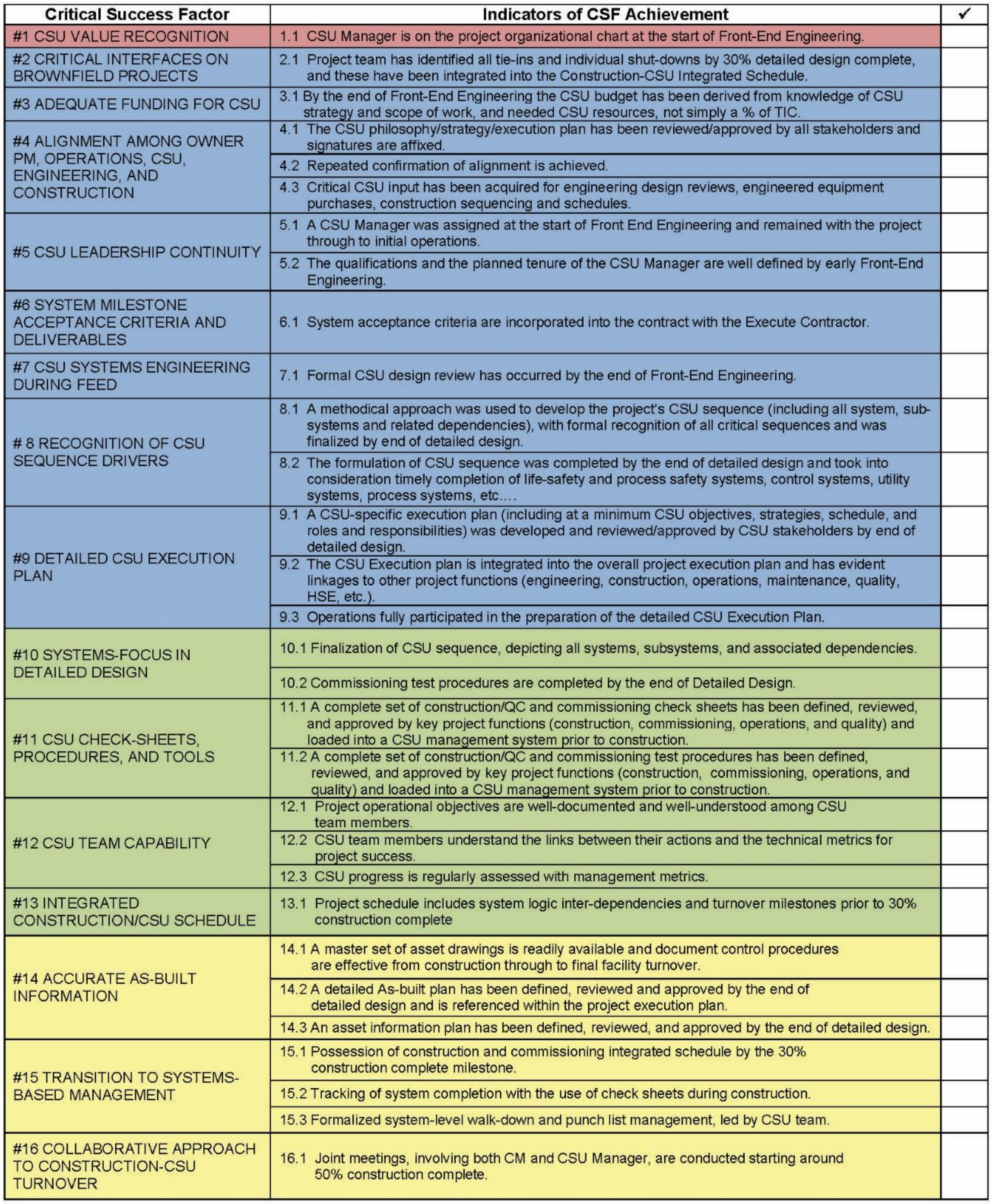
Chapter 11: Checklist Tool

To further support increased industry awareness and implementation of the CSU critical success factors, a simple 2-page tool was devised by the research team, based on key study findings. The checklist tool conveys four types of information:

- Listing of the 16 Critical Success Factors
- Most influential Indicators for CSF Achievement (top 30)
- Timing of implementation of CSFs
- Innovative commissioning tools and their timing of application

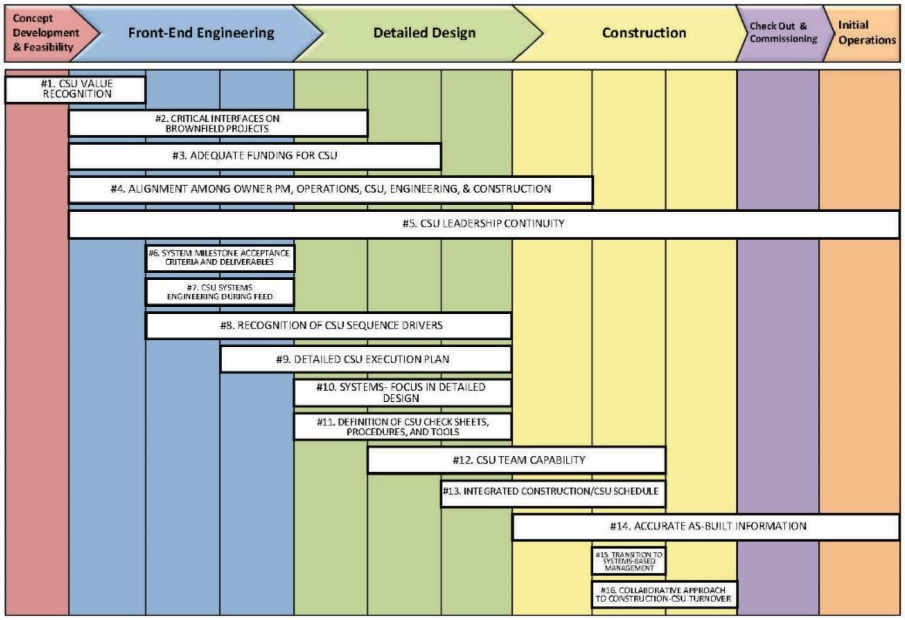
The checklist can be used in the early phases of the project to assist in proper planning and implementation techniques. The checklist may also be used as the project progresses to ensure CSU performance is meeting objectives and expectations. The checklist may be seen on Figure 11-1 (page 1) and 11-2 (page 2).



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% 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 % 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, sub-systems 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, process systems, etc….	
#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, HSE, etc.).	
	9.3 Operations fully participated in the preparation of the detailed CSU Execution Plan.	
#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% 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% 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% construction complete.	

Figure 11-1: CSU Critical Success Factor Checklist (page 1)

CSF Implementation Timing



Innovative CSU Technologies: Timing of Application

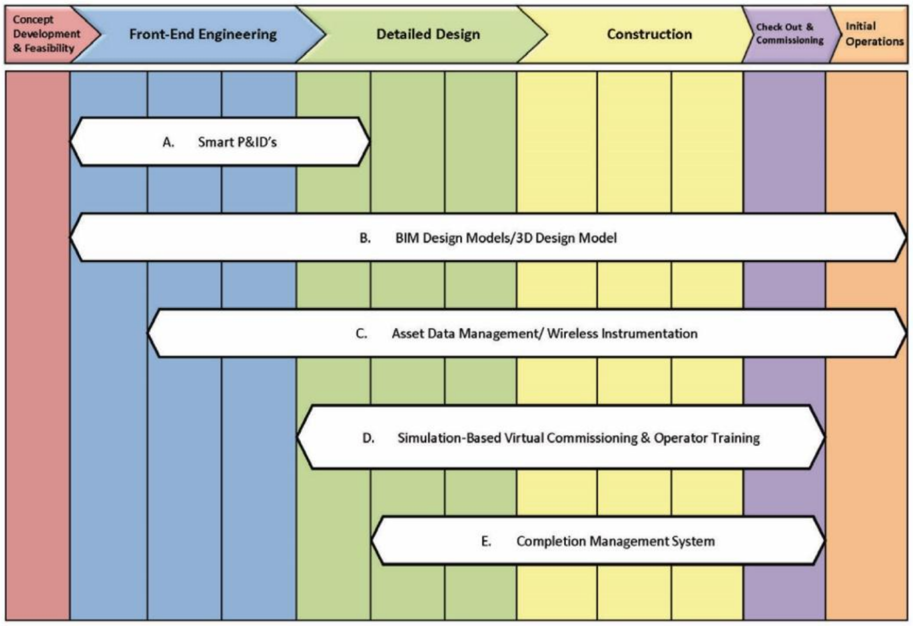


Figure 11-2: CSU Critical Success Factor Checklist (page 2)

Chapter 12: Conclusions and Recommendations

12.1 CONCLUSIONS

Commissioning and start-up success is a requirement for any capital project venture to be successful. Yet, success remains elusive for many projects, particularly for large projects. Achieving CSU success was the focus of this thesis. Sixteen critical success factors were rigorously established and examined in this research in support of that goal.

The team was also able to establish the CSF's relationship to past CII Pub. 121-2, CSF's links to four failed commissioning projects, as well as frequency and timing of CSF implementation. Recognition of barriers to achieving CSF implementation is also a major contribution. Indicators for achievement were developed to provide awareness of CSF implementation requirements. Technologies to improve CSU performance were identified and are also a powerful tool for CSU teams and experts. A checklist tool is provided and will assist CSU teams in assessing their preparation, planning, and status of their respective CSUs. The most significant finding was the validation of the CSFs and their respective indicators of CSU performance. Examining real project data, a statistically significant correlation was shown between implementation of the CSFs and successful CSU performance.

Implementation of these 16 CSFs has been shown to greatly enhance CSU performance. These CSFs are accomplished through early planning and alignment by the entire project team. Project teams (and their clients) should benefit substantially by applying these findings.

12.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the learnings from this study, recommendations have been categorized below. These future studies should allow for better understanding of commissioning and start-up of capital projects.

- Update and modify CII Pub. 121-2 per the discussion in Chapter 7 of this document.
- Review, revise, expand, and update the CSU support tools provided in CII Pub. 121-2.
- Conduct further research regarding the construction-to-CSU turnover, focusing on the transitional phase between these two activities.
- Further align the terminology for activities, functions, roles, and milestones for CSU across industry sectors.
- Further develop emerging technologies that have potential to enhance CSU performance, such as BIM support tools for CSU.
- Conduct more industry research to determine root causes for widespread failed CSU performance across the industry

Appendix A - Survey Assessment Forms

1. Survey of CSF Impact Assessment - *Commissioning and Start-up Critical Success Factor Analysis (Ver. 7).*

2. Survey of Frequency of CSF Accomplishment - *CSU CSF Frequency Assessment (Ver. 4).*

3. Project CSU & CSF Assessment Survey - *Commissioning and Start-up (CSU) Performance and Indicator Assessment.*

4. External Panel Validation of Findings Survey - *RT 312 Best Practices for Commissioning & Startup Implementation Resource: Feedback Form.*

Commissioning & Startup Critical Success Factor Analysis (VER. 7)

TECHNICAL DESCRIPTIVE BACKGROUND **DATE:**
Name: **Current Position or title:** **Yrs of CSU experience:**
Most recent role related to CSU: ( ) leader role / ( ) support role **Phone:** **Email:**
Company Name: **Type of Company?** ( ) Owner /( ) Contractor / ( ) Supplier
Most Common Industry Sector or Sub-sector:

FOR EACH ITEM, PLEASE PUT A CHECK (☑) IN 1 OF THE 7 COLUMNS PROVIDED.

FRAME OF REFERENCE

- **Critical Success Factors (CSF)**: a strategic decision, action, or activity that contributes significantly to C/SU/IO performance success. Thus, CSFs represent high-priority OPPORTUNITIES with strategic benefit.
- **Innovative Future Practices (IFP)**: new CSU applications that are derived from emerging innovations. These applications will likely someday be keys to future step-wise advancement.
- **Standard Operating Procedures (SOP)**: Established basic tactical procedures common to most projects; Very specific; "How-to" oriented; Fundamental to CSU execution

		Check ONLY 1 of 7 Columns						
#	**Potential Critical Success Factor (CSF)**	**CSF**				**NOT CSF**		**No Opinion**
		Least Critical	**Low to MID**	**MID to HIGH**	**Most Critical**	**Innovative Future Practice**	**Standard Operation Procedure**	
	1. CSU Governance/Assurance							
1	OWNER'S CSU ASSURANCE REVIEWS CSU assurance reviews by the project owner should be planned and executed in multiple iterations starting in FEL3/FEED and running until commercial operations							
2	TURNOVER PACKAGE REVIEWS Each CSU discipline lead needs to conduct an independent review of construction turnover packages for completeness.							
3	ALIGNMENT ON MEANING OF CSU SUCCESS The definition of CSU success should be fully aligned with all key project drivers. Lack of alignment may pose a threat to CSU success.							
4	CSU TEAM CAPABILITY CSU team has a good understanding of the facility operations performance metrics-oriented requirements and guarantees, and develops appropriate plans for testing							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
5	GOVERNANCE SIGN-OFFS Governance by technical authorities should occur at two different signoffs: construction to commissioning and startup to operations.							
2. CSU Planning & General Management								
6	CSU VALUE RECOGNITION Establish the business case (including CSU staffing plan) for effective CSU leadership. Recognize the value added from successful CSU (value of 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							
7	ALIGNMENT BETWEEN OWNER-PROJECT MGMT AND OWNER-OPS Sustained alignment between Owner-Project Management and Owner-Operations is a critical requirement for CSU success. This alignment can only be achieved with effective collaboration throughout the life of the project							
8	ALIGNMENT OF CSU WITH ENGINEERING AND CONSTRUCTION The project and CSU will benefit substantially by getting early alignment with Engineering and Construction on CSU systems sequence and related requirements.							
9	ALIGNMENT ON CSU STRATEGY Alignment on CSU strategy and milestones is needed among all key project parties (design, procurement, construction, CSU, and operations).							
10	ALIGNED COMMON UNDERSTANDING CSU effort will benefit substantially from an aligned common understanding of CSU terminology, milestones, systemization, turnover criteria, certification criteria, and test documentation.							
11	CSU AS PROJECT SCOPE DRIVER Timely consideration of CSU as a project scope driver is needed. Scope definition tools (such as PDRI) should address CSU elements.							
12	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.							
13	PROJECT PLANNING & CSU PLANNING INTEGRATION Seek to integrate project planning with CSU planning. Critical linkages include achieving construction quality milestones by area/discipline and systems completion progress tracking							
14	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.							
15	CSU & 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.							

		Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		
#	Potential Critical Success Factor (CSF)	Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	No Opinion
16	CSU-DRIVEN CONSTRUCTION The CSU plan should be treated as a prerequisite for planning and starting construction. Construction should be commissioning-driven.							
17	DETAILED CSU EXECUTION PLAN IN TIMELY MANNER A detailed Commissioning/Handover Execution Plan is prepared in a timely manner so as to be highly useful to the CSU team (draft #1 complete during FEED)							
18	ADEQUATE EXECUTION PLANNING STAFFING & RESOURCES Recognize that CSU activities are an integral part of capital project delivery (rather than operations), and therefore require the same degree of execution planning, including planning for the specific skill mix necessary in both craft and management.							
19	SPECIAL CSU STAFFING SUPPORT Adequate staffing resources and planning efforts to support CSU, including temporary equipment, spares, and specialty services pertaining to CSU.							
20	SYSTEMS COMPLETION DELIVERABLES AND ACTIVITIES Develop a well-defined structure of Systems Completion execution deliverables and activities.							
21	ESTABLISHMENT OF CSU PROCEDURES Establish and approve pre-commissioning/commissioning procedures during FEED, with timely and active participation of the O&M leadership.							
22	RECOGNITION OF CSU SEQUENCE DRIVERS Coordinate with construction planners and managers for construction support during commissioning. Recognize sequence drivers, critical activities to coordinate, clean-build procedures, sequence of flushing (area & system coordination), sequence of leak/hydro testing, preservation steps, system tagging, sequence of loop checks, etc.							
23	TIMELY COMPLETION OF SUPPORTING PROJECTS Timely completion of CSU support infrastructure and other supporting projects for necessary utilities, materials handling, logistics, etc. The project integrated schedule should indicate key related milestones for these projects.							
24	READY TO START COMMISSIONING Confirm that ready-to-start-commissioning includes readiness of physical plant and readiness of people							
25	EFFECTIVE CHANGE MGMT PROCESS Late changes to CSU are to be avoided thru effective change management process. Only changes required for operability, safety, or regulatory compliance are allowed after the 30% model review.							
26	3-DAY CSU PLAN WITH DAILY UPDATE Plan detailed CSU activity with a 3-day plan that is updated daily: work accomplished yesterday, work to be accomplished today, and work to be accomplished tomorrow							
27	COLOR-CODING/DOTTING OF EQUIPMENT/COMPONENTS Color-coded highlighting of components shown on system schematics is a useful way to document progress status at a detailed level. Likewise color-dotting of equipment/components can be an effective way to visibly and physically denote CSU progress status							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
28	COMMISSIONING WORK AUTHORIZATION A commissioning work authorization document is a useful tool to track contractor rework hours required for warranty work needed to fix equipment defects.							
29	TEMPORARY SUPPORT OF TESTING Use temporary utility systems on systems/equipment to prove component performance at the earliest possible opportunity.							
30	SYSTEMS COMPLETION DATABASE Establish and maintain a systems completion database, ensuring that all changes in engineering data are reflected in the system.							
31	PLANT MANAGER RESPONSIBILITY It is the responsibility of the plant manager to convey the importance of timely, effective CSU planning to plant operators.							
	3. CSU Team Organization Staffing/Roles/Involvement							
32	CSU ORGANIZATION CHART The CSU manager should report directly to the project manager, not to the construction manager or operations manager.							
33	CSU SYSTEM LEAD CAPABILITIES Each CSU system lead is a critical role that should be skilled in all facets of the system type							
34	CSU LEADERSHIP CONTINUITY Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.							
35	EARLY CSU INVOLVEMENT IN DESIGN CSU involvement in design should start with development of the first P&IDs. The related skills of operations staff for this early input need to be deliberately cultivated.							
36	SYSTEMS COMPLETION TEAMS Early formation of systems-completion teams, from both Owner and Contractor sides							
37	CSU RACI CHART Define the CSU multi-party RACI chart early, to ensure common understanding of roles and responsibilities, including all phases: testing/inspection specifications, construction quality, systems completion, pre-commissioning, commissioning, startup, and initial operations.							
38	CSU JURISDICTIONAL MATRIX A CSU jurisdictional matrix is needed to define the division of all CSU work responsibilities among construction, startup, and operations.							

		Check ONLY 1 of 7 Columns						
#	Potential Critical Success Factor (CSF)	CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
39	OWNER'S OPS INVOLVEMENT IN PLANNING Effective Owner/Operator participation in CSU planning. Common related challenges that must be addressed: Adequate Ops resources (staff availability); Late input form Ops; Discontinuity in Ops involvement (show-stopper); Ops planners with inadequate "stroke", authority, or breadth of experience/judgment; Interface management/communications problems between Ops and others on Owner project management team; Funding for needed travel by Ops; …							
40	OPS INVOLVEMENT IN FAT PLANNING Operators to participate in FAT scoping/achievement specification for complex, controls-intensive systems							
41	HUMAN-MACHINE INTERFACE DESIGN OF CONTROLS Operations involvement is needed in plant operations human-machine interface (HMI) design of control systems. Accelerated ramp-up is possible with effective HMI.							
42	OPERATIONS INPUT TOPICS Critical issues for Operations input include sequence of system commissioning, approval of CSU procedures, and maintenance requirements, among others.							
43	INTEGRATION OF OPERATIONS INTO CSU Integrate the operations team into commissioning.							
44	OWNER PARTICIPATION IN MANUFACTURING AND FABRICATION Timely participation of Owner's designated and qualified representative to observe/ inspect during key manufacturing and fabrication steps							
45	CSU PARTICIPATION IN DESIGN CSU and Operations should participate in plant design in a timely manner. The 3D design model should be reviewed to ensure access for operations and maintenance needs.							
46	TIMELY CSU STAFF INVOLVEMENT IN CONSTRUCTION Involve CSU staff in construction operations at approx. 75-85% systems construction complete (for each single major system) to participate in mitigation of construction punch list items (with early focus on utility systems, such as water, power, air, …)							
47	LEVEL OF CSU STAFF SUPPORT CSU staff support should match the needs/challenges of the commissioning/startup itself; This applies to both Owner & Contractor(s); Drivers of greater staff support include: # of units; # of systems; scope of project; division of responsibilities between O-PM, Contr., Ops, subs, vendor support, etc.; use of local content; level of experience; familiarity with process technology; local turnover rates; complexity of controls/level of automation; productivity rates needed vs. expected; …							
48	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, etc.							
49	ENGINEERING SUPPORT OF CSU Continuity of engineering leadership's support of CSU is needed from detailed design, thru construction, and thru CSU							

		Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
#	Potential Critical Success Factor (CSF)	Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
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31	PLANT MANAGER RESPONSIBILITY It is the responsibility of the plant manager to convey the importance of timely, effective CSU planning to plant operators.							
	3. CSU Team Organization Staffing/Roles/Involvement							
32	CSU ORGANIZATION CHART The CSU manager should report directly to the project manager, not to the construction manager or operations manager.							
33	CSU SYSTEM LEAD CAPABILITIES Each CSU system lead is a critical role that should be skilled in all facets of the system type							
34	CSU LEADERSHIP CONTINUITY Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.							
35	EARLY CSU INVOLVEMENT IN DESIGN CSU involvement in design should start with development of the first P&IDs. The related skills of operations staff for this early input need to be deliberately cultivated.							
36	SYSTEMS COMPLETION TEAMS Early formation of systems-completion teams, from both Owner and Contractor sides							
37	CSU RACI CHART Define the CSU multi-party RACI chart early, to ensure common understanding of roles and responsibilities, including all phases: testing/inspection specifications, construction quality, systems completion, pre-commissioning, commissioning, startup, and initial operations.							
38	CSU JURISDICTIONAL MATRIX A CSU jurisdictional matrix is needed to define the division of all CSU work responsibilities among construction, startup, and operations.							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
59	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.							
60	CSU REQUIREMENTS & RESPONSIBILITIES IN BIDDING DOCUMENTS Ensure that CSU requirements and responsibilities are included in all appropriate bidding documents. Omissions are too common in the building sector, among others							
61	SPECIFICATION OF SYSTEM REQUIREMENTS Design engineer should explicitly specify written requirements by system, including identification of all supporting design documents that support a single system							
62	SYSTEM MILESTONE ACCEPTANCE CRITERIA Establish specific detailed systems/subsystems acceptance criteria for each major milestone: mechanical completion, turnover, pre-commissioning, commissioning, and handover. All project parties should understand these expectations from the beginning of construction. Required support staffing and funding should be compatible with the effort expectations.							
63	FAT REQUIREMENTS FAT requirements and timing should be fully addressed in the Owner's RFP							
64	CONSTRUCTION'S LEAD INTERFACE ON CSU ISSUES The Owner's construction RFP should identify the contractor's quality manager as the lead person to interact with the CSU manager on turnover issues – from construction start to construction completion.							
65	TURNOVER OF CONSTRUCTION DOCUMENTATION TO CSU Owner's construction RFP should define what and when construction documentation is to be turned over to the CSU manager.							
66	CONSTRUCTION MATERIAL & MANPOWER FOR CSU Owner's construction RFP defines construction material and manpower support required, and for how long, for CSU.							
67	FAT TEST PARAMETERS AND EQUIPMENT Ensure that FAT tests are conducted with the proper test parameters and test equipment to prevent need for re-testing or failure at project site							
68	PUNCH-LIST MGMT PROCEDURE/PROTOCOL Punch-list management procedure/protocol should incorporate different priority categories, stipulate ownership assignment, and be integrated with change management system.							
69	CONTRACTOR WORK-TO-COMPLETE VS. PUNCH LIST WORK Make a distinction between (and avoid confusing) contractor work-to-complete vs. punch list work							

		Check ONLY 1 of 7 Columns						
#	Potential Critical Success Factor (CSF)	CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
70	DETAILED LOTO PROCEDURES LOTO detailed procedures should be developed with input from all groups involved: construction, CSU, etc.							
71	COMMISSIONING-SPECIFIC LOTO PROCEDURES Commissioning-specific LOTO procedures/documentation should be distinguished from construction-specific LOTO procedures/documentation							
72	SCOPE AND METHOD OF ALL INSPECTIONS AND TESTS Team must have a clear definition and understanding of the scope and method of all construction inspections and tests for each piece of tagged-equipment, preferably before initiation of detailed design.							
73	FUNCTIONAL CHECK-OUTS Insure component/system functional checkouts includes adequate check sheet criteria and detailed system commissioning procedures.							
	6. Risk Management/Flawless/Tightness/Preservation							
74	CSU & OPERATIONS RISK MANAGEMENT Project risk management considers all commissioning- and operations-related risks, with documented knowledge of the historical causes of equipment or system failures. Such risks may be sourced in design, procurement, shipping, storage, construction, testing, etc. Critical CSU risks may include initial energization of live systems, new or unfamiliar process technology, high-influence external stakeholders that force deviations from prepared plans (licensor, regulators, jv partners, local community), SIMOPS, newly hired operators, construction-CSU conflicts, failed/counterfeit components, etc.							
75	KEY PROJECT CHARACTERISTICS & CONDITIONS It is very important that CSU planners and managers understand key project characteristics and conditions, especially unique risks to the project and CSU success.							
76	PROACTIVE COMMUNICATIONS TO MINIMIZE CONSTRUCTION-CSU CONFLICTS Proactive communications are needed to minimize construction-CSU conflicts. Such conflicts may pertain to schedule conflicts, responsibility conflicts, and quality/preservation conflicts, among others.							
77	CSU RISK-BASED SCHEDULE CONTINGENCY PLAN As a contingency plan for CSU risk-based schedule, build-in float time for construction delays.							
78	CSU SCHEDULE RISKS CSU planners should be very aware of CSU schedule upset factors such as construction delays, turnover delays (including documentation delays), access problems (e.g., scaffolding in way), equipment failures (sticking valves, faulty instrumentation, pump bearing failures, pump alignment problems, vibration issues, ..); inadequate spare parts; unreliability in design; lack of equipment cleanliness; overly optimistic estimates of durations; among others.							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
79	HAZOP ANALYSIS ON CSU PROCEDURES The CSU team should conduct a HAZOP analysis/review on all CSU procedures							
80	PREPARATION FOR UNEXPECTED SHUTDOWN The CSU team should be prepared for a possible unexpected shutdown during startup by developing appropriate procedures in advance that address needed safety precautions, equipment preservation, easy re-start, etc.							
81	EQUIPMENT PRESERVATION PROGRAM Ensure a rigorous equipment preservation program is planned, implemented, and monitored in a timely manner. This should be initiated upon receipt at gate or fab shop. A management system (and paper trail) are needed to ensure proper care/custody/control by all relevant participants all the way through to operations.							
82	LOOK-AHEAD SCHEDULE AND RISK MANAGEMENT On a weekly basis, integrate CSU risk management with the detailed look-ahead schedule. End-of-shift reports can be an effective source for identifying such risks.							
	7. Plant Design/Plant Control System							
83	LINK SYSTEM IDENTIFICATION WITH DELIVERABLES Link CSU system identification with all project documentation/deliverables: design, procurement, construction, and CSU. This will further enable effective subsequent planning, coordination, and integration.							
84	SIMULATION & CONTROL SYSTEMS Full scale bench-testing of controls systems via simulation software to model all operating conditions can help in timely identification of systems bugs and to elicit timely client feedback.							
85	SMART P&ID APPLICATIONS Smart P&ID models can be helpful for early understanding CSU systems/subsystems/components, etc.							
86	WIRELESS INSTRUMENTATION TECHNOLOGY Wireless instrumentation that can self-calibrate and auto-report device/system status and performance data offers significant benefits for more efficient and reliable CSU performance							
87	CONTROL SYSTEM PROGRAM FIELD-TESTING Control systems programs need to be field-tested under robust real conditions with abundant input from operations personnel							
88	DESIGN OF DRAINS AND VENTS Judicious design (i.e, placement or location) of low-point drains and high-point vents can save time/money in CSU efforts							
89	PIPING DESIGN FOR EASY TESTING Design critical in-line devices (such as flow meters) with removable flanged spool pups for easy insert/testing; Similarly, provide valved- or nozzeled- spools for easy flushing/testing							
90	DESIGN TO SUPPORT LOTO REQUIREMENTS Plant design should support isolation of equipment to support needed LOTO procedures							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
91	RELIABILITY-DRIVEN PLANT DESIGN AND MAINTENANCE PLAN Integration of Owner experience with equipment/systems reliability with plant design and maintenance plan, including C/SU-related planning, technology selection, design, layout, access, etc.							
92	INSTRUMENT TECHNOLOGY Instrumented protective functions (for both mechanical and electric functions) on selective pieces of equipment can serve as a robust fail-safe technology that can enhance CSU performance.							
93	CSU SYSTEMS ENGINEERING CSU Systems Engineering during FEED is the activity of defining CSU systems within a facility and allocating certification records against tagged items. Design of facilities has a major impact on how it is fabricated, tested, integrated, and started up. Therefore, understanding of these impacts during FEED can change the design and save commissioning and startup efforts.							
8. Procurement/Supplier/Materials Management Issues								
94	CSU INPUT TO PROCUREMENT CSU participation in procurement should address scoping and acquisition of vendor technical assistance during CSU, vendor/contractor language/communications compatibility (including need for on-site translators), and procurement responsibility for feedstock, simulants, etc. required for performance testing.							
95	EQUIPMENT ASSET MGMT. Develop a master plan for the development and utilization of a plant equipment asset management database.							
96	SPARES PLANNING AND REVIEW Devote adequate resources to the effective and timely planning for spares. This should address specifications, quantities, schedule, etc.. Have a good Spare parts review and tracking procedure in place to ensure that the correct spare parts are available during commissioning.							
9. O/M Training								
97	CSU STAFF CAPABILITY Cultivate CSU "dual-hatters": CSU staff from major disciplines (mechanical, electrical, instrumentation, and controls) that have capabilities to both commission & operate a particular system.							
98	OPERATIONS TRAINING Operations should be trained with a simulator that presents the final system screens. Adequate time should be allowed for this.							
99	NEW MANUFACTURING PROCESS TECHNOLOGY New manufacturing process technology can present special and significant challenges to new O&M staff. When new process technology is involved, simulation-based training should be considered as an option for increasing commissioning familiarity of responses to unexpected commissioning/startup events/conditions.							
100	CROSS TRAINING WITH CSU All project design engineers and construction managers should have some direct experience with CSU.							

		Check ONLY 1 of 7 Columns						
#	Potential Critical Success Factor (CSF)	CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
101	CSU TRAINING ON ADVANCED EQUIPMENT TECHNOLOGY Special CSU training is needed for projects involving wireless/smart field equipment and electronic smart-marshalling of equipment. Don't assume such skills are already in place;							
102	O&M TRAINING Timely training of O&M contributors to the CSU process should consider a variety of issues, such as new technology role and challenges; relative experience level of operators; need to cultivate new operators; need for interpersonal skills and people compatibility; and achieving team-work/camaraderie among the team.							
103	OPERATIONS RESOURCES Recently retired plant operators may be motivated to serve as effective participants in CSU planning.							
	10. Systems-Based Planning/Controls							
104	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.							
105	CONTRACTOR INCENTIVES FOR SYSTEMS-BASED PROGRESS Include in the contract terms/conditions an incentive clause that links construction contractor payment to measured systems-based progress, starting at approximately 50% construction complete							
106	SYSTEMIZATION CONSIDERATIONS The systemization process must take into account many considerations. Errors in systemization happen when one or more of the following are neglected: controllability, isolatability, jurisdictional involvement/control, and process functionality.							
107	SYSTEMS- FOCUS IN DESIGN The focus of design is mostly commonly on equipment and individual technical disciplines, rather than on systems. A systems-focus during design will raise awareness of how systems will be handed over, tested, and started up. With this mindset more attention will be given to high/low point drains, removable spools for critical inline equipment, and critical isolation points, among other issues.							
108	SYSTEM-BASED SCHEDULES AND WORK HOUR ESTIMATES System-based schedules and work-hour estimates need to accurately reflect the true impact of late delivery of engineering deliverables, construction handover, and systems completion resource requirements.							
	11. CSU Budgeting/Cost Control/Schedule Control							
109	RELIABLE CSU COST / SCHEDULE FORECASTING Reliable CSU cost/schedule forecasting relies upon active involvement of experienced planners throughout the CSU process – not mere "software schedulers"							
110	CSU COST & SCHEDULE ESTIMATES Reliable CSU cost and schedule estimates require detailed itemization at the equipment-device level.							

#	Potential Critical Success Factor (CSF)	Check ONLY 1 of 7 Columns						
		CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
111	ADEQUATE FUNDING FOR CSU Project funding for CSU must be sufficiently adequate and budgeted up-front. The common threat from failure to do so is lack of enough operators and delays in CSU progress.							
112	CSU CONSTRUCTION WISH-LIST BUDGET It is helpful to have a sufficient construction budget for the end-of-construction wish-list provided by the CSU staff.							
113	CSU SEQUENCING CONSIDERATIONS The planned sequence of commissioning should be based on such considerations as plant operations philosophy, ramp-up objectives, plant controls automation objectives, HAZOP awareness, modularization scope, and construction sequence, among other considerations.							
114	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.							
115	INTEGRATED CONSTRUCTION/CSU SCHEDULE A fully integrated construction/pre-commissioning/commissioning schedule is critical to achieving CSU objectives.							
116	DETAILED OPERATIONS-DRIVEN CSU SCHEDULE A detailed operations-driven CSU schedule must be developed that integrates all check/ testing/ approval-milestones for each component and all systems, and shows development of associated support documentation							
117	ADEQUATE DELIVERY TIME FOR CSU SPARE PARTS Ensure that adequate delivery time is allowed for CSU spare parts. This can be very problematic for long-lead internationally-supplied equipment.							
118	CSU RECOVERY PLAN When CSU falls behind plan, prepare a CSU recovery plan that takes into consideration the possibility of additional resources and/or alternate methods/tests, recognizing that safety and quality cannot be compromised. A special assist crew from corporate resources may be provided for in advance.							
	12. Information Technology/Information Management							
119	ASSET DATA MANAGEMENT WITH DIAGNOSTICS Consider use of an asset data management tool in which automated diagnostics can increase awareness of issues/concerns and enable preparation of response plans. For modular projects, such a data system for operating system status/test data makes integration of data among multiple parties easier.							
120	TECHNOLOGY FOR AUTOMATED TEST RECORDS Consider automating equipment/system testing records, including initial run data. Use tablet PCs that contain data sheet templates for more reliable and complete documentation. These tools work best when linked to the asset management database, allowing downloads to occur frequently and quickly (real time). With this approach tablet PCs serve as test equipment.							

		Check ONLY 1 of 7 Columns						
#	Potential Critical Success Factor (CSF)	CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
121	SMART P&IDS Smart P&IDs can enhance CSU planning and execution by enabling automated analysis/manipulation of CSU systems/components and associated properties/attributes.							
122	BI-MODAL STATUS TRACKING DASHBOARD It would be very helpful to have a tracking/evaluation dashboard that concurrently displays the status of both construction area/discipline completion and CSU system completion.							
123	3D DESIGN MODEL FOR TRACKING SYSTEM STATUS The 3D design model can be a very helpful and efficient way to track the status of all system completions and CSU tests							
124	BIM DESIGN MODELS BIM design models can support CSU by addressing CSU spatial needs, component system membership, operations functions, and maintenance functions, among other beneficial functions.							
125	SYSTEM-SPECIFIC CSU PROCEDURES CSU detailed procedures (in contrast to general CSU procedures) should be system-specific, and reviewed periodically for accuracy and completeness.							
126	CONTINUOUS IMPROVEMENT OF CSU TOOLS Continuous improvement of CSU support tools should draw from project-sourced CSU challenges and lessons-learned.							
127	INNOVATIVE YET PROVEN TECHNOLOGIES & TOOLS Incorporate innovative yet proven technologies and tools in the project and CSU support processes. These innovations (such as wireless/smart field equipment, equipment diagnostics, and electronic smart-marshalling) need to be effectively integrated into project CSU systems/procedures.							
128	ELECTRONIC SYSTEM TURNOVER PACKAGES It is helpful to prepare (and formalize) electronic turnover packages for the turnovers of systems from construction to commissioning to owner operations.							
129	CSU DOCUMENT CONTROL Document control during CSU is critical and requires a defined discipline throughout CSU, with adequate support resources							
130	CYBER SECURITY SYSTEMS FOR PLANT DOCUMENTS Cyber security systems for on-demand plant documents need to be robust, yet not hinder site worker access and productivity.							
131	INFORMATION MANAGEMENT SUPPORT OF CSU Define metadata requirements and align information management processes so as to successfully load engineering databases with the data fields needed in support of tracking system boundaries, components, and completions. It is imperative that information management be fully aligned and supportive of systems completion requirements.							

		Check ONLY 1 of 7 Columns						
#	Potential Critical Success Factor (CSF)	CSF				NOT CSF		No Opinion
		Least Critical	Low to MID	MID to HIGH	Most Critical	Innovative Future Practice	Standard Operation Procedure	
132	DEFINITION OF SYSTEMS IN PDMS MODEL The definition of CSU systems in the PDMS model can help further understanding of testing constraints at the fab yard (and therefore what needs to be completed offshore), help quantify hook-up scope, and assist with walk-down preparation.							
133	TECHNOLOGY TO MODEL SYSTEMS & SEQUENCE Project/CSU team has the capability/technology to model and communicate the relationship hierarchy and associated timing-sequence of startup systems and sub-systems.							
	13. Handover/As-Builts/Turnover							
134	ACCURATE AS-BUILT DRAWINGS Accurate as-built drawings are needed to ensure effective planning, implementation, and close-out of CSU activities							
135	CONSTRUCTION TURNOVER WALK-DOWN WITH CONTRACTOR Construction turnover walk-down should be a formal process with the contractor's involvement to ensure completion of punch list and on-schedule performance							
136	CSU-CONSTRUCTION MANAGEMENT COLLABORATION CSU managers should work collaboratively with construction managers in managing construction completion & systems turnover.							
137	WARRANTY TRANSITION PLAN Develop warranty transition plan for each phase of the project. This could include lists of components with active warranties and expiration dates.							
	14. Special for Modular Projects							
138	TESTING BY MODULE FABRICATOR When possible, hydro-testing and air-drying are best accomplished by module fabricators, which can accomplish these steps quicker and at less cost.							
139	MODULE INTEGRATION AT THE FAB YARD CSU productivity and effectiveness on modular projects will be enhanced if module boundaries and systems boundaries support one another. This approach will serve to help maximize ability for pre-shipment testing.							
	Count							

PLEASE RETURN YOUR COMPLETED ASSESSMENT TO:

DR. JIM O'CONNOR
jtoconnor@mail.utexas.edu

CSU CSF Frequency Assessment (VER. 4)

TECHNICAL DESCRIPTIVE BACKGROUND **DATE:**
Name: **Current Position or title:** **Yrs of CSU experience:**
Most recent role related to CSU: ( ) leader role ( ) support role **Phone:** **Email:**
Company Name: **Type of Company?** ( ) Owner ( ) Contractor ( ) Supplier
Most Common Industry Sector or Sub-sector:

PLEASE assess the FREQUENCY OF ACTUAL OCCURRENCE of each stated CSF, by putting A CHECK (☑) IN 1 OF THE 5 COLUMNS.
Please return the complete survey to jtoconnor@mail.utexas.edu by or before July 14. Thanks much!

CSF# (Impact)	Critical Success Factor (CSF)	HOW OFTEN DOES THIS CSF OCCUR ON PROJECTS? Check 1 of 5 Columns				
		Frequency of Occurrence				Don't Know
		Rare	Occasional	Frequent	Common	
1	ALIGNMENT OF CSU/OPERATIONS WITH ENGINEERING AND CONSTRUCTION The project and CSU will benefit substantially by getting early alignment among CSU, Operations, Engineering, and Construction representatives on the key CSU issues of terminology, strategy, systemization, sequence and milestones, turnover criteria, certification criteria, test documentation., and other safety and quality requirements.					
2	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.					
3	COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER CSU managers should work collaboratively with construction managers in managing construction completion & systems turnover. Proactive communications are needed to minimize construction-CSU conflicts.					

CSF# (Impact)	Critical Success Factor (CSF)	HOW OFTEN DOES THIS CSF OCCUR ON PROJECTS? Check 1 of 5 Columns				
		Frequency of Occurrence				Don't Know
		Rare	Occasional	Frequent	Common	
4	**CSU TEAM CAPABILITY** CSU team has a good understanding of the project's operations performance metrics-oriented requirements and guarantees, and possesses the capability to support their achievement.					
5	**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 from the beginning of construction.					
6	**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.					
7	**CSU SEQUENCE CONSIDERATIONS AND 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.					
8	**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.					
9	**ALIGNMENT BETWEEN OWNER PROJECT MANAGEMENT AND OPERATIONS** The definition and key drivers of CSU success should be fully agreed upon by Owner/Project Management					

		HOW OFTEN DOES THIS CSF OCCUR ON PROJECTS? Check 1 of 5 Columns				
CSF# (Impact)	Critical Success Factor (CSF)	Frequency of Occurrence				Don't Know
		Rare	Occasional	Frequent	Common	
	and Owner/Operations. 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.					
10	**CSU EXECUTION PLANNING** 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.					
11	**ADEQUATE FUNDING FOR CSU** Project funding for CSU must be sufficiently adequate and budgeted up-front. The common threat from failure to do so is lack of enough operators, with subsequent delays in CSU progress.					
12	**CSU SYSTEMS ENGINEERING DURING FEED** CSU Systems Engineering during FEED is the activity of defining CSU systems within a facility and assigning certification records for all tagged items. 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.					
13	**SYSTEMS-FOCUS IN DETAILED DESIGN** The focus of design is commonly on equipment and individual technical disciplines, rather than on systems. 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, and LOTO requirements/supports, among other issues. In addition, the 3D design model should be reviewed to ensure access for operations and maintenance.					
14	**FUNCTIONAL CHECK-OUTS AND PROCEDURES** Insure component/system functional checkouts include adequate check sheet criteria and detailed system commissioning procedures.					

		HOW OFTEN DOES THIS CSF OCCUR ON PROJECTS? **Check 1 of 5 Columns**				
CSF# (Impact)	**Critical Success Factor (CSF)**	**Frequency of Occurrence**				**Don't Know**
		Rare	**Occasional**	**Frequent**	**Common**	
15	**CSU LEADERSHIP CONTINUITY** Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.					
16	**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% system construction complete (for each single major system) in order to help mitigate construction punch list items (with particular early focus on utility systems).					
17	**ACCURATE AS-BUILT DRAWINGS** Accurate as-built drawings are needed to ensure effective implementation, and close-out of CSU activities.					

Section I: Project Information and Characteristics

Project Reference # or Name:____

Source Contact Email address: ____

Commissioning and Startup (CSU) includes both Commissioning and Pre-Commissioning activities.

All information provided will be kept confidential per CII research standards, including no reporting of single data point responses, nor any references to any individual companies/projects/names.

PLEASE RETURN YOUR COMPLETED SURVEY TO: jtoconnor@mail.utexas.edu

- Project Location (Region): ☐ Domestic US ☐ Remote/Frontier International ☐ Other International
- Commissioning & Startup Executed By: ☐ Contractor ☐ Owner
- Approximate Number of CSU/Operating Systems: __________________________
- Approx. Project Total Installed Cost: ☐ < $25M ☐ $25M-$100M ☐ $100M-$500M ☐ $500M - $1B ☐ > $1B
- Project Industry Sector/Sub-sector (select one at both levels):

☐ Heavy Industrial
☐ Chemical ☐ Power ☐ Oil/Petroleum ☐ Pulp/Paper ☐ Other Manufacturing

☐ Light Industrial
☐ Automotive ☐ Consumer Products ☐ Food ☐ Water ☐ Wastewater ☐ Other

☐ Pharma/Healthcare/Labs
☐ Hospital ☐ Clinic ☐ Pharm Manufacturing ☐ Research Lab ☐ Education Lab ☐ Other

☐ Other

Section II: CSU Performance Assessment

Select one Satisfaction Level (columns) for each Success Criterion (rows)

CSU Sucess Criterion	**Satisfaction Level**					
	Extremely Satisfied (5)	**Very Satisfied (4)**	**Satisfied (3)**	**Dissatisfied (2)**	**Very Dissatisfied (1)**	**N/A**
1. Product Quality Performance	☐ Product quality **consistently exceeded** project goals.	☐ Product quality goals were **consistently met**.	☐ Product quality goals **were met with expected amounts** of off-spec product.	☐ Product quality **met specification most** of the time but the amount of off-spec product was higher than expected.	☐ Product quality was **met only with significant process and construction rework**.	☐
2. Product Quantity Performance	☐ Production rates **consistently exceeded** project goals.	☐ Production rates **met project goals**.	☐ Production rates **were marginally less** than planned but customers were not affected.	☐ Plant **did not meet** production rates set at project authorization.	☐ Production rates **were significantly lower** than planned and required significant construction rework.	☐
3. CSU Schedule Performance	☐ The CSU **duration was significantly less** than estimated. The process was on-line sooner than expected.	☐ The CSU **duration was as planned**.	☐ The CSU **duration was as planned** but meeting the schedule required **extra levels** of labor and/or materials.	☐ The CSU duration exceeded plan and meeting the schedule required **heroic efforts** on the part of the startup team.	☐ The CSU duration **far exceeded** the original plan.	☐
4. CSU Safety Performance	☐ The CSU **had no reportable injuries and no incidents** requiring any type of medical attention.	☐ The CSU **had no reportable incidents and only a minor number** of incidents requiring medical attention.	☐ The CSU **had no reportable incidents** and a typical number of minor first aid type incidents.	☐ The CSU **had one or more reportable incidents** or a higher number of minor and preventable medical incidents.	☐ The CSU **had one or more lost-time incidents**.	☐
5. Environmental Performance	☐ **No** Were there any reportable releases or spills during startup?				☐ **Yes** Were there any reportable releases or spills during startup?	☐
6. Preparation of CSU Operations Team	☐ Operations Team **was thoroughly prepared** for plant operations challenges	☐ Operations Team **was more than adequately prepared** for plant operations challenges	☐ Operations Team **was prepared** for plant operations.	☐ Operations Team **was not prepared** for plant operations and required additional, unplanned training	☐ Operations Team **was not prepared for plant operations and required a significant** amount of additional unplanned training which resulted in delays	☐
7. CSU Impact on Ongoing Operations	☐ There was **no impact** on ongoing operations.	☐ There was **minimal impact** on ongoing operations.	☐ There were **no unanticipated impacts** on on-going operations.	☐ Ongoing **operations were impacted**.	☐ Ongoing **operations were significantly impacted.**	☐
8. Level of Effort Required by the CSU Team	☐ CSU **work-hours were well below budget**. Level of **stress was much less** than anticipated.	☐ CSU **work-hours were on budget**. Level of **stress was less** than anticipated.	☐ CSU **work-hours were on budget**. Level of **stress was typical**.	☐ CSU **work-hours were slightly above budget**. The level of **stress was greater** than anticipated.	☐ CSU **work-hours were significantly over budget. The level of stress was significantly greater** than anticipated.	☐

Section III: CSU Accomplishments on this Project

Select Yes or No for each Indicator listed.

No.	Description	Yes	No
1.	CSU Manager is on the project organizational chart at the start of Front-End Engineering.	☐	☐
2.	CSU Manager is accountable for leading the team through the systemization process, involving operations, maintenance, and CSU resources.	☐	☐
3.	Commissioning test procedures are completed by the end of Detailed Design.	☐	☐
4.	Possession of construction and commissioning integrated schedule by the 30% construction complete milestone.	☐	☐
5.	Formalized system-level walk-down and punch list management, led by CSU team.	☐	☐
6.	A methodical approach was used to develop the project's CSU sequence (including all system, sub-systems and related dependencies), with formal recognition of all critical sequences and was finalized by end of detailed design.	☐	☐
7.	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.	☐	☐
8.	Several CSU joint meetings held in which all stakeholders were present. These are initiated early and are repeated throughout planning, design, and construction phases.	☐	☐
9.	Critical CSU input has been acquired for engineering design reviews, engineered equipment purchases, construction sequencing and schedules	☐	☐
10.	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 percent of Total Installed Costs (TIC).	☐	☐
11.	Formal CSU design review has occurred by the end of Front-End Engineering.	☐	☐
12.	Project schedule includes system logic inter-dependencies and turnover milestones prior to 30% construction complete.	☐	☐
13.	Joint CSU system walk-downs are conducted, involving both CM and CSU Manager.	☐	☐
14.	CSU progress is regularly assessed with management metrics.	☐	☐
15.	A master set of asset drawings is readily available and document control procedures are effective from construction through to final facility turnover.	☐	☐
16.	All construction/CSU physical access constraints due to brownfield conditions have been identified by 30% detailed design complete.	☐	☐
17.	All project team members understand site permitting requirements.	☐	☐
18.	Repeated confirmation of alignment is achieved.	☐	☐
19.	Identification and finalization of CSU system and subsystem boundaries on P&IDs, one-lines, and controls architecture.	☐	☐
20.	The CSU philosophy/strategy/execution plan has been reviewed/approved by all stakeholders and signatures are affixed.	☐	☐
21.	Project leadership is very familiar with the venture value that would be lost from a 1-day delay in startup of Operations.	☐	☐
22.	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, HSE, etc...).	☐	☐
23.	A CSU Manager was assigned at the start of Front-End Engineering and remained with the project through to initial operations.	☐	☐
24.	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.	☐	☐

25.	Incentive systems are in place to encourage continuity of CSU leadership.	☐	☐
26.	System acceptance criteria are incorporated into the contract with the Execute Contractor.	☐	☐
27.	Preliminary CSU sequence is defined by end of Front-End Engineering.	☐	☐
28.	Finalization of CSU sequence, depicting all systems, subsystems, and associated dependencies.	☐	☐
29.	Tracking of system completion with the use of check sheets during construction.	☐	☐
30.	Construction and pre-commissioning check sheets are finalized by the end of Detailed Design.	☐	☐
31.	Project operational objectives are well-documented and well-understood among CSU team members.	☐	☐
32.	Prior to the start of Front-End Engineering approved CSU budget and schedule are in-hand for CSU planning work.	☐	☐
33.	System/sub-system acceptance criteria are well documented and key parties are aligned on the criteria by the end of Front-End Engineering.	☐	☐
34.	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.	☐	☐
35.	Project team has identified all tie-ins and individual shut-downs by 30% detailed design complete, and these have been integrated into the Construction-CSU Integrated Schedule.	☐	☐
36.	By the end of Front-End Engineering, system boundaries are identified on P&IDs and electrical one-line diagrams.	☐	☐
37.	Joint meetings, involving both CM and CSU Manager, are conducted starting around 50% construction complete.	☐	☐
38.	System boundaries and isolations are developed with full understanding of brownfield operations/controls conditions.	☐	☐
39.	CSU team members understand the links between their actions and the technical metrics for project success.	☐	☐
40.	Short-term scheduling priorities (at a system & sub-system level) are established with input from both CM and CSU Manager.	☐	☐
41.	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.	☐	☐
42.	An asset information plan has been defined, reviewed, and approved by the end of detailed design.	☐	☐
43.	Operations fully participated in the preparation of the detailed CSU Execution Plan.	☐	☐
44.	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, process systems, etc.	☐	☐
45.	If an asset management solution is being used, then an equipment diagnostic alerts utilization plan is in place prior to construction.	☐	☐
46.	The qualifications and the planned tenure of the CSU Manager are well defined by early Front-End Engineering.	☐	☐

RT 312 Best Practices for Commissioning & Startup Implementation Resource

Feedback Form

PLEASE COMPLETE AND RETURN

Reviewer Background

Name		**Company**		**Date of Review**	
Contact Information (including email address)					
Current Job Title					
Total Years of Industry Experience		**No. of Project Commissionings/Startups**			

In your review, please consider the following two questions:

Is any critical content missing? ***Are any significant corrections needed?***

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1. ***Manually mark-up the document and return via mail, fax, or pdf scan/email as instructed below***
2. ***Use TRACK-CHANGES feature in WORD software and return the file as instructed below***
3. ***Use the table below to record your specific comments, noting the page & line numbers for each comment. Add as many additional lines as needed and return as instructed below.***

Please return both your background information and feedback comments/markups to Dr. O'Connor by May 1, 2015 in any of 3 ways:

Via mail: Dr. James T. O'Connor, CAEE Dept., 301 E. Dean Keeton St., Stop C1752, Austin, TX 78712-2100
Via fax: 512-471-3191
Via email: jtoconnor@mail.utexas.edu

Questions? Please email Dr. O'Connor or phone him directly: 512-471-4645 THANKS MUCH!!

No.	Page	Line	Comments
1			
2			
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8			**PLEASE ADD MORE LINES AS NEEDED**

Appendix B - Potential Critical Success Factors and Recommended Practices

Table B-1: Potential Critical Success Factors

No.	Potential Critical Success Factor (PCSF)
1. CSU Governance/Assurance	
1	**OWNER'S CSU ASSURANCE REVIEWS**
	CSU assurance reviews by the project owner should be planned and executed in multiple iterations starting in FEL3/FEED and running until commercial operations
2	**TURNOVER PACKAGE REVIEWS**
	Each CSU discipline lead needs to conduct an independent review of construction turnover packages for completeness.
3	**ALIGNMENT ON MEANING OF CSU SUCCESS**
	The definition of CSU success should be fully aligned with all key project drivers. Lack of alignment may pose a threat to CSU success.
4	**CSU TEAM CAPABILITY**
	CSU team has a good understanding of the facility operations performance metrics-oriented requirements and guarantees, and develops appropriate plans for testing
5	**GOVERNANCE SIGN-OFFS**
	Governance by technical authorities should occur at two different signoffs: construction to commissioning and startup to operations.
2. CSU Planning & General Management	
6	**CSU VALUE RECOGNITION**
	Establish the business case (including CSU staffing plan) for effective CSU leadership. Recognize the value added from successful CSU (value of 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
7	**ALIGNMENT BETWEEN OWNER-PROJECT MGMT AND OWNER-OPS**
	Sustained alignment between Owner-Project Management and Owner-Operations is a critical requirement for CSU success. This alignment can only be achieved with effective collaboration throughout the life of the project
8	**ALIGNMENT OF CSU WITH ENGINEERING AND CONSTRUCTION**
	The project and CSU will benefit substantially by getting early alignment with Engineering and Construction on CSU systems sequence and related requirements.

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
9	**ALIGNMENT ON CSU STRATEGY**
	Alignment on CSU strategy and milestones is needed among all key project parties (design, procurement, construction, CSU, and operations).
10	**ALIGNED COMMON UNDERSTANDING**
	CSU effort will benefit substantially from an aligned common understanding of CSU terminology, milestones, systemization, turnover criteria, certification criteria, and test documentation.
11	**CSU AS PROJECT SCOPE DRIVER**
	Timely consideration of CSU as a project scope driver is needed. Scope definition tools (such as PDRI) should address CSU elements.
12	**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.
13	**PROJECT PLANNING & CSU PLANNING INTEGRATION**
	Seek to integrate project planning with CSU planning. Critical linkages include achieving construction quality milestones by area/discipline and systems completion progress tracking
14	**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.
15	**CSU & 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.
16	**CSU-DRIVEN CONSTRUCTION**
	The CSU plan should be treated as a prerequisite for planning and starting construction. Construction should be commissioning-driven.
17	**DETAILED CSU EXECUTION PLAN IN TIMELY MANNER**
	A detailed Commissioning/Handover Execution Plan is prepared in a timely manner so as to be highly useful to the CSU team (draft #1 complete during FEED)

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
18	**ADEQUATE EXECUTION PLANNING STAFFING & RESOURCES**
	Recognize that CSU activities are an integral part of capital project delivery (rather than operations), and therefore require the same degree of execution planning, including planning for the specific skill mix necessary in both craft and management.
19	**SPECIAL CSU STAFFING SUPPORT**
	Adequate staffing resources and planning efforts to support CSU, including temporary equipment, spares, and specialty services pertaining to CSU.
20	**SYSTEMS COMPLETION DELIVERABLES AND ACTIVITIES**
	Develop a well-defined structure of Systems Completion execution deliverables and activities.
21	**ESTABLISHMENT OF CSU PROCEDURES**
	Establish and approve pre-commissioning/commissioning procedures during FEED, with timely and active participation of the O&M leadership.
22	**RECOGNITION OF CSU SEQUENCE DRIVERS**
	Coordinate with construction planners and managers for construction support during commissioning. Recognize sequence drivers, critical activities to coordinate, clean-build procedures, sequence of flushing (area & system coordination), sequence of leak/hydro testing, preservation steps, system tagging, sequence of loop checks, etc.
23	**TIMELY COMPLETION OF SUPPORTING PROJECTS**
	Timely completion of CSU support infrastructure and other supporting projects for necessary utilities, materials handling, logistics, etc. The project integrated schedule should indicate key related milestones for these projects.
24	**READY TO START COMMISSIONING**
	Confirm that ready-to-start-commissioning includes readiness of physical plant and readiness of people
25	**EFFECTIVE CHANGE MGMT PROCESS**
	Late changes to CSU are to be avoided thru effective change management process. Only changes required for operability, safety, or regulatory compliance are allowed after the 30% model review.
26	**3-DAY CSU PLAN WITH DAILY UPDATE**
	Plan detailed CSU activity with a 3-day plan that is updated daily: work accomplished yesterday, work to be accomplished today, and work to be accomplished tomorrow

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
27	**COLOR-CODING/DOTTING OF EQUIPMENT/COMPONENTS**
	Color-coded highlighting of components shown on system schematics is a useful way to document progress status at a detailed level. Likewise color-dotting of equipment/components can be an effective way to visibly and physically denote CSU progress status
28	**COMMISSIONING WORK AUTHORIZATION**
	A commissioning work authorization document is a useful tool to track contractor rework hours required for warranty work needed to fix equipment defects.
29	**TEMPORARY SUPPORT OF TESTING**
	Use temporary utility systems on systems/equipment to prove component performance at the earliest possible opportunity.
30	**SYSTEMS COMPLETION DATABASE**
	Establish and maintain a systems completion database, ensuring that all changes in engineering data are reflected in the system.
31	**PLANT MANAGER RESPONSIBILITY**
	It is the responsibility of the plant manager to convey the importance of timely, effective CSU planning to plant operators.
3. CSU Team Organization Staffing/Roles/Involvement	
32	**CSU ORGANIZATION CHART**
	The CSU manager should report directly to the project manager, not to the construction manager or operations manager.
33	**CSU SYSTEM LEAD CAPABILITIES**
	Each CSU system lead is a critical role that should be skilled in all facets of the system type
34	**CSU LEADERSHIP CONTINUITY**
	Continuity of CSU management leadership throughout the project is critical. The necessary qualifications of the CSU leadership should be well defined.
35	**EARLY CSU INVOLVEMENT IN DESIGN**
	CSU involvement in design should start with development of the first P&IDs. The related skills of operations staff for this early input need to be deliberately cultivated.
36	**SYSTEMS COMPLETION TEAMS**
	Early formation of systems-completion teams, from both Owner and Contractor sides

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
37	**CSU RACI CHART**
	Define the CSU multi-party RACI chart early, to ensure common understanding of roles and responsibilities, including all phases: testing/inspection specifications, construction quality, systems completion, pre-commissioning, commissioning, startup, and initial operations.
38	**CSU JURISDICTIONAL MATRIX**
	A CSU jurisdictional matrix is needed to define the division of all CSU work responsibilities among construction, startup, and operations.
39	**OWNER'S OPS INVOLVEMENT IN PLANNING**
	Effective Owner/Operator participation in CSU planning. Common related challenges that must be addressed: Adequate Ops resources (staff availability); Late input form Ops; Discontinuity in Ops involvement (show-stopper); Ops planners with inadequate "stroke", authority, or breadth of experience/judgment; Interface management/communications problems between Ops and others on Owner project management team; Funding for needed travel by Ops; …
40	**OPS INVOLVEMENT IN FAT PLANNING**
	Operators to participate in FAT scoping/achievement specification for complex, controls-intensive systems
41	**HUMAN-MACHINE INTERFACE DESIGN OF CONTROLS**
	Operations involvement is needed in plant operations human-machine interface (HMI) design of control systems. Accelerated ramp-up is possible with effective HMI.
42	**OPERATIONS INPUT TOPICS**
	Critical issues for Operations input include sequence of system commissioning, approval of CSU procedures, and maintenance requirements, among others.
43	**INTEGRATION OF OPERATIONS INTO CSU**
	Integrate the operations team into commissioning.
44	**OWNER PARTICIPATION IN MANUFACTURING AND FABRICATION**
	Timely participation of Owner's designated and qualified representative to observe/ inspect during key manufacturing and fabrication steps
45	**CSU PARTICIPATION IN DESIGN**
	CSU and Operations should participate in plant design in a timely manner. The 3D design model should be reviewed to ensure access for operations and maintenance needs.

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
46	**TIMELY CSU STAFF INVOLVEMENT IN CONSTRUCTION**
	Involve CSU staff in construction operations at approx. 75-85% systems construction complete (for each single major system) to participate in mitigation of construction punch list items (with early focus on utility systems, such as water, power, air, …)
47	**LEVEL OF CSU STAFF SUPPORT**
	CSU staff support should match the needs/challenges of the commissioning/startup itself; This applies to both Owner & Contractor(s); Drivers of greater staff support include: # of units; # of systems; scope of project; division of responsibilities between O-PM, Contr., Ops, subs, vendor support, etc.; use of local content; level of experience; familiarity with process technology; local turnover rates; complexity of controls/level of automation; productivity rates needed vs. expected; …
48	**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, etc.
49	**ENGINEERING SUPPORT OF CSU**
	Continuity of engineering leadership's support of CSU is needed from detailed design, thru construction, and thru CSU
50	**VENDOR DATA SUPPORTIVE OF CSU**
	Timely acquisition/processing of vendor data to ensure compatibility with quality and CSU requirements (including instrument and equipment data sheets)
51	**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 and to support associated operator training.
52	**SAFETY, ENVIRON. & PERMITTING PLANNERS INVOLVEMENT**
	Timely and knowledgeable involvement of safety, environmental, and permitting planners in the planning and execution of CSU
53	**CSU SMEs**
	A corporate pool of technical subject matter experts should be available to support critical CSU needs. These individuals can act as external observers and support CSU emergency situations and perform CSU preparedness audits.

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
4. H/S/E; Regulations; Permits	
54	**SAFETY THREATS AND MITIGATION STRATEGIES**
	Identify safety threats and control/mitigation strategies for locales/times when adjacent facility operations are concurrent with adjacent construction or C/SU activity
55	**EFFECTIVE PERMIT WITH SIMOPS**
	Effective management of permits-to-work given SIMOPs (simultaneous operations) is needed. The objective is to avoid any SIMOPS control room bottlenecks, promote early applications, and achieve 48 hr. turnaround on approvals of permit applications. The effort should entail a collaborative assessment of work permit applications involving operations, control room, CSU planners, along with review of 4-, 3-, 2-, and 1-week look-ahead schedules of CSU activity.
56	**REGULATORY REQUIREMENTS MANANGEMENT**
	Respond to regulatory requirements from authorities that grant occupancy certificates and incorporate development and achievement of these requirements into the CSU schedule
57	**REQUIREMENTS FOR SITE CLEARANCE/ ON-BOARDING**
	Ensure that CSU contractors and vendors understand the qualification requirements and lead times for site clearances and on-boarding (e.g., safety training, etc.) in advance of actual mobilization/site entry.
58	**PRE-STARTUP SAFETY REVIEW**
	Institute a pre-startup safety review (PSSR) prior to introduction of chemicals and energy. Each system startup should be preceded by PSSR.
5. Requirements/Quality/FAT/Performance Testing	
59	**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.
60	**CSU REQUIREMENTS & RESPONSIBILITIES IN BIDDING DOCUMENTS**
	Ensure that CSU requirements and responsibilities are included in all appropriate bidding documents. Omissions are too common in the building sector, among others
61	**SPECIFICATION OF SYSTEM REQUIREMENTS**
	Design engineer should explicitly specify written requirements by system, including identification of all supporting design documents that support a single system

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
62	**SYSTEM MILESTONE ACCEPTANCE CRITERIA**
	Establish specific detailed systems/subsystems acceptance criteria for each major milestone: mechanical completion, turnover, pre-commissioning, commissioning, and handover. All project parties should understand these expectations from the beginning of construction. Required support staffing and funding should be compatible with the effort expectations.
63	**FAT REQUIREMENTS**
	FAT requirements and timing should be fully addressed in the Owner's RFP
64	**CONSTRUCTION'S LEAD INTERFACE ON CSU ISSUES**
	The Owner's construction RFP should identify the contractor's quality manager as the lead person to interact with the CSU manager on turnover issues – from construction start to construction completion.
65	**TURNOVER OF CONSTRUCTION DOCUMENTATION TO CSU**
	Owner's construction RFP should define what and when construction documentation is to be turned over to the CSU manager.
66	**CONSTRUCTION MATERIAL & MANPOWER FOR CSU**
	Owner's construction RFP defines construction material and manpower support required, and for how long, for CSU.
67	**FAT TEST PARAMETERS AND EQUIPMENT**
	Ensure that FAT tests are conducted with the proper test parameters and test equipment to prevent need for re-testing or failure at project site
68	**PUNCH-LIST MGMT PROCEDURE/PROTOCOL**
	Punch-list management procedure/protocol should incorporate different priority categories, stipulate ownership assignment, and be integrated with change management system.
69	**CONTRACTOR WORK-TO-COMPLETE VS. PUNCH LIST WORK**
	Make a distinction between (and avoid confusing) contractor work-to-complete vs. punch list work
70	**DETAILED LOTO PROCEDURES**
	LOTO detailed procedures should be developed with input from all groups involved: construction, CSU, etc.
71	**COMMISSIONING-SPECIFIC LOTO PROCEDURES**
	Commissioning-specific LOTO procedures/documentation should be distinguished from construction-specific LOTO procedures/documentation

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
72	**SCOPE AND METHOD OF ALL INSPECTIONS AND TESTS**
	Team must have a clear definition and understanding of the scope and method of all construction inspections and tests for each piece of tagged-equipment, preferably before initiation of detailed design.
73	**FUNCTIONAL CHECK-OUTS**
	Insure component/system functional checkouts includes adequate check sheet criteria and detailed system commissioning procedures.
	6. Risk Management/Flawless/Tightness/Preservation
74	**CSU & OPERATIONS RISK MANAGEMENT**
	Project risk management considers all commissioning- and operations-related risks, with documented knowledge of the historical causes of equipment or system failures. Such risks may be sourced in design, procurement, shipping, storage, construction, testing, etc. Critical CSU risks may include initial energization of live systems, new or unfamiliar process technology, high-influence external stakeholders that force deviations from prepared plans (licensor, regulators, jv partners, local community), SIMOPS, newly hired operators, construction-CSU conflicts, failed/counterfeit components, etc.
75	**KEY PROJECT CHARACTERISTICS & CONDITIONS**
	It is very important that CSU planners and managers understand key project characteristics and conditions, especially unique risks to the project and CSU success.
76	**PROACTIVE COMMUNICATIONS TO MINIMIZE CONSTRUCTION-CSU CONFLICTS**
	Proactive communications are needed to minimize construction-CSU conflicts. Such conflicts may pertain to schedule conflicts, responsibility conflicts, and quality/preservation conflicts, among others.
77	**CSU RISK-BASED SCHEDULE CONTINGENCY PLAN**
	As a contingency plan for CSU risk-based schedule, build-in float time for construction delays.
78	**CSU SCHEDULE RISKS**
	CSU planners should be very aware of CSU schedule upset factors such as construction delays, turnover delays (including documentation delays), access problems (e.g., scaffolding in way), equipment failures (sticking valves, faulty instrumentation, pump bearing failures, pump alignment problems, vibration issues, ..); inadequate spare parts; unreliability in design; lack of equipment cleanliness; overly optimistic estimates of durations; among others.
79	**HAZOP ANALYSIS ON CSU PROCEDURES**
	The CSU team should conduct a HAZOP analysis/review on all CSU procedures

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
80	**PREPARATION FOR UNEXPECTED SHUTDOWN**
	The CSU team should be prepared for a possible unexpected shutdown during startup by developing appropriate procedures in advance that address needed safety precautions, equipment preservation, easy re-start, etc.
81	**EQUIPMENT PRESERVATION PROGRAM**
	Ensure a rigorous equipment preservation program is planned, implemented, and monitored in a timely manner. This should be initiated upon receipt at gate or fab shop. A management system (and paper trail) are needed to ensure proper care/custody/control by all relevant participants all the way through to operations.
82	**LOOK-AHEAD SCHEDULE AND RISK MANAGEMENT**
	On a weekly basis, integrate CSU risk management with the detailed look-ahead schedule. End-of-shift reports can be an effective source for identifying such risks.
	7. Plant Design/Plant Control System
83	**LINK SYSTEM IDENTIFICATION WITH DELIVERABLES**
	Link CSU system identification with all project documentation/deliverables: design, procurement, construction, and CSU. This will further enable effective subsequent planning, coordination, and integration.
84	**SIMULATION & CONTROL SYSTEMS**
	Full scale bench-testing of controls systems via simulation software to model all operating conditions can help in timely identification of systems bugs and to elicit timely client feedback.
85	**SMART P&ID APPLICATIONS**
	Smart P&ID models can be helpful for early understanding CSU systems/subsystems/components, etc.
86	**WIRELESS INSTRUMENTATION TECHNOLOGY**
	Wireless instrumentation that can self-calibrate and auto-report device/system status and performance data offers significant benefits for more efficient and reliable CSU performance
87	**CONTROL SYSTEM PROGRAM FIELD-TESTING**
	Control systems programs need to be field-tested under robust real conditions with abundant input from operations personnel
88	**DESIGN OF DRAINS AND VENTS**
	Judicious design (i.e., placement or location) of low-point drains and high-point vents can save time/money in CSU efforts

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
89	**PIPING DESIGN FOR EASY TESTING**
	Design critical in-line devices (such as flow meters) with removable flanged spool pups for easy insert/testing; Similarly, provide valve- or nozzeled- spools for easy flushing/testing
90	**DESIGN TO SUPPORT LOTO REQUIREMENTS**
	Plant design should support isolation of equipment to support needed LOTO procedures
91	**RELIABILITY-DRIVEN PLANT DESIGN AND MAINTENANCE PLAN**
	Integration of Owner experience with equipment/systems reliability with plant design and maintenance plan, including C/SU-related planning, technology selection, design, layout, access, etc.
92	**INSTRUMENT TECHNOLOGY**
	Instrumented protective functions (for both mechanical and electric functions) on selective pieces of equipment can serve as a robust fail-safe technology that can enhance CSU performance.
93	**CSU SYSTEMS ENGINEERING**
	CSU Systems Engineering during FEED is the activity of defining CSU systems within a facility and allocating certification records against tagged items. Design of facilities has a major impact on how it is fabricated, tested, integrated, and started up. Therefore, understanding of these impacts during FEED can change the design and save commissioning and startup efforts.
8. Procurement/Supplier/Materials Management Issues	
94	**CSU INPUT TO PROCUREMENT**
	CSU participation in procurement should address scoping and acquisition of vendor technical assistance during CSU, vendor/contractor language/communications compatibility (including need for on-site translators), and procurement responsibility for feedstock, simulants, etc. required for performance testing.
95	**EQUIPMENT ASSET MGMT.**
	Develop a master plan for the development and utilization of a plant equipment asset management database.
96	**SPARES PLANNING AND REVIEW**
	Devote adequate resources to the effective and timely planning for spares. This should address specifications, quantities, schedule, etc... Have a good Spare parts review and tracking procedure in place to ensure that the correct spare parts are available during commissioning.

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
9. O/M Training	
97	**CSU STAFF CAPABILITY**
	Cultivate CSU "dual-hatters": CSU staff from major disciplines (mechanical, electrical, instrumentation, and controls) that have capabilities to both commission & operate a particular system.
98	**OPERATIONS TRAINING**
	Operations should be trained with a simulator that presents the final system screens. Adequate time should be allowed for this.
99	**NEW MANUFACTURING PROCESS TECHNOLOGY**
	New manufacturing process technology can present special and significant challenges to new O&M staff. When new process technology is involved, simulation-based training should be considered as an option for increasing commissioning familiarity of responses to unexpected commissioning/startup events/conditions.
100	**CROSS TRAINING WITH CSU**
	All project design engineers and construction managers should have some direct experience with CSU.
101	**CSU TRAINING ON ADVANCED EQUIPMENT TECHNOLOGY**
	Special CSU training is needed for projects involving wireless/smart field equipment and electronic smart-marshalling of equipment. Don't assume such skills are already in place;
102	**O&M TRAINING**
	Timely training of O&M contributors to the CSU process should consider a variety of issues, such as new technology role and challenges; relative experience level of operators; need to cultivate new operators; need for interpersonal skills and people compatibility; and achieving team-work/camaraderie among the team.
103	**OPERATIONS RESOURCES**
	Recently retired plant operators may be motivated to serve as effective participants in CSU planning.
10. Systems-Based Planning/Controls	
104	**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.
105	**CONTRACTOR INCENTIVES FOR SYSTEMS-BASED PROGRESS**
	Include in the contract terms/conditions an incentive clause that links construction contractor payment to measured systems-based progress, starting at approximately 50% construction complete

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
106	**SYSTEMIZATION CONSIDERATIONS**
	The systemization process must take into account many considerations. Errors in systemization happen when one or more of the following are neglected: controllability, isolatability, jurisdictional involvement/control, and process functionality.
107	**SYSTEMS- FOCUS IN DESIGN**
	The focus of design is mostly commonly on equipment and individual technical disciplines, rather than on systems. A systems-focus during design will raise awareness of how systems will be handed over, tested, and started up. With this mindset more attention will be given to high/low point drains, removable spools for critical inline equipment, and critical isolation points, among other issues.
108	**SYSTEM-BASED SCHEDULES AND WORK HOUR ESTIMATES**
	System-based schedules and work-hour estimates need to accurately reflect the true impact of late delivery of engineering deliverables, construction handover, and systems completion resource requirements.
11. CSU Budgeting/Cost Control/Schedule Control	
109	**RELIABLE CSU COST / SCHEDULE FORECASTING**
	Reliable CSU cost/schedule forecasting relies upon active involvement of experienced planners throughout the CSU process – not mere “software schedulers”
110	**CSU COST & SCHEDULE ESTIMATES**
	Reliable CSU cost and schedule estimates require detailed itemization at the equipment-device level.
111	**ADEQUATE FUNDING FOR CSU**
	Project funding for CSU must be sufficiently adequate and budgeted up-front. The common threat from failure to do so is lack of enough operators and delays in CSU progress.
112	**CSU CONSTRUCTION WISH-LIST BUDGET**
	It is helpful to have a sufficient construction budget for the end-of-construction wish-list provided by the CSU staff.
113	**CSU SEQUENCING CONSIDERATIONS**
	The planned sequence of commissioning should be based on such considerations as plant operations philosophy, ramp-up objectives, plant controls automation objectives, HAZOP awareness, modularization scope, and construction sequence, among other considerations.

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
114	**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.
115	**INTEGRATED CONSTRUCTION/CSU SCHEDULE**
	A fully integrated construction/pre-commissioning/commissioning schedule is critical to achieving CSU objectives.
116	**DETAILED OPERATIONS-DRIVEN CSU SCHEDULE**
	A detailed operations-driven CSU schedule must be developed that integrates all check/ testing/ approval-milestones for each component and all systems, and shows development of associated support documentation
117	**ADEQUATE DELIVERY TIME FOR CSU SPARE PARTS**
	Ensure that adequate delivery time is allowed for CSU spare parts. This can be very problematic for long-lead internationally-supplied equipment.
118	**CSU RECOVERY PLAN**
	When CSU falls behind plan, prepare a CSU recovery plan that takes into consideration the possibility of additional resources and/or alternate methods/tests, recognizing that safety and quality cannot be compromised. A special assist crew from corporate resources may be provided for in advance.
12. Information Technology/Information Management	
119	**ASSET DATA MANAGEMENT WITH DIAGNOSTICS**
	Consider use of an asset data management tool in which automated diagnostics can increase awareness of issues/concerns and enable preparation of response plans. For modular projects, such a data system for operating system status/test data makes integration of data among multiple parties easier.
120	**TECHNOLOGY FOR AUTOMATED TEST RECORDS**
	Consider automating equipment/system testing records, including initial run data. Use tablet PCs that contain data sheet templates for more reliable and complete documentation. These tools work best when linked to the asset management database, allowing downloads to occur frequently and quickly (real time). With this approach tablet PCs serve as test equipment.
121	**SMART P&IDS**
	Smart P&IDs can enhance CSU planning and execution by enabling automated analysis/manipulation of CSU systems/components and associated properties/attributes.

Table B-1: Potential Critical Success Factors, cont.

No.	**Potential Critical Success Factor (PCSF)**
122	**BI-MODAL STATUS TRACKING DASHBOARD**
	It would be very helpful to have a tracking/evaluation dashboard that concurrently displays the status of both construction area/discipline completion and CSU system completion.
123	**3D DESIGN MODEL FOR TRACKING SYSTEM STATUS**
	The 3D design model can be a very helpful and efficient way to track the status of all system completions and CSU tests
124	**BIM DESIGN MODELS**
	BIM design models can support CSU by addressing CSU spatial needs, component system membership, operations functions, and maintenance functions, among other beneficial functions.
125	**SYSTEM-SPECIFIC CSU PROCEDURES**
	CSU detailed procedures (in contrast to general CSU procedures) should be system-specific, and reviewed periodically for accuracy and completeness.
126	**CONTINUOUS IMPROVEMENT OF CSU TOOLS**
	Continuous improvement of CSU support tools should draw from project-sourced CSU challenges and lessons-learned.
127	**INNOVATIVE YET PROVEN TECHNOLOGIES & TOOLS**
	Incorporate innovative yet proven technologies and tools in the project and CSU support processes. These innovations (such as wireless/smart field equipment, equipment diagnostics, and electronic smart-marshalling) need to be effectively integrated into project CSU systems/procedures.
128	**ELECTRONIC SYSTEM TURNOVER PACKAGES**
	It is helpful to prepare (and formalize) electronic turnover packages for the turnovers of systems from construction to commissioning to owner operations.
129	**CSU DOCUMENT CONTROL**
	Document control during CSU is critical and requires a defined discipline throughout CSU, with adequate support resources
130	**CYBER SECURITY SYSTEMS FOR PLANT DOCUMENTS**
	Cyber security systems for on-demand plant documents need to be robust, yet not hinder site worker access and productivity.
131	**INFORMATION MANAGEMENT SUPPORT OF CSU**
	Define metadata requirements and align information management processes so as to successfully load engineering databases with the data fields needed in support of tracking system boundaries, components, and completions. It is imperative that information management be fully aligned and supportive of systems completion requirements.

Table B-1: Potential Critical Success Factors, cont.

No.	Potential Critical Success Factor (PCSF)
132	**DEFINITION OF SYSTEMS IN PDMS MODEL**
	The definition of CSU systems in the PDMS model can help further understanding of testing constraints at the fab yard (and therefore what needs to be completed offshore), help quantify hook-up scope, and assist with walk-down preparation.
133	**TECHNOLOGY TO MODEL SYSTEMS & SEQUENCE**
	Project/CSU team has the capability/technology to model and communicate the relationship hierarchy and associated timing-sequence of startup systems and sub-systems.
13.	**Handover/As-Builts/Turnover**
134	**ACCURATE AS-BUILT DRAWINGS**
	Accurate as-built drawings are needed to ensure effective planning, implementation, and close-out of CSU activities
135	**CONSTRUCTION TURNOVER WALK-DOWN WITH CONTRACTOR**
	Construction turnover walk-down should be a formal process with the contractor's involvement to ensure completion of punch list and on-schedule performance
136	**CSU-CONSTRUCTION MANAGEMENT COLLABORATION**
	CSU managers should work collaboratively with construction managers in managing construction completion & systems turnover.
137	**WARRANTY TRANSITION PLAN**
	Develop warranty transition plan for each phase of the project. This could include lists of components with active warranties and expiration dates.
14.	**Special for Modular Projects**
138	**TESTING BY MODULE FABRICATOR**
	When possible, hydro-testing and air-drying are best accomplished by module fabricators, which can accomplish these steps quicker and at less cost.
139	**MODULE INTEGRATION AT THE FAB YARD**
	CSU productivity and effectiveness on modular projects will be enhanced if module boundaries and systems boundaries support one another. This approach will serve to help maximize ability for pre-shipment testing.

Table B-2: Recommended CSU Practices

No.	Recommended CSU Practice
1	**READY TO START COMMISSIONING** Confirm that ready-to-start-commissioning includes readiness of physical plant and readiness of people.
2	**LEVEL OF CSU STAFF SUPPORT** CSU staff support should match the needs/challenges of the commissioning/start-up itself. This applies to both owner and Contractor(s) staff. Drivers of greater staff support include: # of units; # 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 vs. 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 MGMT PROCEDURE/PROTOCOL** Punch-list management procedure/protocol should incorporate different priority categories, stipulate ownership assignment, and be integrated with change management system.
9	**ENGINEERING LEADERSHIP CONTINUITY** Continuity of engineering leadership's support of CSU is needed from detailed design, thru construction, and thru CSU.

Table B-2: Recommended CSU Practices, cont.

No.	**Recommended CSU Practice**
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 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 and to support associated operator training.
13	**CSU SYSTEM LEAD INDIVIDUAL CAPABILITIES** Each CSU system lead is a critical role that should be adequately skilled in all facets of the system type.
14	**CSU REQUIREMENTS & RESPONSIBILITIES IN BIDDING DOCUMENTS** Ensure that CSU requirements and responsibilities are included in all appropriate bidding documents. Omissions are too common in the building 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 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, etc.

Table B-2: Recommended CSU Practices, cont.

No.	**Recommended CSU Practice**
18	**CSU SCHEDULE RISKS & 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., scaffolding in way), equipment failures (sticking valves, faulty instrumentation, pump bearing failures, pump alignment problems, 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 & CONDITIONS** It is very important that CSU planners and managers understand key project characteristics and conditions, especially unique risks to the project and 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** Design engineer should explicitly specify written requirements by system, including identification of all supporting design documents that support a single system.
22	**SAFETY THREATS AND MITIGATION STRATEGIES** Identify safety threats and control/mitigation strategies for locales/times when adjacent facility operations are concurrent with adjacent construction or C/SU activity.
23	**CSU & 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 need for re-testing or failure at project site.
25	**TIMELY COMPLETION OF SUPPORTING PROJECTS** Timely completion of CSU support infrastructure and other supporting projects for necessary utilities, materials handling, logistics, etc. The project integrated schedule should indicate key related milestones for these projects.

Table B-2: Recommended CSU Practices, cont.

No.	Recommended CSU Practice
26	**EFFECTIVE PERMIT WITH SIMOPS** Effective management of permits-to-work given SIMOPs (simultaneous operations) is needed. The objective is to avoid any SIMOPS control room bottlenecks, promote early applications, and achieve 48 hr. turnaround on approvals of permit applications. The effort should entail a collaborative assessment of work permit applications involving operations, control room, CSU planners, along with 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 & CONTROL SYSTEMS** Full scale bench-testing of controls systems via simulation software to model all operating conditions can help in timely identification of systems bugs and to elicit timely client feedback.
29	**SAFETY, ENVIRON. & PERMITTING PLANNERS INVOLVEMENT** Timely and knowledgeable involvement of safety, environmental, and permitting planners in the planning and execution of CSU.

Appendix C - Modifications to CII Pub. 121-2, *Planning for Start-up* Model

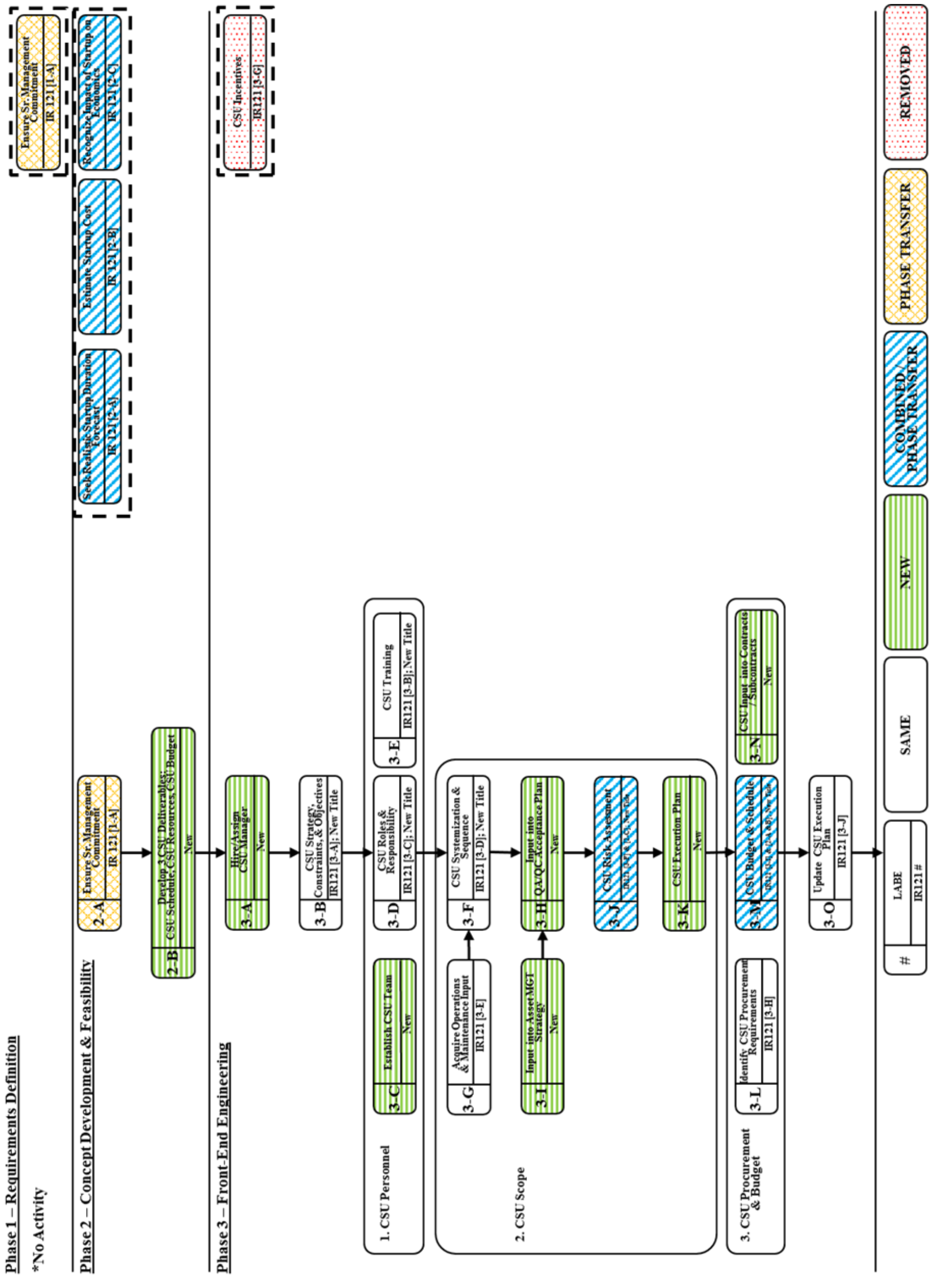

Figure C-1: Modification tracking of 121-2, *Planning for Start-up* model

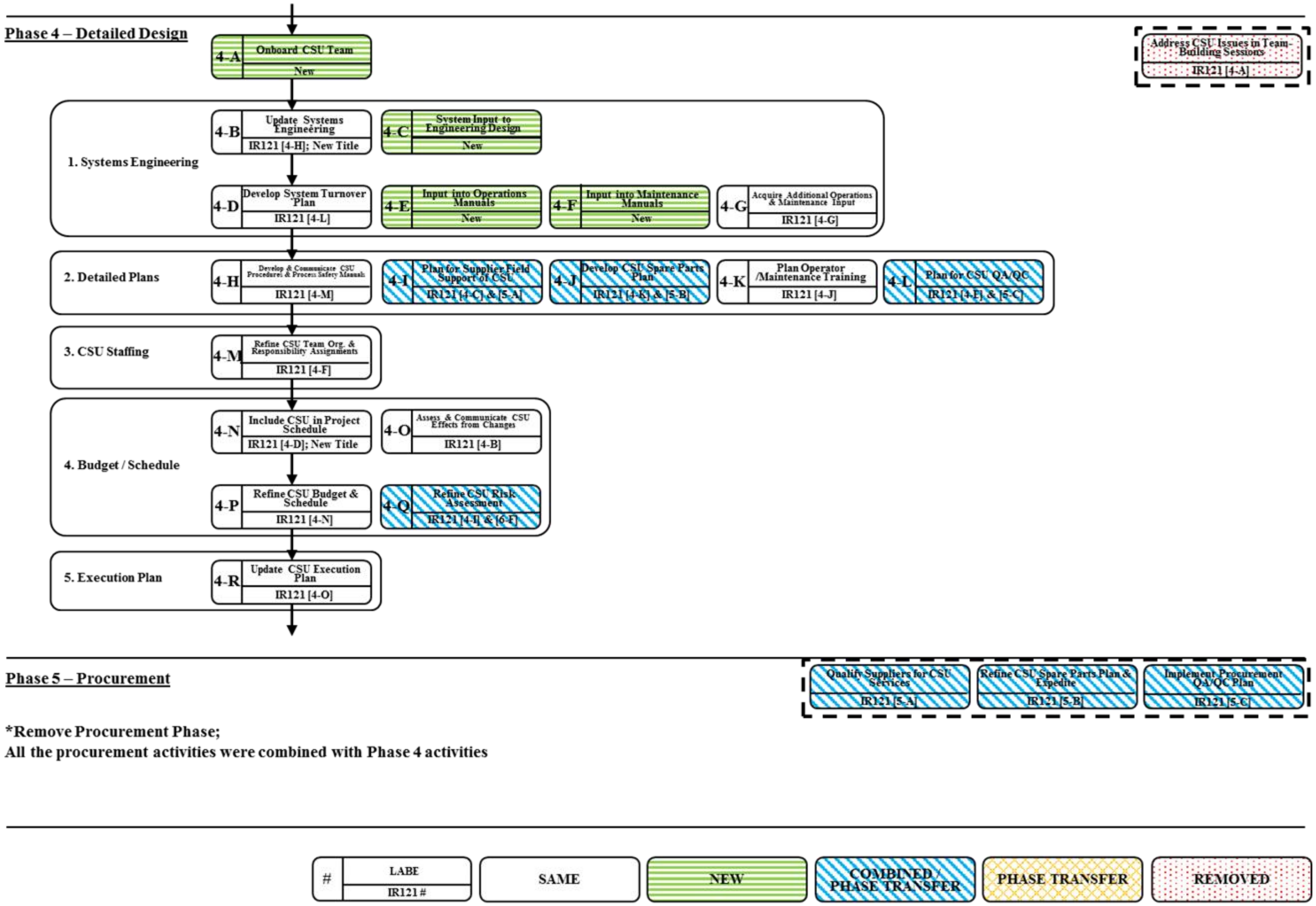

Figure C-1: Modification Tracking of 121-2, *Planning for Start-up* model, cont.

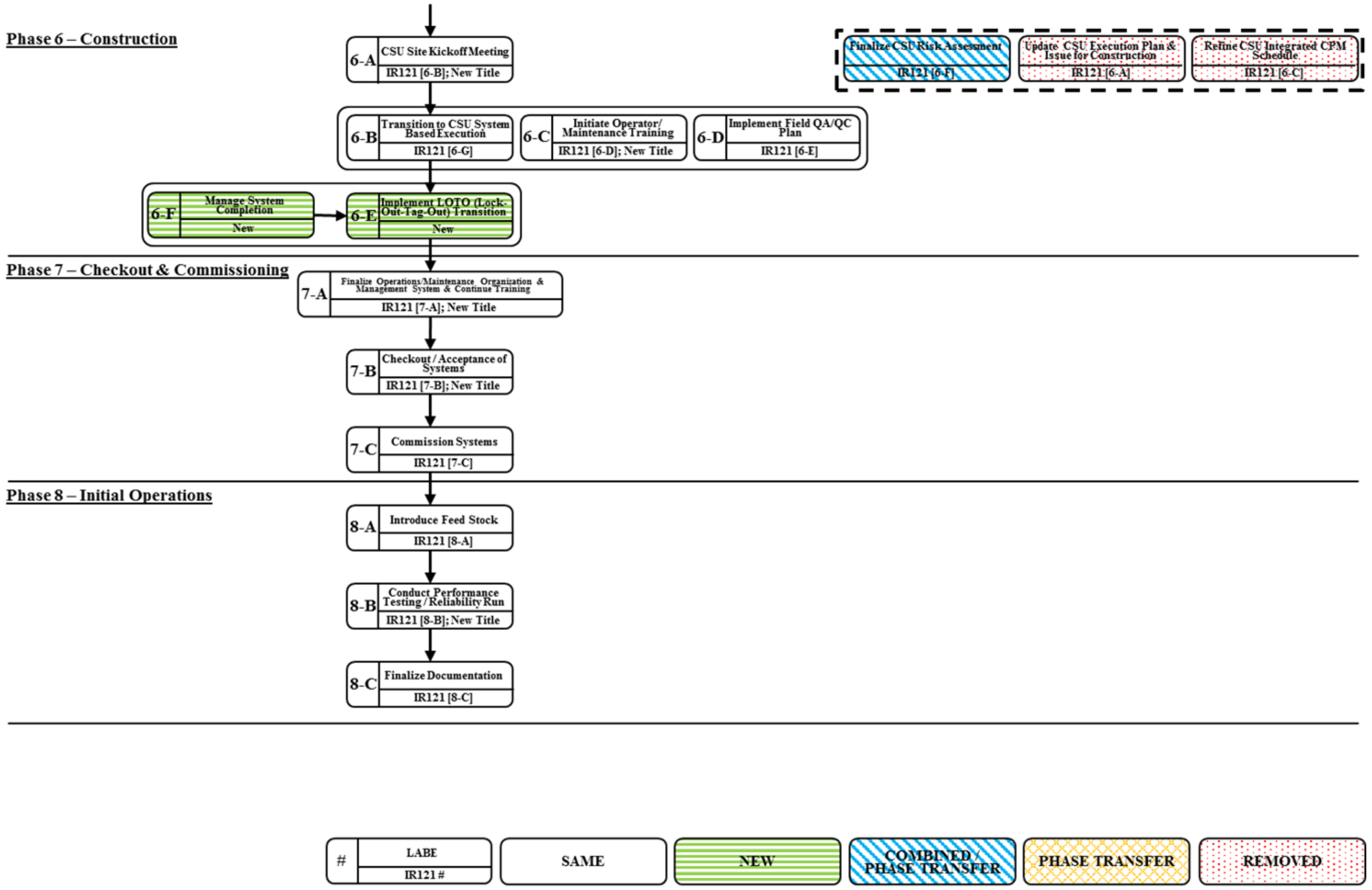

Figure C-1: Modification Tracking of 121-2, *Planning for Start-up* model, cont.

Appendix D - Full Case Studies

Case Study A

Plant X Energy Center

[Source: Internal company report]

Project Description

In 2012, the Plant X Energy Center (coal-fire steam plant) Unit boiler feedpump turbine experienced an uncontrolled overspeed event resulting in significant damage to the turbine and surrounding equipment. The Unit had been brought on line at 1:30 a.m. with the motor-driven boiler feedpump and was operating at about 200 megawatts. Both steam-driven boiler feedpumps were uncoupled from their turbines for the normally scheduled overspeed testing. Tuning of the boiler feedpump turbine steam control and stop valves had not been completed and the boiler feedpump steam stop valves were in the open position. Shortly after 9 a.m., the boiler feedpump turbine steam control valves drifted open without any operator initiated control signal command calling for them to open. With the steam stop valves upstream of the control valves in the open position, main steam immediately drove the boiler feedpump turbine speed to greater than 9000 rpm. Normal maximum running speed is approximately 5600 rpm, and the overspeed protection trip point is set at approximately 6000 rpm. Last stage blades were thrown from the boiler feedpump turbine due to the overspeed event. The boiler feedpump suction line was punctured by a thrown blade, releasing great amounts of water in the area. A group of power and control cables above the boiler feedpump turbine was severed by a thrown blade, pieces of turbine blades were thrown through the turbine room roof and other piping, including the main turbine main steam piping, was impacted.

All personnel were safely evacuated and accounted for, and no personnel injuries were suffered.

Project and CSU-Related Performance or Outcome

The boiler feed pump turbine was uncoupled from the pump and in a reset condition ready for tuning/testing of newly installed Distributed Control System (DCS) controls. In the reset condition, the boiler feed pump turbine's steam stop valves were open and the downstream steam control valves were closed. The steam control valves suddenly went full open and failed to respond to DCS initiated close signals, causing uncontrolled acceleration of the boiler feed pump turbine. The protective devices failed to trip the boiler feed pump turbine in a timely manner, allowing the boiler feed pump turbine to over speed. The boiler feed pump turbine accelerated past its design speed of 5600 revolutions per minute (RPM) resulting in failure. The last stage blading of the boiler feed pump turbine was ejected through the casing, damaging nearby piping and electrical cable trays. A fire erupted at the high-pressure end of the boiler feed pump turbine as the shaft grounding device broke and oil was discharged onto nearby hot steam valves. The fire was extinguished by a combination of deluge fire protection system activation and collateral damage to the boiler feed pump suction line emptying the entire deaerating heater storage tank contents (approximately 60,000 gallons of 300oF water) above the failed boiler feed pump turbine. The plant was evacuated, all personnel were accounted for, and the Unit was removed from service for repairs. Two major aspects of the event are why the uncontrolled acceleration occurred, and why the boiler feed pump turbine failed to trip.

CSU-Related Problems, Opportunities, & Contributing Factors

Possible Causal Factors of the Uncontrolled Acceleration of the Boiler Feed Pump Turbine:

Oil contamination was present in the turbine oil system

The turbine oil tank collects oil after it has flowed through all bearings of the main turbine and boiler feed pump turbines. Pumps mounted on the turbine oil tank pump the oil back to the bearings and to the hydraulic controls of the boiler feed pump turbines. During the outage that preceded this event, the boiler feed pump turbine controls replacement project required use of the oil system for checkout and testing of the newly installed controls. At the same time, an oil system flush was in progress due to the extensive main turbine work that had been completed. Original Equipment Manufacturer (OEM) recommends an oil system flush be performed following major turbine work to ensure dirt and foreign material are removed from the oil prior to operating the main turbine. As a part of the flush, fine-mesh screens were installed over the normal turbine oil tank screen panels inside the turbine oil tank to filter the return oil to the tank. As the oil was flushed through the piping, debris and contaminants were rinsed back to the tank. The fine-mesh screens stopped larger debris, but since the screen has an actual opening size of 0.0059 inches, particles 150 microns or smaller would have easily passed through the screen. Even though the oil flush was conducted using standard methods, it is not normal practice to stroke boiler feed pump turbine valves while the turbine oil system flush is in progress. There was an abnormally large amount of debris on the screens of the turbine oil tank when the Unit was shut down going into the major outage. This oil and its contaminants would have been pumped to the boiler feed pump turbine bearings and mechanical hydraulic control systems during normal operation prior to the outage. The turbine oil system had been drained and cleaned during the outage prior to the flush. While it was drained, the tank was vacuumed out, several spots of flaking paint and rust were noted, and the larger chunks of paint were removed. A few small items of debris were noted in the tank as it was being filled, but it was decided that it would be strained out during the flush.

Degraded filters allowed contaminated oil to get into the servo valve

The Unit boiler feed pump turbine speeds are controlled by a relatively small electrically controlled servo valve on the side of the turbine. Inline duplex filters are in the oil supply to prevent particles from entering the servo valve. The filer assembly consists of two filters, such that one can be changed out online. The in-service filter for the servo valve was found to be degraded to the point of being ineffective. This servo valve has a full stroke distance in one direction of 0.015 inches. The fine-mesh screens used in the oil flush allowed particles to pass that were 0.0059 inches. This particle size is equivalent to nearly half of servo valve full stroke distance. Even though the manufacturer says the servo valve has a "high dirt tolerance," large particles entering the valve likely caused operational issues.

The filters were designed to remove particles larger than 3 microns (0.00012 inches) from the oil entering the servo valve. Each filter is made of stacked cellulose elements that eventually break down and compress making the stack short enough that dirty oil can bypass the filter elements completely. The filter assembly has a high differential pressure alarm that is brought into the DCS, but once the filters get dirty enough, the stacks compress and the differential pressure will begin to drop as oil bypasses the filter media, clearing the alarm. There was not any established preventive maintenance item or any operational schedule to switch to the other filter. The out-of-service filter was in like-new condition, but had a leak in the canister and had been out of service for over a year. The last confirmed replacement of the in-service filter was over five years prior. A replacement canister was ordered and had been onsite for a year to be replaced, but the job had not been completed.

Servo valve was operating under extreme cycling conditions

The servo valve normally makes very small movements to port oil to the bottom of the pilot valve. The pilot operates against spring pressure to port oil either to or from the operating cylinder, which is directly linked to the control valves of the turbine. The servo valve has to port enough oil to get the much larger pilot valve lifted quickly into its null position (where it is neither porting oil to or from the operating cylinder), and then move it only a very small amount to control the speed of the turbine. The controls that drive the servo valve motor were changed during the outage, so the servo valve needed to be re-tuned to its new control loop. In the hours leading up to the event, the servo valve was rapidly cycling due to incomplete tuning. Tuning of this valve may have been impossible due to the buildup of contaminants found in the servo valve body after the event. Trend data of the pilot valve position showed that the pilot valve movement (normally < 1% of full travel) was rapidly swinging more than 15%, up to 20 times a minute. This movement was cycling oil to and from the operating cylinder, but not for long enough duration each cycle to cause the steam control valves to open. Four hours before the over speed event, the Controls tuner noticed the extreme cycling of the servo valve and detuned it. This reduced the swings of the pilot valve from 15% back to 1%, but this was still an extreme amount of movement, and it was still swinging 3-4 cycles/minute. The servo valve failed by sticking in one position, allowing pressure to continue to build under the pilot valve, porting it open, causing the steam control valves to open. After the event, the servo valve was removed from turbine, and was found to have sloppy movement and sticky spots in its travel. These sticky spots were severe enough that the valve would fail to respond to control signals attempting to drive the servo valve back to its rest position. Later, at a servo valve repair facility, the valve was disassembled and found to have sludge and contaminant build-up in the valve ports. It is suspected that the extreme cycling of the servo valve along with dirty oil accelerated the wear on the valve. There were no indications of operational issues with the servo valve before the outage, and the servo valve was not replaced during the outage. Before the event, the servo was rapidly oscillating, which would normally have been enough to cause the steam control valves to oscillate also. Post-event trend data does not support this expectation. There was no evidence available that the DCS initiated the event.

Possible Causal Factors of the Events Leading to Failure to Trip:

Debris and foreign material was found in the trip valve/reset piston assembly

There was a large amount of debris and grit found in the cylinders of the mechanical hydraulic trip system. There were several possible contributors to this accumulation. Most notable, was the failed rubber boot that was designed to provide a seal on the trip valve/reset piston indication rod that penetrates the top of the trip reset assembly at the turbine front standard. This boot was in very poor condition and allowed debris to enter the cylinder. The O-ring that seals the top portion of the trip reset assembly to the front standard top cover was missing. All of these missing seals provided an entry route for dirt and debris. None of the pistons in the trip reset assembly could be verified for proper operation after the incident, since they suffered damage during the event. Trend data collected after the event showed that the trip assembly was taking longer to trip each time it was tripped. Before the outage, the time from initiation of an electronic trip to the time the steam stop valves indicated closed was about 1 second. The first time a trip was initiated as the outage was nearing completion took 2 seconds. Subsequent trips took 4 seconds, then 5 seconds, then 9 seconds. During the failure event, it took 12 seconds from initiation of trip signal to steam stop valves closed. The trip valve may have dumped oil only after being impacted by the turbine rotor during the failure. Repeated operation during testing with contaminated oil likely increased the trip times.

Inoperable mechanical over speed trip governor

When the turbine was disassembled after the over speed event, the condition of the over speed governor was examined. It was found to be non-functional, and showed no evidence of being actuated (extended) during the over speed event. The construction of the governor is a spring-loaded brass plunger with a continuous shaft through the device housing. The plunger could not be moved by applying normal pressure to the end of the shaft. Once it had been freed, it stuck in the trip (extended) position. It is believed that if it had actuated during the event that it would have been found in the extended position due to this stickiness. The housing for the governor was damaged during the event, so it is possible that its operation was altered by the event itself. Based on the data from previous over speed tests, the year prior actual over speed trips were increasing instead of decreasing. According to OEM, a sticking plunger usually frees up with use, and subsequent trips occur at lower RPM. This observation is validated by the earlier data. The over speed governor acts on the same trip finger that is acted on by the manual trip handle and the trip piston, which is used for electrical trips via a solenoid. In this case, since a trip was already in progress from the DCS, the trip finger would have already unlatched the trip valve/reset piston. This assumes that the trip piston operated (even if it was sluggish), which could not be verified. Based on the amount of sludge in the cylinders, it is likely that the trip piston operated, and that the trip valve reset piston assembly was sluggish. If that was the case, the trip finger would already have been rotated out of the way, and the over speed governor would not have had anything on which to act.

Possible Failed Defenses:

General low levels of knowledge and understanding of the boiler feed pump turbine controls

Plant management, operations, engineering and maintenance employees were found to have low level of knowledge regarding the setup and interface of the boiler feed pump turbine control system. This lack of understanding was itself a failed defense by limiting the ability to make informed risk decisions regarding the other failed defenses in the event. This failed defense applies to some degree either directly or indirectly at all levels of the plant organization.

No documented preventive maintenance basis was established for the boiler feed pump turbines, which led to:

- **Deficient operational checks:** The daily and weekly operations activities recommended by the manufacturer were not performed regularly and not recorded. These activities are designed to keep the mechanical hydraulic trip system exercised and provide an early warning if the overall protective scheme has underlying problems that would not otherwise be indicated. No process (check sheet, log record, etc.) existed to incorporate these activities into operational routines. One of the factors in the event was equipment cleanliness. The compromised boot and the missing O-ring allowed dirt to enter the system. In addition, the build-up of dirt on the top of the front standard should not have been present. There were oil-soaked wipes present in the bottom of the control console cabinet, and grime buildup in locations where oil leaks had mixed with dust from coal and fly ash leaks in the building.

- **Deficient equipment maintenance:** The in-service filter for the servo valve was in failed condition. Periodic replacement or inspection needed to be performed. No preventive maintenance had been established for the filters.

Inadequate oversight of Instrumentation tuner during controls checkout phase

This is not directly related to the event, but it addresses questions posed by employees regarding the sequence of events and conduct of testing in progress. The Controls field engineer reloaded the DCS control, which controls the boiler feed pump turbines, on the morning of the event. Due to excessive overshoot in the pilot valve control loop, the boiler feed pump turbine started rolling unexpectedly. The control drop was loaded without the consent of the operations staff or the owner's test personnel present with the field engineer in the computer room. Since the turbine was in AUTO mode, the DCS controls initiated a trip as soon as the turbine speed was 1000 RPM above set speed, but the steam stop valves did not close until 24 seconds later. The turbine was out of control. The turbine speed went above 100% rated speed (5600 RPM), peaking at 5726 RPM.

Inadequate communication between commissioning team members

In a post-event interview with the computer technician involved with the testing of the boiler feed pump turbine controls, the technician stated that when he left on the evening before the event, that he thought no further tuning or testing was to be completed with steam valved in. Turnover from the Controls tuner to the project engineer on the evening before the event was that "there was more work to do, but you should be able to get the over speeds performed." The project engineer was not aware of the computer technician's opinion on the readiness condition of the boiler feed pump turbine controls.

Inadequate mechanical engineering experience involved with the controls replacement project

The designer of the DCS controls for the project strongly recommended having a mechanical engineer onsite to assist with the calibration of the servo and pilot valves. Their advice was declined. A few factors influenced that decision. The station's computer technicians had previous experience calibrating the servo valves, and no mechanical components were to be replaced. There was no mechanical engineering support for the project from either the plant staff or corporate resources. Having a greater depth of mechanical engineering experience involved with the tuning of the servo valve would have been beneficial.

Lack of clear procedures during checkout and testing of new controls

There was not a clearly identified commissioning plan for the new controls, nor were there operational procedures for the new boiler feed pump turbine controls including trip-checks and over speed testing.

Outage schedule pressure

The time available in the in the outage schedule to perform checkout of the controls lessened as the outage progressed. Originally, eight days were allotted after the turbine oil flush to complete the testing and checkout of the new boiler feed pump turbine controls. It was believed that the testing and checkout would require only two days to complete. Additional work scope on the main Low Pressure turbine replacements caused an eleven-day delay getting the turbine oil system restored, which delayed the testing of the boiler feed pump controls. Moving the outage end date up two days due to early completion of critical-path work applied even more pressure to the schedule. The time allotted for testing was compressed into the two days that were believed to be needed. The turbine oil system flush and boiler feed pump turbine valve testing were allowed to be performed concurrently without objection.

Fatigued testing personnel

The project engineer responsible for the project worked 60 hours in the four days leading up to the event. Not including the off-site dinner break earlier in the evening, he had been onsite for nearly 19 hours by the time he left the plant site after attempting to run the boiler feed pump turbine early in the morning. Plant policy prohibits employees from working more than 16 hours in any 24 hour period without prior approval of the plant manager.

Trouble with a related boiler feed pump turbine tuning was not resolved prior to starting the malfunctioned boiler feed pump turbine

The related boiler feed pump turbine was the first of the two boiler feed pump turbines to be tested under live-steam conditions. It proved to be uncontrollable and was tripped off each of three attempts. The two boiler feed pump turbines have identical but separate logic that controls them. A decision was made to try the other boiler feed pump turbine, which also proved unsuccessful. This decision was made in hopes of gaining information from the other turbine that might have been helpful in diagnosing the problems on the original boiler feed pump turbine.

Prior adjustment of the boiler feed pump turbine over speeds

In previous years, the boiler feed pump turbine over speed testing had been stable and in the proper range. In previous tests, the turbine did not trip within specifications on the first two attempts. After several adjustments, it tripped within the range on the last three trials, so testing was concluded. The OEM field service engineer assisting with this investigation noted that even though all three over speed trip speeds were in range, the turbine tripped at a higher speed each trial. This could have indicated that the mechanical over speed plunger was binding in one year, which was how it was found in the following year.

The boiler feed pump turbine was reset for nearly seven hours without the steam control valves being properly tuned

In this condition, the steam control valves were the only thing preventing acceleration of the turbine. It is not advised to remain in this condition for extended periods. The manufacturer's guidance in the instruction manual says, "The steam stop valve trip should never be reset until the unit is ready to be started." Due to stop valve body cracks that have been observed on other boiler feed pump turbine steam stop valve assemblies, operations had been resetting the turbine for a brief period of time (usually 20-30 minutes) before rolling the turbine to allow the stop valve body to warm. This reduces thermal stress on the valve chests. Under normal start-up conditions, it takes roughly two hours for the steam chest wall temperature to stabilize once the turbine is reset. After several attempts to tune and test the related boiler feed pump turbine controls, an attempt was made on the malfunctioning turbine. When the turbine also proved difficult to control, testing was abandoned and the controls tuner was called to be onsite later that morning. Discussions between the project engineer and operations staff included the need to have the turbine ready for tuning. Once the turbine coasted down from the last test of the day, it was reset for the next test, which was to be performed in a few hours. Keeping the turbine reset allowed the wall temperature of the steam chest to rise with the main steam temperature as the start-up progressed, which minimized thermal stresses on the stop valve assembly, but placed the turbine in a ready condition with unstable controls for several hours.

Abnormal operation of the turbine oil tank vapor extractor

OEM instructions recommend operation of the vapor extractor in a manner to maintain a vacuum in the turbine oil tank just enough to keep oil vapors from being vented from the system. This should be somewhere between 0.5 inch water column and 1.5 inches of water column vacuum in the tank. Operators reported that the vacuum is normally run much higher than that (up to 4 inches of vacuum) to minimize oil leakage. Although operating with an increased vacuum helped prevent oil leakage from the system, it also increased the introduction of dirt into the oil system.

- Inadequate redundancy in the trip scheme

  There are several single-point failure modes of the Unit boiler feed pump turbines.

  - There is a single trip solenoid that is energized to trip. That means a positive signal must be received by the controls to trip the turbine electrically. If any power supply problem is encountered (solenoid problems, breaker failure, etc.), or the solenoid valve sticks in the normal position, all electrical tripping is disabled. This was not the cause of this event, but is a design weakness.
  - The lock out solenoid could have failed. If the solenoid would have stuck in the lockout position from the last time it was tested, all tripping, including over speed would have been disabled. This was also found not to be a contributing factor in the event, but it is a significant weakness in design.
  - Reset solenoid could have failed in the reset position from the last time the turbine was reset. If that were to happen, all tripping, including over speed, is disabled. This was also not found to be a contributing factor in the event, but it is a significant weakness in design.

- The trip relay could have stuck in the reset position. This would keep the trip header pressurized, disabling all tripping methods including over speed. This was also found not to be a contributing factor in the event, but it is a significant weakness in design.
- The trip piston could have stuck. This would remove all electrical tripping, but the over speed governor should still be able to function. It is not clear if this was a factor in the event due to the damage inflicted during the event. As found, it was not functional.
- The trip valve/reset piston assembly could have stuck. This would disable all tripping. It is not clear if this was a factor in the event due to the damage inflicted during the event. As found, it was not functional.

Failed defenses in the DCS controls

Although the steam control valves were provided “close” signals by the DCS, if the valves fail to respond to control in a timely manner, the steam stop valves should trip. Logic that would trip the turbine if the steam control valves failed to respond was only active if the controls were in AUTO mode, the boiler feed pump turbine controls were in MANUAL mode.

There were many improvements implemented in the boiler feed pump turbine control logic after the event. One of them was the alarm that monitored the time from when the boiler feed pump turbine received a trip signal to the time it indicated tripped. At the time of the event, it was set at 10 seconds. The longest trip time observed before the event was 9 seconds. This time delay was set at 2 seconds after the event.

Lessons Learned

Contaminated turbine oil and failed barriers to keep those contaminants out of the control oil system for the boiler feed pump turbine led to both the uncontrolled acceleration and the failure to trip events. Many factors contributed to the event.

- Since all turbines on a unit share the same oil supply system, it is essential to maintain that oil system in good condition. Many failed defenses in this event were related to keeping contaminants out of the oil and out of critical components. Abnormal operation of the vapor extractor, deficient operational and maintenance practices, compromised physical barriers, and inadequate filtering are all detrimental to the overall health of the oil system.
- At the time of the failure, the decision had already been reached that the boiler feed pump turbine controls were going to require more off-line testing and tuning. Clearly defined ownership of the equipment by commissioning personnel during checkout phase must be established. This process will be formalized in the future to create jurisdictional boundaries for equipment operation while processes are undergoing major repair efforts or are undergoing commissioning.

Corrective Actions:

Completed or in progress corrective actions (at time of the report):

1. Developed formal written procedures to finish the checkout and testing of the controls for the boiler feed pump turbine. This will be the basis for all future commissioning efforts on boiler feed pump turbine controls.
2. Ensured that qualified engineering support was available (both electrical and mechanical) to support the checkout and testing of the controls. This is complete

for the boiler feed pump turbine controls, but will need to be considered for similar projects in the future.

3. Disassembled and eliminated accumulated debris and contaminants from the trip and control mechanisms of the boiler feed pump turbine. Reassembly ensured that the trip reset mechanism was properly sealed to eliminate paths of debris entry. Periodic inspections will be developed to ensure these barriers remain intact.
4. Performed a high-velocity oil flush of the turbine oil system, making sure all debris and contaminants were removed from the oil. This process should be evaluated as needed in the future.
5. Obtained a Controls engineering re-evaluation and an independent third-party review of the existing boiler feed pump turbine controls logic. The controls replacement team incorporated their suggestions as applicable, which improved the reliability of the controls and trip scheme. The modifications will be recorded and evaluated as potential improvements to all boiler feed pump turbine control logic.
6. Ensured that the following operational checks were performed and documented. Each start of the turbine, initiate a manual trip shortly after roll-off to verify steam valve tightness and verify oil trip system health. Perform thrust bearing wear detector tests, exercise the over speed trip governor, and perform valve tests on the LP and HP steam stop valves weekly.
7. Performed inspection, repair, and non-destructive testing of the impacted high pressure piping to ensure minimum wall thickness remained per engineering code. The affected locations will be inspected and re-evaluated in the future.

8. Performing a preventative maintenance basis review of the boiler feed pump turbine assemblies. This includes basis on the hydraulic controls, turbine and front standard overhauls, and checking the functionality of protective systems. This includes a review of the manufacturer's suggestions regarding the maintenance of the turbine oil system (checking for leaks, monitoring screen differential level, cleaning out the oil tank, increased surveillance of oil sample points, etc.)
9. Replaced all Unit turbine oil tank door gaskets and boiler feed pump oil sump oil seals to minimize potential routes for debris entry into the turbine oil system. A periodic inspection will be developed to ensure these barriers remain intact on both units.
10. The owner is finalizing the previously planned consolidation of the plant engineering and centralized engineering resources. This will allow for streamlined procedures and communications, as well as make additional support resources available to projects in the future. This will provide a greater depth of experience to draw from on future projects.
11. Performing a critical systems assessment of other systems at the station, ensuring that proper maintenance and documentation is being performed appropriately.

Other corrective actions being considered (at time of the report):

12. Establish a periodicity to replace the filters for the servo valve and/or install a differential pressure transmitter across the servo valve filter assembly to monitor the health of the filters.

13. Isolate the boiler feed pump turbine oil systems during oil flushes to prevent contaminants from entering boiler feed pump turbine controls and bearings.
14. During over speed testing of boiler feed pump turbines, no personnel will be allowed in the area of the turbine.
15. Review the plant database to see if other jobs exist that are open, but are in closed job packages. This contributed to the failure to change the filter canister for the servo valve filters.
16. Provide training for all operations employees qualified Operator Assistant and Unit Operator including their supervisors on the boiler feed pump turbine controls. This includes an overview of the control systems, performing periodic operational checks, recognizing abnormal operation, and coordination of start-up activities such as pre-warming.
17. Perform a review of procedures (Operations Department Logs, Reading Sheets, Check Sheets, & Rounds).
18. Develop and implement procedures to delineate responsibilities during commissioning activities.
19. Evaluate speed deviation logic in the DCS controls and implement protection for deviation events while controls are in the manual mode.
20. Update the over speed trip procedure to include notes to help identify abnormal or inconsistent indications, and outline situations where further testing might be required.
21. Install a pressure transmitter and alarm point to monitor proper vacuum on the turbine oil tank.

22. Evaluate the possibility of a filtration system that would filter the oil for the entire tripping and control oil for the boiler feed pump turbines. This would eliminate some of the potential sludge buildup in the trip system components, and act as a pre-filter for the servo valve filters.
23. Re-evaluate installing a redundant testable dump manifold that would replace the existing trip scheme and all of the single point failure modes of the controls.
24. Establish a DCS control drop load procedure that outlines the potential impacts to various systems affected by each controller.
25. Replace the existing servo valve control setup with a valve or other device that is more easily controlled from the existing DCS.
26. Establish a team that would evaluate the practices in place at each facility and ensure that the best practices are being followed.

Links to CSFs

CSF #1 – CSU VALUE RECOGNITION

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

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

There was shown to be low level knowledge of the start-up across all stakeholders. This lack of alignment also led to failed oversight during the Instrumentation tuning and created an environment where high levels of communication were not achieved. Also pressure to meet the schedule created an environment where decisions were rushed.

CSF #8 – RECOGNITION OF CSU SEQUENCE DRIVERS

A lack of understanding of the primary sequences and procedures for start-up was present. Improper protocol and start-up sequencing was conducted, leading to pump failure.

CSF #9 – DETAILED CSU EXECUTION PLAN

Proper execution planning was not undertaken, with inadequate oversight and communication playing a large factor. No set procedures were defined and planning for the start-up neglected to allot enough schedule days. Proper sequencing was not followed due to a lack of planning.

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 start-up of additional equipment was allowed to proceed without proper milestones being met or achieved.

CSF #12 – CSU TEAM CAPABILITY

The CSU team did not have experienced personnel that were familiar with the feedpump turbine and controls. Also, a mechanical engineer was recommended to be on site by the controls provider, but this expertise was not included on the CSU team.

CSF #13 - INTEGRATED CONSTRUCTION/CSU SCHEDULE

The CSU schedule was feeling pressure to get the feedpump turbine up and operational, with the outage schedule being lessened. Proper allocation of time to perform a sound start-up and achieve all objectives was necessary.

CSF #16 - COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER

Collaboration should have been a top priority as the outage scheduled was reduced. Increased communication could have ensured proper protocols were met prior to start-up of the feedpumps.

Figure D-1: Wreckage on the exhaust hood and low-pressure end bearing

Figure D-2: Last stage blading roots and diaphragm

Case Study B

Urban Water Pumping Station

Project Description

Project consisted of Electrical and Control System upgrades for a potable water pumping station. The contractor, utility client, and the businesses requiring water service were the primary stakeholders. This project was a major infrastructure upgrade to provide redundancy to a critical 200MGD potable water facility in a major urban area in the western United States, where water is a crucial and vital resource.

The brown field project included replacing all the medium voltage pump switch gear, upgrading and adding high voltage transformers with dual substation feeds, and the programmable logic controller (PLC) migration from the Bristol Babcock remote terminal unit (RTU) platform to the Allen Bradley Control Logix PLC platform within the pump station. In the rate of flow control station, the project scope included the PLC migration, and instrument upgrades within the rate of flow control station (ROFC). The supervisory control and data acquisition (SCADA) scope of work included the testing and validation of the new screen sets with the PLC programs. The project also involved the upgrade and retrofit of butterfly valve actuators and controls for three parallel 48” high pressure water mains inside the pump station (ROFC #1, #2, and #3). The initial plan was for only one line to be taken out of service at a time, allowing for the other two parallel lines to continue providing service. This was to be done for all three lines. The facility had to remain in operation during the entire project and scheduled outages were to be planned and approved prior to any shutdowns. This facility is a high importance facility within the infrastructure of the city. If this facility is not in operation the amount of work and money involved to re-route water flow is non-recoverable for the client.

Project and CSU-Related Performance or Outcome

During installation of the new valve actuator on ROFC #1, the contractor had the connection spool fabricated incorrectly. When the spool piece was fabricated, it assumed the actuator moved in a counter-clockwise motion, when the opposite was true. During submittal review, only the material was checked, and not the layout angle of the spool. When the valve actuator was connected to the closed valve and stroked in what the team assumed was the OPEN position, actually ended up stroking the valve CLOSED. This action forced the valve seal to reverse and bind within the pipeline. At this point the valve could not be moved in either direction, due to the valve actuator reading full close. Since the spool connector was fabricated incorrectly, the valve's logic assumed it was trying to open the valve, when in reality it was closed. The valve position was not marked prior to shutdown of the line, causing further confusion during installation of the new actuator.

The contractor's staff were not able to lie to the valve actuator because it was all solid state positioning within the actuator housing. Solid state specifies the valve position indicators on the circuit boards are integrated into the valve actuator itself. A new spool connector had to be fabricated and installed. Once that was complete, the valve was opened forcing the seat of the valve back into the proper position. As a result of rework, the valve had to be leak tested in both directions and passed the specified tests.

During the commissioning of the 48" butterfly valve actuator on ROFC #1, the valve was stroked several times with the owner's PLC programmer, owner's Inspector, Controls Integrator, Start-up manager, and Engineer present. Each valve was stroked three separate times and timed at 90 seconds for the full stroke of the valve. This information was provided to the owner's PLC programmer for input into the valve PID. There was a major lack of communication on the required stroke time of the valves. At no point in time did Operations or Maintenance inform the teams that the original valve actuators had a stroke time of 15 minutes and not 90 seconds, as programmed. Experienced personnel missed this fact, and experienced operators were not present.

In another part of the facility, the contractor had to relocate and extend the flood switch within the building. Rather than terminate the flood switch on terminal blocks they decided to butt splice the wires and extend them to the new PLC location. This was the incorrect method for extending the flood switches. After the first valve on ROFC #1 was finally ready to bring online, it was put into operation. Final PID tuning was performed. For the next three days all the ROFC valves were in use and the station was fully operational. After the three day period, ROFC #2 was taken offline to begin the retrofit of the controls and valve actuators.

At some point during the ROFC #2 conversion, ROFC #3 had to be taken offline temporarily. This was a decision by the owner's maintenance team. This left only the newly converted ROFC #1 online and providing service, contradicting the original plan of only one line out of service at any one moment. While work continued on ROFC #2 and #3, there was an intermittent Flood Alarm that was traced back to the extended flood switch modified previously. This false alarm initiated a shutdown and caused ROFC #1 to close in 90 seconds, and not 15 minutes which was the original intent and design. As a result, the 96" downstream pipeline that fed this station was now pumping against a closed valve. This caused a rupture in the 96" line that came bubbling out of the ground within a minute of the ROFC #1 valve closing. The overall shutdown control strategy for the 96” pipeline had the ROFC valve close times at 15 minutes, which was assumed to be enough time to adjust pressures and prevent pumping against a closed valve. It was assumed at the time that human error caused the flood alarm and emergency shutdown and not the faulty butt splice.

The owner now had to reroute water to meet the water demands of major downtown businesses and tourist destinations. ROFC#3 was then quickly repaired by the owner’s team so service could be provided once the repairs were completed. From the time that the leak was identified and the repairs completed, the system was down for 36 hours. During that time, crews were onsite around the clock. The repairs to the 96” line were completed and the process of chlorination and de-chlorination had to begin. After the repairs had been made, the owner would not allow use of ROFC #1 because of the actuator timing, ROFC #2 was half way through the retrofit of that valve, so that only left the non-upgraded ROFC #3 to provide service.

Due to this incident, the owner did not trust the upgrades made on ROFC #1 and #2, and required the Contractor to conduct tests of specified functionality prior to upgrading ROFC #3. The entire project could not progress forward at that moment, until ROFC #1 and #2 could be repaired and proven to the owner to work as specified. The valve actuator control boards needed to be reprogrammed at the factory and shipped back. The reprogramming would change the shut time to 15 minutes from 90 seconds. There was a major miscommunication between the Contractor and Programmer and when the new boards arrived, the timing had not been changed it was still at 90 seconds full stroke. In the end, the project was shut down for three full weeks until the new boards were installed, tested, and verified. After the new boards were tested and the PID tuning completed, ROFC #1 was put back into service. ROFC #2 upgrades and modifications were completed at the same time and put into service. The owner was very skeptical about the operation of the new valve actuators and would not allow work to start on ROFC #3 until their comfort level was satisfied on the actuators for ROFC #1 and #2. This caused an additional two weeks' delay in the project schedule.

During the two week period that the facility was in operation there was another false Flood Alarm that caused the entire system to shut down. However, with the properly programed actuators, adjustments were made and no failures in the system occurred. This time the facility was unoccupied, which eliminated human error as the cause of the shutdown. Upon further investigation, the faulty connection on the Flood Switch that caused the initial, unintended shutdown, was found and corrected.

CSU-Related Problems, Opportunities, & Contributing Factors

The butt splice connection was not made correctly creating a false and intermittent Flood Alarm. This incorrect procedure should have been identified in the inspection of the connection as it was noted that the flood switch factory wiring would not reach the new termination locations. A splice was known to be necessary, so verification of proper extension of the alarm should have been verified. There was a major miscommunication factor between the CSU team and its suppliers. This lack of leadership and continuity created an environment where the valve timing was consistently and drastically incorrect. This that could have been avoided with proper communication.

There was also a lack of understanding in working in a brownfield application. Only one line should have been taken offline at a time to help serve as a redundant line in case an emergency occurred. Also, plant operations should have been consulted during start-up and may have been able to prevent the incorrect timing sequence being installed on the valve actuators. This overall lack of alignment contributed to a major failure during start-up.

Impact of CSU Failure

The failure resulted in the rerouting of water and loss of service to a major urban center and possible threats to worker safety. Severe delays to project schedule also resulted.

Lessons Learned

For brownfield expansions/upgrades, involve system maintenance personnel (that are very familiar with existing equipment configurations/operations) in the detailed planning and HAZOP analysis of system CSU. This especially applies for system-critical devices or devices that are otherwise unfamiliar to many of those involved in the project. Planning for control system upgrades must fully consider the operating properties/conditions of all critical equipment and components.

- Lack of continuity among Start-up Managers can contribute to a chain of events, leading to failure.
- Maintenance support must buy-in to the CSU process and share in CSU success/failure.
- Have access to and reference specification sheets on existing equipment data (i.e. stroke time for valves).

Links to CSFs

CSF#2 - CRITICAL INTERFACES ON BROWNFIELD PROJECTS

A complete and thorough understanding of the existing facility operations and equipment is needed in all brownfield projects. Knowledge of interim operations, emergency protocols, and upstream/downstream impacts would have assisted in this start-up.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Early project alignment and planning was 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 a vast amount of technical expertise or input. The mechanical and process engineer 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 start-up.

CSF#5 – CSU LEADERSHIP CONTINUITY

The CSU team was also incomplete, without a single, continuous start-up manager to oversee Commissioning and Start-up on the Contractor's team. Requirements and qualifications for this manager were not defined in this project.

CSF#11 – CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

A lack of access to specification data, and the absence of check-sheets during start-up were a contributing factor to this failure. Functional checkouts were not performed prior to the installation of the actuators.

CSF #12 - CSU TEAM CAPABILITY

The CSU team was limited in the understanding of the original operating parameters of the existing equipment and plant. No expert knowledge from the plant operators was solicited during planning for start-up and unfamiliarity with the system led to the failure.

Case Study C

Project Y Downstream Chemical Plant

Project Description

The project involved the construction and start-up of a new, downstream petrochemical plant on the Gulf Coast. New plant contained approximately 2000 total Inputs/Outputs (I/O), with over 200 control valves and 600 transmitters. The new plant was a similar design to an existing, 10-year old plant near the same site. The additional construction of the new plant was warranted due to the orders of the existing plant being far exceeded. Output for the new plant was already sold out for the first 12 months following start-up of the plant.

Installation was also to include a new and unfamiliar level of control system device security firewalls and protection against outside cyber-attacks. This required installation, testing, and setup prior to operations of the new plant. If during plant handover to the owner the security system was not fully operational, a penalty was to be assessed to the EPC firm for completion lateness.

Project Y was a doubling of the existing plant's size, and design of the plant processes were well known. However, a different EPC contractor from the existing plant was selected for construction of the new plant. The owner of the plants suggested the new plant would be largely a copy of the existing plant, so little in the way of process changes or upgrades was indicated and the assumption was Construction and Start-up would proceed smoothly due to this mirrored design. The new plant was put into a fast-track schedule, under the assumption that replication of the existing plant was the primary concern.

Project and CSU-Related Performance or Outcome

Though construction was achieved without major delays, Commissioning and Start-up was ultimately late by approximately two months. This was attributed to many factors, including excessive on-the-job training, ghost chasing of control loop anomalies, and rotating equipment issues not being reduced. Also at the time of handover to the owner for Initial Operations, it was noted that the cyber security plan had been violated and turned over in an undetermined state. The new plant had many process changes, as compared to the existing plant, signifying many owner changes throughout all phases, though the owner initially indicated an exact design replicating the existing facility. The assumption was these changes would be incorporated easily, though that was not the case.

Late start-up charges/penalties exceeded $3 million and over $15 million in viable production was lost. A $3 million early start-up bonus to the EPC contractor was also not awarded. An additional $10,000 fee was assessed to the EPC contractor for failure to handover a fully functional and proper cyber security system. For all the good faith work and reputation the EPC had built with the owner, an unfavorable impression was left between the EPC and end user plant personnel. This bad relationship from the delayed start-up resulted in the EPC not being awarded additional phases of work for the owner.

The new plant design neglected to use electronic smart marshalling technologies (which allow for flexibility in making modifications) for the I/O due to many changes in desired functions during the Detailed Design phase. An additional 3 weeks in schedule could have been saved. This schedule reduction would have netted the plant an additional $4 million in realizable, early profits and made the plant far easier to modify later in its lifecycle. Asset Management Software (AMS) field device diagnostics were also not fully utilized, although they were included in the design. This was due to the EPC and owner not fully understanding their value to project start-up. This software is capable of helping speed up Commissioning and Start-up time by 40-55%, reducing loop ghost chasing 70-85% and reducing documentation time for As-Builts by 65 %. No training on these advantageous and beneficial tools was conducted, so the schedule savings benefits could not take place.

CSU-Related Problems, Opportunities, & Contributing Factors

Commissioning and Start-up personnel were not properly trained on new AMS device diagnostics technologies and best practices. There was also a lack of training on the new cyber security features and capabilities. This new system was new and different for the CSU team, but not overly difficult for training. This lack of training led to unnecessary delays and troubleshooting issues.

The CSU capital budget was also not sufficient and did not allow for 3-6 man weeks of a SMEs (Subject Matter Experts) to provide on-site support. Had SMEs been available, a far more effective and efficient commissioning and start-up of the more complex smart field devices could have occurred. Both the owner and EPC were to blame for not fully realizing the need for these experts and requiring their participation prior to Initial Operations.

As a result, no start-up best practices were shared and utilized regarding the new technologies and security requirements. As-Built data/documentation was completed but unreliable and scattered at best. The new system could have easily organized, displayed, and printed out all the required details quite easily, had the CSU users been properly trained on the full functionality of the devices.

Impact of CSU Failure

The failure resulted in significant loss of production and associated cash flow ranging in the tens of millions of dollars. Extra time and cost were required to achieve required product quality. Additionally, there was a loss of contractor's substantial early start-up bonus.

Lessons Learned

Earlier involvement and planning of the CSU team in the project phases is crucial to achieve a smoother Commissioning and Start-up. More frequent and reaffirmed alignment of resources and training needs is required and should be agreed upon by both owner and EPC. A sufficient budget process that delivers appropriate and skilled resources at the site when needed is imperative. Savings from proper training that results in much improved schedule and performance measures, can be further enhanced by including SMEs in the CSU.

Similar projects in operation currently utilize smart field devices with asset management and self- diagnostic capabilities, which are designed to aid immensely in Commissioning and Start-up. Not realizing and utilizing the full potential of these capable tools can be detrimental to the CSU process and team. Their use is not just in Commissioning and Start-up or plant turnarounds, but can be valuable during operations for the life cycle of the plant.

Links to CSFs

CSF#1 - CSU VALUE RECOGNITION

No member of the CSU team, including the CSU manager, knew the value recognition and procedures (or best practices and CSF's) to help achieve a bonus level CSU accomplishment. As a result, the project achieved penalties due to delayed handover. Affordable CSU team training applied early and the use of a few supplier certified SME's at site, could have potentially saved millions of dollars.

CSF#3 - ADEQUATE FUNDING FOR CSU

The budget for Commissioning and Start-up lacked the necessary amounts of funding for a successful start-up. There was a lack of funding for both the CSU team and operator training. A small amount of expenditures could have potentially eliminated millions of dollars in lost revenue due to delayed plant operations.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Early project phase alignment, planning and development of training and key resources needs were not accomplished. Key issues, drivers, and strategies were not identified early in the project. The CSU team involvement was minimized until too late in project without effective collaboration. Also the owner made far more process changes that they had originally stated when what was initially indicated was a carbon copy plant to the existing plant.

Project Management was also not aligned with its new Operating plant staff, and therefore Operations and Project Management had many clashes, delays in schedule, creation of excess costs, as well as an increase in risk. Understanding of TICC (Total Installed and Commissioned Costs) is crucial to the CSU mission of meeting the schedule of saleable product produced by owner at the promised date, grade and quality.

CSF#6 - SYSTEM MILESTONE ACCEPTANCE CRITERIA AND DELIVERABLES

Milestone acceptance criteria was vague and left gaps in the set up & test specifications. Milestone dates for completion and the required deliverables were ill-defined. These expectations were not well understood by the EPC prior to Commissioning and Start-up.

CSF#8 - RECOGNITION OF CSU SEQUENCE DRIVERS

Critical interfaces to the existing plant and availability of experienced operator resources when needed was not well planned. Recognition and even definition of key CSU sequences and sequence drivers was not well planned and discussed. A lack of communication of these drivers was also present.

CSF#9 - DETAILED CSU EXECUTION PLAN

Execution planning was conducted too late or not at all. The proper mix of skill in CSU craft and management was not achieved, with lack of contribution by the Plant Operators. There was no established plan for the multitude of training on instrumentation and the new security system.

CSF#11 - CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

System functional checkouts weren't performed for the security system. The criteria lacked scope, breadth, and depth to effectively achieve a functional system.

CSF #12 - CSU TEAM CAPABILITY

The CSU team lacked the understanding and knowledge of the multitude of CSU systems and did not possess the expertise to identify potential problems and concerns prior to Commissioning and Start-up, such as the need to incorporate SMEs.

CSF #13 - INTEGRATED CONSTRUCTION/CSU SCHEDULE

The Integrated Construction/CSU schedule was developed late, did not emphasize or promote collaboration, and did not share with the key CSU team the Operations performance metrics and guarantees for the project.

CSF#14 - ACCURATE AS-BUILT INFORMATION

Without the adequate training of CSU team members, clearer roles and requirements, and the use of SME's, the asset management database was not properly loaded. The self-documenting As-Built drawings tool was only partially utilized and partially correct. The full benefit of As-Built information was not able to be utilized by the CSU team or plan operators.

CSF#16- COLLABORATIVE APPROACH TO CONSTRUCTION-CSU TURNOVER

There was a lack of a collaborative approach in regards to CSU in the beginning stages of the project. The CSU team was brought on too late to effectively work with system handover from the construction team. Conflict arose when systems weren't ready and training was ineffective.

Case Study D

Power Generating Facility: Selective Catalytic Reduction Ammonia Unit Forwarding Line

Project Description

The project was a brownfield, power-generating facility, operated by a subsidiary of a major electric utility corporation. Main portion of work consisted of the construction of new ductwork between the boiler and exhaust. The project also consisted of the construction of a Selective Catalytic Reduction Ammonia Unit Forwarding Line. The primary purpose of this new system is to clean flue gas from the boiler prior to exhaust in an effort to reduce NOx gases. The project involved the installation of approximately 40 new systems at a cost of $100 Million.

Project and CSU-Related Performance or Outcome

During the Initial Operations phase of the project, an incident involving the release of ammonia gas occurred inside the facility. At 1 a.m. a high ammonia (NH_3) concentration was detected at a storage tank area sensor and plant personnel manually activated an Emergency-Stop Pushbutton, which automatically closed supply valves from the ammonia tanks. A contracted Environmental Emergency Response Team was mobilized to the site to respond to the leak of ammonia and investigate the source. Fears raised at the time estimated that the possibility of over 100 lbs. of ammonia had been leaked to the environment.

After investigation, the location of the leak was determined to be in a pipe trench running from the storage area with multiple other lines. The line was wrapped in insulation, but had become soaked with ammonia due to the slow leak of ammonia over an unknown timespan. The leak was due to a threaded union connection becoming loose and allowing gases to leak. It was unknown at the time how long the leak had been occurring due to the insulation that was installed on the lines.

The insulation was removed and the union was retightened. Under monitoring, the anhydrous ammonia was placed back in service while the Environmental Emergency Response Team monitored for continued leakage. An operator remained on scene for communication to the control room. During the test, the leak began to occur once more. In response, the Environmental Emergency Response Team tightened the union a little more and the leak was stopped. The area of the incident remained barricaded for the remainder of the weekend as a precaution.

Ultimately, the environmental risk and exposure was not as severe as originally feared. It was estimated that only 10 lbs. of ammonia was released, though the potential risk for further environmental exposure was a concern. During investigation of the incident it was determined that the union where the leak occurred was not the correct type of union. A fully welded union was specified, but instead a threaded union was installed. This incorrect installation was the cause of this leak. Once the leak was stopped, the welded coupling was installed as per specifications.

During the CSU phase of the project, all threaded and welded connections were checked against the As-Built Drawings. However, during construction, the deviating union was installed, but not communicated and marked on the As-Built drawings. This field modification was made without engineering review and resulted in the connection not being checked during initial testing and commissioning. Though passing a standard leak test during start-up, no other system-specific integrity tests were performed, and the insulated pipe made visual inspection impossible.

CSU-Related Problems, Opportunities, & Contributing Factors

Contributing factors to this failure included the following:

- Installation of incorrect materials and components during Construction phase - fallible component (threaded union) in a pressurized NH_3 system.
- Inadequate communications between Engineering, Construction, and Operations. Neither the Start-up team, Engineering, nor Plant Operators were aware of the installed union on the pressurized NH_3 line during Construction. Decision to deviate from the specified union was made at the field level, with no Engineering input. Field personnel were unaware of issues and complications experienced in the past with threaded unions in pressurized NH_3 lines and the reason welded couplings were specified. Plant personnel onsite during incident were unaware that the Unit Forwarding Line was pressurized with NH_3.
- Inspection, examination, and testing of Ammonia piping system was not conducted according to required procedure ASME B31.1. Roles and responsibilities relative to proper testing procedures were not understood. Requirements of testing protocol were not understood by start-up team. Start-up utilized a typical "O & M" type leak test, which was the only integrity test performed prior to pressurizing with NH_3. The union was insulated making visual inspection impossible.

Impact of CSU Failure

The failure resulted in significant safety and environmental threats to facility personnel and the local community due to release of a potentially toxic chemical. At the time of occurrence, the amount of ammonia was not known and was feared to be high.

Lessons-Learned

Many lessons-learned resulted from this failure:

- On NH_3, and other similar systems, construction should be given, or take, less latitude to make field modifications without engineering review. "As-Built" drawings critically associated with a pressurized chemical system should be reviewed prior to performing testing on the system.
- Critical information regarding pressurization and testing of the NH_3 system needs to be communicated to appropriate plant personnel and start-up team.
- Enhance and encourage a system of communication for system owners, technical services, etc… to share lessons learned and best practices in accordance with company compliance guidelines.
- For NH_3, and similar systems, integrity testing should be assigned to construction and performed to applicable codes/standards, and functionality testing should be assigned to the Start-up team. Review turnover packages to ensure testing roles and responsibilities are clearly defined and that required testing meets specifications.
- On pressurized NH_3 lines, and similar systems, evaluate a reliable method to reference the required testing procedures on design documents and specifications to aid communication in the field.

- Proper documentation of the applicable testing protocol and desired results should be completed prior to introduction of NH_3 into the system.
- Evaluate and define training needs related to roles and responsibilities related to construction and/or start-up team.
- Deviations from approved testing procedures must be reviewed and approved by the appropriate Engineering team.
- Assign a committee to review how to design, construct, start-up/check-out, and operate pressurized systems involving hazardous fluids or gases within the Company.

Links to CSFs

CSF#2 - CRITICAL INTERFACES ON BROWNFIELD PROJECTS

Properly communicated existing plant protocols and procedures would have revealed the flaw in using threaded union couplings on pressurized ammonia lines. Operator education and a more thorough understanding of the system could have potentially stopped the failure prior to it occurring.

CSF #4 - ALIGNMENT AMONG OWNER PM, OPERATIONS, CSU, ENGINEERING, AND CONSTRUCTION

Lack of alignment between Engineering, Construction, and Operations led to a gap in information that ultimately led to the ammonia leak. Collaboration was lacking during Engineering and Construction phases, which ultimately posed safety and environmental risks during Initial Operations on a brownfield project.

CSF #9 - DETAILED CSU EXECUTION PLAN

Plant operations should have been more thoroughly involved during Construction and reviewed system start-up procedures. Input should have been provided during the Construction phase and CSU. CSU staff required a more thorough understanding of operations and the need for specialized milestone acceptance criteria.

CSF#11 - CSU CHECK-SHEETS, PROCEDURES, AND TOOLS

Functional checkouts for the Ammonia Forwarding Line were not adequate, and check sheet and detailed system commissioning procedures were ill defined. Testing of the ammonia line required more stringent tests than a standard leak test which was not defined to 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 be established prior to system start-up and initial operations. Development of supportive documentation, including proper test protocols, should have been listed for achievement 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, visual inspection could not be performed, therefore requiring reliance on accurate As-Builts. It was not discovered the union was incorrectly installed, until a leak occurred.

Appendix E - Project CSU & CSF Assessment Data

Table E-1: Project Summary Characteristics

Project	Approx. No. of CSU Systems	Approx. Project Cost	Industry Sector	CSU Perf. Score	Ind. for Achiev.	Top 25 Ind. for Achiev.	Status
1	5	< $25M	Heavy Industrial - Power	30	30	17	More Successful
*2	75	$500M - $1B	Heavy Industrial - Chemical	18	16	7	Less Successful
*3	5	< $25M	Light Industrial - Water	14	22	12	Less Successful
4	7	< $25M	Light Industrial - Water	33	24	16	More Successful
*5	4	< $25M	Heavy Industrial - Power	13	1	0	Less Successful
6	100	$500M - $1B	Heavy Industrial - Power	32	37	22	More Successful
7	47	$100M - $500M	Other	30	37	22	More Successful
9	5	$25M - $100M	Heavy Industrial - Chemical	34	43	25	More Successful
10	872	> $1B	Heavy Industrial - Oil/Petroleum	30	35	22	More Successful
11	35	$100M - $500M	Heavy Industrial - Other Manufacturing	30	43	25	More Successful
12	28	$25M - $100M	Heavy Industrial - Power	21	25	10	Less Successful
13	15	$25M - $100M	Pharma/Healthcare/ Labs - Clinic	21	12	2	Less Successful
14	27	$100M - $500M	Pharma/Healthcare/ Labs - Research Lab	31	29	18	More Successful
15	41	$25M - $100M	Pharma/Healthcare/ Labs - Pharm Manufacturing	33	25	17	More Successful
16	27	$100M - $500M	Heavy Industrial - Power	15	23	11	Less Successful

Table E-1: Project Summary Characteristics, cont.

Project	Approx. No. of CSU Systems	Approx. Project Cost	Industry Sector	CSU Perf. Score	Ind. for Achiev.	Top 25 Ind. for Achiev.	Status
18	35	> $1B	Heavy Industrial - Power	24	28	12	Less Successful
19	14	$25M - $100M	Pharma/Healthcare/ Labs - Research Lab	36	38	25	More Successful
20	5	< $25M	Pharma/Healthcare/ Labs - Research Lab	30	22	13	More Successful
* 21	41	< $25M	Heavy Industrial - Power	26	31	16	Less Successful
22	100	$500M - $1B	Heavy Industrial - Power	36	43	23	More Successful
23	270	> $1B	Heavy Industrial - Oil/Petroleum	23	15	8	Less Successful
24	350	> $1B	Heavy Industrial - Oil/Petroleum	35	35	21	More Successful
25	25	$500M - $1B	Heavy Industrial - Power	29	30	12	Less Successful
26	100	> $1B	Heavy Industrial - Other Manufacturing	28	12	4	Less Successful
27	5	< $25M	Light Industrial - Wastewater	32	28	13	More Successful

* Commissioning Failure Case Studies

Table E-2: Project Commissioning Performance Averages

CSU Success Criteria		**More Successful Projects Average Score**	**Less Successful Projects Average Score**	**Delta**
	1. Product Quality Performance	4.07	2.55	1.52
	2. Product Quantity Performance	4.07	2.55	1.52
	3. CSU Schedule Performance	3.93	2.18	1.75
	4. CSU Safety Performance	4.67	4.18	0.48
	5. Environmental Performance	5.00	3.55	1.45
	6. Preparation of CSU Operations Team	3.93	2.36	1.57
	7. CSU Impact on Ongoing Operations	4.42	2.44	1.97
	8. Level of Effort Required by CSU Team	3.20	1.73	1.47

Table E-3: Project CSF Implementation Averages

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
1	CSU Manager is on the project organizational chart at the start of Front-End Engineering.	#1	73.33%	27.27%	46.06%
2	CSU Manager is accountable for leading the team through the systemization process, involving operations, maintenance, and CSU resources.	#7	80.00%	63.64%	16.36%
3	Commissioning test procedures are completed by the end of Detailed Design.	#10	57.14%	18.18%	38.96%
4	Possession of construction and commissioning integrated schedule by the 30% construction complete milestone.	#15	80.00%	27.27%	52.73%
5	Formalized system-level walk-down and punch list management, led by CSU team.	#15	100.00%	63.64%	36.36%
6	A methodical approach was used to develop the project's CSU sequence (including all system, sub-systems and related dependencies), with formal recognition of all critical sequences and was finalized by end of detailed design.	#8	93.33%	54.55%	38.79%
7	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	73.33%	63.64%	9.70%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
8	Several CSU joint meetings held in which all stakeholders were present. These are initiated early and are repeated throughout planning, design, and construction phases.	#4	93.33%	63.64%	29.70%
9	Critical CSU input has been acquired for engineering design reviews, engineered equipment purchases, construction sequencing and schedules	#4	93.33%	27.27%	66.06%
10	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 percent of Total Installed Costs (TIC).	#3	64.29%	27.27%	37.01%
11	Formal CSU design review has occurred by the end of Front-End Engineering.	#7	50.00%	9.09%	40.91%
12	Project schedule includes system logic inter-dependencies and turnover milestones prior to 30% construction complete.	#13	66.67%	45.45%	21.21%
13	Joint CSU system walk-downs are conducted, involving both CM and CSU Manager.	#16 r	80.00%	63.64%	16.36%
14	CSU progress is regularly assessed with management metrics.	#12	86.67%	45.45%	41.21%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
15	A master set of asset drawings is readily available and document control procedures are effective from construction through to final facility turnover.	#14	100.00%	81.82%	18.18%
16	All construction/CSU physical access constraints due to brownfield conditions have been identified by 30% detailed design complete.	#2	53.33%	36.36%	16.97%
17	All project team members understand site permitting requirements.	#2	86.67%	81.82%	4.85%
18	Repeated confirmation of alignment is achieved.	#4	85.71%	36.36%	49.35%
19	Identification and finalization of CSU system and subsystem boundaries on P&IDs, one-lines, and controls architecture.	#10	78.57%	54.55%	24.03%
20	The CSU philosophy/strategy/execution plan has been reviewed/approved by all stakeholders and signatures are affixed.	#4	80.00%	27.27%	52.73%
21	Project leadership is very familiar with the venture value that would be lost from a 1-day delay in startup of Operations.	#1	86.67%	81.82%	4.85%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
22	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, HSE, etc...).	#9	93.33%	36.36%	56.97%
23	A CSU Manager was assigned at the start of Front-End Engineering and remained with the project through to initial operations.	#5	73.33%	9.09%	64.24%
24	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.	#11	66.67%	27.27%	39.39%
~~25~~	~~Incentive systems are in place to encourage continuity of CSU leadership.~~	~~#5~~	~~20.00%~~	~~36.36%~~	~~-16.36%~~
26	System acceptance criteria are incorporated into the contract with the Execute Contractor.	#6	66.67%	63.64%	3.03%
27	Preliminary CSU sequence is defined by end of Front-End Engineering.	#7	66.67%	54.55%	12.12%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
28	Finalization of CSU sequence, depicting all systems, subsystems, and associated dependencies.	#10	93.33%	45.45%	47.88%
29	Tracking of system completion with the use of check sheets during construction.	#15	93.33%	54.55%	38.79%
30	Construction and pre-commissioning check sheets are finalized by the end of Detailed Design.	#10	60.00%	27.27%	32.73%
31	Project operational objectives are well-documented and well-understood among CSU team members.	#12	100.00%	27.27%	72.73%
32	Prior to the start of Front-End Engineering approved CSU budget and schedule are in-hand for CSU planning work.	#1	60.00%	27.27%	32.73%
33	System/sub-system acceptance criteria are well documented prior to finalization of bid documents and key parties are aligned on the criteria by the end of Front-End Engineering.	#6	40.00%	9.09%	30.91%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
34	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	66.67%	36.36%	30.30%
35	Project team has identified all tie-ins and individual shut-downs by 30% detailed design complete, and these have been integrated into the Construction-CSU Integrated Schedule.	#2	78.57%	45.45%	33.12%
36	By the end of Front-End Engineering, system boundaries are identified on P&IDs and electrical one-line diagrams.	#7	64.29%	54.55%	9.74%
37	Joint meetings, involving both CM and CSU Manager, are conducted starting around 50% construction complete.	#16	100.00%	54.55%	45.45%
38	System boundaries and isolations are developed with full understanding of brownfield operations/ controls conditions.	#2	92.31%	72.73%	19.58%
39	CSU team members understand the links between their actions and the technical metrics for project success.	#12	93.33%	36.36%	56.97%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
40	Short-term scheduling priorities (at a system & sub-system level) are established with input from both CM and CSU Manager.	#16	93.33%	72.73%	20.61%
41	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	93.33%	18.18%	75.15%
42	An asset information plan has been defined, reviewed, and approved by the end of detailed design.	#14	40.00%	36.36%	3.64%
43	Operations fully participated in the preparation of the detailed CSU Execution Plan.	#9	66.67%	18.18%	48.48%
44	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, process systems, etc.	#8	93.33%	54.55%	38.79%
45	If an asset management solution is being used, then an equipment diagnostic alerts utilization plan is in place prior to construction.	#11	14.29%	9.09%	5.19%

Table E-3: Project CSF Implementation Averages, cont.

Question No.	Question	CSF	More Successful Projects Average Yes Score	Less Successful Projects Average Yes Score	Delta (> 30% = Top Indicator)
46	The qualifications and the planned tenure of the CSU Manager are well defined by early Front-End Engineering.	#5	73.33%	27.27%	46.06%

Table E-4: Commissioning Performance vs. CSF Implementation scatterplot data

	Project Number	Commissioning Performance	CSF Implementation	
		CSU Success Criterion Score	Composite Score for Top 25 Indicators	Normalized Indicator Score (0 -1)
More Successful CSU Projects	P1	30	17	0.68
	P4	33	16	0.64
	P6	32	22	0.88
	P7	30	22	0.88
	P9	34	25	1
	P10	30	22	0.88
	P11	30	25	1
	P14	31	18	0.72
	P15	33	17	0.68
	P17	34	25	1
	P19	36	25	1
	P20	30	13	0.52
	P22	36	23	0.92
	P24	35	21	0.84
	P27	32	13	0.52
Less Successful CSU Projects	P2	18	7	0.28
	P3	14	12	0.48
	P5	13	0	0
	P12	21	10	0.4
	P13	21	2	0.08
	P16	15	11	0.44
	P18	24	12	0.48
	P21	26	16	0.64
	P23	23	8	0.32
	P25	29	12	0.48
	P26	28	4	0.16

Table E-5: Regression Analysis Data

Regression Statistics	
Multiple R	0.758819601
R Square	0.575807187
Adjusted R Square	0.558132486
Standard Error	4.586459728
Observations	26

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	685.2991381	685.2991381	32.57804483	7.02009E-06
Residual	24	504.8547081	21.03561284		
Total	25	1190.153846			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	16.77910901	2.100828253	7.986901826	0.00000003249
Normalized (0 -1)	17.69743503	3.100614819	5.707718006	0.00000702009

Lower 95%	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
12.4432126	21.11500542	12.4432126	21.11500542
11.29808057	24.0967895	11.29808057	24.0967895

Appendix F - Research Team Membership

Research Team 312: Best Practices for Commissioning and Start-up

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