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Links between Modularization Critical Success Factors and Project Performance

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Links between Modularization Critical Success Factors and Project Performance

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Dedication

I dedicate this dissertation to my parents, Bok-Gil Choi and Se Young An. There is no doubt in my mind that without their continual support and love I could not have completed the PhD process. Particular thanks also go to my sister, Yoon Jeong Choi, for her support and love.

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Links between Modularization Critical Success Factors and Project Performance

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Through the exporting of a portion of site-based work to fabrication shops, modularization (MOD) can enhance efficiency in the construction industry. The industry, however, applies modularization at only a low level. To reach higher levels of modularization, the EPC industry needs new approaches. Previous studies have identified the current trends in and barriers to the industry's application of modularization. Moreover, in 2013, the Construction Industry Institute's (CII) Research Team 283 identified 21 critical success factors (CSFs) that create an optimum environment for a broader and more effective use of modularization. However, the researcher has identified a need to better understand the relative significance of MOD CSFs and their associations with project performance. Thus, the research was conducted to provide recommendations for better project performance by identifying correlations between the accomplishment of MOD CSFs and project performance and examining actual modular projects' MOD CSF accomplishment. This study identified four statistically significant positive correlations. Those are between the accomplishment of MOD CSFs and: 1) cost performance; 2) schedule performance; 3) Construction performance; and 4) Startup performance. In addition to the correlation analysis, the study also identified the CSFs that appear to contribute the most to 1) "Modular Project Success", 2) Construction success, 3) Startup

success, 4) Cost performance, and 5) Schedule performance. To collect information on the actual industrial modular projects, the study surveyed industry experts. By using this study, many industrial project stakeholders from owners to fabricators, designers and EPC contractors, will be able to understand the relationships between MOD CSFs and project performance. Such an understanding should motivate them to achieve better project performance through implementing modularization CSFs.

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Chapter 1: Introduction

1.1 Background

The technique of exporting a portion of site-based work to a fabrication or module assembly shop is commonly referred to as modularization. This well-established technique can improve the efficiency and productivity of the construction industry. Since its introduction, the value and benefits of modularization have been widely recognized. These include lower capital costs, improved scheduled performance, increased productivity, higher overall quality, increased safety performance, reduced waste, and better environmental performance. However, the industry continues to struggle to achieve high levels of modularization. In recent years, the rapid development of the modularization technique has resulted in its reemergence.

1.2 Research Needs

According to a 2011 survey, nearly 98% of industry players expected to be using, by 2013, prefab/modularization. However, fewer than half (37%) of these companies were using it at high or very high levels (McGraw-Hill 2011). Previous studies have explored current trends and advantages in modularization as well as some of the barriers to its application. However, these studies failed to raise modularization to an optimum level within the construction industry. Moreover, few studies have sought to identify either its success factors or its expert practitioners' practices. To help clear up such issues, Construction Industry Institute (CII) Research Team (RT) 283 created an optimum environment for broader and more effective use of modularization by providing modularization's Critical Success Factors (CII 2013). However, the researcher identified a lack of 1) understanding of MOD Critical Success Factors (CSFs) and their accomplishment status; and 2) understanding on relative significance of CSFs and their associations with project performance.

While some companies had successfully employed pre-fabrication, pre-assembly, modularization, and offsite fabrication (PPMOF), as CII RT 171 noted, the industry in general had yet to fully capitalize on PPMOF's potential to improve projects (CII 2002). Thus, this research made a commitment to fill the gap above on the literature to help industrial project stakeholders from owners to fabricators, designers and Engineering, Procurement, and Construction (EPC) contractors to understand the industrial modularization and MOD CSFs, and motivate them to achieve better project performance.

1.3 Research Objectives

The primary goal of this research is to better understand the relationships between MOD Critical Success Factors and project performance. It goes about this by identifying correlations between project performance and the accomplishment of MOD CSFs. Several terms were defined by CII RT 283 and adopted for the dissertation research:

- ***Module****:* Portion of plant fully fabricated, assembled, and tested away from the final site placement, in so far as is practical (CII 2012)
- ***% Modularization***: Portion of original site-based work hours (excluding site preparation & demolition) exported to fabrication shops (CII 2012)

The research questions are:

1. Are there differences among MOD business case initiation timing in MOD CSF accomplishment?

2. Are there differences among MOD business case initiation timing in project performance?
3. Is there an association between MOD CSF accomplishment and project performance?
4. Is there an association between MOD extent and MOD CSF accomplishment?
5. Are there project performance differences by the accomplishment of individual CSFs?

The secondary goal of the research is to examine actual accomplishment of modular projects' CSFs.

1.4 RESEARCH HYPOTHESES

A total of three sets of research hypotheses were developed to identify correlations. The main research hypotheses are as follows: 1) Project performance is associated with the accomplishment of MOD CSFs and with MOD business cases initiation timing, and 2) the accomplishment of MOD CSFs is associated with MOD business case initiation timing, and 3) modularization extent is associated with the accomplishment of MOD CSFs. The accomplishment of modularization CSFs was measured in two ways: degree of accomplishment and timing of accomplishment (the measurements of these accomplishment are detailed in Chapter 3: Research Methodology) and both variables were used to test the research hypotheses.

The research hypotheses are outlined below.

1. PROJECT PERFORMANCE METRICS are associated with:

1.1 degree of MOD CSF accomplishment

1.2 timing of MOD CSF Accomplishment

1.3 MOD business case initiation timing

2. MOD CSF ACCOMPLISHMENT is associated with:

2.1 MOD business case initiation timing

3. MOD EXTENT is associated with:

3.1 degree of MOD CSF accomplishment

3.2 timing of MOD CSF accomplishment

1.5 Research Scope and Limitations

Limited to Industrial Projects

The scope of this research concerns primarily the industry's sub-sector, including process and manufacturing facilities such as offshore facilities, petro-chemical plants, power plants, and pharmaceutical plants.

Modular Projects

What is not part of the research scope is non-modular projects. The data collection was focused on modular projects that actually implement the MOD technique. Hence, the study will make no comparison between non-modular and modular projects. Figure 1 illustrates the frequency of % MOD. The researcher checked its skewness through a Q-Q plot (Appendix A), which compares a sample of data on the vertical axis to a statistical population on the horizontal axis. The pattern is linear enough to conclude that the data are normally distributed.

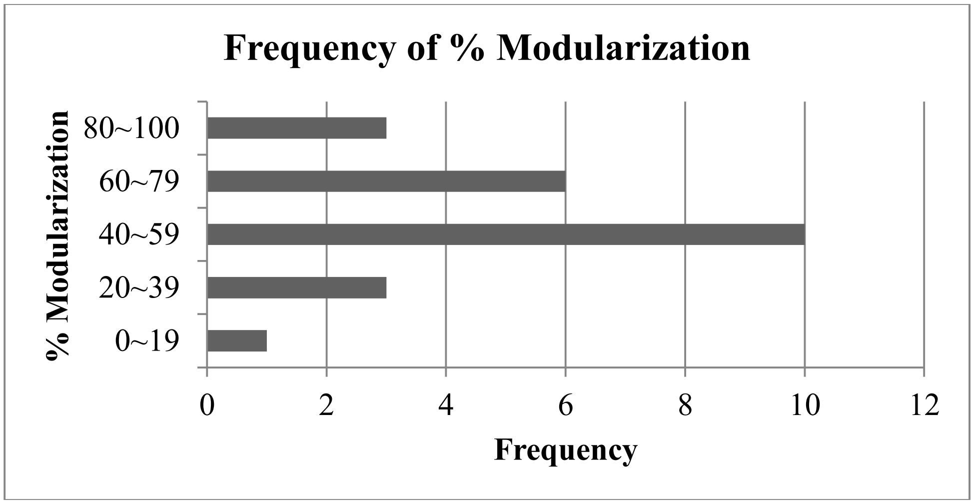


Figure 1. Frequency of % Modularization

Timing of the study

The research problems were identified in early October 2012. The data collection were executed between March and October of 2013.

Data Sources

Believing the probability sampling approach to be impractical for the research, the researcher did not apply it. In selecting a data-collection approach and the number of projects, the researcher considered the data collection difficulties incurred by the limited number of modular projects in the industry, the high value to modular project information and its experience, and practical limitations (time, money, and workforce). This non-probability sampling allows that the collected sample may or may not represent the entire population accurately. Thus, the generalizability of the results of the research may be limited.

The researcher contacted a total of 94 modular experts, received information from 25 sample projects through a survey questionnaire sent out to 20 modular experts (response rate was 21.28%, see Figure 2). The respondents were asked to provide information on their most recent modular project.

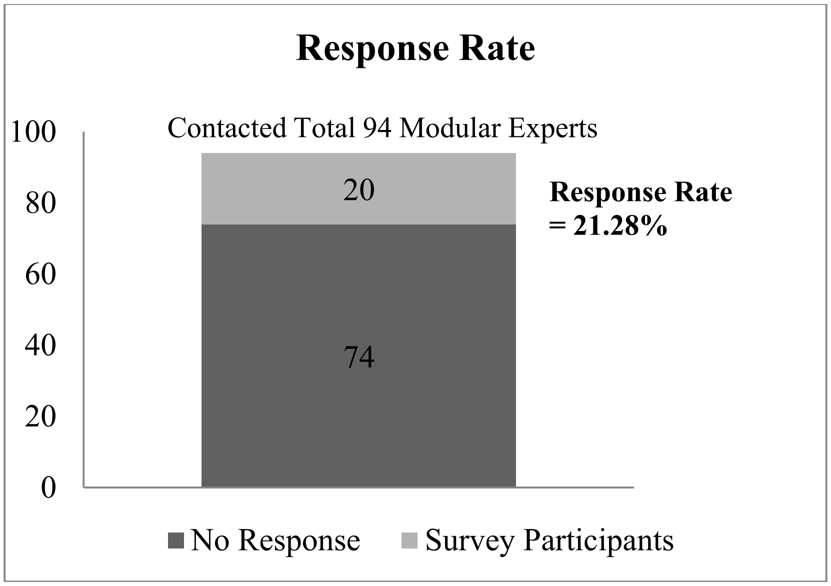


Figure 2. Number of Contacted Experts and Response Rate

The collected sample projects can be grouped into four groups (Figure 3): CII Modularization Community of Practices (MCOP), Front-end-planning Community of Practices (FEPCOP), CII Implementation Resource (IR) Publication Reviewers, and others. The researcher would like to note that there might be a possible bias on the understanding of CSFs among these groups because the MCOP and the IR283 Reviewer groups had a better understanding of CSFs than did the FEPCOP and the Others groups; indeed, the MCOP and the IR283 Reviewer groups were familiar with the MOD CSFs. For this reason, the researcher took pains to clarify CSFs for the FEPCOP and the Others groups.

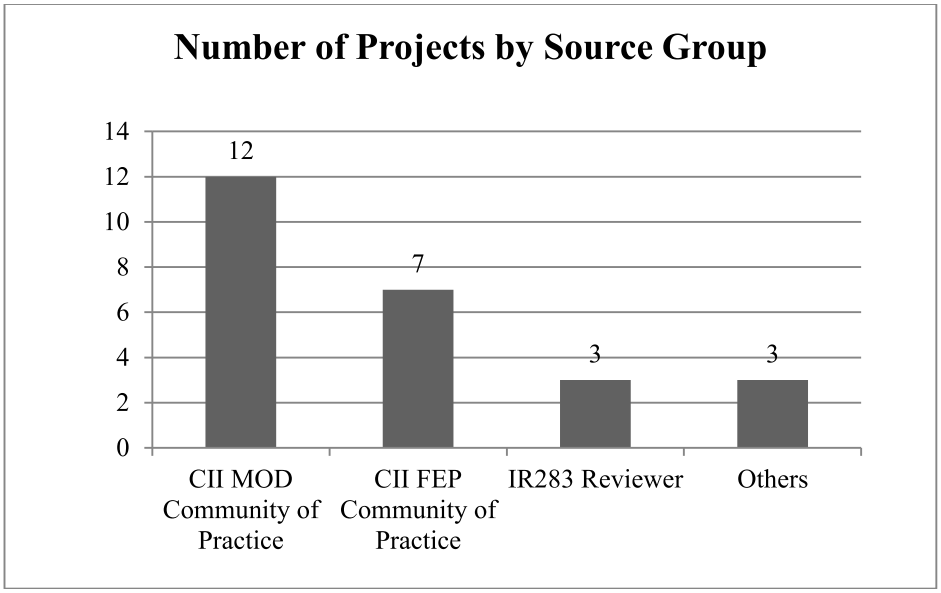


Figure 3. Number of Projects by Source Group

In addition, there might be an additional possible bias due to the collected samples' company level of expertise. As Figure 4 illustrates, a total of 21 sample projects were from CII-member companies and 4 were from Non-CII-member companies. Since CII-member companies are leading engineering and construction owners, governmental agencies, contractors, and suppliers involved in capital facilities processes worldwide (CII 2013), the research results may represent a higher result than the average industry status.

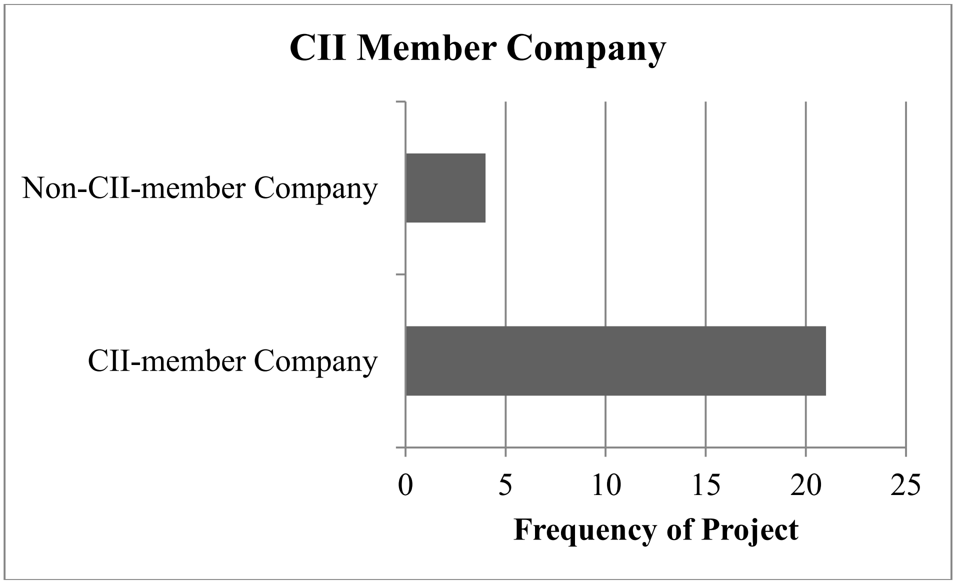


Figure 4. CII-member Company vs. Non-CII-member Company

1.6 DISSERTATION STRUCTURE

The remainder of the study is organized into six chapters, a set of appendices, and references. Chapter 2 presents a review of previous studies that encompasses definition of terms, industry status, the research trend on modularization, advantages and disadvantages of modularization, difference in execution plan in modularization, success factors for higher modularization, standardization strategy, standardization with modularization, and the CII Research Report 283 Industrial Modularization. Chapter 3 delineates the research methodology; it outlines the flow of the study, the research design, the preliminary investigation, findings from preliminary case studies and MOD COP Feedback, the instrumentation, the pilot study, the data collection procedure, the description of modular projects sample, the data analysis methodology, and the validation methodology. Chapter 4 investigates industry accomplishment status on modularization CSFs. Chapter 5 presents identified associations between MOD CSF accomplishment and project performance. Chapter 6 summarizes the research findings and recommendations. The dissertation concludes with a list of references.

Chapter 2: Literature Review

2.1 Introduction

What is the current status of modularization? What have studies covered and what remains to be covered? These questions are addressed through the following literature review. Sections 2 through 10 present reviews of previous studies: definition of terms, the industry status, the research trend on modularization, advantages and disadvantages of modularization, differences in execution plans in modularization, success factors for higher modularization, standardization strategy, and standardization with modularization. Section 11 summarizes CII Research Report 283 Industrial Modularization focused on the CSFs portion. The most important contribution in CII RT 283 is its identification of 21 CSFs. The CSFs serve as the foundation of this dissertation study. Finally, the literature review summarizes the items missing from the literature.

2.2 Definition of Terms

Substantial variation in definitions and terminology were found in the literature review because modularization is by no means a new concept and as such has been utilized many times in the past, has been discussed extensively, and has been defined in many ways. The researcher adopted or defined the following definitions for the dissertation research:

- **Modularization**: "the preconstruction of a complete system away from the job site that is then transported to the site. The modules are large in size and possibly may need to be broken down in to several smaller pieces for transport" (Haas et al. 2000).

- **Module**: “a major section of a plant resulting from a series of remote assembly operations and may include portions of many systems; usually the largest transportable unit or component of a facility” (Tatum et al. 1987).
- **Prefabrication**: “a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation” (Tatum et al. 1987).
- **Preassembly**: “a process by which various material, prefabricated components and/or equipment are joined together at a remote location for subsequent installation as a unit. It is generally focused on a system” (Tatum et al. 1987).
- **Off-site Fabrication**: “the practice of preassembly or fabrication of components both off the site and onsite at a location other than at the final installation location” (CII 2002).
- **PPMOF (Prefabrication, Preassembly, Modularization, and Offsite Fabrication)**: several Manufacturing and installation techniques, which move many fabrication and installation activities from the plant site into a safer and more efficient environment (CII 2004).
- **% Modularization**: Sum of modules’ work hours exported to fabrication shops versus originally planned stick-built site work hours for total work scope
    - $\%_{MOD} = \frac{WH_F}{WH_P}$ Where:
    - WH_F = Onsite estimated modularized components’ Work Hours (direct and indirect, at stick-built productivity rates) exported to a module fabrication/assembly shop/yard away from the final

    workface, excluding site establishment, site preparation, and demolition.
    - WH_T= Total estimated stick-built Work Hours (direct and indirect) estimated for the whole project (total scope), excluding site establishment, site preparation, and demolition.
    - (Modularization does not include prefabrication or preassembly work scopes that are not included in a module.) (CII 2012)

- **BIM**: a building information model (BIM) is defined as "a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (NIBS 2007)
- **Conceptual Project Layout**: Preliminary plans for location of both permanent and temporary facilities that should include consideration of site accessibility lay down areas, and surface runoff/drainage plans as well as an economic evaluation of the facilities' layout. (CII 2006)
- **Project Execution Plan**: An integrated and coordinated program for completing all project activities and achieving all project objectives. In order to be effective, such a plan should be prepared by the owner or their representative during the conceptual planning phase of the project. (CII 2006)
- **Standardization**: The attempt to design elements of a facility in a consistent manner in such a way to promote repetition, increase productivity, and reduce field errors. (CII 2006) Standardization of project refer to all activity to make a large scale project as identical as to other

similar project by means of standardization of design, reducing output variability, strategic planning, standardization of procurement and construction. (Karim and Nekoufar 2011)

- **Tolerance**: The range of variation permitted in a specified dimension or location without impacting structural integrity, operating capability, or abutting components.(CII 2006)
- **Primary Project Driver** (influencing the execution of the project): Major elements that contributes to the project execution
    - Cost, schedule, balanced (cost & schedule), other (assume safety is a given)
- **Business Case Drivers for MOD**: Factors that direct business objectives and modularization which explains why the modular project was needed
    - Such as schedule, labor cost, labor productivity, labor supply, safety, environmental (including weather), regulatory, legal, site access, site attributes, security/confidentiality, & other
- **Project Barriers**: Obstacles that prevent the project execution or achieving business objectives of the project
    - Such as contract terms, weather (extreme), logistics challenges (transportation of modules), environmental impact, organizational change, scope change, labor issues, regulating impact, external stakeholders, material shortage, major quality problems, change in demand for product, change in project profitability, change in financing environment, safety incident, equipment delivery, team turnover, & other

Prefabrication, preassembly, modularization, and off-site fabrication sometimes collectively termed as "prework" in the industry (Haas et al. 2000; Song et al. 2005). The author found that the building sectors vary in how they define the above terms, even disagreeing (since the building and industrial sectors are different) on adopting "module," which was defined by Tatum et al. (1987), CII (2002), and (Gibb 1999). The term off-site production (OSP) has often been identified in the modular building industry (Blismas et al. 2006). Readers may understand well how these sectors differ and adopt the definition appropriate to their industry.

2.3 Industry Status

In recent years, modularization has developed rapidly. According to the McGraw Hill Construction's SmartMarket Report, which conducted an Internet survey in 2011, nearly 98% of industry players expect to use prefab/modularization by 2013 (McGraw-Hill 2011). However, the industry continues struggling to achieve high levels of modularization. The survey identified that only 37% of the players have been using modularization at a high or very high level (McGraw-Hill 2011). Recently, many studies have revaluated modularization. In 2011, McGraw Hill estimated a new trend regarding the reemergence of prefab and modularization (McGraw-Hill 2011). Over the next 20 years, its growing prevalence could advance significantly the productivity and competitiveness of the capital facilities sector of the U.S. construction industry (NRC 2009).

2.4 RESEARCH TREND ON MODULARIZATION

Since its introduction, modularization's process has been well established, its values and benefits widely recognized. Many previous studies have examined or identified the benefits of using the modularization technique and determined that, when properly used, the technique offers a great opportunity to improve project performance in industrial projects (Song et al. 2005; Tatum et al. 1987). A full discussion of the historical development is outside the scope of this paper, but the author has summarized the research trends on the topic according to the industrial and building sectors, advanced technologies in the modular building industry, and CII studies.

An early study conducted by Tatum et al. (1987) documented applications of PPMOF in both industrial and building construction projects. The research identified the driving factors of PPMOF, including adverse site and local area conditions, contractors or suppliers' capabilities, advantages of manufacturing conditions, demanding schedule, owner or regulatory demands, potential cost savings, specialized design requirements, and standardization.

Haas and colleagues (2000), seeking to determine trends and effects on the construction workforce, conducted a study of prefabrication and preassembly but excluded modularization. The study determined the relative weight of the drivers, advantages, impediments, as well as the impact of technology on prefabrication and preassembly. The three drivers of the use of prefabrication and preassembly were schedule, workforce issues, and economic factors. The study also identified that in prefabrication and preassembly, productivity and safety levels were higher, skill levels the same, and wage levels lower. Haas and colleagues (2000) insisted that these techniques had the potential to reduce project duration, improve productivity, reduce labor costs, and shorten the supply chain.

Song et al. (2005) identified factors that influence decisions on using PPMOF. The author developed a strategic decision tool for evaluating the applicability of PPMOF in industrial projects. They concluded that what was required for successful implementation of PPMOF was systematic analysis and early decision making. Furthermore, they contended that PPMOF had become more viable with recent advances in design and Information Technology (IT).

Over the past few decades, the house-building industry has been rigorous in adopting and utilizing off-site techniques (Pan et al. 2012). Many researchers have conducted studies on off-site techniques in the building industry. The history of the technique's development is well documented in Gibb's publication (Gibb 1999). There, Gibb formally addressed off-site fabrication regarding its context, principles, applications, and implications in the building sector. Thus far, studies have identified and examined the benefits, drivers, barriers, and success factors in preassembly building industry from owner's perspective (Gibb and Isack 2003); the benefits and disadvantages of offsite technologies in the UK building industry (Blismas et al. 2006; Goodier and Gibb 2007); and the benefits, barriers, and applications of standardization and preassembly in construction industry (Pasquire and Gibb 2002). Yet, even in the building modular industry, the researcher has found there to be deficient holistic studies on the CSFs of building modularization and what enables such CSFs.

The key technologies to promote the use of PPMOF are automation, visualization (BIM), and simulation. Thus various studies have been conducted in these areas (Alwisy and Al-Hussein 2010; Han et al. 2012; Mohamed et al. 2007; Mohsen et al. 2008; Olearczyk et al. 2009). Neelamkavil (2008) presented an overview of the types of automation techniques prevalent in the modular and prefabrication areas. These included the following: robotic automation, crane and movement automation, virtual reality and simulation, schedule automation, sensor-base control, and order processing automation.

CII has conducted several studies in PPMOF, funding studies (summarized above) conducted by Tatum et al.(1987) and Song et al. (2005). RT 171, led by the CII (2002), identified the benefits and limitations in the use of PPMOF in the industrial sector and provided a knowledge-based guide and tool to improve up-front decisions.

Many past studies have explored the benefits of industrial modularization as well as some of the barriers to its application. Also, many studies on off-site techniques in the building industry have been found. What they have so far failed to do, however, is raise modularization to an optimum level within the construction industry. Moreover, few studies have sought to identify, from expert practitioners' practices, either its CSFs or its enablers holistically.

2.5 Advantages of Modularization

Since its introduction, modularization's process has been well established, its values and benefits widely recognized. This literature review describes its uses and benefits (lower capital costs, improved scheduled performance, increased productivity, higher overall quality, increased safety performance, reduced waste, better environmental performance, and fewer site-based permits). Table 1 summaries the literature of modularization advantages.

Table 1 Summary of Advantages of Modularization

	Advantages of Modularization	Literatures
1	**Lower Capital Costs**	Fagerlund 2001; Gotlieb et al. 2001; Jameson 2007; Lapp and Golay 1997; Post 2010; Rogan et al. 2000
2	**Improved Scheduled Performance**	CII 1987; CII 2002; CII 2011; Burke and Miller 1998; Gibb 1999; Gotlieb et al. 2001; Jameson 2007; Judy 2012; Lapp and Golay 1997; MBI 2010; McGraw-Hill 2001; Post 2010; Rogan et al. 2000; SCS_Energy 2006; Williams 2011
3	**Increased Productivity**	Jameson 2007; Jergeas 2010; McGraw-Hill 2011; Murtaza et al. 1993; Rogan et al. 2000; SCS_Energy 2006
4	**Higher Overall Quality**	Judy 2012; Lapp and Golay 1997; SCS_Energy 2006
5	**Increased Safety Performance**	CII 2002; Court et al. 2009; Jameson 2007; Judy 2012; MBI 2010; SCS_Energy 2006
6	**Reduced Waste and Better Environmental Performance**	KBR 2009; MBI 2010; Tam et al. 2007
7	**Reduced Site-based Permits**	Jameson 2007; SCS_Energy 2006

Cost

One of the key drivers in choosing to modularize is its cost benefit. Offsite labor costs can be reduced, onsite accommodation costs reduced (Fagerlund 2001; Gotlieb et al. 2001), staff budget reduced (Gotlieb et al. 2001), material delivery costs reduced (Fagerlund 2001), onsite crane usage minimized (Fagerlund 2001), and cost of transporting workers to a remote location reduced (Rogan et al. 2000). According to the literature, modularizing could lower costs by about 15% (Post 2010; Rogan et al. 2000). Such were the savings that Lapp and Golay claimed in capital costs between a modular nuclear power plant and a conventional one (Lapp and Golay 1997). Savings of 18.1% were estimated in a modular gasoil hydrotreater project (Jameson 2007); savings of 15% were estimated for a solid fuel-fired facility modularization (Gotlieb et al. 2001).

Schedule

Studies suggest that modularization shortens construction schedules (CII 1987; CII 2011; Rogan et al. 2000). Reduced construction schedules were reported in several articles, journals, and papers (Gotlieb et al. 2001; Jameson 2007; Judy 2012; Lapp and Golay 1997; MBI 2010; McGraw-Hill 2011; Post 2010; Rogan et al. 2000; SCS_Energy 2006). Most of the work can be done in a fabrication shop, nullifying weather issues and facilitating more efficient work processes (CII 2002). Moreover, modularization allows for parallel construction-fabrication schedules (Burke and Miller 1998; Judy 2012; Rogan et al. 2000; SCS_Energy 2006).

Labor

Aside from the aforementioned labor cost benefits, several other labor benefits drive modularization. Having secure, skilled labor in a fabrication shop is one such driver (Murtaza et al. 1993). Fabrication off-site may also be due to labor shortages and unqualified onsite labor (Jameson 2007).

Furthermore, modularization appears to increase labor productivity. In 2010, modularization was selected as one of the "top 10 areas for construction productivity improvement on Alberta oil and gas construction projects" (Jergeas 2010). In fact, labor productivity increases were reported on several assorted projects (Jameson 2007; McGraw-Hill 2011; Rogan et al. 2000; SCS_Energy 2006).

Quality

Modular construction also leads to improved quality control (Lapp and Golay 1997). By eliminating dust and drywall debris, for instance, a modular wall system helped maintain the "clean build protocol" in a bulk vaccine manufacturing facility project (Judy 2012). Quality control was excellent in the Astoria Energy Project in New York; air-cooled condensers were assembled on the welds with no mechanical failures (SCS_Energy 2006).

Safety

Shifting offsite work to a controlled, shop environment significantly reduces the overall safety risks. Modularization can result in improved worker safety through reduced exposures to inclement weather, temperature extremes, hazardous operations, and hot or elevated fabrication activities (CII 2002; Court et al. 2009; Jameson 2007; Judy 2012; MBI 2010). It was out of concern for safety, according to SCS_Energy, that air-cooled condensers were assembled at a shop in Albany, N.Y. for the Astoria Energy project; otherwise, workers would have been welding near water and working at heights with extensive rigging involved (SCS_Energy 2006).

Environment

The "green" benefits of modularization have also recently been recognized (MBI 2010). Reductions in material waste, air and water pollution, dust and noise, and overall energy costs result from modularization (MBI 2010). Prefabrication, it has been asserted, is one of the best solutions to minimizing construction waste, a key part of the lean philosophy (Tam et al. 2007).

Reduced Site-based Permits

Modularization influences the types and number of permits needed. It can curb hazardous operations and hot or height fabrication activities involving extensive rigging and welding (Jameson 2007; SCS_Energy 2006). Furthermore, modularization can mitigate the effects of a lengthy permitting process by initiating the project in a fabrication shop while waiting for the authorization on site (Jameson 2007).

2.6 Disadvantages and Impediments of Modularization

Modularization's wider adoption is impeded for reasons that vary from business to technical to logistical. Table 2 summaries the literature of modularization disadvantages.

Table 2 Summary of Disadvantages and Impediments of Modularization

	Disadvantages/Impediments of Modularization	Literatures
1	**Cost Barrier**	Akagi et al. 2002; Lapp and Golay 1997
2	**Coordination Barrier**	Fagerlund 2001
3	**Engineering Design Barrier**	Akagi et al. 2002; Ericsson and Erixon 1999; Fagerlund 2001; Lapp and Golay 1997
4	**Procurement Barrier**	Akagi et al. 2002
5	**Owners & Contractors Capability**	Akagi et al. 2002; Deemer 1996; Jameson 2007; Jumbo_Shipping 2008; Youdale 2009; Youdale 2010

Cost Barrier

Modularization could raise initial project costs (Lapp and Golay 1997). To design modules on time and within quality and safety standards, companies need to invest more sooner. For modular design, companies need more complete engineering. The cost of transportation also rises with bigger cranes, bigger ships, and other considerations (Akagi et al. 2002).

Coordination Barrier

Increased engineering calls for much more extensive coordination between stakeholders and between engineering and construction (Fagerlund 2001). The parties need to communicate earlier and much more often. This may be challenging; resources might not be in place or, due to their scarcity or cost, may be hard to get in place.

Engineering Design Barrier

As many systems in plants are highly interconnected (Ericsson and Erixon 1999), the actual characteristics of modules make them vulnerable to change (Lapp and Golay 1997). Once a design is made for a conventional plant, refashioning it to be modular will not achieve the same benefits as designing from the start for modules (Akagi et al. 2002). The project scope needs to be well defined and frozen early. Owners and other stakeholders may be put off modularizing at the prospect of losing flexibility (Fagerlund 2001).

Procurement Barrier

Another deterrent is the procuring of materials, particularly "big-ticket" equipment. Modules are made in parallel and designed and fabricated early. Hence, big-ticket equipment has to be procured in advance. Consequently, project stakeholders must advance the delivery schedule of such components (Akagi et al. 2002).

Logistics Barriers

Logistical challenges are also possible. One such challenge may be an insufficient supply of heavy and mega lifts. The shortage of heavy lift cranes appears to be worldwide (Youdale 2010). Crawlers having 5,000 tons of capacity are an unlikely development (Youdale 2009). This fact may discourage owners and contractors to build more and/or bigger modules on a certain project.

Another deterrent is the shipping of modules. As construction sites offer minimal storage space, pre-assembled units have to be shipped in the correct sequence (Jumbo_Shipping 2008). Extra considerations at the construction site include difficulty ensuring assembly space, need for temporary structures for lifting and transport, and increased complexity of managing storage of materials (Akagi et al. 2002).

Third, module sizes are constrained by transport restrictions, possibly limiting the extent of modularization in a project (Deemer 1996). Overland shipping limits in the U.S. are summarized for each state by Jameson (2007) in terms of length, width, height, and gross weight. Moreover, many municipalities, counties, and townships have their own restrictions, making logistics difficult to manage without an experienced shipping and traffic coordinator (Jameson 2007).

Owner & Contractors Capability Barriers

The methods and benefits of modularization are often unknown to owners. By tending to postpone early decisions on the feasibility of modularization, owners can in fact preclude it (Song 2002). All these impediments are enhanced by the lack of experienced contractors who could overcome those (Tam et al. 2007).

2.7 Differences in Execution Plan in Modularization

Several differences in execution planning in modularization were documented from the literature. Table 3 summaries the literature of differences in execution planning in modularization.

Table 3 Summary of Differences in Execution Plan in Modularization

	Execution Plan Differences	Literatures
1	**Organization & Staffing Differences**	CII 1987; Jameson 2007; SCS_Energy 2006 ;Wong et al. 2011
2	**Planning, Communication, and Alignment**	Akagi et al. 2002; Jameson 2007; Tam et al. 2007
3	**Early Decision**	Burke and Miller 1998; Fagerlund 2001; Post 2010; Song 2002
4	**Cost Analysis**	Jameson 2007
5	**Design Differences**	Getlieb et al. 2001; SCS_Energy 2006
6	**Shipping Limitation Considerations**	Jameson 2007
7	**Detailed Design Deliverables**	Jameson 2007
8	**Constructability Considerations**	CII 1987; Jameson 2007

Organization & Staffing Differences

For modularization to succeed, a project needs optimal organization and extra staff. SCS_Energy claimed that their experienced contractors and knowledgeable craft personnel made their modularization succeed (SCS_Energy 2006). SCS_Energy reported one of its challenges being identifying a qualified fabricator with a competent workforce and direct ocean access (SCS_Energy 2006). The literature shows that successful modularization hinges on contractors and fabricators having skills, capabilities, and experience at modularization planning and execution.

The literature detects the need for an extra special staff. The project needs a modularization coordinator, someone who can coordinate crafts for the module, controls resources, and manage site workspace (CII 1987). The project needs a shipping and traffic coordinator, someone in charge of transporting modules across the country (Jameson 2007). The project needs marine surveyors, individuals in charge of overall ship and barge arrangements (SCS_Energy 2006) when module(s) is/are shipped from overseas. Finally, the project needs a structural engineer, someone who understands weight management, who can determine module weight and Center-of-Gravity (COG); modular structures are more complex than conventional ones due to all their transport, handling, and placement (Wong et al. 2011).

Planning, Communication, and Alignment

Many studies stress that wider use of modularization requires extensive and excellent communication and coordination between all stakeholders during all phases (Akagi et al. 2002; Jameson 2007; Tam et al. 2007). Having these two elements help align stakeholders with the objective, planning, and benefits of modularization as it concerns engineering, procurement, fabrication and construction.

Early Decision

An important success factor one study identified was incorporating a modularization strategy at project opportunity framing (Burke and Miller 1998). Song and Post argued, in separate studies, that having early processes and decisions regarding modularization method would promote project success and maximize potential benefits (Post 2010; Song 2002). Regarding modularization decision tool, Fagerlund presented a tool called MODEX, developed by CII, which assists modularization decision making and helps the decision maker determine the feasibility of using modularization (Fagerlund 2001).

Cost Analysis

The most critical activity in deciding on modularization is coming up with a cost analysis of it over stick-built. As noted above, the benefits of modularization can be achieved in maximum when optimum level of modularization is accomplished. For a project to succeed, a team may need to see a clear economic advantage over stick-built construction. Jameson provided an extensive list of items for cost analysis which includes: labor cost, labor productivity, structural steel design and fabrication, shop versus field assembly hours, insulation and fireproofing subcontractor cost, schedule extension and field indirect cost, foundation design and installation cost, transportation and crane cost (Jameson 2007). For further cost analysis, one might also consider the items covered in the literature on modularization (Modularization's benefits, tradeoffs, and impediments).

Design Differences

Modular design differs in several ways from stick-built design. Modular design is more complex, so extra engineering is needed. This holds true not only for the module design itself but also for incorporating components within the module; there is extra consideration for lifting, transporting, handling, placing, connecting, and structuring. SCS_Energy reported where they invested extra: their module designs and plans for securing the vessel and boilers, the provision of a lifting area, and prevention of the movement for transport (SCS_Energy 2006). For this, they installed additional temporary beams and wedged against the modules to protect them. Gotlieb et al. asserted that the most significant difference between modularization and stick-built designs is in the maximum usage of skid-mounted equipment (Gotlieb et al. 2001). They also pointed out that the layout of the structure for the modules is unique; the floor slab may be thicker for floor mounted pipe supports and equipment (Gotlieb et al. 2001).

Shipping Limitation Considerations

Another success factor is a clear understanding that module envelope limitations. Once stakeholders decide to proceed with modularization, before the design even begins, they should carry out a module envelope limitation study. Jameson highlighted the importance of shipping limitations and discussed the trade-offs of larger modules. Even larger modules allow greater potential for the quantity, size, and spacing; however, challenges are associated with fabrication, transportation, and erection (Jameson 2007). Furthermore, there needs to be incorporated into the module design access and maintainability (Jameson 2007).

Detailed Design Deliverables

Among detailed design deliverables, general arrangement information is required early. Jameson held that during the engineering phase special consideration in the plant arrangement and layout is required regarding end user's specifications and spacing requirements (Jameson 2007). These considerations also may include information on plan layout, dimensions, Center-of-Gravity, weights, locations, and so forth.

Constructability Considerations

When considered early on and in the right manner, modularization promotes constructability. Jameson conducted a constructability review to meet the work site and fabrication concerns to ensure that the scheduled sequence of module fabrication matched the preferred erection sequence in the field (Jameson 2007). CII provided an action plan deliverables to help decision making that supported constructability considering modularization opportunities with the scooping of packaged unites (CII 1987)

2.8 Success Factors for Higher Levels of Modularization

Success factors for higher levels of modularization were also documented from the literature. Table 4 summaries the literature of success factors for higher levels of modularization.

Table 4 Summary of Success Factors for Higher Levels of Modularization

	Success Factors for Higher Levels of Modularization	**Literatures**
1	**Early Consideration**	Burke and Miller 1998; Fagerlund 2001; Post 2010
2	**Alignment**	Akagi et al. 2002; Tam et al. 2007
3	**New Technology**	CII 2002; Post 2010 Neelamkavil 2009
4	**Design**	Akagi et al. 2002; Ericsson and Erixon 1999
5	**Standardization**	CII 2007; CII 2011; Ulrich et al. 1993; Venkatachalam et al. 1993
6	**Fabrication Infrastructure**	Akagi et al. 2002; CII 2011; Lapp and Golay 1997
7	**Improvements in Logistics**	Youdale 2009

Many factors go into implementing industrial modularization successfully. Tatum et al. (1987) determined that the use of PPMOF can bring about many changes in projects and add new demands on or complexity to project organization, engineering, procurement, planning, monitoring, coordination, communication, and transportation. Also, design change flexibility decreases. In the building modular sector, Gibb and Isack (2003) identified several success factors, from the owner's viewpoint, for preassembly implementation. Those success factors are early design freeze, reasonable lead times, sufficient time for pre-site prototyping, early vendors involvement, and owner's understanding of its benefits and limitations. For higher levels of modularization in the industrial sector, however, there is no holistic research on CSFs. Documented success factors include early consideration, alignment on drivers, new technology, design freeze, standardization, fabrication infrastructure, and improvement in logistics.

Early Consideration

A modularization strategy should ideally be incorporated at project inception (Burke and Miller 1998; Post 2010). Song et al. (2005) insisted that successful implementation of PPMOF requires systematic analysis and early decision making based on specific factors of the project. Given the issues involved in early decision-making, they presented a tool developed by CII (2002) that assists in modularization decision making. The tool, called MODEX, helps experts determine the feasibility of modularizing a project.

Alignment

Greater use of modularization could be facilitated by unrestrained involvement of construction, during all phases of work, with design (Akagi et al. 2002; Tam et al. 2007). If all parties were aligned, they would all be informed of the various benefits, thus increasing the likelihood of successful implementation.

New Technology

Technology can also help modularization gain wider use. Advances in design and information technologies, CII points out, go a long way towards allowing modularization to become more viable (CII 2002). One such example is the increasing use of and advances in 3D technology and building information modeling (BIM).

Automation is expected to help the prefab and modular construction industry (Neelamkavil 2009). According to Neelamkavil (2009), automation technologies include automated design, automated supply network and materials management, robotics automation in prefab factories, automated construction site, virtual reality and simulation, and scheduling automation and sensor-based control.

Design

Modularization could be more feasible if design followed the best modular design principles. To do this, one of the most basic changes would be in the sequence of design (Akagi et al. 2002). Furthermore, to make designs more applicable to modularization, the literature suggests controlling design variants. The literature urges designers to reduce interdependency between elements (Ericsson and Erixon 1999). As a controlling design variant, Milberg (2002) presented the potential for tolerance allocation techniques by using 3-D modeling in generating, evaluating, and selecting more robust designs.

Standardization

The shipbuilding and automotive industries have recommended the use of standard/subsequent design. The automotive industry to a great extent applies the idea of design for manufacturing (Ulrich et al. 1993; Venkatachalam et al. 1993). In their modern shipbuilding analysis, CII recommends the use of block design and thus standard design (CII 2007). By standardizing modules, cost benefits can be obtained through resulting economies of scale (CII 2011). In the building industry, Gibb and Isack (2001) presented briefly on standardization and its implications from the client's perspective.

Fabrication Infrastructure

Purpose-built module fabrication facilities can make module construction more feasible. Akagi and colleagues (2002) assert that building a factory designed specifically to build modules for nuclear power plants onsite allowed for a greater number of modules to be built (Akagi et al. 2002). An initial investment in fabrication facilities is necessary (CII 2011) and such facilities would need to have a large output to successfully amortize its expenses (Lapp and Golay 1997).

Improvements in Logistics

Lastly, inexperienced contractors and owners can meet their cost and schedule goals by working with integrated service companies. Such companies provide integrated planning, logistics, heavy lifting, and transport (Youdale 2009). Modular construction could gain wider acceptance with greater availability of larger cranes.

2.9 Standardization Strategy

The industry has for many years utilized standardization, defining it in many ways. Some of these definitions by the construction industry follow.

- "The extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability." (Gibb and Isack 2001)
- "The attempt to design elements of a facility in a consistent manner in such a way to promote repetition, increase productivity, and reduce field errors." (CII 2006)
- "Standardization of project refers to all activity to make a large scale project as identical as to other similar project by means of standardization of design, reducing output variability, strategic planning, standardization of procurement and construction." (Karim and Nekoufar 2011)

Gibb and Isack (2001) briefly introduced the concept of standardization to the construction industry, addressing its implications from the owner's view, though their study excluded the industrial sector. They found that owners expect an increased use of standardization when the industry recognized its value. As a success factor to maximize the benefits of standardization, CIRIA (1999) insisted that key decisions must be made early in the construction process. In the industrial sector, O'Connor et al. (2009) addressed the benefits, through a case study of four replicated low sulphur gasoline projects, of applying standard plant design engineering strategy with subsequent replication of that construction at several sites. They argued that the standardization strategy could significantly increase productivity and the ability of achieving an owner's targeted project value objectives.

2.10 Standardization with Modularization

In the construction and other industries, the concept of combining standardization and modularization is nothing new. CIRIA (1999) covered standardization and pre-assembly principles and strategy, and a simple standardization procedure. Gibb (2001) discussed the historical development of standardization and pre-assembly applications, and presented the general benefits and implications of the optimized use of standardization and pre-assembly mainly from the building and civil and infra projects case analysis.

The literature has reported that the global shipbuilding industry is a leader in adopting the concept, and they successfully transformed itself over the past two decades from the conventional one-off fabrication (stick-built construction) to one that utilizes design standardization and modularization. One CII (2007) research team examined the shipbuilding industry to identify techniques that could be adapted in to the construction industry. According to them, the shipbuilding industry innovated itself from being a conventional one-off, stick-built industry to one that utilizes the concept of IPD—a concept that heavily uses standardization, modularization, automation, and supply chain integration (CII 2007). They asserted that the advantage of IPD can be shorter schedules, lower material costs, higher quality, safer construction, reduced risks to owner and contractors, and an environment amenable to implementing advanced technologies such as automation and robotics (CII 2011). Thus, they recommended the construction industry adapt standardization with modularization.

In terms of general benefits of standardization and modularization, significant productivity improvements were reported by repetitive building (standardization) with PPMOF (Green and May 2005) as well as increased predictability and efficiency (Gibb 2001). Furthermore, Gibb (2001) insisted that it could better control risk and increase safety, health, productivity, and quality performance. Pasquire and Gibb (2002) also listed the general potential benefits of standardized modules (components): tried and tested track record, available replacement parts, more predictable lead-in times, increased productivity through familiarization both in design and on-site, greater certainty of completion date, predictable quality and performance, reduction of waste, minimized overall project time, off-site inspection, and use of the same components on follow-on projects.

There is no guarantee, however, that an owner will benefit from implementing standardization and pre-assembly (modularization). Indeed, CIRIA (1999) asserted its implementation in the construction industry faced certain barriers, barriers that are akin to the lessons learned from standardization and pre-assembly in the construction industry. Namely, those are failing to consider all relevant costs, to get full project team commitment, to measure benefits, to stimulate innovation, to involve manufacturers and suppliers early, to make key decisions at optimum time, to apply standardization and pre-assembly within an overall business or project strategy, and to change process from construction to manufacturing. In the study of the shipbuilding industry's standardization with modularization, its barriers include a lack of integration among industry players of the standardization with modularization approach; owner's preference for customization; the ability to repeat a design, fabrication plant capabilities, codes, and standards; diverse inspection and test requirements, and investment in the future (CII 2011).

Previous studies have identified success factors for higher implementation and higher benefits of standardization and pre-assembly. In the construction industry, these success factors are understood and enjoy the commitment to them from the whole project team, early agreement/establishment of critical information, better management, earlier design decisions than for conventional process, and responding to the new manufacturing process by project management (Gibb 2001). Gibb (2001) contended that contemporary business systems, information technology and management techniques can be the enablers for more sophisticated standardization. In the shipbuilding industry, the researcher identified such success factors as a cultural transformation into IPD, a well-defined and integrated supply chain, and high use of automation and robotics (CII 2007).

2.11 CII Research Report 283 Industrial Modularization (CII 2013)

Previous studies have explored current trends in modularization as well as some of the barriers to its application. What they failed to do is raise modularization to an optimum level within the construction industry. Moreover, few studies have sought to identify either its success factors or its expert practitioners' practices. RT 283, led by the CII, was established to address, through collaborative research, this situation. In framing their purpose, RT 283 posed this question: "What changes or adaptations in traditional project work processes are required to create an optimum environment for broader and more effective use of modularization?" More specifically:

- What CSFs drive modularization's success?

- Who is responsible for these?
- When are they most critical?
- How frequently is each achieved – and what special efforts are needed?

This CII RT 283 Industrial Modularization literature review section is summarized and organized into five elements: 1) research methodology for CSFs, 2) definitions, 3) overview of high-impact CSFs, 4) CSFs analysis by project phase and responsible/lead party, and 5) CSFs frequency analysis.

Critical Success Factors Research Methodology

To answer above questions, from a listing of 72 potential factors, the 21 high-impact CSFs have been identified and assessed. Each of the top CSFs was then further characterized by lead organization and preferred timing. These parameters are further described here:

- Lead Organization: The organization that is most likely to spearhead or be responsible for the implementation of the CSF.
- Timing: Recommended optimal timing for implementation or deployment of the CSF.

Lastly, to further understand the role and implementation challenges of each CSF, RT members were surveyed for their opinion on the current relative frequency of occurrence of each CSF.

Overview of High-Impact Critical Success Factors (CII 2013)

The potential factors (total 72) were identified, described, and then analyzed for impact by 19 modularization authorities (on a 4.0 scale). There were 21 CSFs that received a score of 3.0 or more. These were determined to be high-impact CSFs and are presented as follows:

- **CSF#1 MODULE ENVELOPE LIMITATIONS** (Impact score 3.83): Preliminary transportation evaluation should result in understanding module envelope limitations.
- **CSF#2 ALIGNMENT ON DRIVERS** (3.79): Owner, consultants, and critical stakeholders should be aligned on important project drivers as early as possible in order to establish the foundation for a modular approach.
- **CSF#3 OWNER'S PLANNING RESOURCES & PROCESSES** (3.58): As a potentially viable option to conventional stick building, early modular feasibility analysis is supported by owner's front-end planning and decision support systems, work processes, and team resources support. Owner "comfort zones" are not limited to the stick-built approach.
- **CSF#4 TIMELY DESIGN FREEZE** (3.58): Owner & Contractor are disciplined enough to effectively implement timely staged design freezes so that modularization can proceed as planned.
- **CSF#5 EARLY COMPLETION RECOGNITION** (3.42): Modularization business case should recognize and incorporate the economic benefits from early project completion that result from modularization, and those resulting from minimal site presence and reduction of risk of schedule overrun.
- **CSF#6 PRELIMINARY MODULE DEFINITION** (3.42): Front-end planners and designers need to know how to effectively define scope of modules in a timely fashion.
- **CSF#7 OWNER- FURNISHED/LONG LEAD EQUIPMENT SPECIFICATION** (3.42): Owner-furnished and long-lead equipment (OFE) specification and delivery lead time should support a Modular approach.
- **CSF#8 COST SAVINGS RECOGNITION** (3.42): Modularization business case should incorporate all cost savings that can accrue from the modular approach. Project teams should avoid the knee-jerk misperception that modularization always has a net cost increase.

- **CSF#9 CONTRACTOR LEADERSHIP** (3.39): Front-end Contractor(s) should be proactive - supporting the Modular approach on a timely basis and prompting Owner support, when owner has yet to initiate.
- **CSF#10 CONTRACTOR EXPERIENCE** (3.37): Contractors (supporting all phases) have sufficient previous project experience with the modular approach.
- **CSF#11 MODULE FABRICATOR CAPABILITY** (3.37): Available, well-equipped Module-Fabricators have adequate craft, skilled in high-quality/tight-tolerance Modular fabrication.
- **CSF#12 INVESTMENT IN STUDIES** (3.32): Owner should be willing to invest in early studies into Modularization opportunities in order to capture full benefit.
- **CSF#13 HEAVY LIFT/SITE TRANSPORT CAPABILITIES** (3.32): Needed heavy lift/site transport equipment and associated planning/execution skills are available and cost-competitive.
- **CSF#14 VENDOR INVOLVEMENT** (3.28): OEMs and technology partners need to be integrated into the modularized solution process in order to maximize related beneficial opportunities.
- **CSF#15 O&M PROVISIONS** (3.26): Module detailed designs should incorporate and maintain established O&M space/access needs.
- **CSF#16 TRANSPORT INFRASTRUCTURE** (3.22): Needed local transport infrastructure is available or can be upgraded/modified in a timely fashion while remaining cost-competitive.
- **CSF#17 OWNER DELAY AVOIDANCE** (3.16): Owner has sufficient resources and discipline to be able to avoid delays in commitments on commercial contracts, technical scope, and finance matters.
- **CSF#18 DATA FOR OPTIMIZATION** (3.05): Owner and Pre-FEED/FEED contractor(s) need to have management tools/data to determine the optimal extent

of modularization, i.e., maximum NPV (that considers early revenue streams) vs. % Modularization.

- **CSF#19 CONTINUITY THROUGH PROJECT PHASES** (3.00): Disconnects should be avoided in any contractual transition between Assessment, Selection, Basic Design, or Detailed Design phases; their impacts can be amplified with Modularization.
- **CSF#20 MANAGEMENT OF EXECUTION RISKS** (3.00): Project risk managers need to be prepared to deal with any risks shifted from the field to engineering/procurement functions.
- **CSF#21 TRANSPORT DELAY AVOIDANCE** (3.00): Environmental factors such as hurricanes, frozen seas, or lack of permafrost, in conjunction with fabrication shop schedules, do not result in any significant project delay.

CSFs by Project Phase & Responsible/Lead Party

The CSFs were analyzed for the best timing of deployment by project phase and to identify the best responsible or lead party. Figure 5 and Figure 6 illustrate the findings from these analyses.

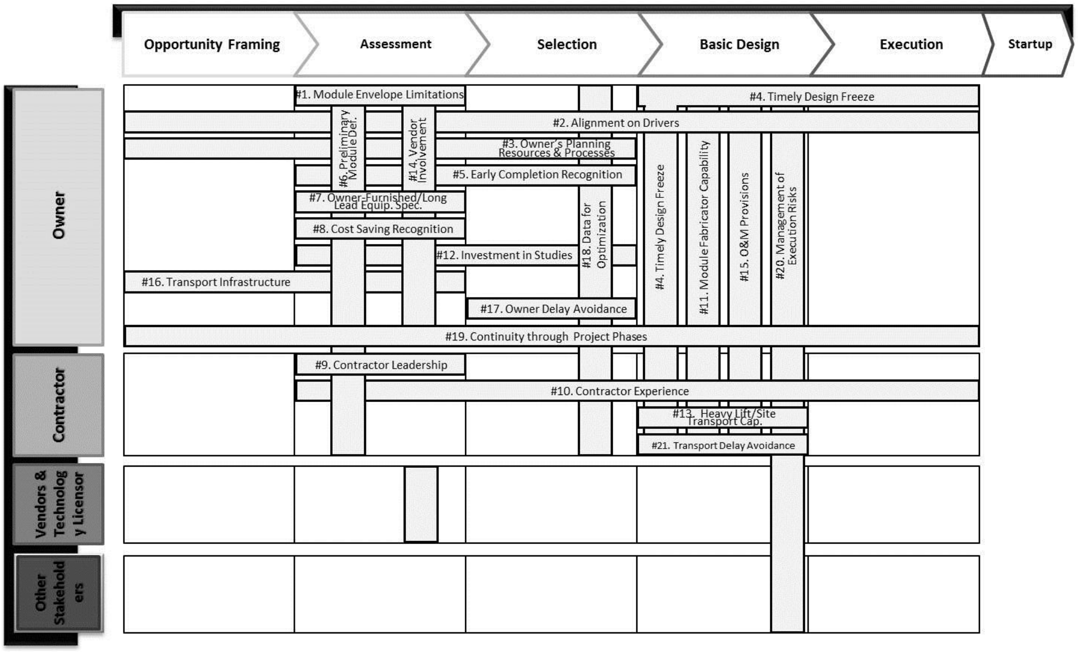


Figure 5. CSFs Fabric: Timing vs. Responsible Party (CII 2013)

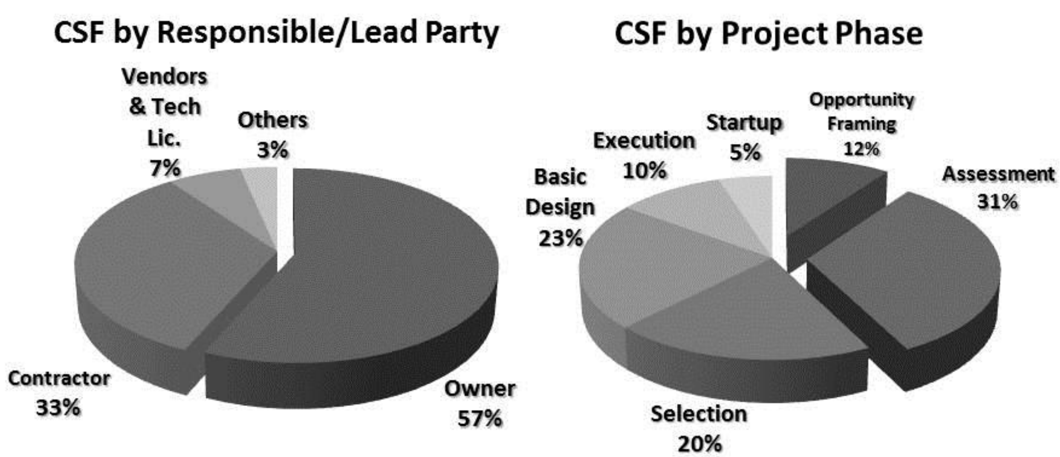


Figure 6. CSFs Distribution by Responsible/Lead Party and Timing of Implementation (CII 2013)

Who is responsible for seeing that CSFs are fully addressed? The project owner primarily, with the contractors being secondary. As for timing, ensuring the success of modularization is most critical during the Assessment and Selection phases. Interestingly, only 15% of CSFs are related to the Execution and Startup phases. To facilitate successful modularization, significant owner involvement is clearly needed early on.

CSFs Frequency Analysis

CSFs were also evaluated for the frequency of their implementation. It became clear that more industry initiative is needed to raise the frequency of those poorly performing CSFs. Table 5 and Table 6 summarize a detailed analysis of overall modularization success and implementation frequency.

Table 5 Detail Analysis Result of Overall Modularization Success (CII 2013)

	Impact to Overall MOD Success		
CSF#	**Avg.**	**Stand Dev.**	**Range**
1	3.83	0.38	1
2	3.79	0.42	1
3	3.58	0.51	1
4	3.58	0.61	2
5	3.42	0.77	2
6	3.42	0.77	2
7	3.42	0.69	2
8	3.42	0.69	2
9	3.39	0.78	2
10	3.37	0.68	2
11	3.37	0.68	2
12	3.32	0.89	3
13	3.32	0.58	2
14	3.28	0.83	3
15	3.26	0.65	2
16	3.22	0.55	2
17	3.16	0.83	3
18	3.05	0.78	3
19	3.00	0.77	2
20	3.00	0.88	3
21	3.00	1.00	3

Table 6 Detail Analysis Result of Implementation Frequency (CII 2013)

	Frequency of Implementation		
CSF#	**Avg.**	**Stand Dev.**	**Range**
1	2.72	1.07	4
2	2.39	0.92	4
3	2.00	1.00	4
4	2.17	1.10	4
5	2.22	0.88	4
6	2.44	0.70	3
7	2.63	0.62	2
8	2.22	1.11	4
9	1.94	1.26	4
10	2.17	1.10	4
11	3.22	1.00	4
12	1.94	0.75	3
13	3.33	0.77	3
14	2.06	0.80	3
15	3.06	0.94	3
16	2.61	1.24	4
17	1.50	1.04	3
18	1.44	1.04	3
19	2.17	0.99	4
20	2.11	0.90	3
21	1.83	1.20	3

These detail analyses were conducted to identify possible inconsistent agreement on CSFs impact score and implementation frequency. Figure 7 illustrates the results of the frequency analysis when combined with the impact analysis.

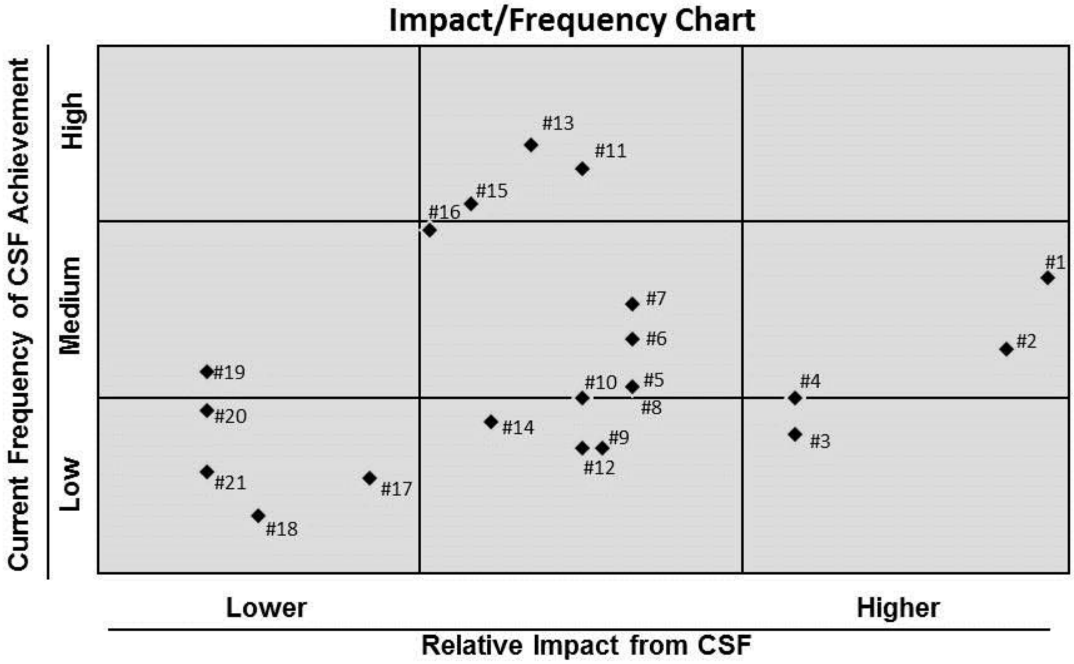


Figure 7. CSF Frequency and Impact (CII 2013)

The frequency survey result of CSFs was represented visually in Figure 8 where it was mapped into a stairway graphic. The purpose is to show that increased efforts are needed to accomplish the Occasional, Rare, and Very Rare CSFs, especially for those with high impact rankings (as indicated in the CSF numbering). To increase modularization, for example, what appear to be challenging but valuable opportunities are Owner's planning resources and processes, and Contractor leadership.

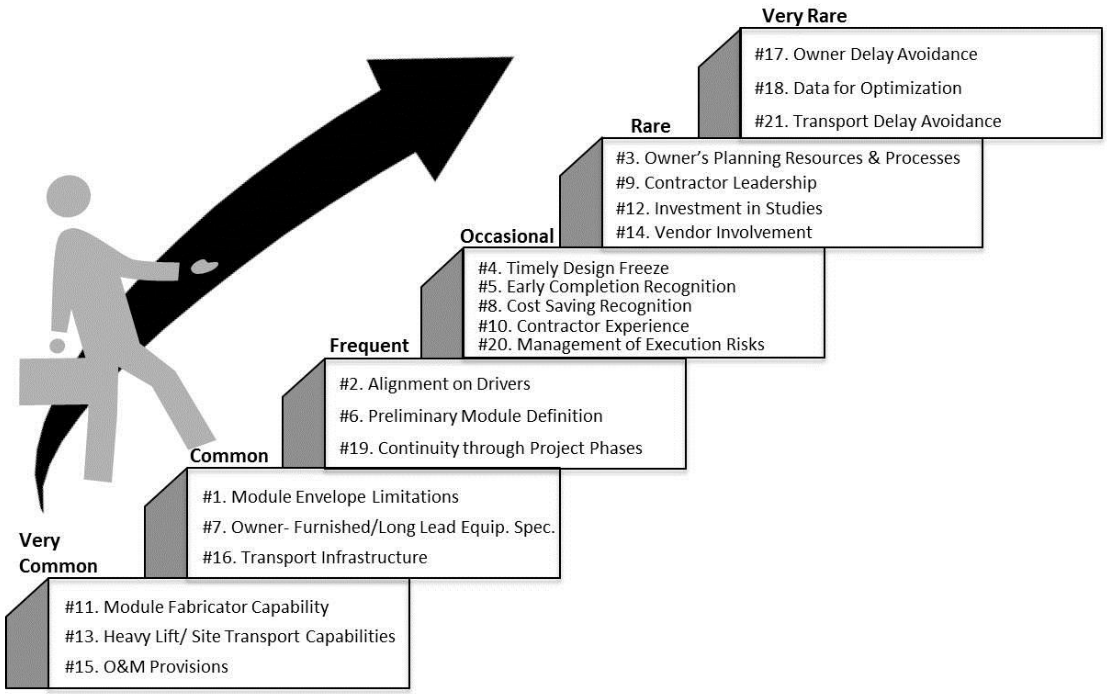


Figure 8. CSF Frequency Stairway (CII 2013)

These results were compared with actual sample projects CSFs accomplishment at "Chapter 4 CSFs Accomplishment Analysis."

The following is a summary of the CSFs in CII RR 283.

1. The top five CSFs indicates that project teams should pay particular attention to module envelope limitations, team alignment on project drivers, adequate owner planning resources and processes, timely freeze of scoping and design, and due recognition of possible early completion from modularization.

2. More industry effort is needed to accomplish the Occasional, Rare, and Very Rare CSFs, particularly for those with high impact rankings such as Owner's planning resources and processes, and Contractor leadership
3. More than half of the factors require leadership and implementation by project owners. For successful modularization to occur, the message is clear: substantial owner involvement must occur early.
4. Assessment and Selection phases are of greatest significance for ensuring modularization success through CSFs with regard to timing.

2.12 SUMMARY OF THE LITERATURE REVIEW

In the industrial and construction industries, a number of research projects and related publications have laid out the historical development, benefits, challenges, trends, execution plan differences in modularization, standardization strategy, and implications that are associated with the techniques of modularization and related prefabrication, preassembly, modularization, and off-site fabrication (PPMOF).

A great deal of the literature recognizes the value, benefits, and uses associated with modularization. The literature draws attention to such benefits as increased productivity, lower capital costs, greater quality, safer working environments, reduced site safety exposures, and less impact on the environment. The literature also describes to what little degree modularization is being applied in the industry as well as the impediments to higher levels of modularization. Impediments include cost barriers, engineering design, procurement, logistics, expertise and culture. Ways to overcome such impediments are also offered in the literature.

Many studies have reported their practices on modularization execution plans. The summarized topics in the literature reviews are organization and staffing differences, planning, communication, and alignment, early decision, cost analysis, design differences, shipping limitation considerations, and detailed design deliverables.

A review of the literature also confirmed that the concept of combining standardization with modularization is not new; it has been discussed for many years and successfully utilized in the global shipbuilding industry. Numerous studies have identified its implications, general values, drivers, and barriers in the building modular sector.

To raise modularization to an optimum level within the construction industry, CII RT 283 identified and assessed 21 CSFs. The CSFs were analyzed for the best timing of deployment by project phase and identified by the most responsible or lead party. The CSFs were also evaluated for how frequently they were accomplished.

By providing modularization CSFs, RT 283 helped conceptualize and create an optimum environment for the broader and more effective use of modularization. What the literature is short on, however, is a clarification of the relative significance of CSFs and their associations with the extent of modularization and project performance. The literature needs a study that examines correlations between the accomplishment of modularization CSFs and project performance. Also missing is characterizations of current actual status of MOD CSF accomplishment. Such a characterization could help industry players understand the status of MOD CSF accomplishment and prompt them to achieve better project performance.

Chapter 3: Research Methodology

3.1 Introduction

The primary goal of this research is to provide recommendations for better project performance by identifying correlations between MOD CSF accomplishment and project performance. The secondary goal of the research is to examine actual modular projects' accomplishment of CSFs. Meeting these objectives should clarify the relative significance of CSFs and their associations with project performance. The research aims to resolve a problem facing the industry—how to achieve high levels of modularization, aid industry players to understand the modularization industry status, and motivate them to achieve better project performance through implementing modularization CSFs. The research methodology was developed to support the research purpose. Chapter 3 organizes the research methodology into the following sections: research methodology flow, research design, the preliminary investigation, findings from preliminary case studies and MOD COP feedback, instrumentation, the pilot study, data collection, the description of modular projects sample, data analysis, its validation, and a summary of the research methodology.

3.2 Research Methodology Flow

In planning and executing the research, this work followed the traditional steps. Figure 9 summarizes the research methodology flow.

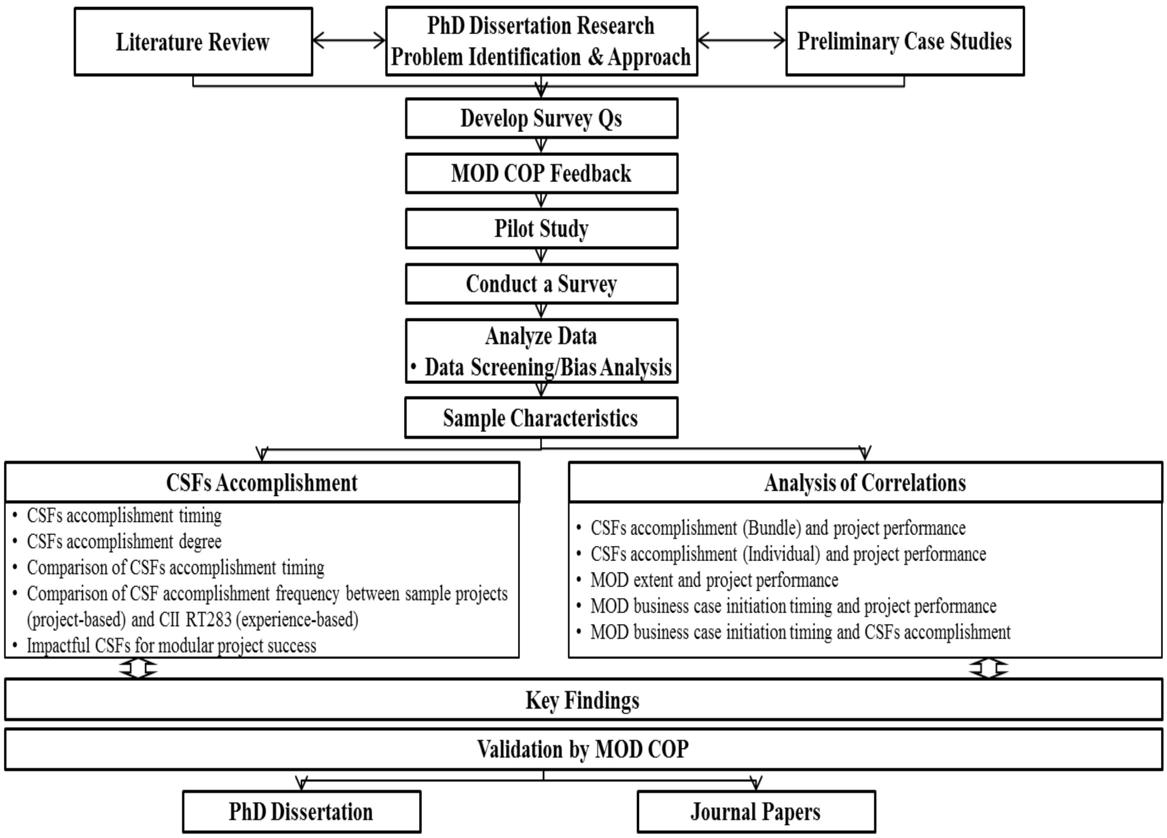


Figure 9. Research Methodology Flow Chart

First, the researcher identified the problems and selected the appropriate research method. This first step was conducted concurrently with the literature review and the preliminary case studies. The related literature was organized into ten groups: definition of terms, industry status, research trend on modularization, advantages of modularization, disadvantages of modularization, difference in execution plan in modularization, success factors for higher modularization, standardization strategy, standardization with modularization, and the CII Research Report 283 Industrial Modularization. The literature review (Chapter 2) revealed the gaps in research, which led to five preliminary case projects being studied. The summary of the five preliminary case projects appear in the following section (Section 3.4). The literature review and the preliminary case studies helped the researcher clearly define the problem. Subsequently, research hypotheses were formulated and the variables and area of interest defined.

Next, the study developed the research design, specific data collection procedure, and data analysis approach. The researcher, having selected the survey as the research instrumentation, developed a draft of a survey questionnaire. To elaborate the survey questionnaire, the researcher asked the CII Modularization COP team to review it and provide feedback; a pilot study was then conducted. The CII Modularization COP is a formal venue for the exchange of knowledge that is useful in planning, designing, and executing modularization of varying levels of complexity on capital facility projects. The Modularization COP is composed of members who share a vision of guiding the capital projects industry to enhanced project performance through modularization (CII 2012). With these efforts, several revisions were progressively made to the questionnaire. The survey questionnaire's revised contents and their reasons are summarized in the survey version found in Appendix C.

The third step was defining the population and target projects. The CII Modularization COP and the Front-End-Planning COP supported searching for candidate modular projects and experts capable of answering the questionnaire. In March 2013, the researcher distributed the survey questionnaires to the target respondents. Data collection continued until October 2013. A total of 25 sample projects were collected and their information analyzed. Such analyses examined 1) the industry status on MOD CSF accomplishment, and 2) the correlations between the accomplishment of modularization CSFs and project performance. The researcher then set down the research findings and drew conclusions. Later the key findings were validated by the modularization COP in a face-to-face meeting. In the end, the final output of the research—the dissertation—will be published. Furthermore, several academic papers are planned.

3.3 RESEARCH DESIGN

Correlational and descriptive research methodologies were used in this study. A correlational research methodology was used to examine the correlations between the accomplishment of modularization and project performance. This method was selected because it allows one to determine how much variation in one factor corresponds with variations in one or more other factors (Isaac and Michael 1981). This method is commonly used when experiments' methods or controlled manipulation cannot, for practical reasons, be conducted. In this study, the variables include the degree score of CSFs accomplishment in modularization, the score of CSFs accomplishment in terms of timing, extent of modularization, and project performance.

A descriptive research methodology was used to characterize the current industrial modularization status and to describe the CSFs accomplishment status. This method was selected because it enables one to describe systematically, factually, and accurately the characteristics of an existing area of interest (Isaac and Michael 1981). In this study the characteristics of interest include types of modularized units/sub-units, reported avg. % schedule and cost savings compared to stick built, business drivers for MOD, project difficulties recognized, impediments for MOD application, advantages from MOD application, reluctance to respond/need industry's attention, conduct of optimization analysis, MOD business case initiation timing, characteristics of jobsite and module fabrication/assembly shops, and economic impact of standardization with modularization.

Several limitations are expected regarding the research methodology and interpreting the research findings. The following are limitations regarding the correlational research.

- "It does not necessarily identify cause-and-effect relationships." (Isaac and Michael 1981)
- "It exercises less control over the independent variables." (Isaac and Michael 1981)
- "It is prone to identify false relational patterns or elements that have little or no reliability or validity." (Isaac and Michael 1981)

The following is the limitation of the descriptive research.

- "It does not necessarily seek or explain relationships, test hypotheses, make predictions, or get at meanings and implications." (Isaac and Michael 1981)

3.4 Preliminary Investigation

A total of five case projects were analyzed for preliminary investigation. To better understand the different characteristics of each project, also investigated for each project were the background and basic information such as the total installation cost, the project phase when the interviews were conducted, the industry sector/subsector, the original primary project driver, and the project location.

The results were preliminary and the analysis conducted for only selected items. The preliminary case studies were intended to provide a springboard to build theories and to help the researcher clearly define the research problem. The five preliminary case studies provided several valuable lessons that helped in the developing of the questionnaire. These findings are addressed in the following sections.

The background and basic information of each project were investigated. These five projects were executed by different companies in different locations with a variety of project characteristics. In the preliminary case studies, the researcher examined a total of three correlations; those between the: 1) number of the accomplishment of MOD CSFs and the percent modularization, 2) percent modularization and the project performance, and 3) the number of the accomplishment of MOD CSFs and the project performance. To examine the correlations, the study measured from the five case projects the number of the accomplishment of MOD CSFs, percent modularization, and project performance. To claim statistical significance, further research with more case projects was needed. Nevertheless, the researcher was able to identify a positive correlation between the number of the accomplishment of MOD CSFs and the project performance within the five projects. Lastly, describing modular projects sample was conducted through business drivers and project barriers.

3.5 Findings from Preliminary Case Studies and MOD COP Feedback

The five preliminary case studies yielded several valuable findings. The CII Modularization COP members also contributed feedback by reviewing several early versions of the survey questionnaire. Several discussions were conducted through teleconference calls. A great deal of feedback was received.

The lessons from the preliminary case studies and modularization COP feedback are summarized below.

1) Needed information:

- more insight into optimal timing for each CSF

- relative significance of modularization CSFs

2) Needed:

- clearer explanation of % modularization definition
- detailed explanation of each CSF
- measuring degree of the accomplishment of MOD CSFs
- multiple choice-type questions to increase collection rate
- separate questions for fabrication shop (steel and pipe) and assembly (modules) shops
- questions for measuring extent (percent modularization, largest module, heaviest module, total number of modules, and total tonnage of modules)
- align project phase definition to front-end-loading
- at least 15 projects to draw significant findings

These lessons learned proved valuable in developing the questionnaire. Especially helpful was the Modularization COP members' feedback. All this led to changes being made not only to the survey questionnaire but also to the research methodology.

3.6 INSTRUMENTATION

Survey Questionnaire

To gather data, a survey questionnaire approach was selected. Gathering information through surveys is one type of correlation and descriptive research. The survey questionnaire was carefully developed to measure the data correctly. Typically, one of the defects of this approach is that, should questions arise, no one is available to answer them (Jackson 2003). Hence, questions had to be quite clear. The researcher gave special attention to the following:

- Ask an adequate number of questions while avoiding an overwhelming amount, thus making only reasonable demands on the respondents' time and effort.
- Proper attention to format, grammar, printing, and so forth, limiting potential misinterpretations of a question.
- Adequately explain and define items.
- Develop questions that properly measure the data.

Adhering to these guidelines, the questionnaire was developed and revised. The final version of the survey questionnaire can be found in Appendix B. Revisions made to the questionnaire can be found in Appendix C–Survey Questionnaire Revisions by Survey Version.

The survey questionnaire is organized into four sections with a total of 44 questions. The four sections are: 1) project characteristics, 2) standardized module, 3) CSFs, and 4) project performance. Project characteristics focuses on examining the characteristics of a project. The questions in this section concern a project's general information, fabrication and module assembly shop information, modularization information such as common module and modularization extent, advantages and impediments of the project, and project drivers. In the second section, respondents are asked to answer only if the project utilized standardization. This is to help with describing the status of the modularization industry regarding standardization. The questions in this section concern standardized modules, standardized module extent, economic advantages and disadvantages from standardization application, and impediments. Section 3 examines the accomplishment of modularization CSFs. As can be seen in Table 7, the respondents were asked to assess the accomplishment of MOD CSFs in terms of degree and timing.

Table 7 Questionnaire for Modularization CSFs Accomplishment

#	Critical Success Factors	NOT Accomp. (0%)	Partially Accomp. (30%)	Mostly Accomp. (70%)	Fully Accomp. (100%)	If Accomplished, When? (ref. Q8)				
						Opportunity Framing	Assessment	Selection	Basic Design	EPC
A	"**Module Envelope Limitations**" prior to Selection									
B	"**Alignment on Drivers**" prior to Selection									
C	"**Owner's Planning Resources & Processes**" prior to Selection									
D	"**Timely Design Freeze**" prior to EPC									
E	"**Early Completion Recognition**" prior to Basic Design									
F	"**Preliminary Module Definition**" prior to Basic Design									
G	"**Owner- Furnished/Long Lead Equipment Specification**" prior to Basic Design									
H	"**Cost Savings Recognition**" prior to Basic Design									
I	"**Contractor Leadership**" prior to Basic Design									
J	"**Contractor Experience**" prior to EPC									
K	"**Module Fabricator Capability**" prior to EPC									
L	"**Investment In Studies**" prior to Basic Design									
M	"**Heavy Lift/Site Transport Capabilities**"									
N	"**Vendor Involvement**" prior to Basic Design									
O	"**O&M Provisions**"									
P	"**Transport Infrastructure**" prior to Basic Design									
Q	"**Owner Delay Avoidance**" prior to EPC									
R	"**Data For Optimization**" prior to Basic Design									
S	"**Continuity Through Project Phases**"									
T	"**Management of Execution Risks**"									
U	"**Transport Delay Avoidance**"									

The 21 MOD CSFs were defined in an independent attachment–a PDF format slide. The respondents, if they were unfamiliar with CSFs, were asked to read the attachment before answering the question. It also helped them correctly answer the accomplishment of modularization CSFs.

Finally, in examining project performance, it was measured by project function and by project objectives. Project objectives included safety, quality, cost, schedule, change management, field productivity, shop productivity, environmental, and sustainability. The success and performance were measured according to six levels: N/A = not applicable/don't know, 5 = exceeded expectations, 4 = between 3 and 5, 3 = met expectations, 2 = between 1 and 3, and 1 = significantly off plan. So as to compare with stick built, respondents were asked about percent schedule savings and cost savings.

Most of the questions/statements were closed-ended, partially open-ended, and of the rating-scale type. The study limited its wholly open-ended questions to avoid burdening the respondents.

Survey Schedule

The survey questions were developed between October 2012 and March 2013. Feedback from CII Modularization COP was obtained concurrently. Surveys were sent out in March 2013. The data collection was completed in October 2013. The data analysis was conducted between October and November 2013. Next, CII Modularization COP validated the key findings in January 2014.

3.7 PILOT STUDY

A pilot study was conducted to test the survey questionnaire and to make judgments about its validity. The pilot study included the help of two industry experts. One was the author of an article in *Power Magazine* and who had conducted an electrical industrial modular project. The other was a former project control manager with about 15 years of experience in power plant project execution. The focus of the pilot study was to root out incomprehensible instruction, unclear wording, insufficient detail, difficult sections, and irrelevant or inconvenient questions. The researcher asked these experts the following questions:

1) Were the questions clear and easy to answer? If not, how could they be simplified?
2) How long did it take you to fill out the questionnaire?
3) Did you find any typographical errors?
4) Are there any other comments or suggestions you could offer to help improve the survey?

To clarify problem questions, appropriate changes were made to the survey. Revisions made to the survey questionnaire can be found in Appendix C.

3.8 Data Collection Procedure

Data collection was conducted between March and October 2013. The respondents were asked to complete the survey in one of two ways: a) manually mark-up the document and return via mail or PDF scan/email, or b) use the track-changes feature in Microsoft Word. This approach generally produces less sampling bias–the tendency for one group to be overrepresented in a sample–than do phone surveys or personal interviews. Furthermore, this approach eliminates the problem of interviewer bias–the tendency for the person asking the questions to influence the participants' answers (Jackson 2003).

A cover letter was included describing the general information and the purpose of the study as well as instructions. Respondents were assured that sensitive information such as personal identity, company name, and productivity data would be sanitized and not released without sanitization in the dissertation or in any article. Respondents unfamiliar with the CSFs were asked to gain a full understanding of all 21 before answering the survey. To aid them in this, a PDF format CSF slide presentation was attached to the survey questionnaire.

3.9 Description of Modular Projects Sample

The population of the research is any project that implemented recently the modular technique. The population is not limited to a certain location (country) or company. Since surveying the entire population is infeasible, the researcher selected sample projects from the population and administered them the survey.

The research made use of the nonrandom-sampling method. Random sampling was primarily avoided for three reasons: 1) an unwillingness on the part of companies to share information regarding modular project from the companies due to the value of the modularization experience and information, 2) limited number of experts capable of answering the questions, and 3) limited time, money, and workforce to randomly collect the sample. The researcher aimed to contact the project manager or superintendent who actually executed the project. The CII Modularization COP and Front-end-planning COP aided in finding adequate experts. The researcher also contacted CII publication reviewers and other modular experts outside of CII member companies. It is assumed that the effort made to find appropriate respondents was adequate.

In this section, the modular projects sample was described by assessing the following items.

- industry group and subsector
- company type
- physical completion at the time of data collection

- total installed cost (TIC) and duration
- primary project driver
- project jobsite and fabrication/assembly shop location(s)
- types of modularized units/sub-units
- reported avg. % schedule and cost savings compared to stick built
- business drivers for MOD
- project difficulties recognized
- impediments for MOD application
- advantages from MOD application
- reluctance to respond/need industry's attention
- conduct of optimization analysis
- MOD business case initiation timing
- characteristic of jobsite and module fabrication/assembly shops
- economic impact of standardization with modularization

The list of these items for the study of describing modular projects sample were identified through an intensive literature review and a preliminary case study. Most of the 25 sample projects completed the questionnaires on these items.

To describe/characterize the sample modular projects, the study used descriptive statistics. Descriptive statistics are numerical measures that describe “a distribution by providing information on the central tendency of the distribution, the width of the distribution, and the distribution’s shape” (Jackson 2003). The collected data were represented by frequency distributions and bar graphs/histograms. Furthermore, central tendency (mean, median, and mode) and variation (range and standard deviation) were measured per item.

Industry Group and Subsector

Figure 10 and Figure 11 illustrate the frequency of industry group (and their subsector) of the collected sample projects. The scope and limitations of the research have been addressed in Section 1.5, Research Scope and Limitations, and since most of sample projects are from industrial projects, the interpretation of the findings should be limited to the industrial sector. The researcher would like to point out that diverse industrial sample projects were collected, as Figure 11 illustrates.

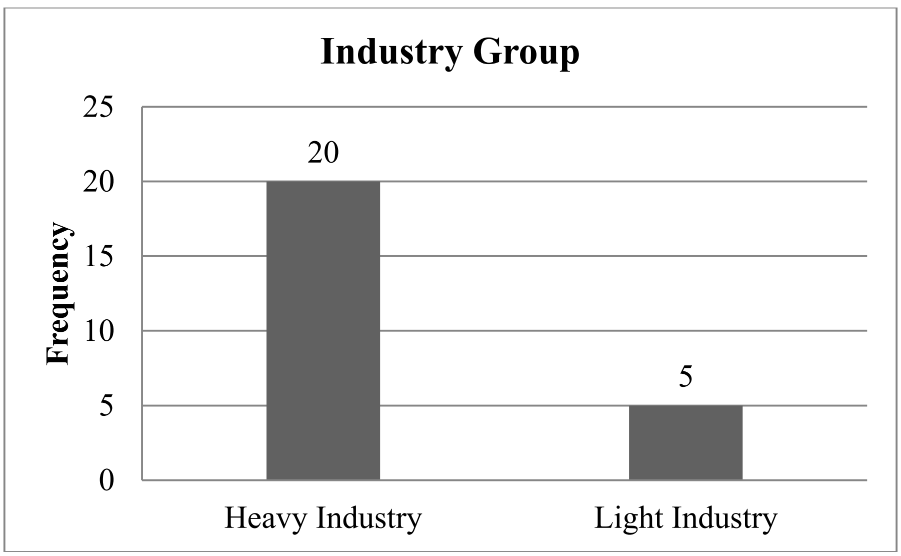


Figure 10. Frequency of Industry Group

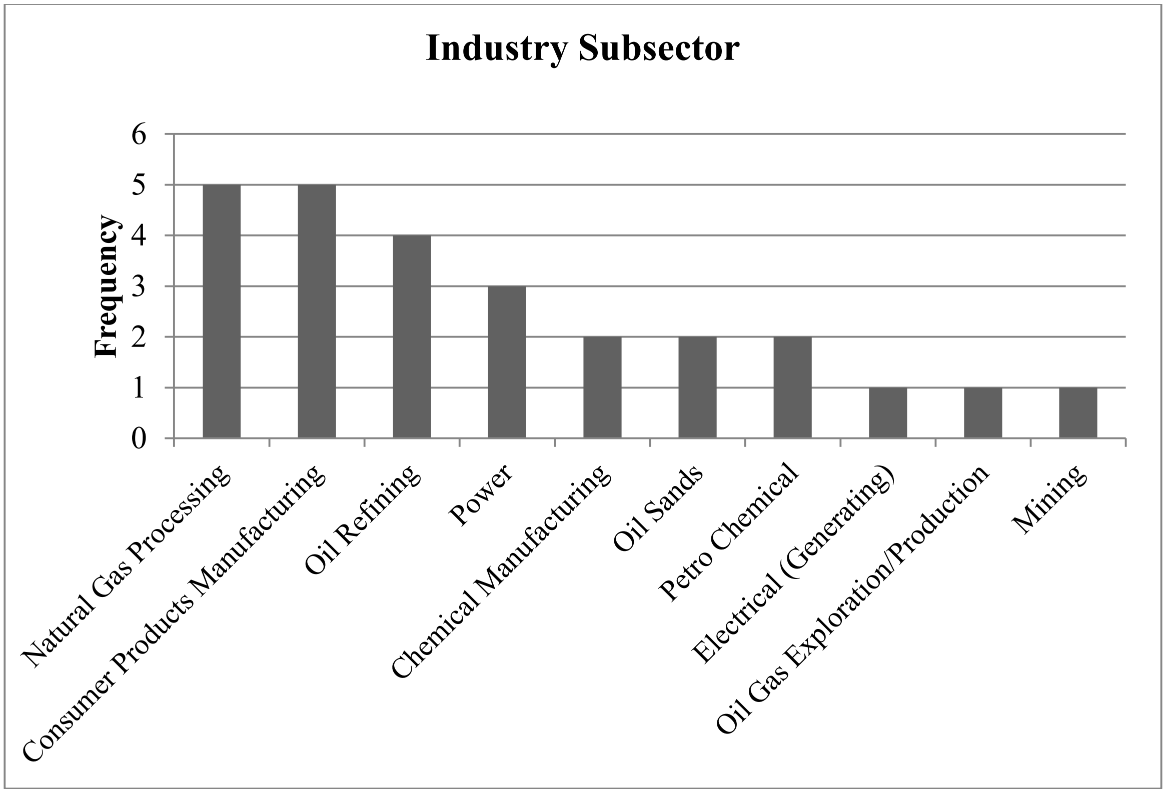


Figure 11. Frequency of Industry Subsector

Company Type

Figure 12 illustrates the company type of the collected sample projects. As the figure illustrates, the proportion of Owner and Contractor are nearly equal. This indicates the collected information does not over- or under-represent Owner or Contractor.

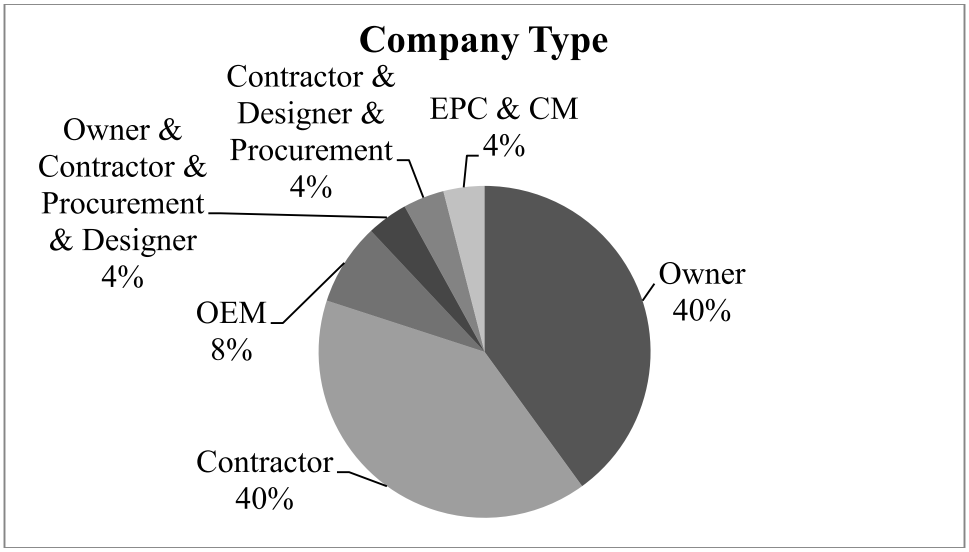


Figure 12. Company Types

Physical Completion at the Time of Data Collection

To collect data on more recent projects, the sample projects were not limited to completed projects only. For this reason, some projects were unable to complete the Startup and/or Construction project performance questionnaire. Figure 13 illustrates the frequency of physical completion of sample projects at the time of data collection.

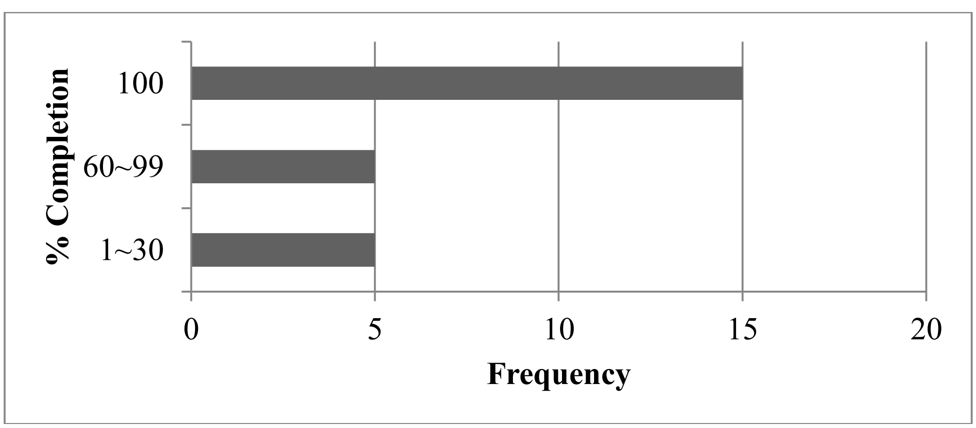


Figure 13. Physical Completion at the Time of Data Collection

Total Installed Cost (TIC) and Duration

Frequency of total installed cost (TIC) and duration of the sample projects are illustrated in Figure 14 and Figure 15. The sum of collected sample project TIC is $80.18 billion and the median TIC of sample projects is $0.3 billion. The sum of collected sample project duration is 703 months and the median duration of sample projects is 24 months. This research defined duration as the number of months for the project to go from the start of site construction to actual/target mechanical completion. The participants were asked to provide, if the dates were available, the actual duration.

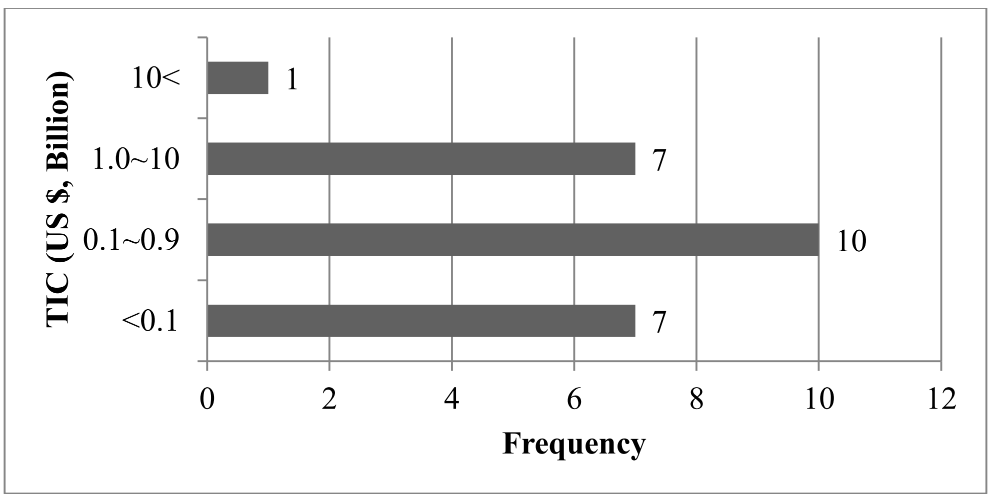


Figure 14. Frequency of Total Installed Cost (TIC) of the Sample Projects

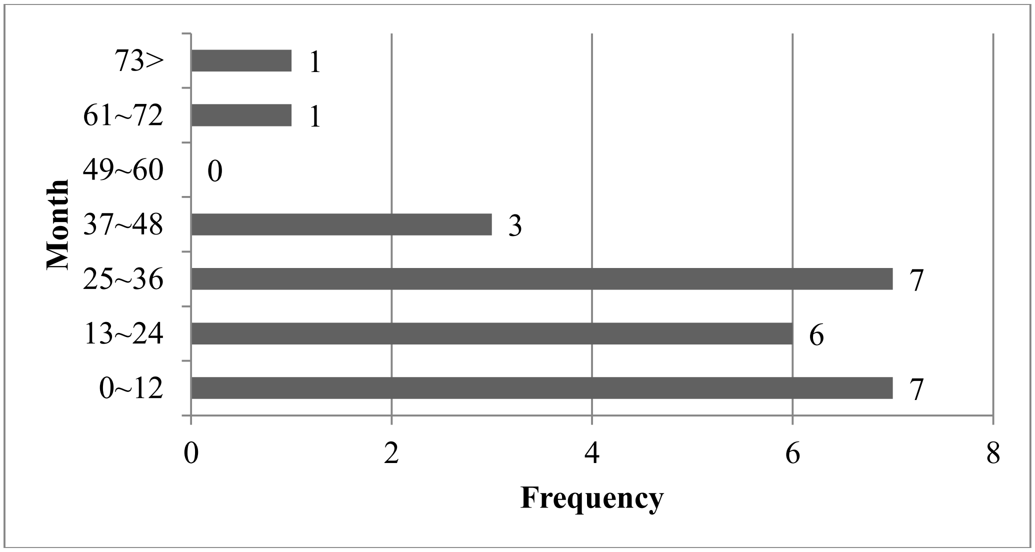


Figure 15. Frequency of Sample Projects Duration

Primary Project Driver

The primary project driver of a sample project that influenced the execution of the project was measured. The primary project driver is defined as the major element that contributes to project execution. The researcher asked the respondents to assume "Safety" as a given. As Figure 16 illustrates, most of the sample projects indicated that their primary project driver was either "Cost" or "Schedule." Here, "Balance" indicates that both "Cost" and "Schedule" were the influencing drivers in project execution.

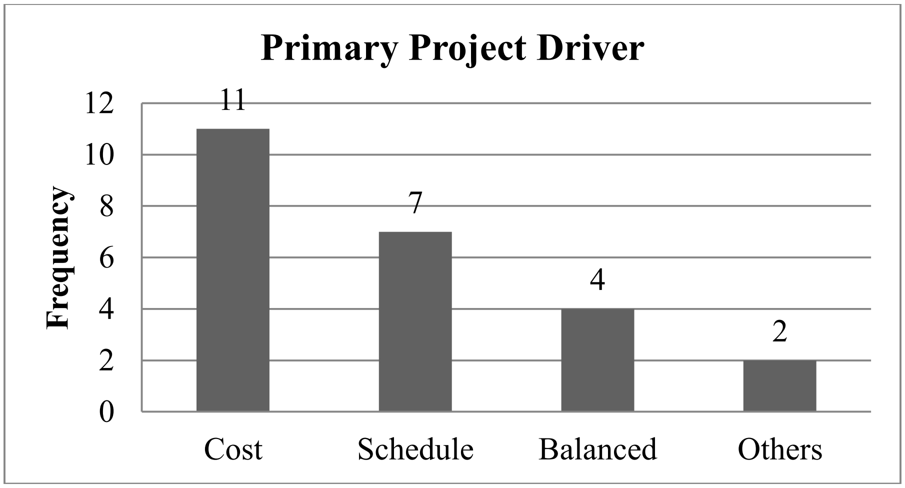


Figure 16. Frequency of Primary Project Driver

Project Jobsite and Fabrication/Assembly Shop Location(s)

Project jobsite location and module fabrication and assembly shop location were assessed and grouped by major country or continent. Aside from Asia, as Figure 17 and Figure 18 illustrate, there was no significant portion difference among other countries. Only 8% of the sample projects' jobsites were located at Asia, but about 30% of module fabrication and assembly shops were located in Asia. The researcher speculates that the national hourly compensation costs and/or productivity rate difference may have contributed to this result. From these figures, the researcher was able to identify the global modularization phenomenon. It should be noted that the productivity rate of site and module fabrication shops can vary even within the same region. One modular expert commented that there were over 200 module fabrication shops worldwide and their capability varies a lot shop to shop.

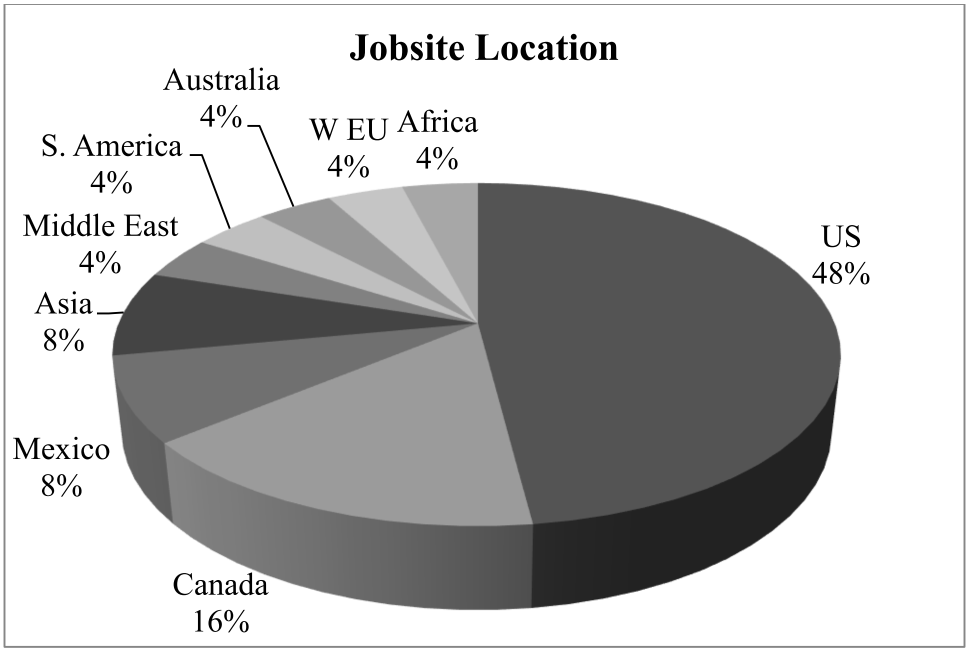


Figure 17. Project Jobsite Location

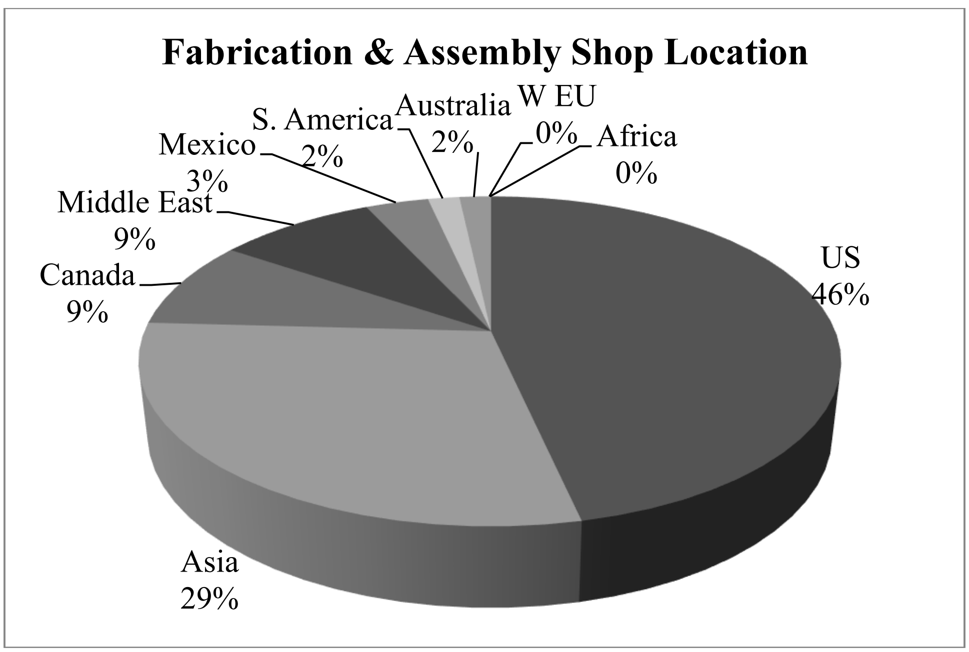


Figure 18. Module Fabrication and Assembly Shop Location

In addition to the above analysis, project performance was analyzed by project, project objective, and project function, and all this is presented in Appendix D.

Types of Modularized Units/Sub-units

To identify the most common types of units/sub-units in the industrial projects, the respondents were asked to report/check all types of module units/sub-units that had been modularized on the sample project with the following modules.

- Process Equipment
- Loaded Piperacks
- Utility Equipment
- Structural Modules
- Dressed Up Vessels
- Other Buildings
- Power Distribution Centers
- Remote Instrument Buildings
- Power Generation Equipment
- Others

For consistency, the definition of a module was given in the survey questionnaire.

- Module: Portion of plant fully fabricated, assembled, and tested away from the final site placement, in so far as is practical.

Figure 19 illustrates the frequency of all types of modularized units/sub-units. The five most common types of modularized units/sub-units are process equipment, loaded piperacks, utility equipment, structural module, and dressed-up vessels. Other reported modules were electrical substations, conveyor towers and components, and major equipment with auxiliaries. One validation feedback claimed that power distribution centers and dressed-up vessels are more commonly modularized for their projects. It should be noted that common types of units/sub-units may vary by the nature of the project.

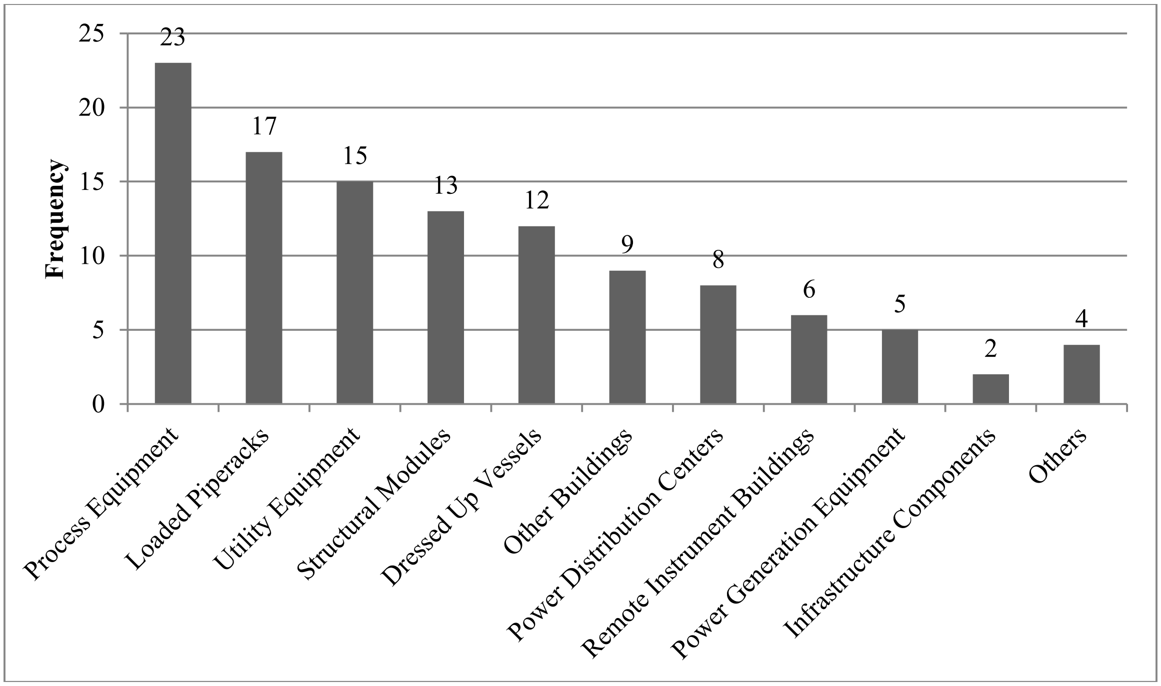


Figure 19. Types of Modularized Units/Sub-units

Reported Avg. % Schedule and Cost Savings Compared to Stick Built

To understand better the benefits of modularization, the study assessed the approximated percent schedule and cost savings compared to stick built. Figure 20 and Figure 21 illustrate percent schedule and cost savings compared to stick built and Table 8 summarizes the central tendency (mean and median) and variation (range, minimum, maximum, and standard deviation). The savings were measured in percentage since nearly all the respondents were reluctant to share hard numbers of cost and schedule savings.

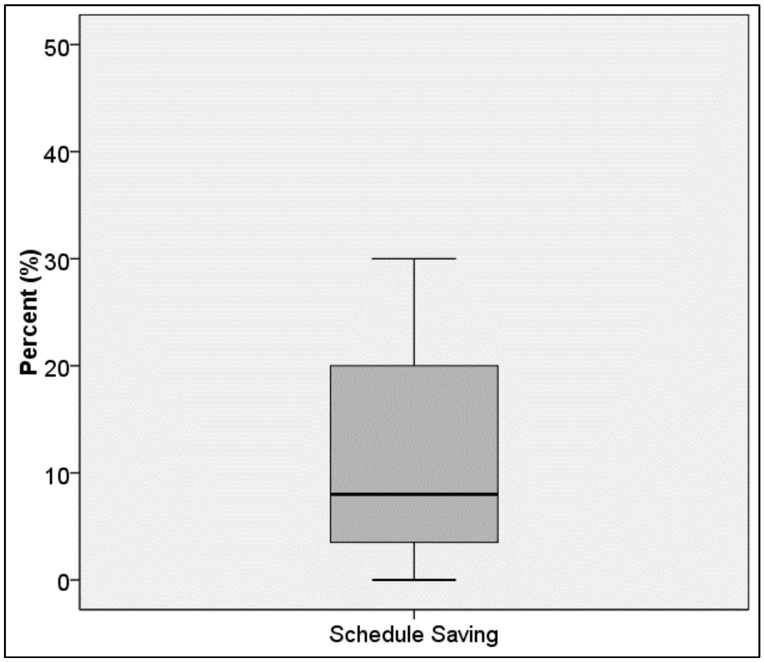


Figure 20. Percent Schedule Savings Compared to Stick Built

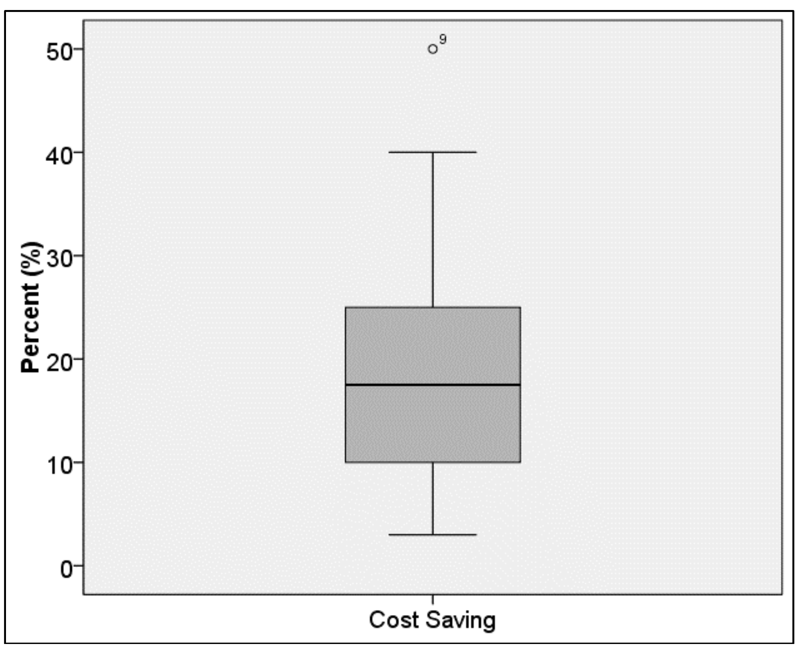


Figure 21. Percent Cost Savings Compared to Stick Built

Table 8 Percent Schedule and Cost Savings

	Schedule	Cost
N	15*	14*
Average	12.00	19.14
Min	0	3
Max	30	50
Standard Dev.	10.99	13.60
Range	30	47
Median	8	17.50

Of the 25 sample projects, only 15 reported their schedule savings and only 14 reported their cost savings. (Several projects reported only schedule savings or cost savings.) The average percent schedule savings was 12.50% and the average percent cost savings was 19.20%. The median percent schedule savings was 9% and the median percent cost savings was 20%. One extreme data was excluded from this study (80%). The researcher speculates that in that case the participant might have reported the percent savings in reverse (20% saving to 80%). However, the researcher failed to get an answer from the participant in follow-up questions.

The reader is cautioned to interpret this finding with care. The questionnaire asked only about their savings and did not measure their losses due to respondents' reluctance to share such information. Thus, the reported percent schedule and cost savings may be overrepresented. Furthermore, most of the reported savings are an expert's opinion—based on the sample project. Most respondents asserted that it was difficult to get the exact savings without a modular project and a stick-built project being executed together in exactly the same circumstances. This is why the participant was asked to report the percent schedule and cost savings based on their experience. This may not precisely represent the percent schedule and cost savings; however, the researcher believes that the reader may gain an understanding of the benefits of modularization, when well implemented, through their maximum and median percent schedule and cost savings.

Some experts claimed that many industrial projects select modularization even though the expected cost and schedule savings compared to stick-built are minimal or none. This is because a company recognizes that risks (weather interruptions protection, safety, schedule, quality control, and so forth) are more controllable in modular projects compared to stick-built.

Business Case Drivers for Modularization

"Business case drivers for modularization" is defined in this research as factors that direct business objectives and modularization and explain why the modular project was needed. These factors include schedule, labor cost, labor productivity, labor supply, safety, quality, environmental, regulatory, legal, site access, site attributes, security/confidentiality, sustainability, predictability/reliability, and disruption. Figure 22 illustrates the frequency of business case drivers for modularization. The top six popular business case drivers (10 or more sample projects commonly reported) for modularization were schedule, labor supply, labor productivity, labor cost, safety, and quality.

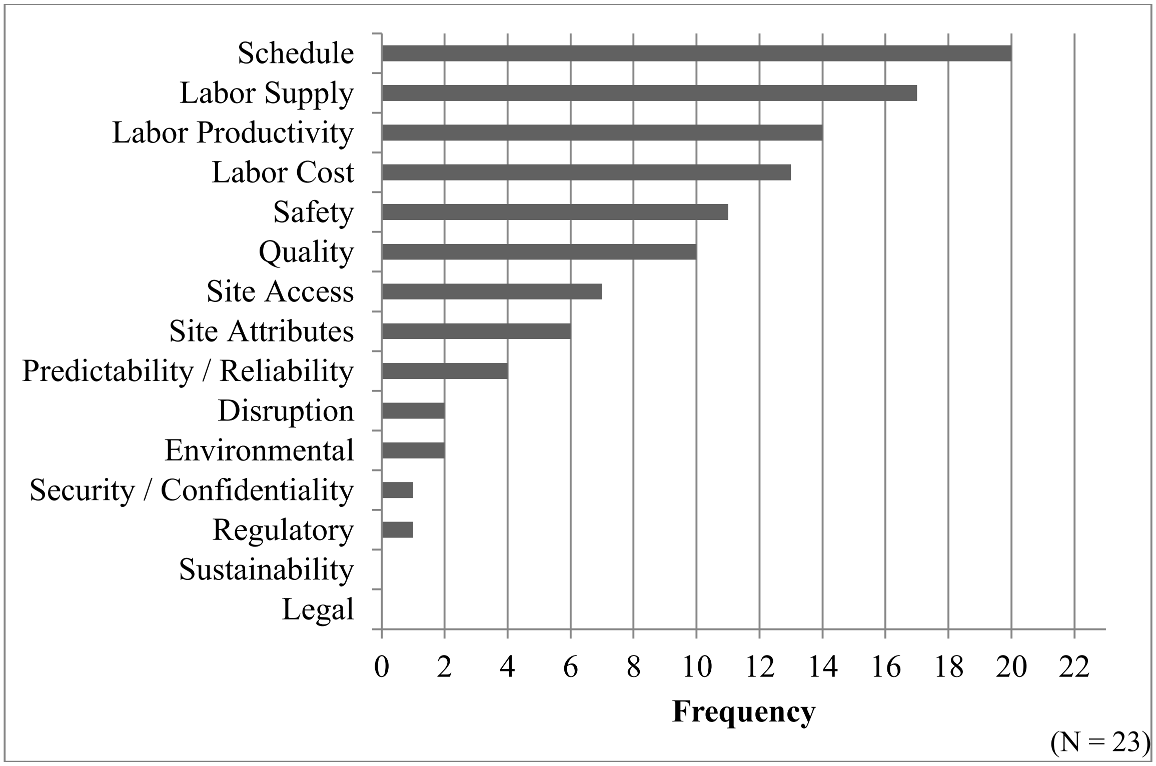


Figure 22. Business Case Drivers for Modularization

Recognized Project Difficulties

To understand common project difficulties in sample projects, the respondents were asked to report the project difficulties that they have recognized as leading to added cost or delay. Drawing from the literature review, a list of difficulties was drawn up and provided in the survey questionnaire with instructions to respondents to check all that apply. Those difficulties were contract terms, weather (extreme), logistics challenges (transportation of modules), environmental impact, organizational change, scope change, labor issues, regulating impact, external stakeholders, material shortage, major quality problems, change in demand for product, change in project profitability, change in financing environment, safety incident, equipment delivery, team turnover, and other. Figure 23 illustrates the frequency of project difficulties.

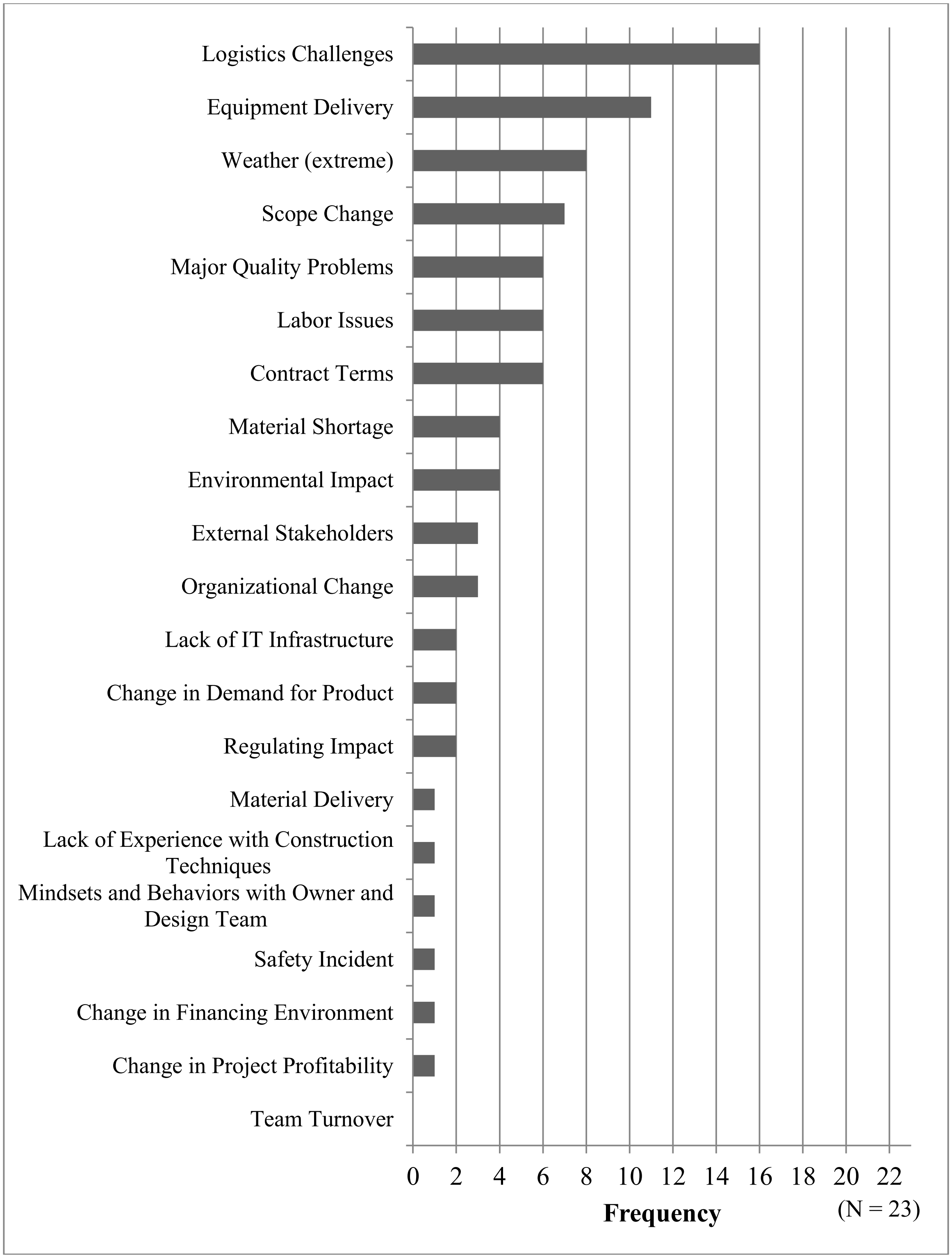


Figure 23. Project Difficulties

Impediments for Modularization Application

To identify the most common impediments of applying modularization, respondents looked over a list of impediments. The provided impediments were initial cost investment, coordination, anti-module oriented design, heavy lift, owner capability/tendency, contractor capability, fabricator capability, logistics, shipping limits, design freeze, transport restrictions, and other. Figure 24 illustrates the frequency of reported impediments of modularization application. The five most common impediments were owner capability/tendency, lack of design freeze, coordination, shipping limits, and transport restrictions. Other reported impediments for modularization application were local labor requirement, materials management, vendor data and IFC (industry foundation classes) in engineering phase, quality control, EPC tendency to build it non-modular, and government regulations. One participant highlighted that global modularization is currently constrained by the various government regulations and restrictions, units, standards, and shipping limits, and data transfer regulations.

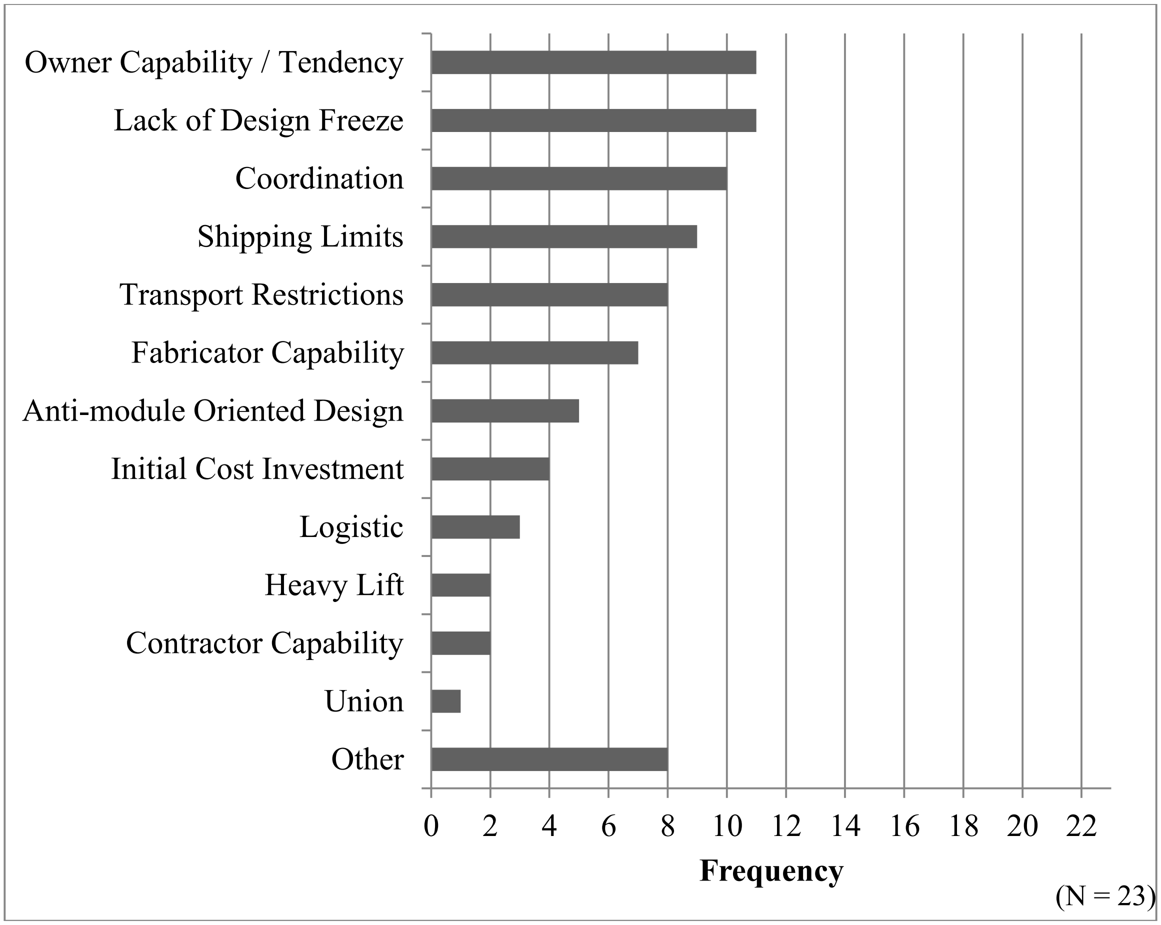


Figure 24. Impediments of Modularization Application

Advantages from Modularization Application

To identify the most common advantages from applying modularization, a list of the advantages were provided in the survey questionnaire and the respondents were asked to check all that applied to that sample project. The list of the advantages was developed through the literature review presented in Chapter 2. The advantages were overall lower cost, improved schedule, increased productivity, increased safety, reduced waste, better environmental performance, reduced site-base permits, and other. The four most common advantages from applying modularization were improved schedule, overall lower cost, increased safety, and increased productivity. Figure 25 illustrates the frequency of the advantages from modularization application.

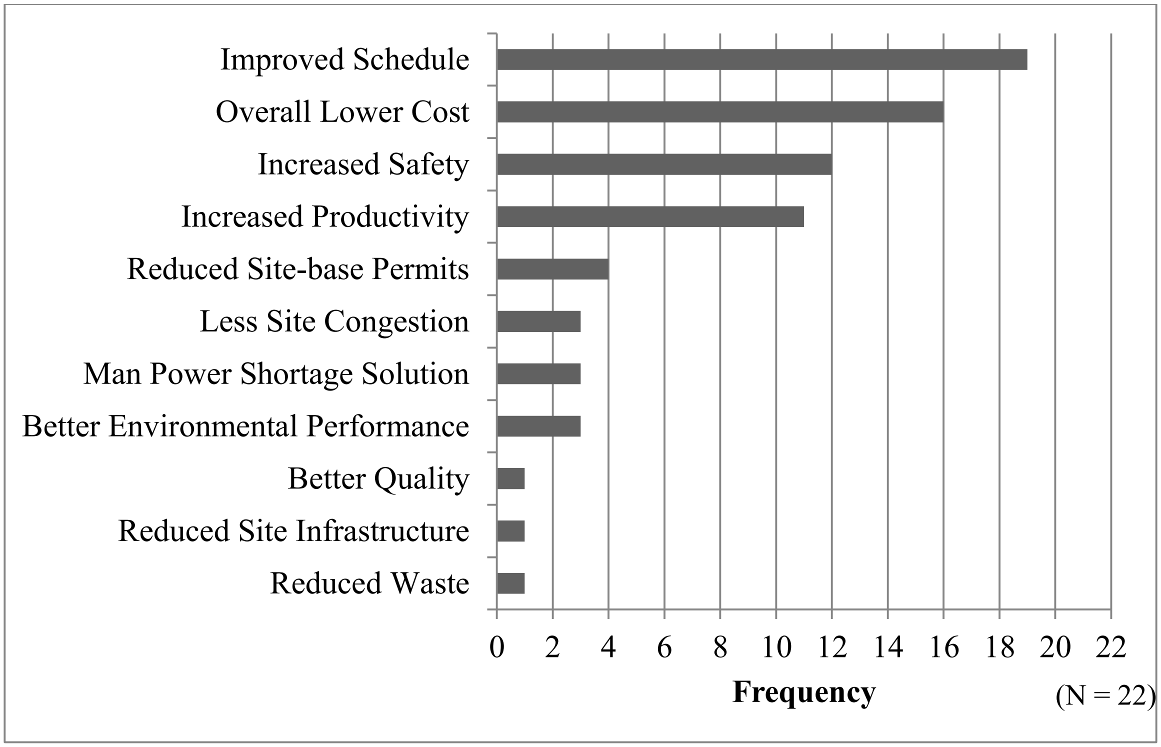


Figure 25. Advantages from Modularization Application

Further analysis on advantages from using modularization was conducted by the primary project driver. Figure 26, Figure 27, and Figure 28 illustrate the portion of advantages from modularization application by different primary project drivers. From this analysis, the researcher was able to identify the different characteristic of advantages from modularization application. As illustrated in Figure 26, the most common advantages were overall lower cost and improved schedule (nearly 60%) from modularization application on cost-driven projects (N = 11). In contrast, the most common advantages on schedule-driven projects were schedule, increased productivity, and safety (N = 7). On the balanced projects (N = 4), the advantages from modularization application were reported evenly.

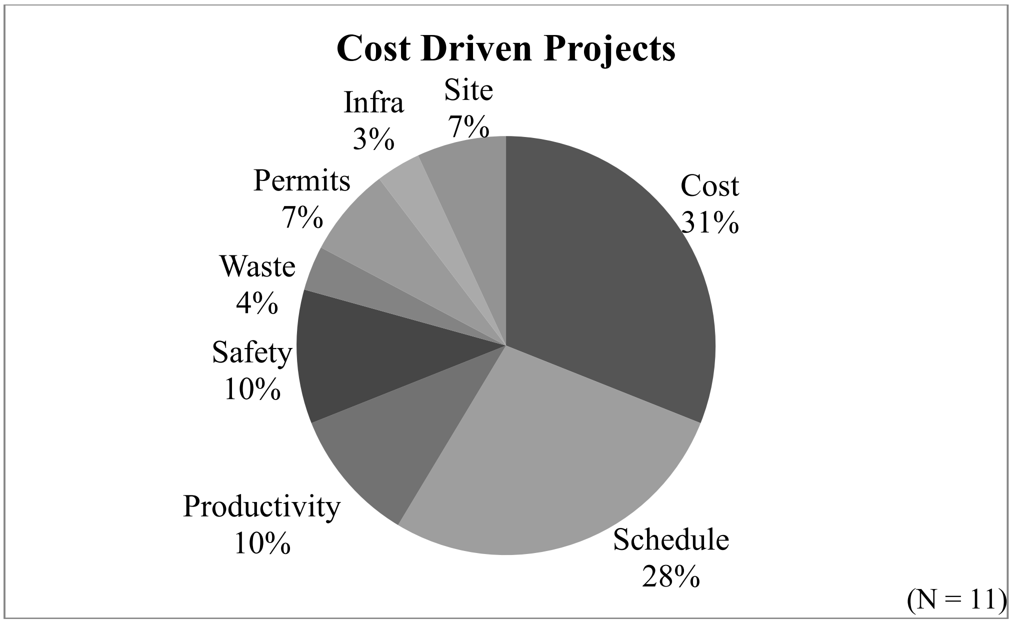


Figure 26. Advantages from Modularization Application on Cost-driven Projects

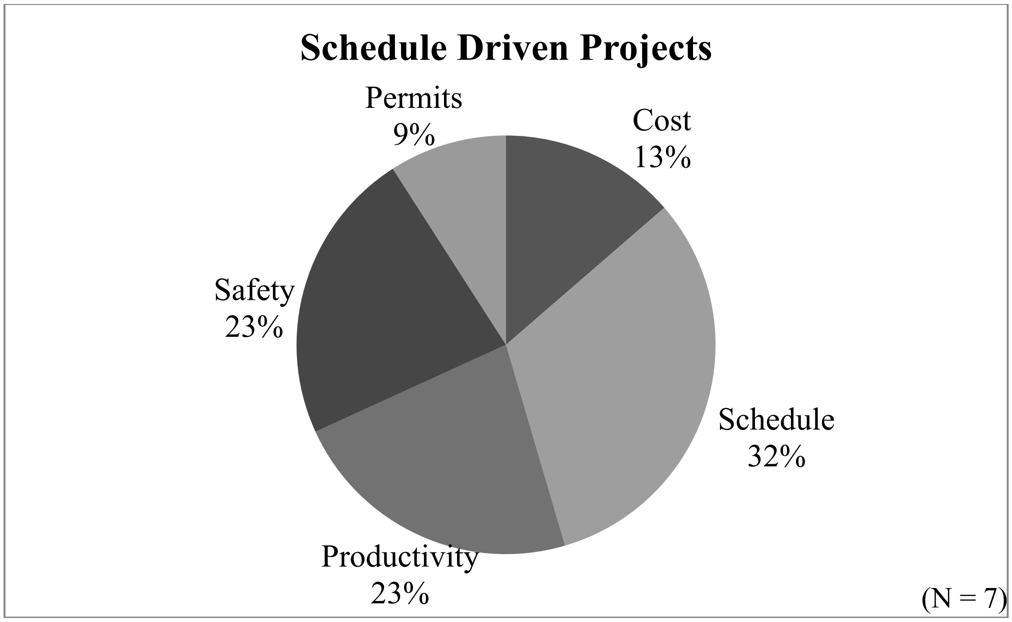


Figure 27. Advantages from Modularization Application on Schedule-driven Projects

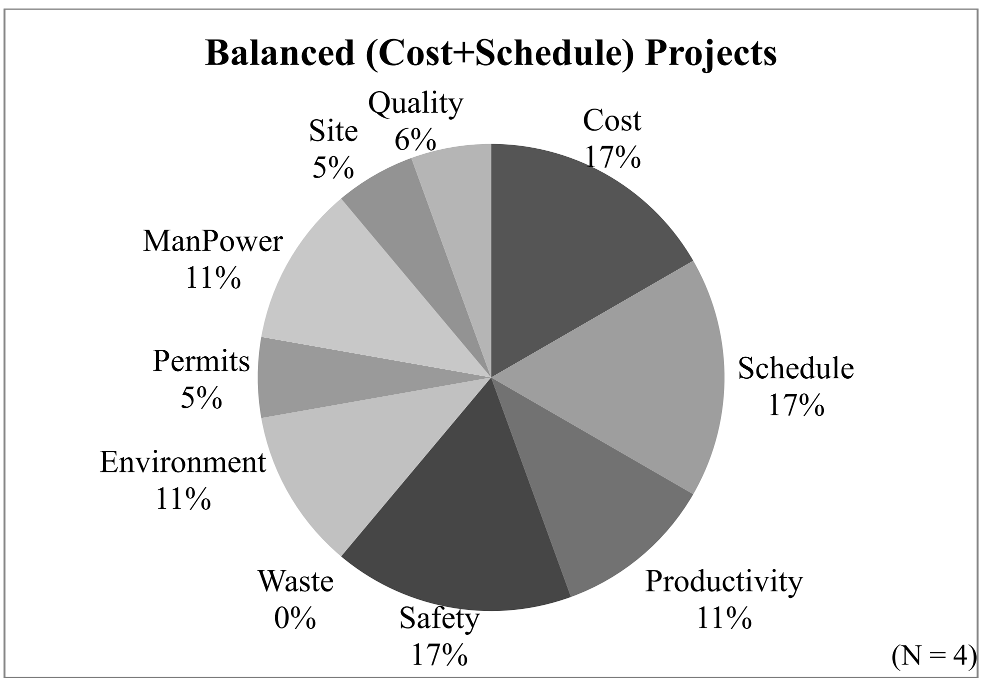


Figure 28. Advantages from Modularization Application on Balanced Projects

Average Project Performance by Project Objective

Project performance was measured by project objectives, which included safety, quality, cost, schedule, change management, field productivity, shop productivity, environmental, and sustainability. The performance was measured according to six levels: N/A = not applicable/don't know, 5 = exceeded expectations, 4 = between 3 and 5, 3 = met expectations, 2 = between 1 and 3, and 1 = significantly off plan. As project performance may vary by primary project driver, the study checked the performance difference among primary project drivers. Figure 29 illustrates the average project performance by project objective and primary project driver. All types of projects (cost driven, schedule driven, and others) met or were above expectations on safety, environmental, and sustainability. Interestingly, cost-driven and schedule-driven projects accomplished particularly better project performance than other types of projects in terms of cost, schedule, change management, field productivity, environmental, and sustainability.

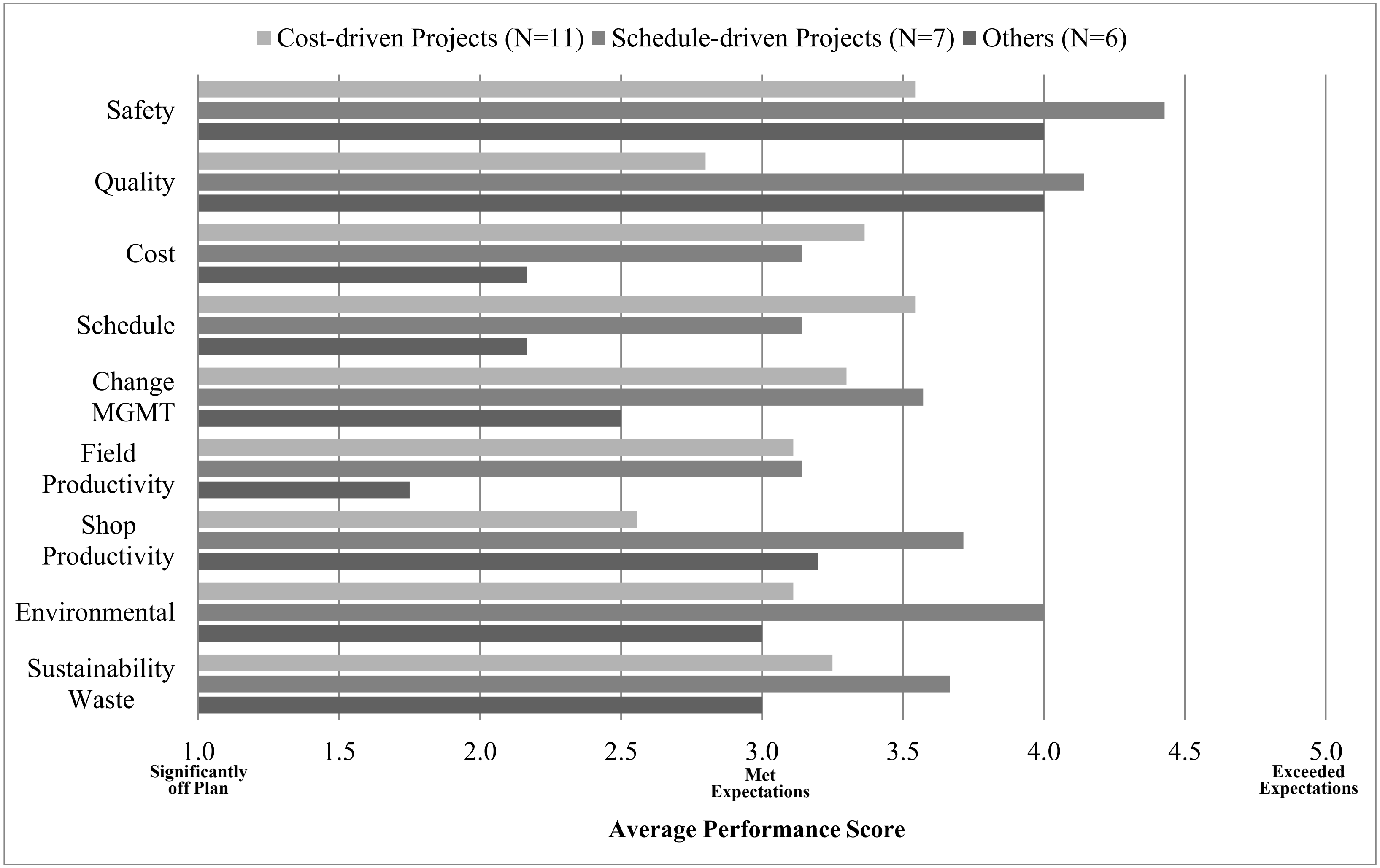


Figure 29. Average Project Performance by Project Objective

Reluctance to Respond / Need Industry's Attention

This section highlights the variables where the respondents were reluctant to respond or neglected to provide information. Figure 30 shows the frequency of projects that were returned without information. This result was due to confidentiality issues and the industry's lack of attention.

First, several respondents stated that they could not provide Field Productivity and Shop Productivity information out of an interest in confidentiality. Such reluctance was not unexpected as it consistently reared itself in the preliminary study, pilot study, and MOD COP feedback. This confidentiality issue continues to adversely impact on the study of productivity in the construction industry.

Second, as Figure 30 illustrates, the industry neglected to provide information on environment and sustainability benefits/performance. Several respondents stated that they do not measure or have the metrics to measure these issues. Many industry players appear to consider "green" benefits as secondary factors.

In contrast, the literature review identified that academia recently recognized and highlighted the "green" benefits of modularization application (MBI 2010). These "green" benefits includes reductions in material waste, air and water pollution, dust and noise, and overall energy costs (MBI 2010). Prefabrication, it has been asserted, is one of the best solutions to minimizing construction waste, a key part of the lean philosophy (Tam et al. 2007). To gather greater benefits from utilizing modularization, the industry needs to pay closer attention to "green" benefits. The researcher believes that such attention could lead to the improvement and higher benefits.

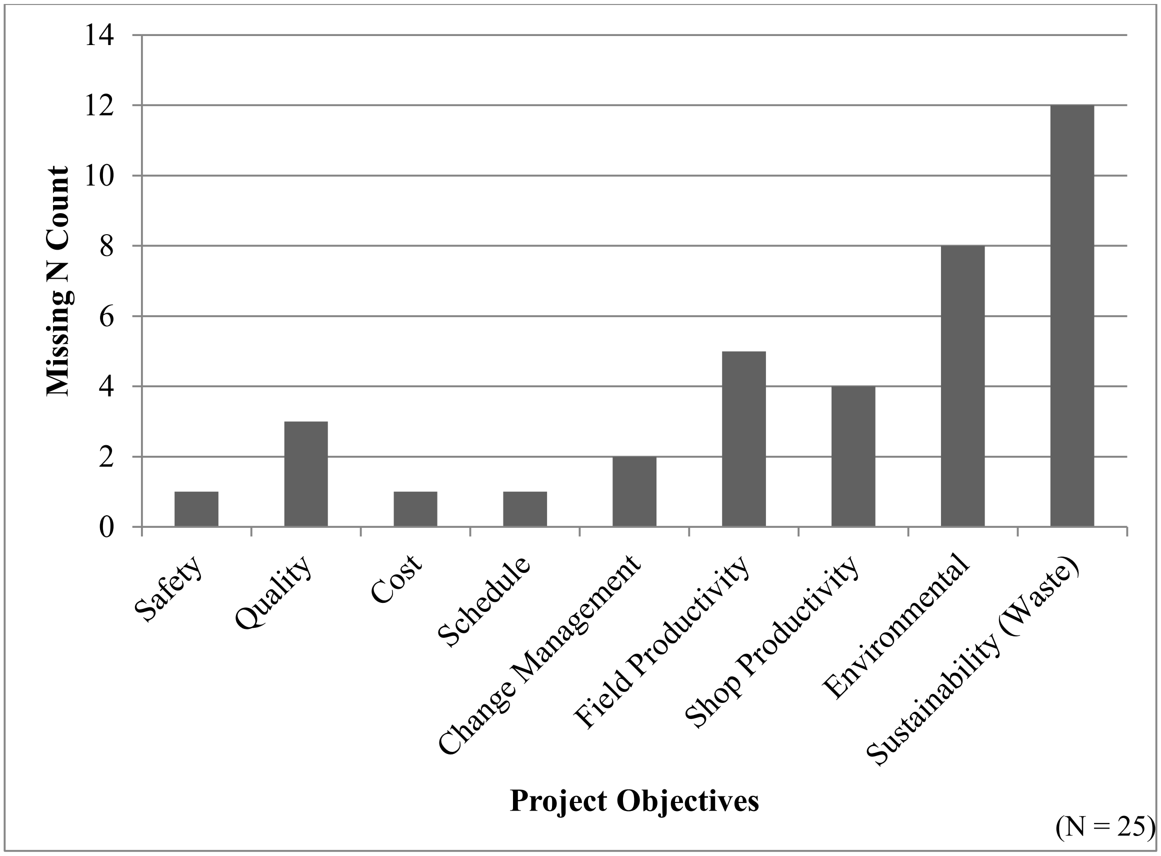


Figure 30. Reluctance to Respond / Need Industry's Attention

Conduct of Optimization Analysis

CII IR283 provided the modular execution business case process to answer "what is the optimum proportion of work hours that should be moved offsite in the module scope?" (CII 2013). Research Team 283 stated that optimization analysis, identifying optimum extent of modularization, can be calculated by considering project drivers and a project's objectives and by a high level assessment of modularization potential in terms of high/medium/low percentages of work hours moved offsite (CII 2013). Through this optimization analysis, higher profits can be obtained.

To understand the current status of conduct of optimization study, the respondents were asked to answer whether the project analyzed or identified the optimal extent of modularization. The response rate for this question was low because the Contractors were unable to answer such a question; indeed, the optimization study is usually conducted by Owners. Nonetheless, the researcher was able to conclude that still there are many modular projects that did not execute the optimization analysis, as Figure 31 illustrates, and the industry needs to conduct the optimization studies to gain higher profits.

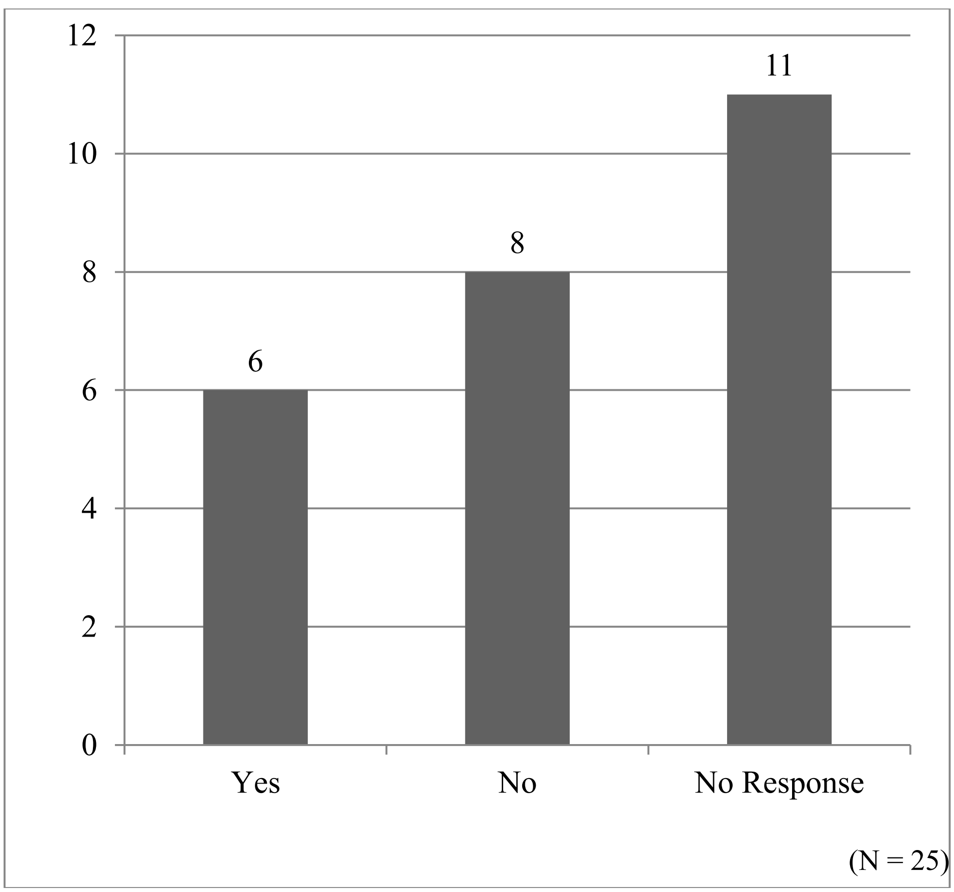


Figure 31. Conduct of Optimization Analysis

Modularization Business Case Initiation Timing

CII IR283 recommends conducting a modularization business case at the project's initiation or Opportunity Framing phase because "modularization opportunities typically decrease in terms of options as a project develops" and "the potential for attaining maximum benefit from adopting the optimum modular execution also decreases over a project's life cycle" (CII 2013).

To understand the current industry status on modularization business case initiation timing, this study was conducted. As Figure 32 illustrates, only 16% of sample projects conducted modularization business case study at Opportunity Framing. Furthermore, nearly 25% of sample projects conducted the modularization case study between Selection and Early in Detail Engineering. These results, in general, indicate that the industry, to obtain higher benefits from modularization application, should pay more attention to initiating the modularization business case study much earlier than the current initiation timing.

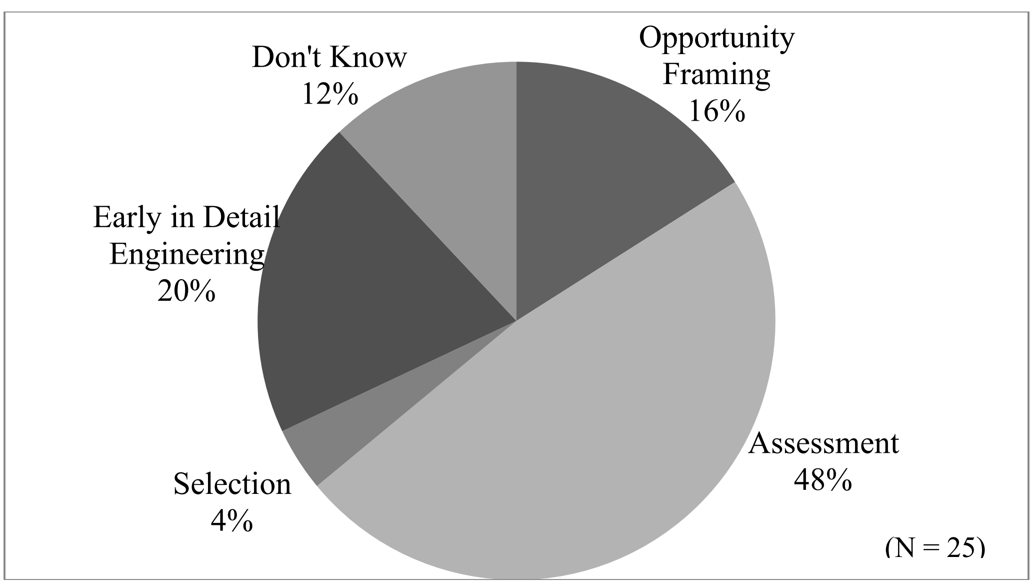


Figure 32. Modularization Business Case Initiation Timing

Characteristic of Jobsite and Module Fabrication/Assembly Shops

It would be beneficial to understand the characteristics of jobsite and module fabrication and assembly shops of modular projects sample. To do so, the following items were analyzed.

- Jobsite characteristics
    - Jobsite labor availability (Figure 33)
    - Jobsite labor quality (Figure 34)
    - Expected jobsite labor productivity (Figure 35)
    - Actual jobsite labor productivity (Figure 36)
- Module fabrication/assembly shops characteristics
    - Fabrication site(s) labor availability (Figure 37)
    - Fabrication site(s) labor quality (Figure 38)
    - Expected modularization fabrication site(s) labor productivity (Figure 39)
    - Actual modularization fabrication site(s) labor productivity (Figure 40)

When the jobsite labor market is compared to the fabrication site(s) labor market, the availability of the former (Figure 33) was lower than that of the latter (Figure 37). Furthermore, the former's quality (Figure 34) was lower than the latter's quality (Figure 38). Interestingly, as Figure 33 illustrates, numerous sample projects reported that their jobsite labor availability was inadequate or non-existent. In addition, as Figure 38 illustrates, many sample projects reported that their fabrication site(s) labor quality was high. In terms of labor productivity, as Figure 35 illustrates, more than half of the sample projects reported that their expected jobsite labor productivity was worse or far worse than average. In addition, as Figure 39 illustrates, the majority of sample projects reported that their expected module fabrication site(s) labor productivity ranged between "far better than average" and "average" (compared to company norms). These findings support the argument that the drivers for modularization application are an inadequate or non-existent labor supply and lower labor productivity at jobsite, better labor productivity and high quality of labor at module fabrication/assembly site(s)/shop(s).

The problems were identified in actual jobsite labor productivity and module fabrication site(s)/shop(s) labor productivity. As Figure 36 and Figure 40 illustrate, nearly half the sample projects failed to meet their expectations on labor productivity. Considering that one of the drivers for modularization application is better labor productivity at fabrication site(s)/shop(s), this finding may impact the modularization decision makers. This finding might be an indication that the industry is overestimating labor productivity at the jobsite and module fabrication site(s)/shop(s). In fact, the industry may need to take special care when estimating the labor productivity or inspect the cause for failing to meet expectations and then improve labor productivity so that it can meet expectations. To do so, productivity improvement programs are needed for the field and the shop.

Furthermore, detailed analysis is needed to measure the impact of poor actual labor productivity at jobsite and module fabrication site(s)/shop(s). By comparing the impact of poor labor productivity at a jobsite and module fabrication site(s)/shop(s), the modularization decision maker would be able to make a better decision on optimal modular extent to maximize modularization benefits.

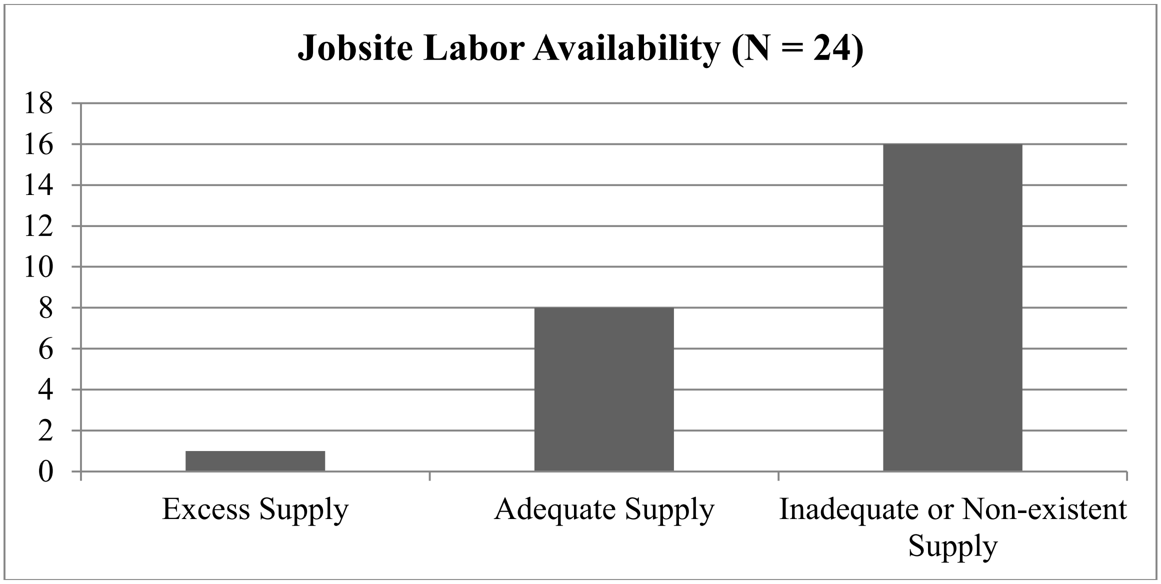


Figure 33. Jobsite Labor Availability

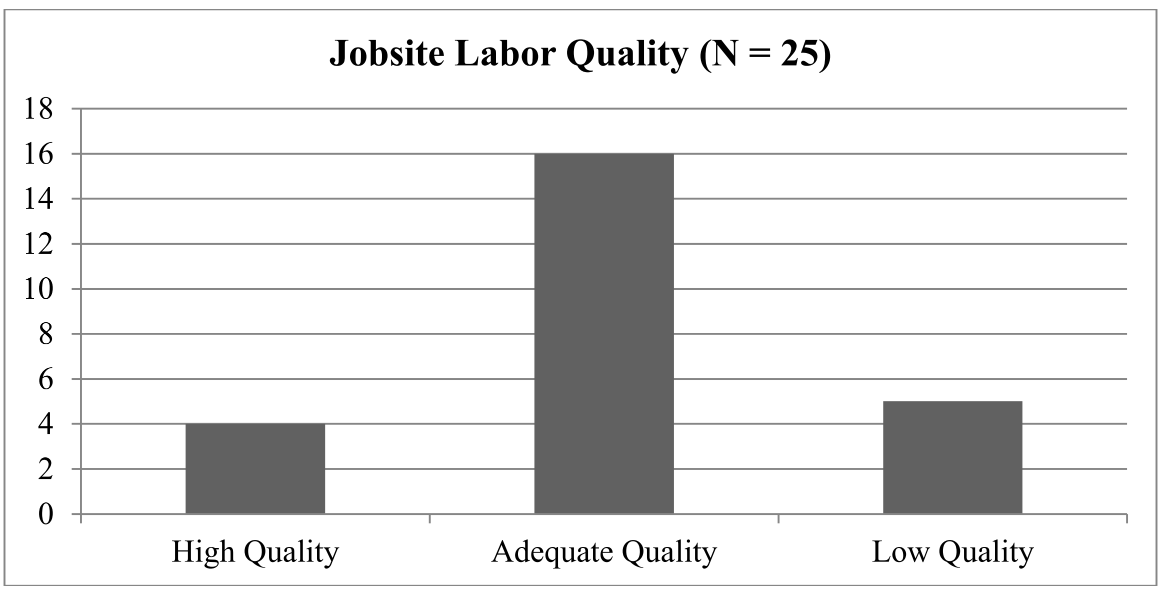


Figure 34. Jobsite Labor Quality

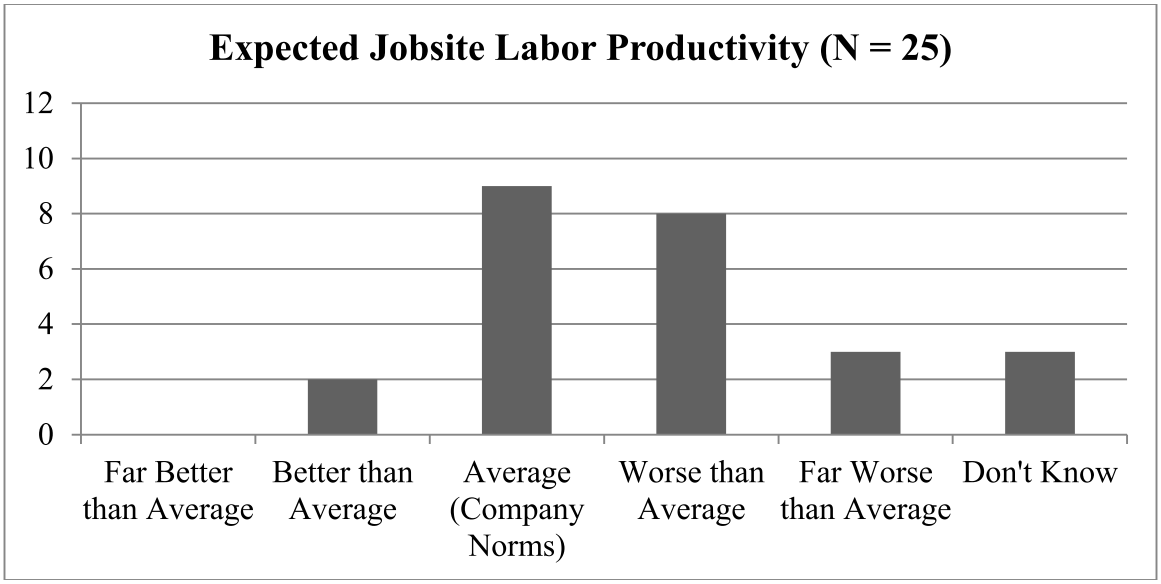


Figure 35. Expected Jobsite Labor Productivity

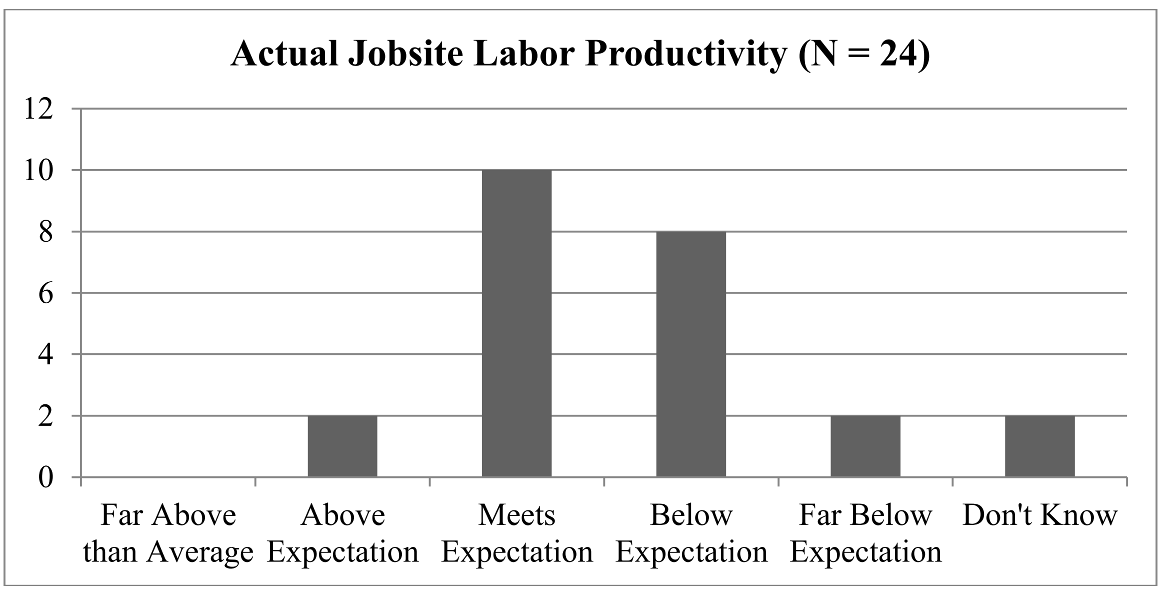


Figure 36. Actual Jobsite Labor Productivity

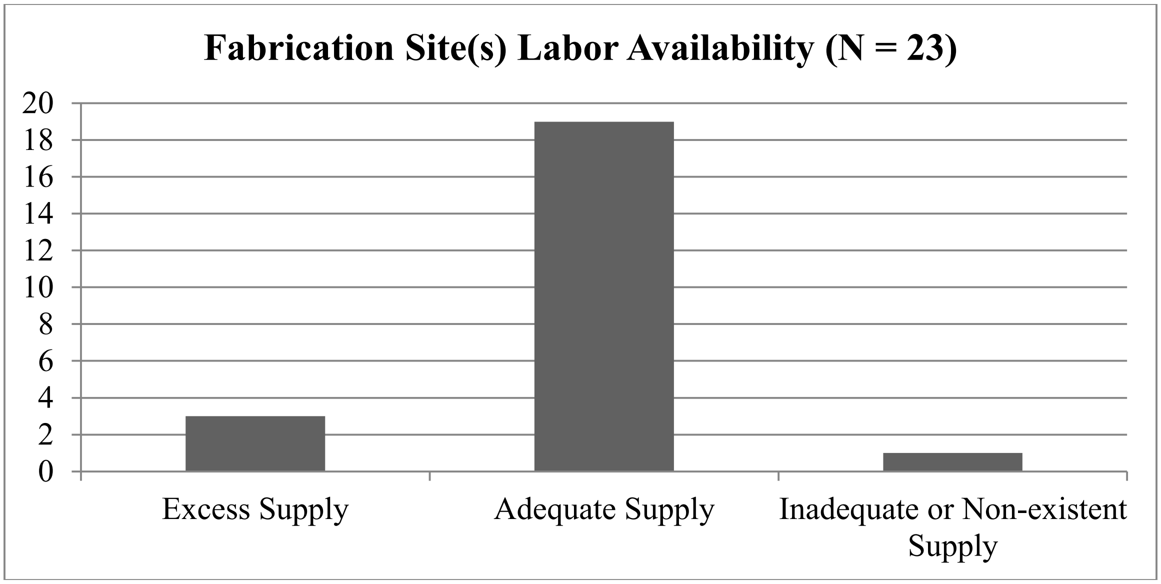


Figure 37. Fabrication Site(s) Labor Availability

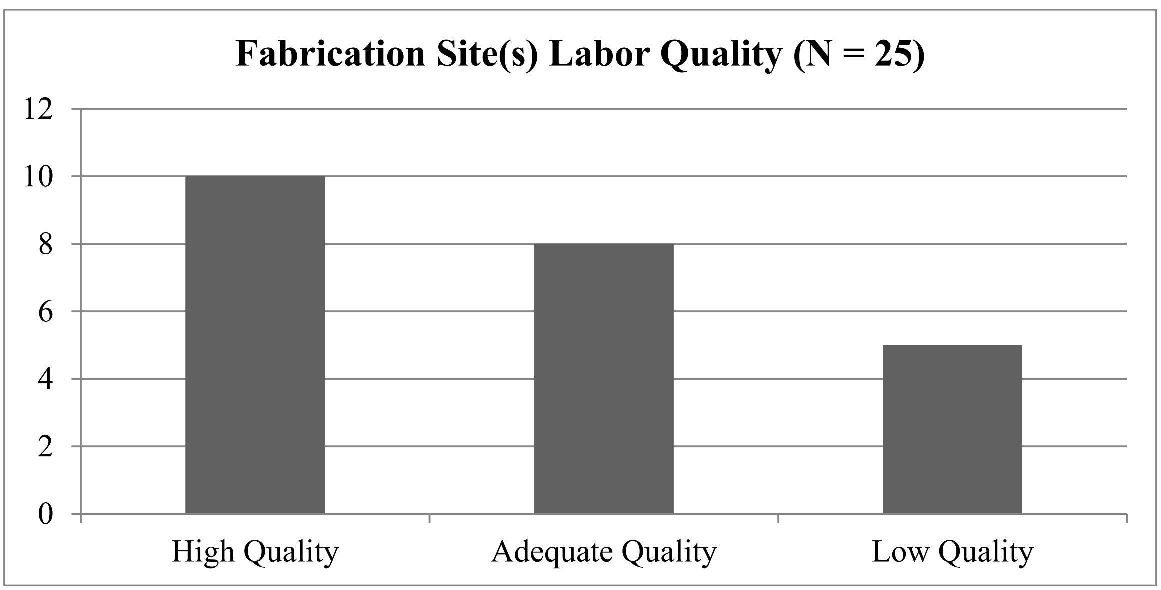


Figure 38. Fabrication Site(s) Labor Quality

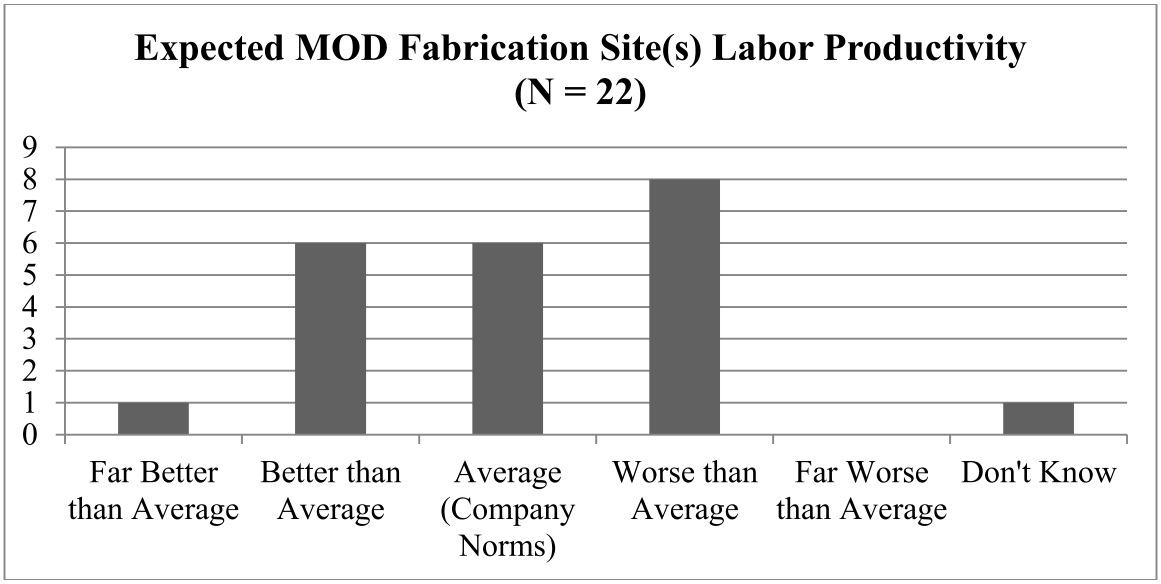


Figure 39. Expected Modularization Fabrication Site(s) Labor Productivity

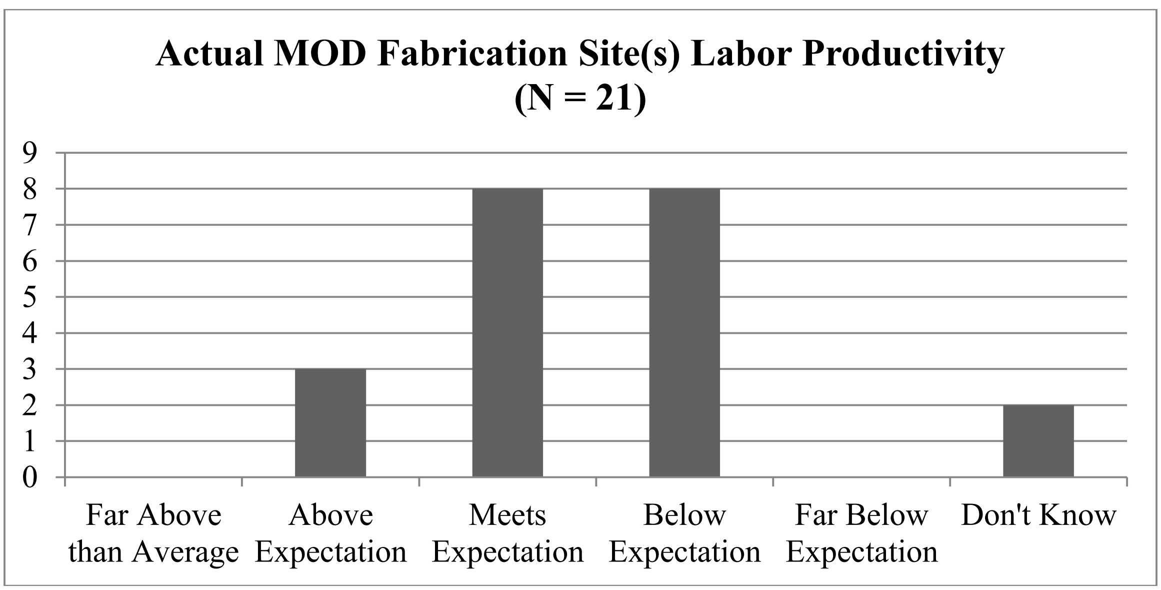


Figure 40. Actual Modularization Fabrication Site(s) Labor Productivity

Economic Impact of Standardization with Modularization

CII RT283 identified ten types of benefits and three trade-offs for standardization benefits (CII 2013). Furthermore, their contributing factors or reasons are discussed and documented. However, they did not assess the impact of advantages and disadvantages from modular standardized plants. Thus, if the sample projects implemented standardization with modularization, the researcher asked the respondents to assess its impact. Based on a listing of the ten types of advantages and the three types of disadvantages from CII IR 283 (CII 2013), the respondents were asked to assess the relative significance of impacts for economic advantages and disadvantages of their projects. They were asked to mark the impact of each advantage/disadvantage low (1), medium (3), High (5), or no impact (0). Table 9 presents assessment result of the relative significance of impacts for the ten economic advantages and the three economic disadvantages of design standardization.

Table 9 Economic Impact of Standardization with Modularization.

ECONOMIC IMPACT	**Impact Score (1 – 5)**	**Rank**
Type of Advantage		
1. Design Only Once and Reuse Multiple Times	4	1
2. Design & Procure in Advance / Respond to Schedule Needs	3.5	2
3. Accelerated, Parallel Engineering for Site Adaptation	3.5	2
4. Learning Curve in *Fabrication*	2.875	5
5. Volume Discounts in Procurement	2.5	8
6. Construction Materials Management Cost Savings	2	10
7. Learning Curve in *Module Installation/Site Construction*	2.875	5
8. Learning Curve in *Commissioning/Startup (planning & execution)*	3.25	4
9. Learning Curve in *Operations & Maintenance*	2.75	7
10. O&M Materials Management Cost Savings	2.5	8
Type of Disadvantage		
1. Cost of Assessing the Market and Establishing Scope	1.25	3
2. Cost of Establishing the Design Standard	2.25	1
3. Sacrificed Benefits from Conventional Customization	2.125	2

Four of ten advantages achieved impact scores of 3.0 or above on a 5.0 scale (medium to high impact). These four significant advantages included design only once and reuse multiple times; design and procure in advance/respond to schedule needs; accelerated, parallel engineering for site adaptation; and learning curve in commissioning and start-up (planning & execution). Six of the remaining advantages fell between 2.0 and 3.0. However, none of the three disadvantages scored 3.0 or above on the 5.0 scale (medium to high impact). Participants reported very low impact on the cost of assessing the market and establishing scope disadvantage.

The owner representatives reported another economic advantage from design standardization application—minimization of owner technical resources utilization, which allowed them to work on alternative tasks.

Some impediments/challenges for design standardization of modules from the case projects were as follows:

- Overcoming internal barriers. Developing the team's understanding of the advantages of design standardization.
- Selecting one vender for all the applications for standardized equipment and materials. Each site had their preferred vendors for equipment.
- Alignment between owner representative and manufacturing personnel to standard design concept

Some key implementation lessons from the modular standardized power plant (MSP) application are as follows:

- Developing an MSP design requires time, money, and resources. MSP initial development is not a good candidate for an owner's fast-track project; though once the MSP has been developed, fast-track projects are even more applicable. Plan on assigning your best design resources to MSP development. Close interaction with major equipment vendors is a must.
- Changes in conventional engineering are required for the MSP approach. Design objectives must be altered from the traditional way of executing engineering. Design engineers need to thoroughly understand the range of variable values to be accommodated through design, and that subsequent

design variation accommodations must be thoroughly scrutinized and controlled.

- When selling an MSP application project, plan on conducting an early meeting to discuss the customer's specifications and the advantages of the MSP approach.

Summary of Description of Modular Projects Sample

This chapter has described the modular projects sample by assessing the following items.

- industry group and subsector
- company type
- physical completion at the time of data collection
- total installed cost (TIC) and duration
- primary project driver
- project jobsite and fabrication/assembly shop location(s)
- types of modularized units/sub-units
- reported avg. % schedule and cost savings compared to stick built
- business drivers for MOD
- project difficulties recognized
- impediments for MOD application
- advantages from MOD application
- reluctance to respond/need industry's attention
- conduct of optimization analysis
- MOD business case initiation timing
- characteristic of jobsite and module fabrication/assembly shops

- economic impact of standardization with modularization

In the study of types of modularized units/sub-units, the five most common modules were identified: process equipment, loaded piperacks, utility equipment, structural module, and dressed up vessels. Other reported modules are electrical substations, conveyor towers and components, and major pieces of equipment with auxiliaries.

The study of percent schedule and cost savings compared to stick built identified a median percent schedule savings of 9% and a median cost savings of 20%. From the study, the researcher was able to understand the benefits of modularization with their maximum and median percent schedule and cost savings.

The study also identified the top six popular business case drivers for modularization: schedule, labor supply, labor productivity, labor cost, safety, and quality.

To understand common project difficulties in sample projects, the respondents were asked to report the project difficulties they have come to recognize as leading to added costs or delays. Those difficulties are contract terms, weather (extreme), logistics challenges (transportation of modules), environmental impact, organizational change, scope change, labor issues, regulating impact, external stakeholders, material shortage, major quality problems, change in demand for product, change in project profitability, change in financing environment, safety incident, and equipment delivery.

The study identified the most common impediments of modularization application: owner capability/tendency, lack of design freeze, coordination, shipping limits, and transport restrictions.

Looking at the advantages of utilizing modularization, the study developed a list of them (found through the literature review) and provided them in the survey questionnaire; the respondents were asked to check all that applied on the sample project.

The top four common advantages are improved schedule, overall lower cost, increased safety, and increased productivity.

In the study of average modular project performance by project objective, all types of projects (cost driven, schedule driven, and others) met or rose above expectations regarding safety, environmental, and sustainability issues. Interestingly, cost-driven and schedule-driven projects accomplished particularly better project performance than other types of projects on cost, schedule, change management, field productivity, environmental, and sustainability.

Several respondents stated that they could not provide "Field Productivity" and "Shop Productivity" information due to confidentiality concerns. Furthermore, the industry neglected to provide the information on environmental and sustainability benefits/performance. Several respondents stated that they did not measure or have a metric to measure these issues. To gather higher benefits from modularization application, the industry should turn more attention to the potential "green" benefits.

To understand the current status of conduct of optimization study, the respondents were asked whether the project analyzed or identified optimal extent of modularization. The researcher was able to conclude that there are still many modular projects that do not execute the optimization analysis and the industry, to gain higher profits, needs to give attention to conducting optimization studies.

The study took a look at the modular project sample's timing of initiation of modularization business cases. Of the sample projects that conducted modularization business case studies, only 16% did so at Opportunity Framing and 25% of them did so between Selection and Early in Detail Engineering. These results indicate that, in general, the industry, to obtain higher benefits from modularization application, needs to pay greater attention to initiating the modularization business case study much earlier than they do now.

To understand characteristics of jobsite and module fabrication and assembly shops, the following items were analyzed.

- Jobsite characteristics
    - jobsite labor market quantity
    - jobsite labor market quality
    - expected jobsite labor productivity
    - actual jobsite labor productivity
- Module fabrication/assembly shops characteristics
    - fabrication site(s) labor market quantity
    - fabrication site(s) labor market quality
    - expected modularization fabrication site(s) labor productivity
    - actual modularization fabrication site(s) labor productivity

The finding supported the argument that the drivers for modularization application are inadequate or non-existent labor supply and lower labor productivity at jobsite, better labor productivity, and high quality of labor at module fabrication/assembly site(s)/shop(s). Furthermore, the findings indicated that the industry may need to be careful about avoiding the overestimation of the labor productivity or that it may need to inspect the cause of expectations not being met and improve labor productivity to meet expectation.

The study assessed the economic impact of standardization with modularization. The four significant advantages included design only once and reuse multiple times; design and procure in advance/respond to schedule needs; accelerated, parallel engineering for site adaptation; and learning curve in commissioning and start-up (planning & execution). On a 5.0 scale, however, none of the three disadvantages scored 3.0 or above (medium to high impact).

3.10 Data Analysis

Measuring CSFs Accomplishment

Descriptive statistics were used to measure MOD CSF accomplishment status. The CSF accomplishment degree and CSF accomplishment timing were analyzed according to each CSF and by each project. The analysis according to each CSF was conducted to identify the most impactful CSFs and those most delayed. In addition, the accomplishment of CSFs was analyzed by each project to identify correlations with other variables.

The degree of CSF accomplishment was measured at four levels: 1) not accomplished (0%), 2) partially accomplished (30%), 3) mostly accomplished (70%), and 4) fully accomplished (100%). The researcher calculated the CSF accomplishment degree (D_A) by computing the percent of mostly or fully accomplished projects among all the sample projects/CSFs.

- D_A (CSF Accomplishment Degree Score) = percent of sample projects with mostly or fully accomplished CSFs

In this study, to measure CSF accomplishment timing, the researcher divided the project phase into five stages: 1) Opportunity Framing, 2) Assessment, 3) Selection, 4) Basic Design, and 5) Engineering, Procurement and Construction (EPC). The respondents were asked to assess the accomplishment of MOD CSFs for the sample project by timing. Figure 41 illustrates how the study measured the timing score of the accomplished MOD CSFs. First, the frequency of projects by project phase were counted (gray boxes). Next, the study counted the frequency of projects accomplished between "prior to the recommended timing by CII RT283" and "one phase after" (dot pattern box); the study excluded the frequency of projects accomplished two phases later than the recommended timing (horizontal pattern box). The CSF accomplishment-timing score (T_A) was obtained using the following equation.

- T_A (CSF Accomplishment Timing Score) = percent of sample projects reported early, on-time, or one phase late compared to CII RT283's recommended timing.

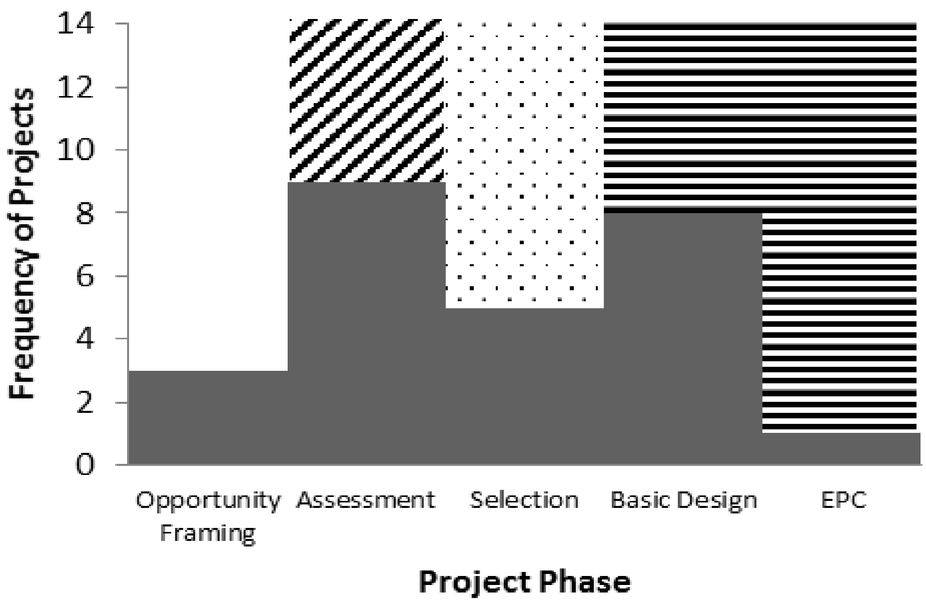


Figure 41. Measuring the Timing Score of MOD CSF Accomplishment

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

Normalization of Accomplishment Scores (Degree & Timing)

The calculating of the degree score and the timing score of MOD CSF accomplishment were normalized for several reasons: 1) it's reasonable that the sample project was not able to accomplish the CSF (not applicable); 2) the participant was unable to obtain information on the CSF due to limited access to all of the project's information or when the CSF was accomplished by another stakeholder who refused to proffer the information.

When some CSFs for the project are not applicable or cannot be answered (due to lack of authority or no available data), becoming "N/A", the maximum possible CSFs accomplishment score is not 100% (21 CSFs). To compare the CSFs accomplishment and to solve this issue, a normalization process was conducted. To normalize a CSF accomplishment score, the study divided its accomplishment score to the altered (lowered) maximum possible score. For example, after the assessment, there could have been a maximum possible degree score of CSF accomplishment of 86% (18 CSFs) since some (3) CSFs may have been "N/A." If out of this total, the score was 76% (16 CSFs), it could be normalized by dividing 76% (16 CSFs) by 86% (18 CSFs). The normalized score would thus be 88% (18.67 CSFs).

Examining the Correlations

For this analysis, correlational research methods and correlational statistics were used. This approach is suitable for the analysis because the correlational method is "a type of non-experimental method that describes the relationship between two measured variables" (Jackson 2003). A scatter plot—a figure showing the relationship between two variables—was made to facilitate the correlation interpretation. For all the links, positive correlations are expected.

For all the links, the study calculated a Pearson's product-moment correlation coefficient, referred to as Pearson's r. When both variables are measured on an interval or ratio scale, the most commonly used correlation coefficient is the Pearson's product-moment correlation coefficient (Jackson 2003). With the correlation coefficient, the researcher was able to determine the magnitude of a relationship. The formula for Pearson's r is

$$\mathrm{r} = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N})(\sum Y^2 - \frac{(\sum Y)^2}{N})}}$$

When r is close to 1.00, a strong positive relationship may be interpreted between the two variables. In addition, by squaring the correlation coefficient, the coefficient of determination can be calculated; this measures the proportion of the variance in one variable that is accounted for by another variable.

Furthermore, for this analysis, regression analysis was used. A researcher using regression is able to predict an individual's score on one variable by knowing one or more other variables (Jackson 2003). The regression analysis involves determining the equation for the best-fitting line for a data set. From this analysis, the regression formula:

$$\hat{Y} = bX + a$$

will be calculated where $\hat{Y}$ is the predicted value for the Y variable, *b* is the slope of the line, X represents an individual's score on the X variables, and *a* is the *y*-intercept. The formula for computing *b* is:

$$b = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2}$$

The formula for a is:

$$a = \bar{Y} - b(\bar{X})$$

Once, the researcher identifies the regression formula, one variable to another can be predicted. For this research, the prospect of identifying the regression formula was intriguing. The *y*-intercept, *a*, allows us to identify the minimum accomplishment level of modularization CSFs. Moreover, the slope of the line, *b*, tells us the practical power of the modularization CSFs.

Calculating "Modular Project Success"

"Modular Project Success" was calculated by weighing the function components. The weight of each function component was calculated by surveying the 12 modular experts from the CII MOD COP and averaging their individual weights. These modular experts were highly experienced in the modular technique (averaging 29+ years industry experience; an average of 8 modular projects in the last 5 years). The function components include Engineering, Procurement, Fabrication, Construction (with shipping and handling), and Startup. Figure 42 illustrates the calculated weights of each function component for "Modularization Project Success." The study result shows that Engineering contributes the most to "Modularization Project Success" followed by Fabrication, Construction, and Procurement. Startup was the function that least contributed to "Modularization Project Success."

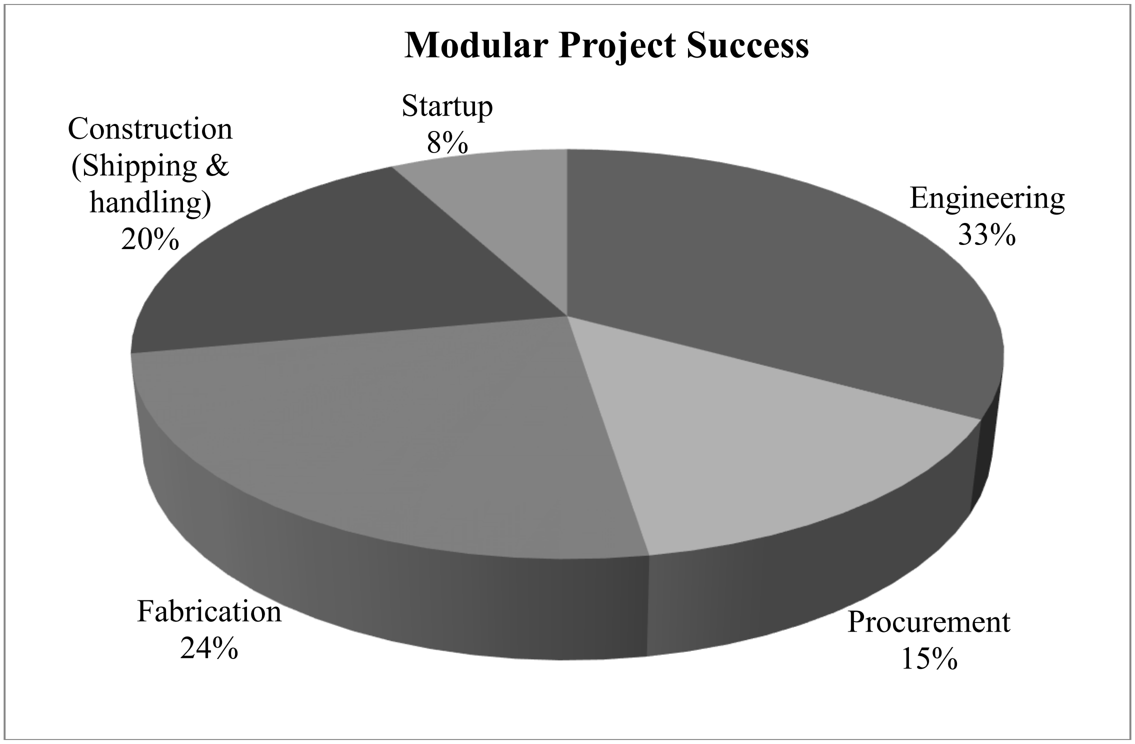


Figure 42. Weights of Each Function Components for "Modular Project Success"

Thus, the formula for “Modular Project Success” is: MODULAR PROJECT SUCCESS = Σ (0.33 * Engineering + 0.15 * Procurement + 0.24 * Fabrication + 0.20 * Construction + 0.08 * Startup)

In addition to calculating the average of weights, the researcher decided to calculate the median and standard deviations of each weight to better understand them. The calculated results are presented in Table 10. In the analysis of standard deviations, Engineering had the highest standard deviations and Fabrication and Startup had the lowest. This could be interpreted as meaning there are some disagreement on weights of Engineering compared to weights of Fabrication and Startup.

Table 10 Function Components Weight Analysis Result (N = 12)

	Weight (Mean)	Weight (Median)	Standard Deviations
Engineering	32.92	30	13.05
Procurement	14.58	12.5	8.11
Fabrication	24.58	25	5.82
Construction (Shipping & handling)	20.00	20	9.53
Startup	7.92	10	3.96

3.11 VALIDATION

Members of the CII MOD COP validated the study's key findings. The validation was conducted at the CII MOD COP face-to-face meeting on January 22, 2014. For two hours, the research key findings were presented to meeting participants along with an extra feedback session. The backgrounds of the MOD COP members who participated in the validation were analyzed. Twelve Modular experts from the MOD COP and one academic researcher from the University of Texas at Austin participated in the validation. The modular experts were highly experienced in the modular technique (avg. 29+ years industry experience with an average of 8 modular projects in the last 5 years) and most of them had not participated in the project information-gathering survey. The validation participants' names and their affiliations are presented in Appendix J.

In this validation process, a feedback form was distributed to the reviewer. These are questions that were asked in the feedback form (Appendix E):

- Is any critical content (link) missing?

- Are any significant corrections needed?
- Does any finding conflict with your experience?
- Which findings are most interesting or should be emphasized? (limit to 5 to 10)

A total of 72 comments were collected from the validation process. The researcher went through every comment received item by item and reacted to them one of three ways: 1. Responded to, 2. disagreed with or neglected, or 3. recognized as already being in place/no change needed. Consequently, the researcher responded to 42 comments, disagreed with 5, and recognized that no changes were needed for 25 comments. The detailed responses can be found in Appendix F. After a thorough validation process, the final outputs of research were generated.

3.12 Summary of Research Methodology

Correlational and descriptive research methodologies were used in this study. First, to get a handle on the overall flow of the research, a research methodology flow chart was illustrated and explained. This flow chart was developed to facilitate achieving the research objectives and to analyze the research hypotheses. As the survey approach is better suited to correlational and descriptive research, the survey questionnaire was developed. Its process of development and revisions were made through the CII COP review and the pilot study have been summarized. Furthermore, the study addressed the pilot study, data collection procedure, the population and sample of the study, data analysis plan, and validation plan. The research methodology chapter concluded with this summary of the research methodology.

Chapter 4: CSFs Accomplishment Analysis

4.1 INTRODUCTION

The purpose of this chapter is to shed light on modularization CSFs and to ascertain the status of their accomplishment in terms of degree and timing. First, the researcher wanted to know which CSFs are accomplished most commonly and which remain elusive or difficult to achieve. Second, the researcher investigates the CSFs that appear to contribute the most to Project Performance Metrics. Furthermore, this section attempts to validate CII RT283's frequency survey result by comparing it with the accomplishment found on the sample projects. This study will help many stakeholders better understand what's needed for the industry to achieve higher levels of MOD and better project performance.

To help with this, the following items were measured:

- Degree of accomplishment for each CSF, across the entire sample
- Timing of CSF accomplishment for each CSF
- Analysis of CSF accomplishment by project phase
- Analysis of CSF accomplishment by project

From the above measurements, the following items were analyzed:

- Lowest CSFs in terms of degree of accomplishment among sample projects
- Highest CSFs in terms of degree of accomplishment among sample projects
- Timeliest CSFs in terms of accomplishment timing among sample projects
- Most delayed CSFs in terms of accomplishment timing
- CSFs that contribute the most to "Modular Project Success"
- CSFs that contribute the most to Construction success

- CSFs that contribute the most to Startup success
- CSFs that contribute the most to Cost performance
- CSFs that contribute the most to Schedule performance
- Comparison of CSF accomplishment timing
- Comparison of CSFs accomplishment frequency between sample projects (Project Based) and CII RT 283 (Experience Based)

CSFs accomplishment was assessed by project staff and measured according to four levels: 1) not accomplished (0%), 2) partially accomplished (30%), 3) mostly accomplished (70%), and 4) fully accomplished (100%). The researcher calculated the CSF accomplishment degree (D_A) by using the following equation.

- D_A (CSF Accomplishment Degree Score) = percent of sample projects with mostly or fully accomplished CSFs

To analyze CSF accomplishment timing, the researcher divided the projects into five phases: 1) Opportunity Framing, 2) Assessment, 3) Selection, 4) Basic design, and 5) Engineering, Procurement and Construction (EPC), and asked respondents to assess CSF accomplishment by timing. A CSF accomplishment timing score (T_A) was obtained using the following equation.

- T_A (CSF Accomplishment Timing Score) = percent of sample projects reported early, on-time, or one phase late compared to CII RT283's recommended timing.

The detailed methodology for assessing the actual accomplishment of a modular project's CSFs is addressed in Chapter3: Research Methodology.

4.2 DEGREE OF CSFS ACCOMPLISHMENT BY CSF

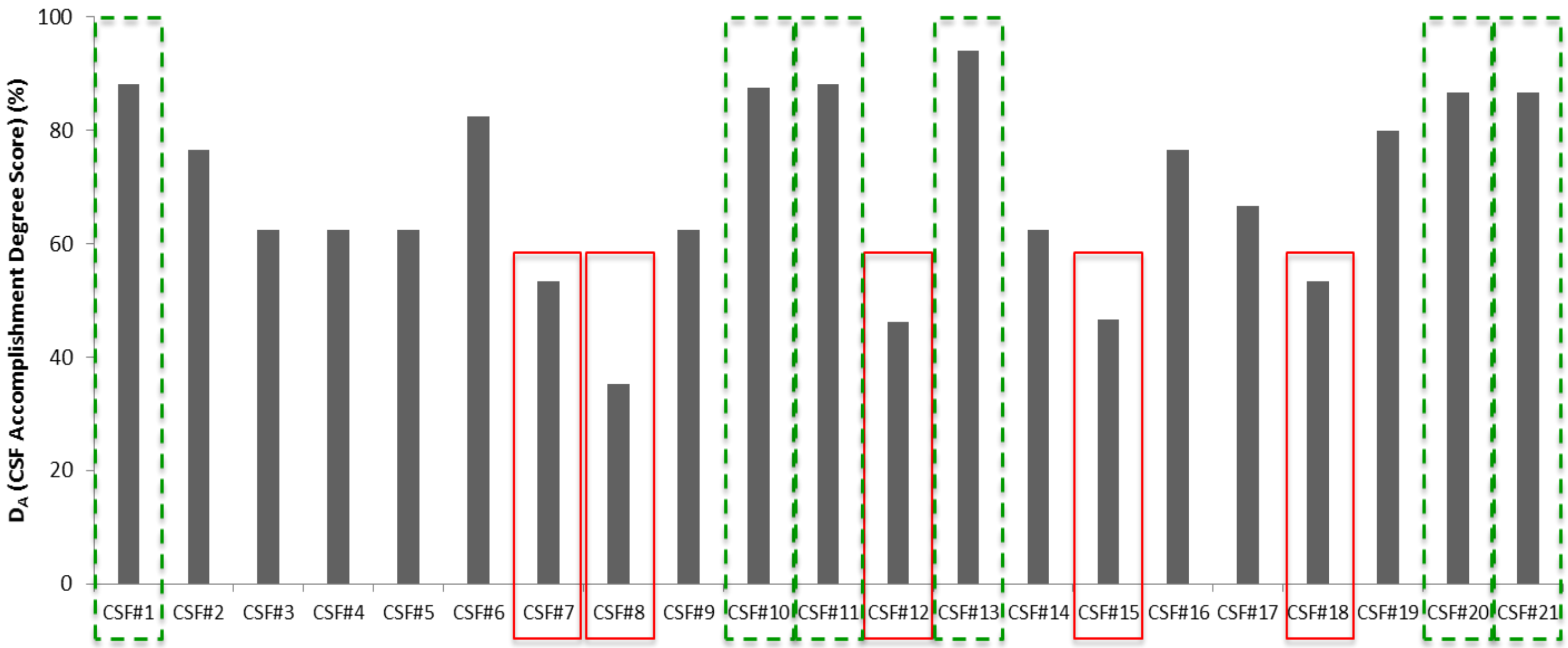
As noted, the researcher wanted to know which CSFs are accomplished most commonly and which remain elusive or are difficult to achieve. The results are presented in Figure 43. The average of the total CSF Accomplishment Degree Score (D_A) is 69.56%. The study identified, in terms of degree of accomplishment, the five lowest and six highest CSFs.

The five LOWEST CSFs in terms of degree of accomplishment degree are:

- CSF8. Cost Saving Recognition (D_A = 35.29%)
- CSF12. Investment in Studies (D_A = 46.15%)
- CSF15. O&M Provisions (D_A = 46.67%)
- CSF18. Data for Optimization (D_A = 53.33%)
- CSF7. Owner-furnished/Long Lead Equipment Specification (D_A = 53.33%)

The six HIGHEST CSFs in terms of accomplishment degree are:

- CSF13. Heavy Lift / Site Transport Capabilities (D_A = 94.12%)
- CSF1. Module Envelope Limitations (D_A = 88.24%)
- CSF11. Module Fabricator Capability (D_A = 88.24%)
- CSF10. Contractor Experience (D_A = 87.24%)
- CSF21. Transport Delay Avoidance (D_A = 86.67%)
- CSF20. Management of Execution Risks (D_A = 86.67%)



N	17	17	16	16	16	17	15	17	16	16	17	13	17	16	15	17	15	15	15	15	15
Missing	8	8	9	9	9	8	10	8	9	9	8	12	8	9	10	8	10	10	10	10	10
% Accomp.	88.24	76.47	62.50	62.50	62.50	82.35	53.33	35.29	62.50	87.50	88.24	46.15	94.12	62.50	46.67	76.47	66.67	53.33	80.00	86.67	86.67

Figure 43. Degree of CSFs Accomplishment by each CSF

4.3 ANALYSIS OF CSF ACCOMPLISHMENT TIMING FOR EACH CSF

Another purpose of this study was to understand the industry MOD CSFs accomplishment status in terms of timing and to identify, in relation to CII RT283's recommended timing, those most delayed. For this analysis, it summed the frequency of projects accomplished either before or on the timing recommended by CII RT283 or one phase later; the study excluded the frequency of projects accomplished two phases later. All the twenty one CSFs accomplishment timing analysis result can be found in Appendix H.

Timeliest CSFs in Terms of Accomplishment Timing

The timeliest CSFs included the following:

- CSF4. Timely Design Freeze (T_A = 100.00%)
- CSF9. Contractor Leadership (T_A = 100.00%)
- CSF10. Contractor Experience (T_A = 100.00%)
- CSF11. Module Fabricator Capability (T_A = 100.00%)
- CSF13. Heavy Lift/Site Transport Capabilities (T_A = 100.00%)
- CSF15. O&M Provisions (T_A = 100.00%)
- CSF19. Continuity through Project Phases (T_A = 100.00%)
- CSF20. Management of Execution Risks (T_A = 100.00%)
- CSF21. Transport Delay Avoidance (T_A = 100.00%)

Figure 44 through Figure 52 illustrate these nine. In the figures, an upward-diagonal-pattern box ( ) represents recommended implementation timing by CII RT283; a dotted-pattern box ( ) represents one phase late, and a horizontal-line-pattern box ( ) represents more than one phase late.

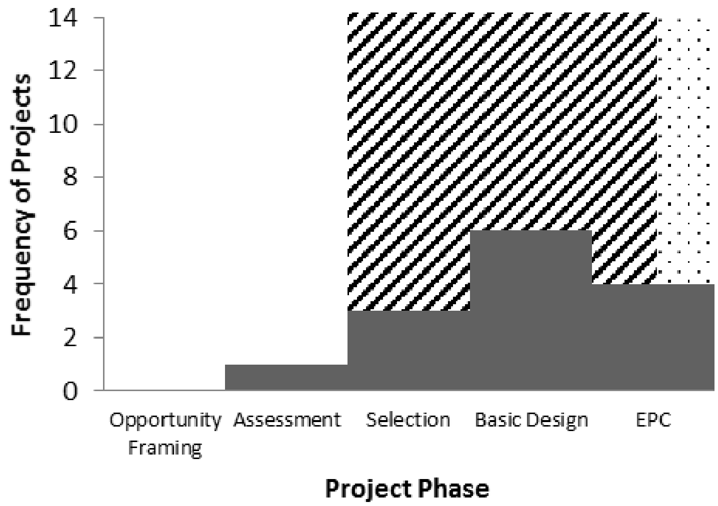


Figure 44. Frequency of Sample Projects Accomplishment Timings on CSF4

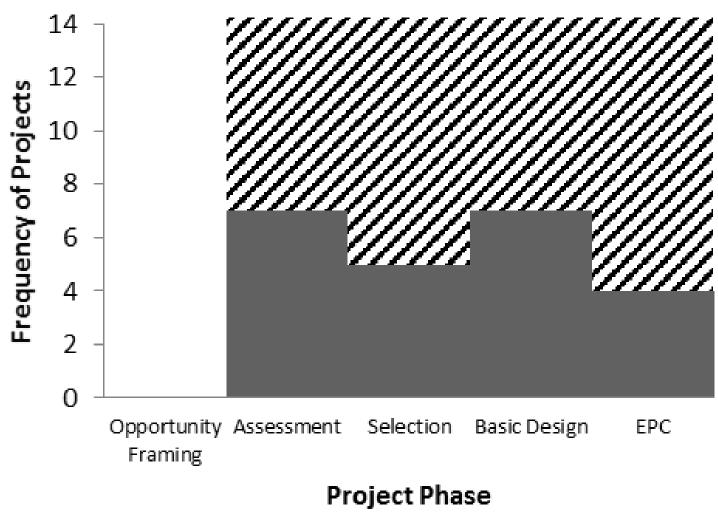
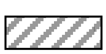
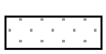


Figure 45. Frequency of Sample Projects Accomplishment Timings on CSF9

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

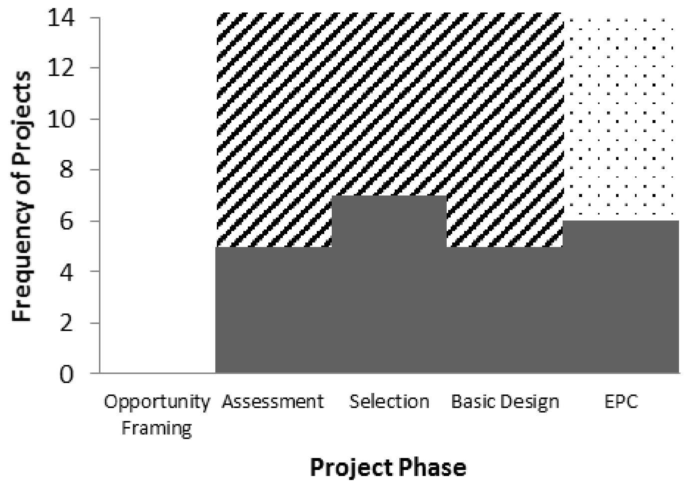


Figure 46. Frequency of Sample Projects Accomplishment Timings on CSF10

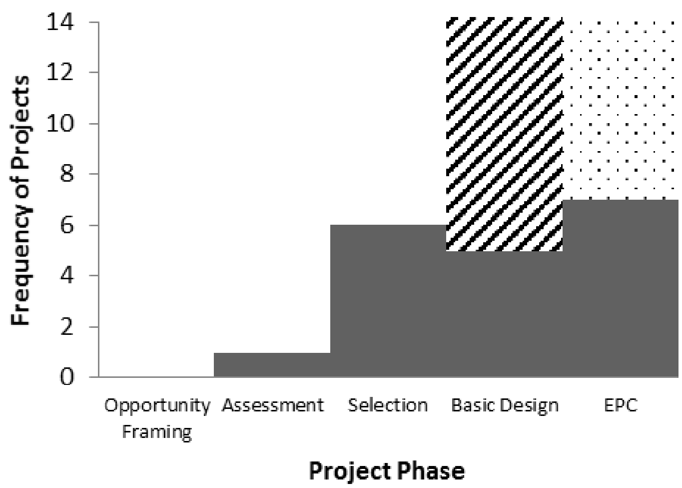


Figure 47. Frequency of Sample Projects Accomplishment Timings on CSF11

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

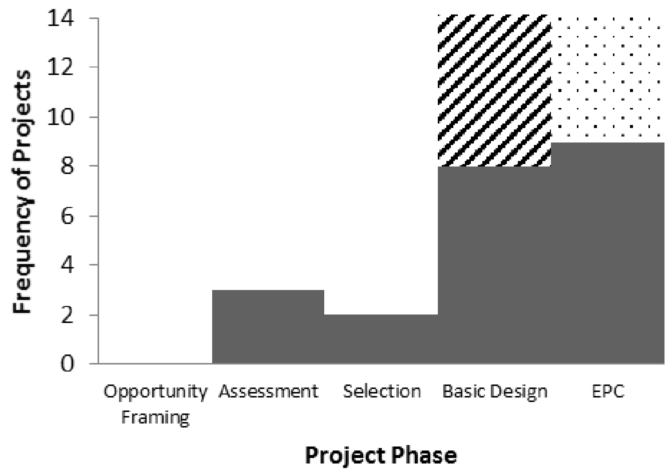


Figure 48. Frequency of Sample Projects Accomplishment Timings on CSF13

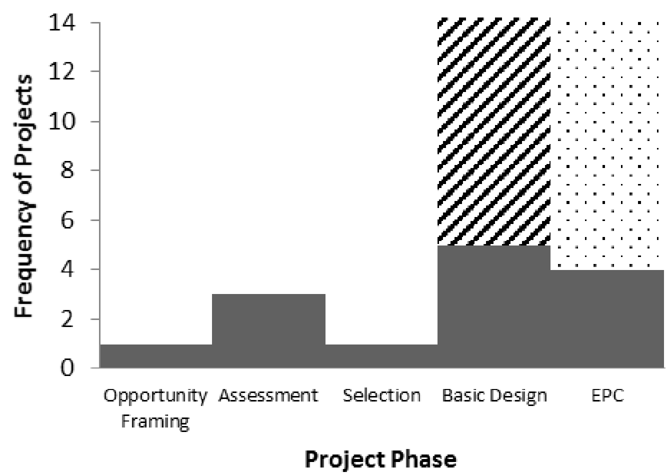


Figure 49. Frequency of Sample Projects Accomplishment Timings on CSF15

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

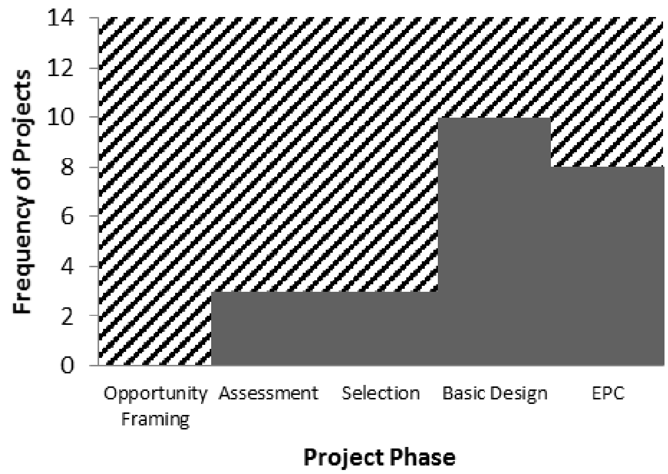


Figure 50. Frequency of Sample Projects Accomplishment Timings on CSF19

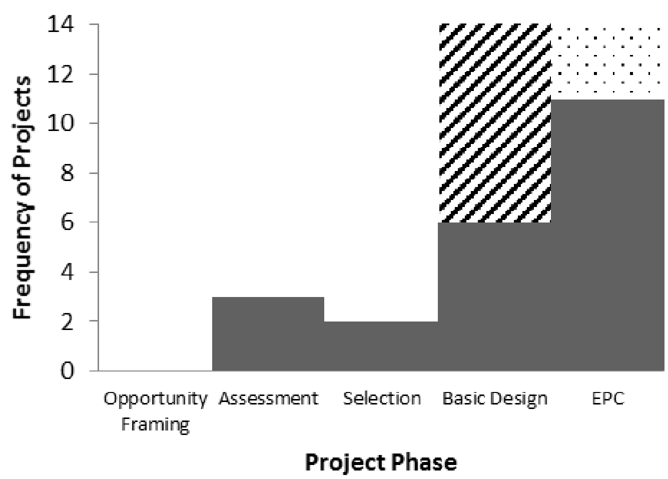


Figure 51. Frequency of Sample Projects Accomplishment Timings on CSF20

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

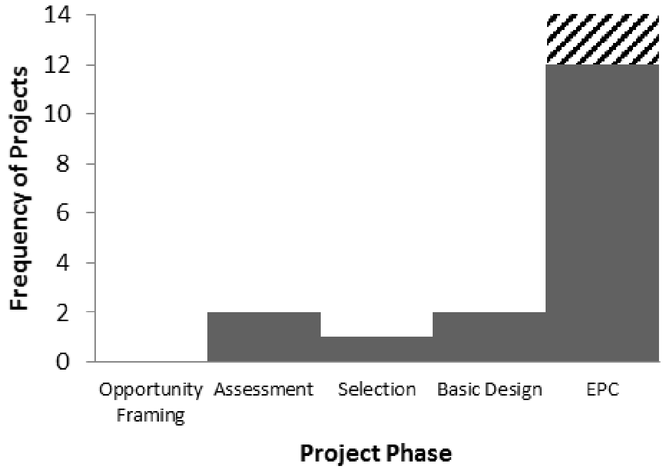


Figure 52. Frequency of Sample Projects Accomplishment Timings on CSF21

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

Most Delayed CSFs in Terms of Accomplishment Timing

The most delayed CSFs in terms of accomplishment timing include the following:

- CSF14. Vendor Involvement (T_A = 33.33%)
- CSF16. Transport Infrastructure (T_A = 55.0%)
- CSF1. Module Envelope Limitations (T_A = 65.38%)
- CSF5. Early Completion Recognition (T_A = 72.22%)
- CSF6. Preliminary Module Definition (T_A = 72.73%)
- CSF8. Cost Saving Recognition (T_A = 73.68%)

Figure 53 through Figure 58 illustrate these six. These six most delayed CSFs warrant further attention. Either the industry should endeavor to accomplish these CSFs earlier or CII may need to reexamine whether their recommended implementation timings are in fact realistic or reasonable.

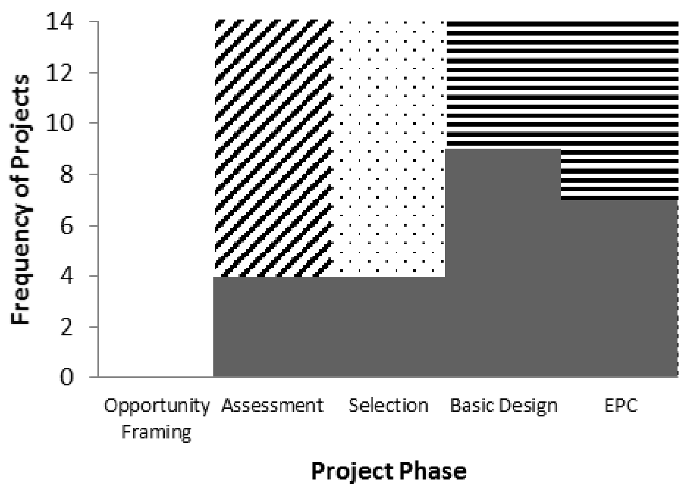


Figure 53. Frequency of Sample Projects Accomplishment Timings on CSF14

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

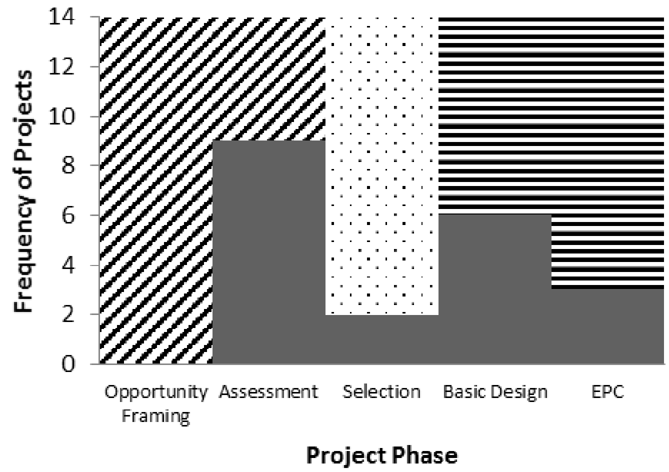


Figure 54. Frequency of Sample Projects Accomplishment Timings on CSF16

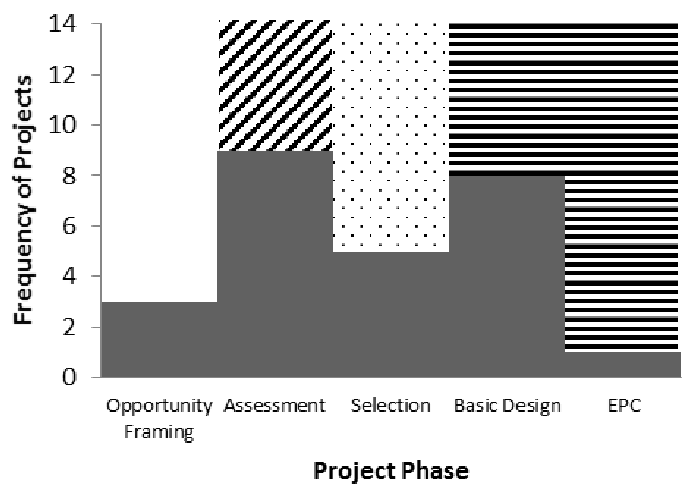


Figure 55. Frequency of Sample Projects Accomplishment Timings on CSF1

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

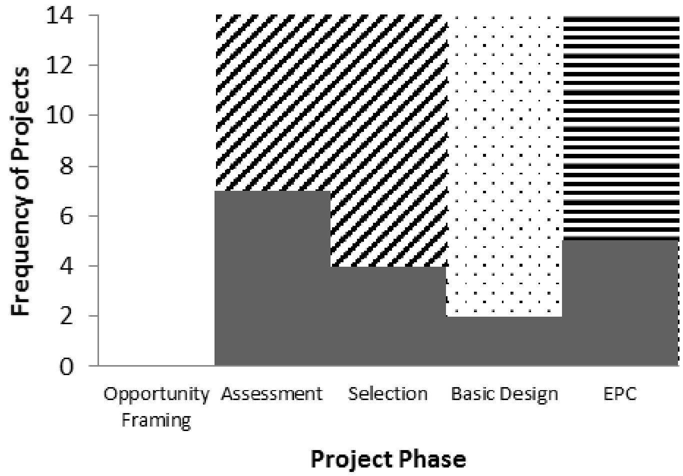


Figure 56. Frequency of Sample Projects Accomplishment Timings on CSF5

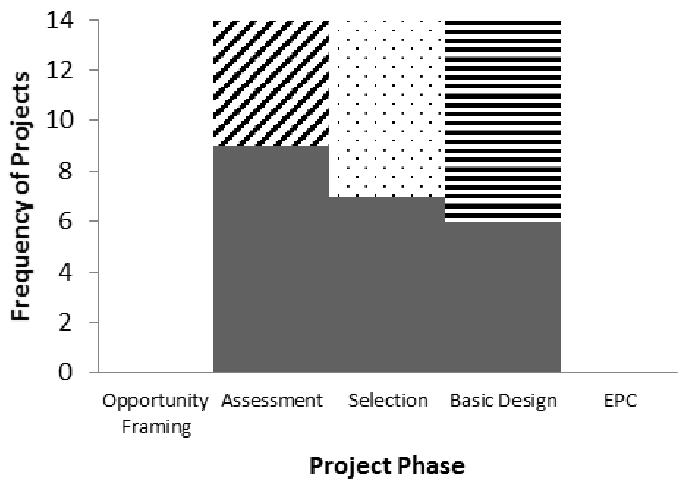


Figure 57. Frequency of Sample Projects Accomplishment Timings on CSF6

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

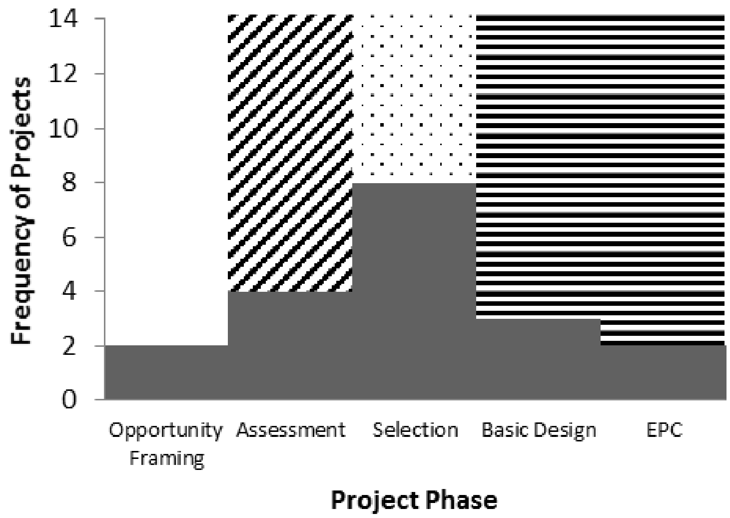


Figure 58. Frequency of Sample Projects Accomplishment Timings on CSF8

Legend

: Recommended implementation timing by CII RT283

: One phase late

: More than one phase late

4.4 CSFs that Contribute The Most to Project Performance Metrics: Significant Differences in CSF Accomplishment Degree (Group by Dependent Variable)

The researcher investigated the CSFs that appear to contribute the most to:

- "Modular Project Success"
- Construction success
- Startup success
- Cost performance
- Schedule performance

As described in Chapter 3: Research Methodology, the project performance metrics were measured according to six levels: N/A = not applicable/don't know, 5 = exceeded expectations, 4 = between 3 and 5, 3 = met expectations, 2 = between 1 and 3, and 1 = significantly off plan. The study was conducted by comparing the difference of each CSF's degree of accomplishment between the respective "Best Group" and "Worst Group." The sample projects which were assessed with performance metric scores of "exceeded expectations" or "between exceeded expectations and met expectations" were assigned to "Best Group" (except for the "Modular Project Success" analysis). The sample projects which were assessed with performance metrics score of "met expectations", "between met expectations and significantly off plan", or "significantly off plan" were assigned to "Worst Group".

CSFs that contribute the most to "Modular Project Success"

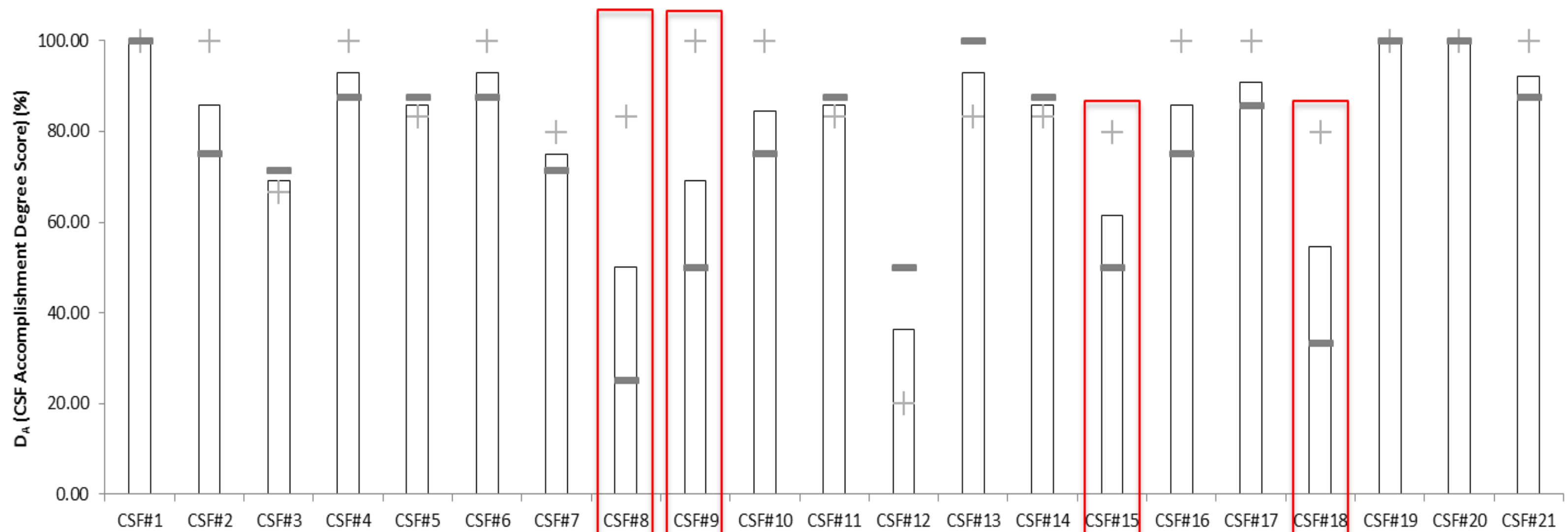
The study investigated CSFs that appear to contribute the most to "Modular Project Success." To do so, as described in Chapter 3: Research Methodology, the function component weights for "Modular Project Success" were assessed by the CII MOD COP. These weights were multiplied by each function performance score to calculate "Modular Project Success". The formula for "Modular Project Success" was:

MODULAR PROJECT SUCCESS = Σ (0.33 * Engineering + 0.15 * Procurement + 0.24 * Fabrication + 0.20 * Construction + 0.08 * Startup)

For this study, there were 14 sample projects with sufficient data for this analysis (including all function score values with no "N/A"). The researcher grouped these sample projects into two groups: more successful projects (N = 6) and less successful projects (N = 8). The more successful group's average "Modular Project Success" score was 3.80 (on a scale of 1-5) while that of the less successful group was 3.01. Each group's CSFs Accomplishment Scores (D_A) was recalculated. Next, the delta (variance) of the CSFs Accomplishment Scores between the more successful and less successful groups was calculated for each CSF. The result of this analysis can be seen in Figure 59. Identified were the four highest delta (Δ) CSFs, which can be interpreted as the CSFs that appear to contribute the most to "Modular Project Success." These are:

- CSF8 Cost Savings Recognition (ΔD_A = Δ58.33%)
- CSF9 Contractor Leadership (ΔD_A = Δ50.00%)
- CSF18 Data for Optimization (ΔD_A = Δ46.67%)
- CSF15 O&M Provisions (ΔD_A = Δ30.00%)

These CSFs may be particularly significant in acting as differentiators of best and worst overall performing "Modular Project Success." The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of "Modular Project Success."



	CSF#1	CSF#2	CSF#3	CSF#4	CSF#5	CSF#6	CSF#7	CSF#8	CSF#9	CSF#10	CSF#11	CSF#12	CSF#13	CSF#14	CSF#15	CSF#16	CSF#17	CSF#18	CSF#19	CSF#20	CSF#21
Total N	14	14	13	14	14	14	12	14	13	13	14	11	14	14	13	14	11	11	12	14	13
Total % Accomp.	100.00	85.71	69.23	92.86	85.71	92.86	75.00	50.00	69.23	84.62	85.71	36.36	92.86	85.71	61.54	85.71	90.91	54.55	100.00	100.00	92.31
Best Group* N	6	6	6	6	6	6	5	6	5	5	6	5	6	6	5	6	4	5	4	6	5
Best Group % Accomp.	100.00	100.00	66.67	100.00	83.33	100.00	80.00	83.33	100.00	100.00	83.33	20.00	83.33	83.33	80.00	100.00	100.00	80.00	100.00	100.00	100.00
Worst Group* N	8	8	7	8	8	8	7	8	8	8	8	6	8	8	8	8	7	6	8	8	8
Worst Group % Accomp.	100.00	75.00	71.43	87.50	87.50	87.50	71.43	25.00	50.00	75.00	87.50	50.00	100.00	87.50	50.00	75.00	85.71	33.33	100.00	100.00	87.50
Delta	0	25	-4.76	12.5	-4.17	12.5	8.57	58.33	50	25	-4.17	-30.00	-16.67	-4.167	30	25	14.29	46.67	0	0	12.5

*Avg. Best Group's MOD Project Success Score = 3.80; Avg. Worst Group's MOD project Success Score = 3.01

+ Best Group's Avg. D_A — Worst Group's Avg. D_A □ Highest Delta CSFs

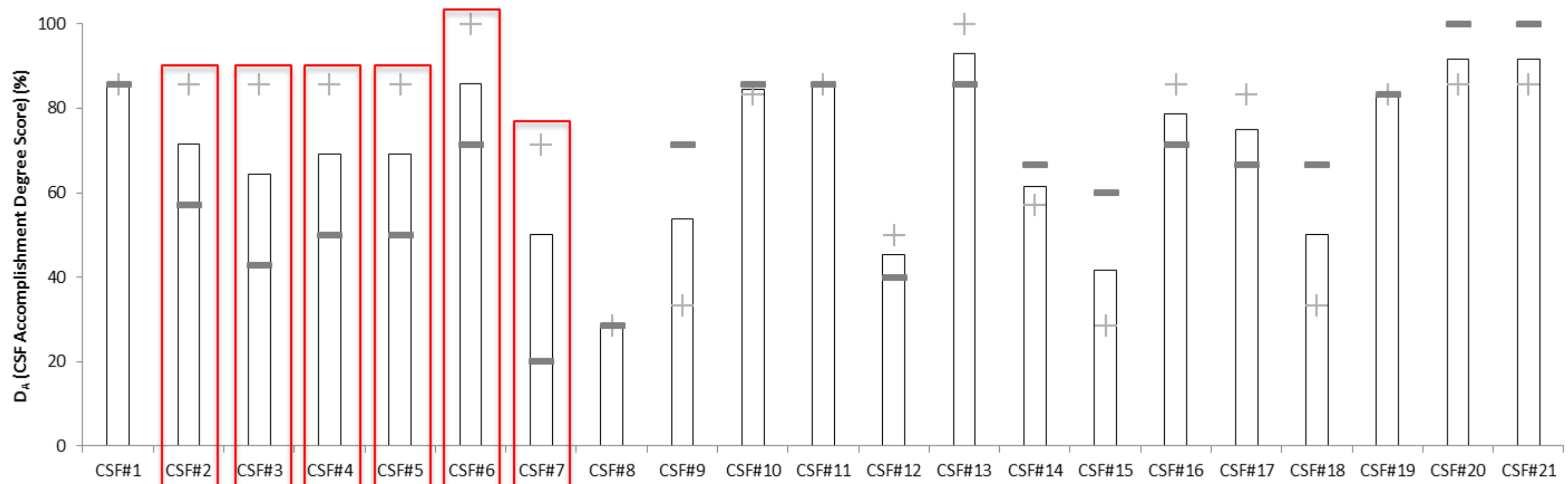
Figure 59. Accomplishment Delta Analysis between "Best" and "Worst" Groups in terms of "Modular Project Success

CSFs that contribute the most to Construction Success

For this study, there were 14 sample projects with sufficient data for this analysis. The researcher grouped these sample projects into two groups: Best Group (N = 7) and Worst Group (N = 7) with regard to Construction performance. As described above, the sample projects which got Construction success metric score "exceeded expectations" or "between exceeded expectations and met expectations" were assigned to "Best Group." The sample projects which got Construction success metrics score between "met expectations" and "significantly off plan" were assigned to "Worst Group". The Best Group's average Construction success score was 4.00 (on a scale of 1-5) while that of the Worst Group was 2.57. Each group's CSFs Accomplishment Scores (D_A) was recalculated. The result of this analysis can be seen in Figure 60. Identified were the six highest delta (Δ) CSFs, which can be interpreted as the CSFs that appear to contribute the most to Construction success. These are:

- CSF7 Owner-Furnished/Long Lead Equipment Specification (ΔD_A = 51.43%)
- CSF3 Owner's Planning Resources & Processes (ΔD_A = Δ42.86%)
- CSF4 Timely Design Freeze (ΔD_A = Δ35.71%)
- CSF5 Early Completion Recognition (ΔD_A = Δ35.71%)
- CSF2 Alignment on Drivers (ΔD_A = Δ28.57%)
- CSF6 Preliminary Module Definition (ΔD_A = Δ28.57%)

These CSFs may be particularly significant in acting as differentiators of best and worst overall performing Construction success. The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of Construction success.



	CSF#1	CSF#2	CSF#3	CSF#4	CSF#5	CSF#6	CSF#7	CSF#8	CSF#9	CSF#10	CSF#11	CSF#12	CSF#13	CSF#14	CSF#15	CSF#16	CSF#17	CSF#18	CSF#19	CSF#20	CSF#21
Total N	14	14	14	13	13	14	12	14	13	13	14	11	14	13	12	14	12	12	12	12	12
Total % Accomp.	85.71	71.43	64.29	69.23	69.23	85.71	50.00	28.57	53.85	84.62	85.71	45.45	92.86	61.54	41.67	78.57	75.00	50.00	83.33	91.67	91.67
Best Group* N	7	7	7	7	7	7	7	7	6	6	7	6	7	7	7	7	6	6	6	7	7
Best Group % Accomp.	85.71	85.71	85.71	85.71	85.71	100.00	71.43	28.57	33.33	83.33	85.71	50.00	100.00	57.14	28.57	85.71	83.33	33.33	83.33	85.71	85.71
Worst Group* N	7	7	7	6	6	7	5	7	7	7	7	5	7	6	5	7	6	6	6	5	5
Worst Group % Accomp.	85.71	57.14	42.86	50.00	50.00	71.43	20.00	28.57	71.43	85.71	85.71	40.00	85.71	66.67	60.00	71.43	66.67	66.67	83.33	100.00	100.00
Delta	0.00	28.57	42.86	35.71	35.71	28.57	51.43	0.00	-38.10	-2.38	0.00	10.00	14.29	-9.52	-31.43	14.29	16.67	-33.33	0.00	-14.29	-14.29

*Avg. Best Group's Construction Success Score = 4.00; Avg. Worst Group's Construction Success Score = 2.57

+ Best Group's Avg. D_A — Worst Group's Avg. D_A Highest Delta CSFs

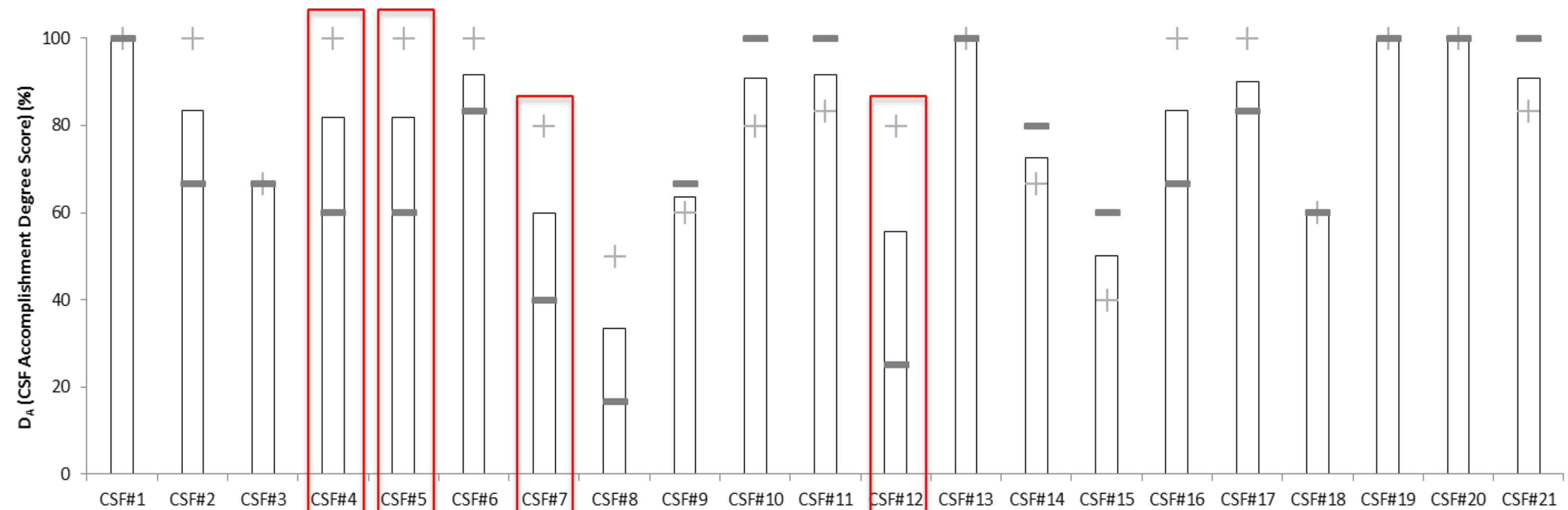
Figure 60. Accomplishment Delta Analysis between "Best" and "Worst" Groups in terms of Construction Success

CSFs that contribute the most to Startup Success

For this study, there were 12 sample projects with sufficient data for this analysis. The researcher grouped these sample projects into two groups: Best Group (N = 6) and Worst Group (N = 6) with regard to Startup Success. The sample projects which got Startup success metric score "exceeded expectations" or "between exceeded expectations and met expectations" were assigned to "Best Group." The sample projects which got Startup success metrics score between "met expectations" and "significantly off plan" were assigned to "Worst Group". The Best Group's average Startup success score was 4.33 (on a scale of 1-5) while that of the Worst Group was 2.67. Each group's CSFs Accomplishment Scores (D_A) was recalculated. The result of this analysis can be seen in Figure 61. Identified were the four highest delta (Δ) CSFs, which can be interpreted as the CSFs that appear to contribute the most to Startup success. These are:

- CSF12 Investment in Studies ($\Delta D_A = \Delta 55.00\%$)
- CSF4 Timely Design Freeze ($\Delta D_A = \Delta 40.00\%$)
- CSF5 Early Completion Recognition ($\Delta D_A = \Delta 40.00\%$)
- CSF7 Owner-Furnished/Long Lead Equipment Specification ($\Delta D_A = 40.00\%$)

These CSFs may be particularly significant in acting as differentiators of best and worst overall performing Startup Success. The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of Startup success.



	CSF#1	CSF#2	CSF#3	CSF#4	CSF#5	CSF#6	CSF#7	CSF#8	CSF#9	CSF#10	CSF#11	CSF#12	CSF#13	CSF#14	CSF#15	CSF#16	CSF#17	CSF#18	CSF#19	CSF#20	CSF#21
Total N	12	12	12	11	11	12	10	12	11	11	12	9	12	11	10	12	10	10	10	11	11
Total % Accomp.	100.00	83.33	66.67	81.82	81.82	91.67	60.00	33.33	63.64	90.91	91.67	55.56	100.00	72.73	50.00	83.33	90.00	60.00	100.00	100.00	90.91
Best Group* N	6	6	6	6	6	6	5	6	5	5	6	5	6	6	5	6	4	5	5	6	6
Best Group % Accomp.	100.00	100.00	66.67	100.00	100.00	100.00	80.00	50.00	60.00	80.00	83.33	80.00	100.00	66.67	40.00	100.00	100.00	60.00	100.00	100.00	83.33
Worst Group* N	6	6	6	5	5	6	5	6	6	6	6	4	6	5	5	6	6	5	5	5	5
Worst Group % Accomp.	100.00	66.67	66.67	60.00	60.00	83.33	40.00	16.67	66.67	100.00	100.00	25.00	100.00	80.00	60.00	66.67	83.33	60.00	100.00	100.00	100.00
Delta	0.00	33.33	0.00	40.00	40.00	16.67	40.00	33.33	-6.67	-20.00	-16.67	55.00	0.00	-13.33	-20.00	33.33	16.67	0.00	0.00	0.00	-16.67

*Avg. Best Group's Startup Success Score = 4.33; Avg. Worst Group's Startup Success Score = 2.67

+ Best Group's Avg. D_A — Worst Group's Avg. D_A ☐ Highest Delta CSFs

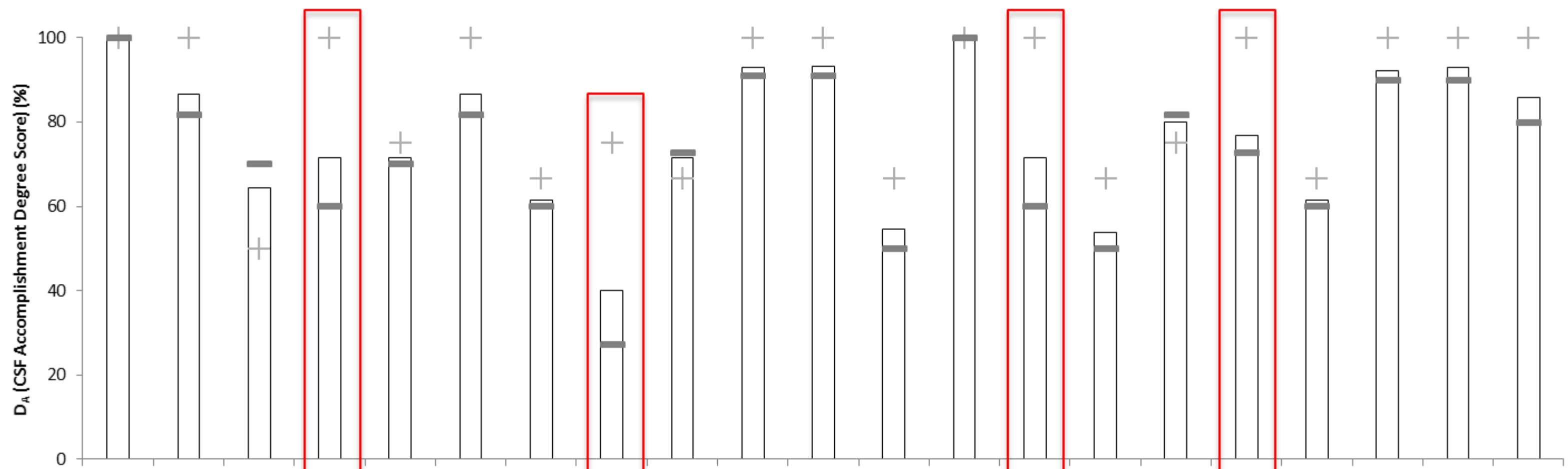
Figure 61. Accomplishment Delta Analysis between "Best" and "Worst" Groups in terms of Startup Success

CSFs that contribute the most to Cost Performance

For this study, there were 15 sample projects with sufficient data for this analysis (including all function score values with no "N/A"). The researcher grouped these sample projects into two groups: Best Group (N = 4) and Worst Group (N = 11) with regard to Cost performance. The sample projects which got cost performance metric score "exceeded expectations" or "between exceeded expectations and met expectations" were assigned to "Best Group." The sample projects which got cost performance metrics score between "met expectations" and "significantly off plan" were assigned to "Worst Group". The Best Group's average cost performance score was 4.50 (on a scale of 1-5) while that of the Worst Group was 2.64. Each group's CSFs Accomplishment Scores (D_A) was recalculated. The result of this analysis can be seen in Figure 62. Identified were the four highest delta (Δ) CSFs, which can be interpreted as the CSFs that appear to contribute the most to cost performance. These are:

- CSF8 Cost Saving Recognition ($\Delta D_A = \Delta 47.73\%$)
- CSF4 Timely Design Freeze ($\Delta D_A = \Delta 40.00\%$)
- CSF14 Vendor Involvement ($\Delta D_A = \Delta 40.00\%$)
- CSF17 Owner Delay Avoidance ($\Delta D_A = \Delta 27.27\%$)

These CSFs may be particularly significant in acting as differentiators of best and worst overall performing Cost performance. The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of Cost performance.



	CSF#1	CSF#2	CSF#3	CSF#4	CSF#5	CSF#6	CSF#7	CSF#8	CSF#9	CSF#10	CSF#11	CSF#12	CSF#13	CSF#14	CSF#15	CSF#16	CSF#17	CSF#18	CSF#19	CSF#20	CSF#21
Total N	15	15	14	14	14	15	13	15	14	14	15	11	15	14	13	15	13	13	13	14	14
Total % Accomp.	100.00	86.67	64.29	71.43	71.43	86.67	61.54	40.00	71.43	92.86	93.33	54.55	100.00	71.43	53.85	80.00	76.92	61.54	92.31	92.86	85.71
Best Group* N	4	4	4	4	4	4	3	4	3	3	4	3	4	4	3	4	2	3	3	4	4
Best Group % Accomp.	100.00	100.00	50.00	100.00	75.00	100.00	66.67	75.00	66.67	100.00	100.00	66.67	100.00	100.00	66.67	75.00	100.00	66.67	100.00	100.00	100.00
Worst Group* N	11	11	10	10	10	11	10	11	11	11	11	8	11	10	10	11	11	10	10	10	10
Worst Group % Accomp.	100.00	81.82	70.00	60.00	70.00	81.82	60.00	27.27	72.73	90.91	90.91	50.00	100.00	60.00	50.00	81.82	72.73	60.00	90.00	90.00	80.00
Delta	0.00	18.18	-20.00	40.00	5.00	18.18	6.67	47.73	-6.06	9.09	9.09	16.67	0.00	40.00	16.67	-6.82	27.27	6.67	10.00	10.00	20.00

*Avg. Best Group's Cost Performance Score = 4.50; Avg. Worst Group's Cost Performance Score = 2.64

+ Best Group's Avg. D_A — Worst Group's Avg. D_A Highest Delta CSFs

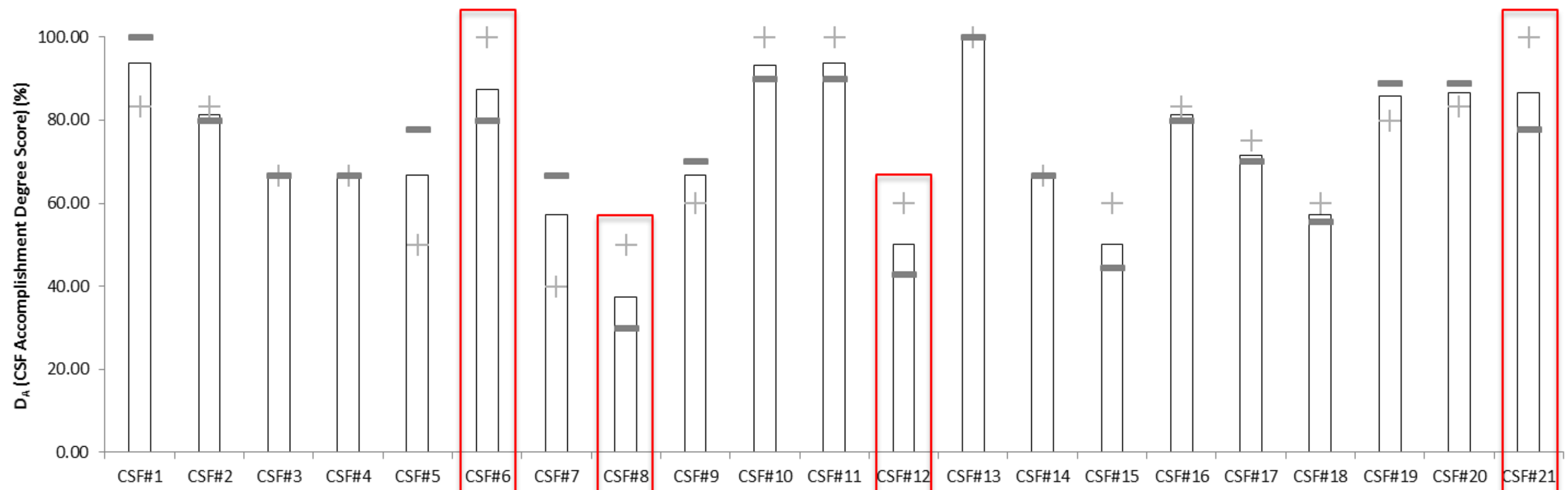
Figure 62. Accomplishment Delta Analysis between "Best" and "Worst" Groups in terms of Cost Performance

CSFs that contribute the most to Schedule Performance

For this study, there were 16 sample projects with sufficient data for this analysis (including all function score values with no "N/A"). The researcher grouped these sample projects into two groups: Best Group (N = 6) and Worst Group (N = 10) with regard to Schedule performance. As described above, the sample projects which got Schedule performance metric score "exceeded expectations" or "between exceeded expectations and met expectations" were assigned to "Best Group." The sample projects which got Schedule performance metrics score between "met expectations" and "significantly off plan" were assigned to "Worst Group". The Best Group's average Construction Success score was 4.33 (on a scale of 1-5) while that of the Worst Group was 2.80. Each group's CSFs Accomplishment Scores (D_A) was recalculated. The result of this analysis can be seen in Figure 63. Identified were the four highest delta (Δ) CSFs, which can be interpreted as the CSFs that appear to contribute the most to Schedule performance. These are:

- CSF21 Transport Delay Avoidance ($\Delta D_A = \Delta 22.22\%$)
- CSF6 Preliminary Module Definition ($\Delta D_A = \Delta 20.00\%$)
- CSF8 Cost Saving Recognition ($\Delta D_A = \Delta 20.00\%$)
- CSF12 Investment in Studies ($\Delta D_A = \Delta 17.14\%$)

These CSFs may be particularly significant in acting as differentiators of best and worst overall performing Schedule performance. The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of Schedule performance.



	CSF#1	CSF#2	CSF#3	CSF#4	CSF#5	CSF#6	CSF#7	CSF#8	CSF#9	CSF#10	CSF#11	CSF#12	CSF#13	CSF#14	CSF#15	CSF#16	CSF#17	CSF#18	CSF#19	CSF#20	CSF#21
Total N	16	16	15	15	15	16	14	16	15	15	16	12	16	15	14	16	14	14	14	15	15
Total % Accomp.	93.75	81.25	66.67	66.67	66.67	87.50	57.14	37.50	66.67	93.33	93.75	50.00	100.00	66.67	50.00	81.25	71.43	57.14	85.71	86.67	86.67
Best Group* N	6	6	6	6	6	6	5	6	5	5	6	5	6	6	5	6	4	5	5	6	6
Best Group % Accomp.	83.33	83.33	66.67	66.67	50.00	100.00	40.00	50.00	60.00	100.00	100.00	60.00	100.00	66.67	60.00	83.33	75.00	60.00	80.00	83.33	100.00
Worst Group* N	10	10	9	9	9	10	9	10	10	10	10	7	10	9	9	10	10	9	9	9	9
Worst Group % Accomp.	100.00	80.00	66.67	66.67	77.78	80.00	66.67	30.00	70.00	90.00	90.00	42.86	100.00	66.67	44.44	80.00	70.00	55.56	88.89	88.89	77.78
Delta	-16.67	3.33	0.00	0.00	-27.78	20.00	-26.67	20.00	-10.00	10.00	10.00	17.14	0.00	0.00	15.56	3.33	5.00	4.44	-8.89	-5.56	22.22

*Avg. Best Group's Schedule Performance Score = 4.33; Avg. Worst Group's Schedule Performance Score = 2.80

+ Best Group's Avg. D_A — Worst Group's Avg. D_A ▭ Highest Delta CSFs

Figure 63. Accomplishment Delta Analysis between "Best" and "Worst" Groups in terms of Schedule Performance

4.5 COMPARISON OF CSF ACCOMPLISHMENT LEARNINGS

To shed light on the industry's status on CSFs accomplishment timing at a high level, the study compared a ratio of CII RT283's recommended CSF implementation timing and a ratio to that of the actual sample projects' CSFs accomplishment timing. Figure 64, adopted from CII IR283 (CII 2013), illustrates CSF distribution by timing of implementation. Figure 65 illustrates the CSF distribution of an actual sample project's CSFs by timing of accomplishment. To develop this figure, the study examined the distribution of sample projects CSFs accomplishment by project phase; the result can be found in Appendix I. As Figure 64 illustrates, CII RT283 recommended that nearly 43% of CSFs be implemented between Opportunity Framing and Assessment. As Figure 65 shows, however, only 30% were accomplished in actual sample projects. Based on this result, the researcher was able to conclude that the industry, in practice, needs to accomplish more CSFs in earlier phases. Likewise, RT283's recommendation on CSF timing may deserve some re-consideration.

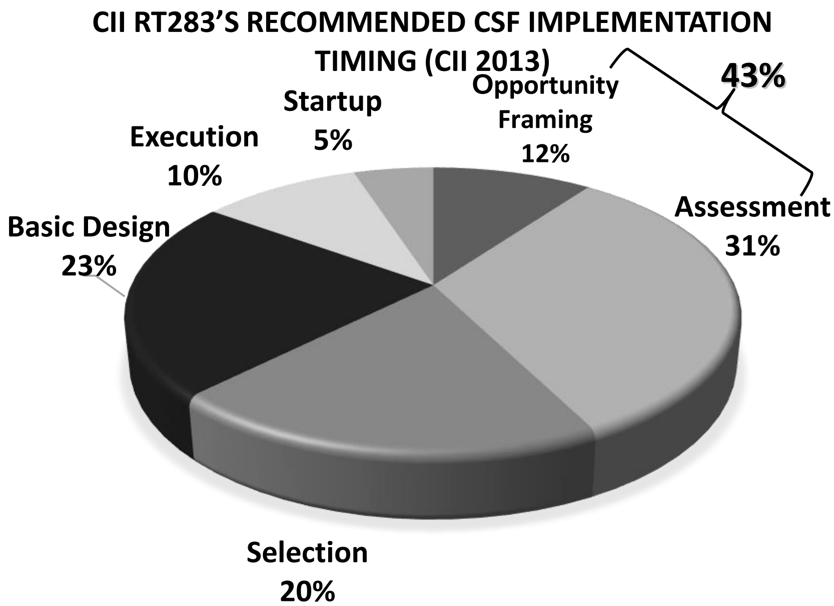


Figure 64. CII RT283's Recommended CSF Implementation Timing (CII 2013)

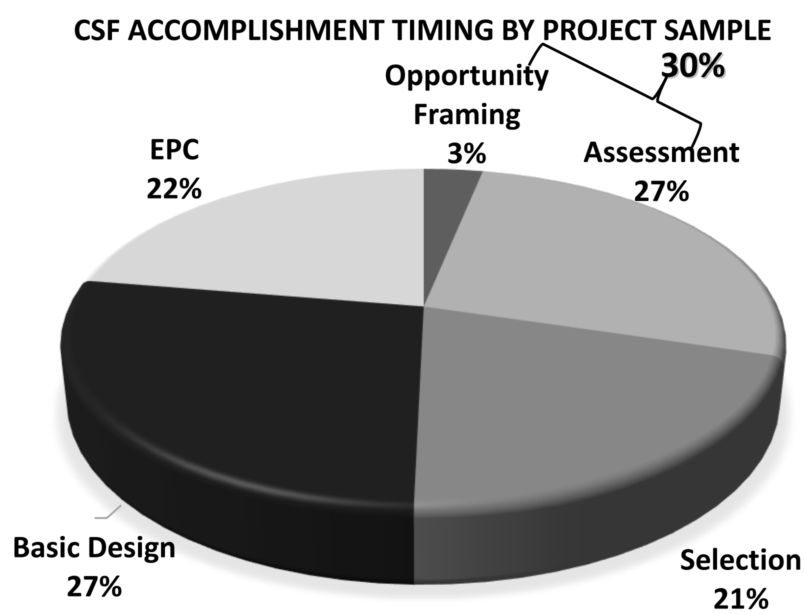


Figure 65. CSF Accomplishment Timing by Project Sample

4.6 COMPARISON OF CSF ACCOMPLISHMENT FREQUENCY BETWEEN SAMPLE PROJECTS AND CII RT 283

CII RT283 also examined how often CSFs actually occur or are accomplished on projects (CII 2013). CII RT283 surveyed about 20 industry experts to quantify the current frequency of occurrence of each CSF. Due to this methodology, their findings relied on the experience of experts. This was necessary to validate their survey results by comparing actual accomplishment in sample projects since these may better represent the current industry status. To compare these two on the same scale, normalization was conducted for CII RT283's survey results. Figure 66 illustrates a comparison analysis of CSF accomplishment frequency between actual sample projects accomplishment (actual project based) and CII RT283's industry experts' survey result (experience based estimation).

Relatively small variances in most of the CSFs were identified between the actual sample projects' accomplishment and CII RT283's industry experts' survey result, as Figure 66 illustrates. This result indicates that CII RT283's industry experts made a good estimation of the current frequency of occurrence of each CSF.

The study did identify, however, three significant overestimated CSFs and three underestimated CSFs. The overestimated CSFs refer to those having a high RT283's survey result but low actual accomplishment in sample projects. The underestimated CSFs refer to the converse of such a situation. This analysis was conducted through normalization to compare two results. Hence, it highlighted only three significant overestimated CSFs and three underestimated CSFs. This process was conducted by computing the variance (delta) amount between average variance (0.11) and that of each CSF.

The three most overestimated CSFs are:

- CSF7 Owner- Furnished/Long Lead Equipment Specification
- CSF8 Cost Savings Recognition
- CSF15 O&M Provisions

The three most underestimated CSFs are:

- CSF10 Contractor Experience
- CSF20 Management Of Execution Risks
- CSF21 Transport Delay Avoidance

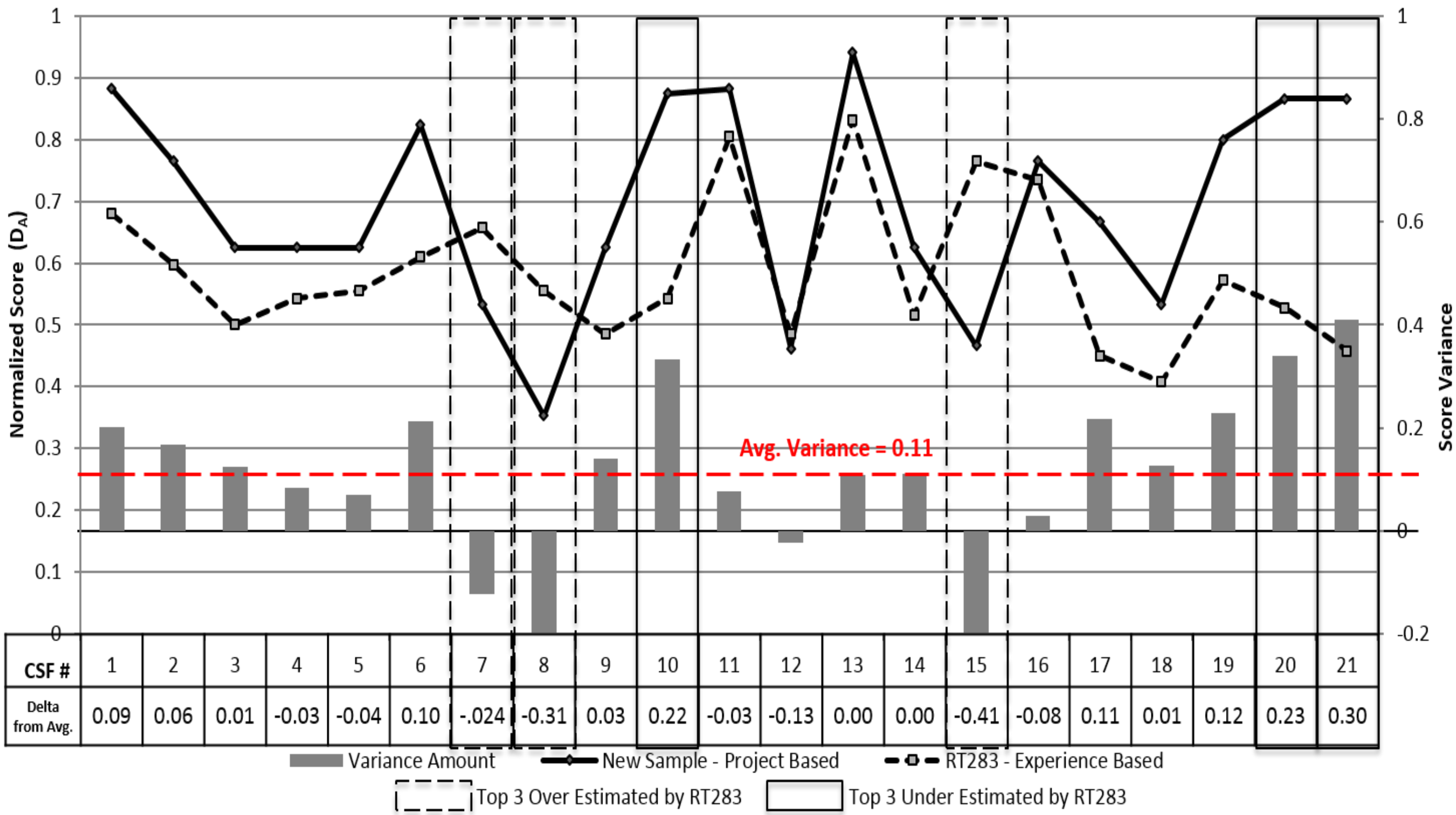


Figure 66. Comparison of CSFs Accomplishment Frequency between Sample Projects and CII RT 283

4.7 Summary of CSFs Accomplishment Findings

This chapter has aimed to clarify the modularization CSFs and to shed light on the status of modularization CSFs' accomplishment in terms of degree and timing. This section has also tried to validate CII RT283's frequency survey result.

To achieve such an aim, the following items were measured:

- Degree of accomplishment for each CSF, across the entire sample
- Timing of CSF accomplishment for each CSF
- Analysis of CSF accomplishment by project phase
- Analysis of CSF accomplishment by project

From the above measurements, the following items were analyzed:

- Lowest CSFs in terms of degree of accomplishment among sample projects
- Highest CSFs in terms of degree of accomplishment among sample projects
- Timeliest CSFs in terms of accomplishment timing among sample projects
- Most delayed CSFs in terms of accomplishment timing
- CSFs that contribute the most to "Modular Project Success"
- CSFs that contribute the most to Construction success
- CSFs that contribute the most to Startup success
- CSFs that contribute the most to Cost performance
- CSFs that contribute the most to Schedule performance
- Comparison of CSF accomplishment timing
- Comparison of CSFs accomplishment frequency between sample projects (Project Based) and CII RT 283 (Experience Based)

CSFs with lowest degree of accomplishment degree are:

- CSF8. Cost Saving Recognition (D_A = 35.29%)
- CSF12. Investment in Studies (D_A = 46.15%)
- CSF15. O&M Provisions (D_A = 46.67%)
- CSF18. Data for Optimization (D_A = 53.33%)
- CSF7. Owner-furnished/Long Lead Equipment Specification (D_A = 53.33%)

The industry may wish to strive to accomplish more of these five CSFs.

CSFs with highest accomplishment degree are:

- CSF13. Heavy Lift / Site Transport Capabilities (D_A = 94.12%)
- CSF1. Module Envelope Limitations (D_A = 88.24%)
- CSF11. Module Fabricator Capability (D_A = 88.24%)
- CSF10. Contractor Experience (D_A = 87.24%)
- CSF21. Transport Delay Avoidance (D_A = 86.67%)
- CSF20. Management of Execution Risks (D_A = 86.67%)

Timeliest CSFs are:

- CSF4. Timely Design Freeze (T_A = 100.00%)
- CSF9. Contractor Leadership (T_A = 100.00%)
- CSF10. Contractor Experience (T_A = 100.00%)
- CSF11. Module Fabricator Capability (T_A = 100.00%)
- CSF13. Heavy Lift/Site Transport Capabilities (T_A = 100.00%)
- CSF15. O&M Provisions (T_A = 100.00%)
- CSF19. Continuity through Project Phases (T_A = 100.00%)

- CSF20. Management of Execution Risks (T_A = 100.00%)
- CSF21. Transport Delay Avoidance (T_A = 100.00%)

Most delayed CSFs in terms of accomplishment timing are:

- CSF14. Vendor Involvement (T_A = 33.33%)
- CSF16. Transport Infrastructure (T_A = 55.0%)
- CSF1. Module Envelope Limitations (T_A = 65.38%)
- CSF5. Early Completion Recognition (T_A = 72.22%)
- CSF6. Preliminary Module Definition (T_A = 72.73%)
- CSF8. Cost Saving Recognition (T_A = 73.68%)

The researcher investigated the CSFs that appear to contribute most to:

- "Modular Project Success"
- Construction success
- Startup success
- Cost performance
- Schedule performance

The study was conducted by comparing each CSF's degree of accomplishment between "Best Group" and "Worst Group."

The CSFs that appear to contribute the most to "Modular Project Success" are:

- CSF8 Cost Savings Recognition (ΔD_A = 58.33%)
- CSF9 Contractor Leadership (ΔD_A = Δ50.00%)
- CSF18 Data for Optimization (ΔD_A = Δ46.67%)
- CSF15 O&M Provisions (ΔD_A = Δ30.00%)

The CSFs that appear to contribute the most to Construction success are:

- CSF7 Owner-Furnished/Long Lead Equipment Specification (ΔD_A = 51.43%)
- CSF3 Owner's Planning Resources & Processes (ΔD_A = Δ42.86%)
- CSF4 Timely Design Freeze (ΔD_A = Δ35.71%)
- CSF5 Early Completion Recognition (ΔD_A = Δ35.71%)
- CSF2 Alignment on Drivers (ΔD_A = Δ28.57%)
- CSF6 Preliminary Module Definition (ΔD_A = Δ28.57%)

The CSFs that appear to contribute the most to Startup success are:

- CSF12 Investment in Studies (ΔD_A = Δ55.00%)
- CSF4 Timely Design Freeze (ΔD_A = Δ40.00%)
- CSF5 Early Completion Recognition (ΔD_A = Δ40.00%)
- CSF7 Owner-Furnished/Long Lead Equipment Specification (ΔD_A = 40.00%)

The CSFs that appear to contribute the most to Cost performance are:

- CSF8 Cost Saving Recognition (ΔD_A = Δ47.73%)
- CSF4 Timely Design Freeze (ΔD_A = Δ40.00%)
- CSF14 Vendor Involvement (ΔD_A = Δ40.00%)
- CSF17 Owner Delay Avoidance (ΔD_A = Δ27.27%)

The four CSFs that appear to contribute the most to Schedule performance are:

- CSF21 Transport Delay Avoidance (ΔD_A = Δ22.22%)
- CSF6 Preliminary Module Definition (ΔD_A = Δ20.00%)
- CSF8 Cost Saving Recognition (ΔD_A = Δ20.00%)
- CSF12 Investment in Studies (ΔD_A = Δ17.14%)

Table 11 summarizes the analysis results of CSF accomplishment. In this analysis, the researcher could identify significant difference (since most of projects accomplished high D_A), among the 21 CSFs, in the following: CSF1, CSF10, CSF11, CSF13, CSF20, and CSF21. Appearing to contribute to more than two project performance metrics are the following CSFs:

- CSF4. Timely design freeze
- CSF5 Early Completion Recognition
- CSF6 Preliminary Module Definition
- CSF7 Owner-Furnished/Long Lead Equipment Specification
- CSF8. Cost Saving recognition
- CSF12 Investment in Studies

The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of project performance.

CII RT283 recommended that nearly 43% of CSFs be implemented between Opportunity Framing and Assessment. The study found, however, that in actual sample projects only 30% of CSFs were accomplished. Based on this result, the researcher was able to conclude that the industry, in practice, needs to accomplish more CSFs in earlier phases. Likewise, RT283's recommendation on CSF Timing may deserve some re-consideration.

These findings should help many stakeholders better understand what's needed for the industry to achieve higher levels of MOD and better project performance.

Table 11 Summary: Accomplishment Delta Analysis between "Best" and "Worst" Groups

#	CSF	High D_A	Significant Association? Project Objective: Cost	Significant Association? Project Objective: Schedule	Significant Association? Project Function: Construction	Significant Association? Project Function: Startup
CSF1	Module envelope limitations	√				
CSF2	Alignment on drivers				√	
CSF3	Owner's planning resources & processes				√	
CSF4	Timely design freeze		√		√	√
CSF5	Early completion recognition				√	√
CSF6	Preliminary module definition			√	√	
CSF7	Owner-furnished/long lead equipment spec.				√	√
CSF8	Cost savings recognition		√	√		
CSF9	Contractor leadership					
CSF10	Contractor experience	√				
CSF11	Module fabricator capability	√				
CSF12	Investment in studies			√		√
CSF13	Heavy lift/site transport capabilities	√				
CSF14	Vendor involvement		√			
CSF15	O&M provisions					
CSF16	Transport infrastructure					
CSF17	Owner delay avoidance		√			
CSF18	Data for optimization					
CSF19	Continuity through project phases					
CSF20	Management of execution risks	√				
CSF21	Transport delay avoidance	√		√		

Chapter 5: Analysis of Correlations

5.1 Introduction

The main purpose of this study was to investigate the correlations between MOD CSF accomplishment and project performance. The main research questions are:

1. Are there differences in MOD CSF accomplishment by MOD business case initiation timing?
2. Are there differences in project performance by MOD business case initiation timing?
3. Is there an association between MOD CSF accomplishment and performance?
4. Is there an association between MOD extent and MOD CSF accomplishment?
5. Are there project performance differences by the accomplishment of individual CSFs?

5.2 MOD Business Case Initiation Timing and CSF Accomplishment

In this study, the researcher tried to answer the following research question.

1. Are there differences in MOD CSF accomplishment by MOD business case initiation timing?

To answer this, the following null hypotheses were set.

a. In degree of MOD CSF accomplishment, no difference exists among MOD business case initiation timings.
b. In the timing of MOD CSF accomplishment, no difference exists among MOD business case initiation timing.

The research (alternative) hypotheses are described below:

a. In degree of MOD CSF accomplishment, differences do exist among MOD business case initiation timing.

b. In the timing of MOD CSF accomplishment, differences do exist among MOD business case initiation timing.

There was three timings of MOD business case initiation (independent variable): 1) Opportunity Framing, 2) Assessment, and 3) After Assessment. Independent samples t tests were used by two independent variables (Opportunity Framing and Assessment; Assessment and After Assessment; and Opportunity Framing and After Assessment). Thus, a total of six t tests were conducted for this study. The examined t tests are:

1) a difference between Opportunity Framing and Assessment in degree of MOD CSF accomplishment,

2) a difference between Opportunity Framing and After Assessment in timing of MOD CSF accomplishment,

3) a difference between Assessment and After Assessment in timing of MOD CSF accomplishment,

4) a difference between Opportunity Framing and Assessment in timing of MOD CSF accomplishment,

5) a difference between Opportunity Framing and After Assessment in timing of MOD CSF accomplishment,

6) a difference between Assessment and After Assessment in timing of MOD CSF accomplishment.

The researcher failed to reject the null hypotheses (relevant stats). This was mainly due to small sample size of each group. From a descriptive analysis, however, two tendencies were identified: 1) projects which initiated MOD business cases early accomplished more CSFs at a higher degree; and 2) projects which initiated MOD business cases early accomplished more CSFs on time. The CSFs accomplishment degree score and timing score by business case initiation timing are shown in Figure 67 and Figure 68.

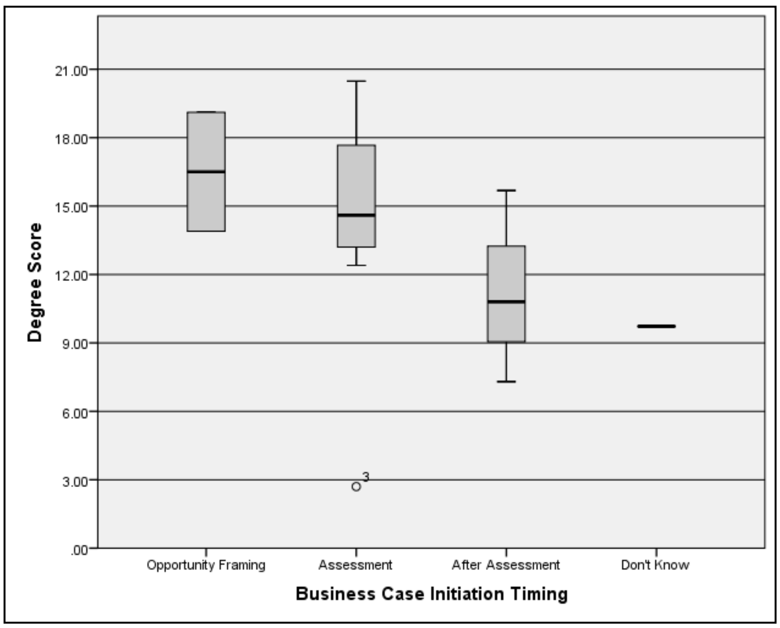


Figure 67. CSFs Accomplishment Degree Score by Business Case Initiation Timing

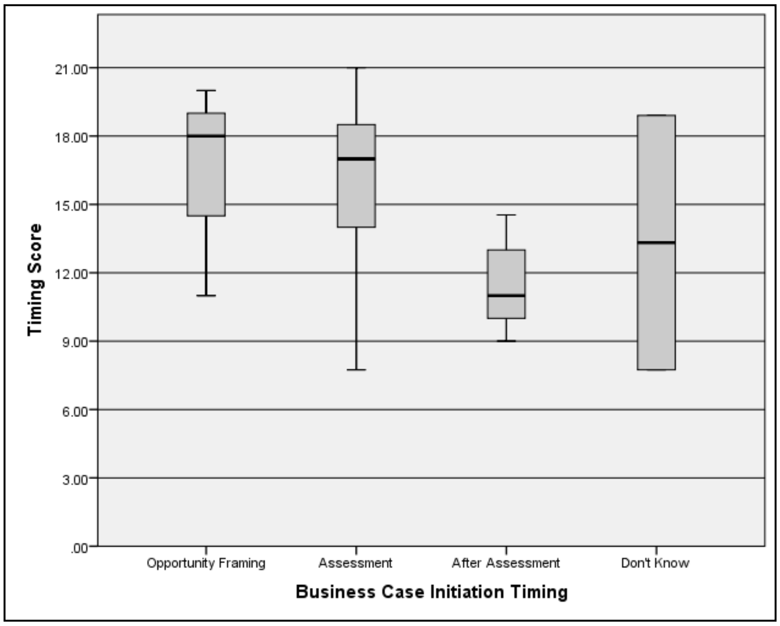


Figure 68. CSFs Accomplishment Timing Score by Business Case Initiation Timing

5.3 MOD Business Case Initiation Timing and Cost and Schedule Performance

In this study, the researcher tried to answer the following research question.

1. Are there differences in project performance by MOD business case initiation timing?

To answer these research questions, the following null hypotheses were set.

a. In cost performance, no differences exist in the timings of initiation among MOD business cases.

b. In schedule performance, no differences in the timings of initiation among MOD business cases.

The research (alternative) hypotheses are described below:

a. In cost performance, differences do exist in the timings of initiation among MOD business cases.

b. In schedule performance, differences do exist in the timings of initiation among MOD business cases.

Independent sample t tests were used with two independent variables (Opportunity Framing and Assessment; Assessment and After Assessment; and Opportunity Framing and After Assessment). Thus, a total of six t tests were conducted for this study. The examined t tests are:

1) a difference between Opportunity Framing and Assessment in cost performance,
2) a difference between Opportunity Framing and After Assessment in cost performance,
3) a difference between Assessment and After Assessment in cost performance,
4) a difference between Opportunity Framing and Assessment in schedule performance,
5) a difference between Opportunity Framing and After Assessment in schedule performance,
6) a difference between Assessment and After Assessment in schedule performance.

The researcher failed to reject the null hypotheses (relevant stats). This result was mainly due to the small sample size in each group. However, two tendencies were identified. Projects that initiated MOD business case during Opportunity Framing achieved 1) better cost performance on average, and 2) better schedule performance on average. The cost and schedule performances by MOD business case initiation timings are presented in Figure 69 and Figure 70.

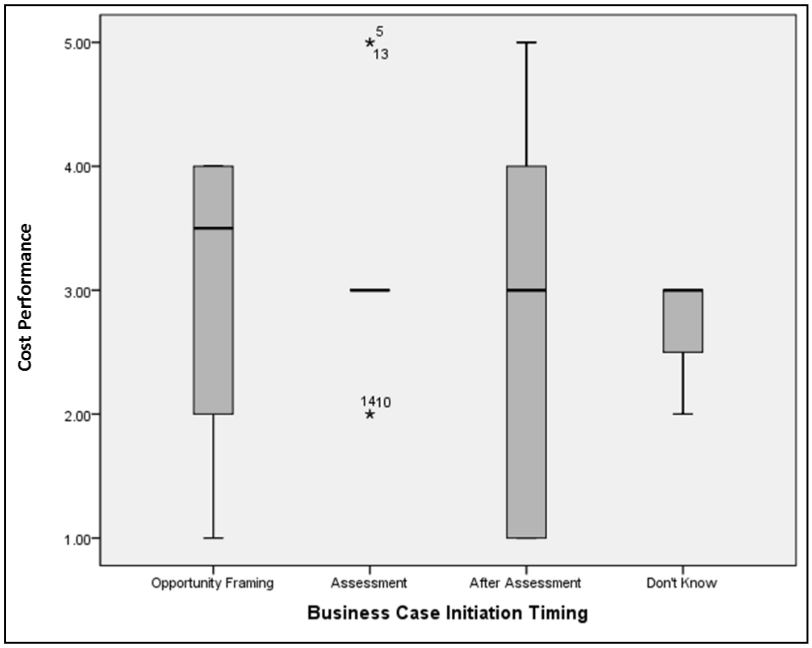


Figure 69. Cost Performance by Business Case Initiation Timing

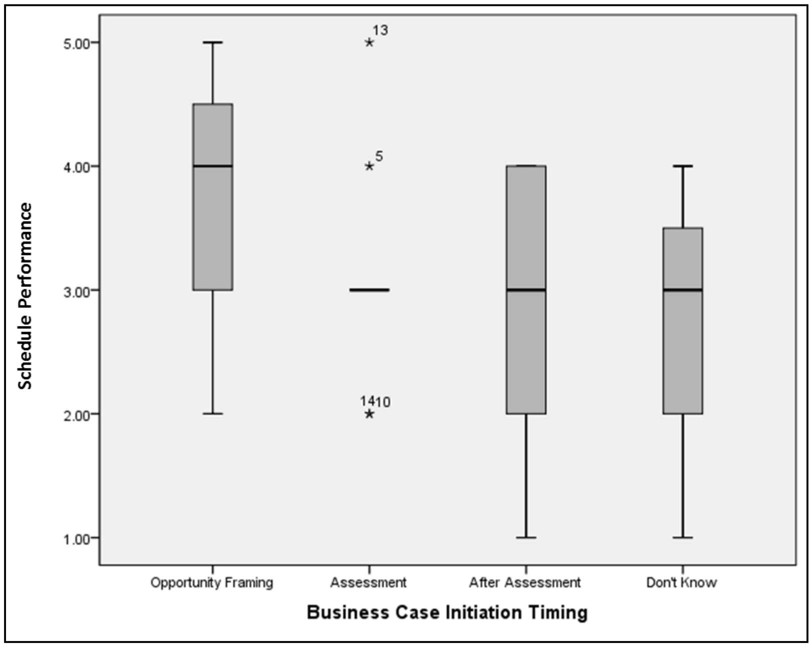


Figure 70. Schedule Performance by Business Case Initiation Timing

5.4 CSF ACCOMPLISHMENT AND PROJECT PERFORMANCE

In this study, the researcher tried to answer the following research question.

1. Is there an association between MOD CSF accomplishment and project performance metrics?

For this analysis, the study used correlational research methods and correlational statistics, suitable for such analysis because they are "a type of non-experimental method that describes the relationship between two measured variables" (Jackson 2003). A scatter plot, a figure showing the relationship between two variables, was made to facilitate the correlation interpretation. To determine the magnitude of the relationship, the study calculated a Pearson's product-moment correlation coefficient, referred to as

Pearson's r. R square is also calculated because it indicates the percentage of variance in the dependent variable that can be predicted from the independent variable.

In the analysis, the null hypothesis was tested at the significance level of 0.10. Thus, if the p value or sig. (SPSS labels this "p value Sig.") is greater than 0.10, the null hypothesis is accepted; otherwise, the research (alternative) hypothesis is accepted. This level is the probability of a Type I error or the probability of rejecting the null hypothesis when it is actually true. A more liberal level was used (the significance level of 0.10) because the research deals with the construction industry's information which is an area less well-controlled. Thus, a small effect may be difficult to detect.

To answer the research question above, the following null hypotheses were set.

a. There is no association between degree score of MOD CSF accomplishment and Cost performance.
b. There is no association between degree score of MOD CSF accomplishment and Schedule performance.
c. There is no association between degree score of MOD CSF accomplishment and Construction performance.
d. There is no association between degree score of MOD CSF accomplishment and Startup performance.

The research (alternative) hypotheses are described below:

a. There is an association between degree score of MOD CSF accomplishment and Cost performance.
b. There is an association between degree score of MOD CSF accomplishment and Schedule performance.
c. There is an association between degree score of MOD CSF accomplishment and Construction performance.

d. There is an association between degree score of MOD CSF accomplishment and Startup performance.

Statistically significant positive correlations were found in all the research hypothesis analyses as described below.

Association between Degree of MOD CSF Accomplishment and Cost Performance

A statistically significant positive correlation between MOD CSF accomplishment and cost performance was found: $R^2 = 0.543$, Sig. = 0.001. The positive correlation means that, in general, projects that accomplish more MOD CSFs tend to have better cost performance and those that do not tend to have worse performance. The effect size of R = .737 is considered, for this area of research, very large. The statistical analysis result of association between degree score of MOD CSF accomplishment and cost performance is summarized in Table 12.

Table 12 Statistical Analysis Result of Association between Degree of MOD CSF Accomplishment and Cost Performance

N	R	R Square	F	Sig.	Result (<0.10 or not)
16	.737	.543	16.657	.001	**Significant**

There were sixteen sample projects with sufficient data for this analysis: Average $D_A = 0.75$, Average Cost Performance = 3.00. A scatter plot, showing the relationship between degree of MOD CSF accomplishment and cost performance, is shown in Figure 71.

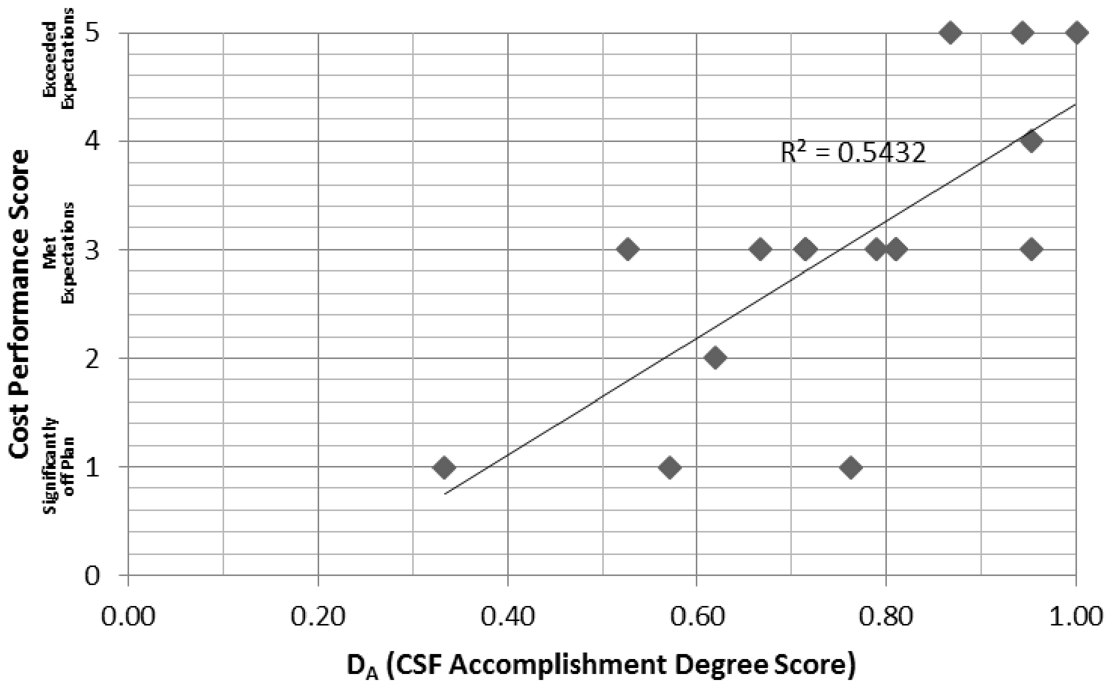


Figure 71. Association between Degree of MOD CSF Accomplishment and Cost Performance

Association between Degree of MOD CSF Accomplishment and Schedule Performance

A statistically significant positive correlation between MOD CSF accomplishment and schedule performance was found: $R^2 = 0.612$, Sig. < 0.001. The positive correlation means that, in general, projects that accomplish more MOD CSFs tend to have better schedule performance and those that do not tend to have worse performance. For this area of research, the effect size of R = .783 is considered very large. The statistical analysis result of association between degree score of MOD CSF accomplishment and schedule performance is summarized in Table 13.

Table 13 Statistical Analysis Result of Association between Degree of MOD CSF Accomplishment and Schedule Performance

N	R	R Square	F	Sig.	Result (<0.10 or not)
16	.783	.612	22.127	.000	**Significant**

There were sixteen sample projects with sufficient data for this analysis: Average D_A = 0.75, Average Schedule Performance = 3.06. A scatter plot, showing the relationship between degree of MOD CSF accomplishment and schedule performance, is shown in Figure 72.

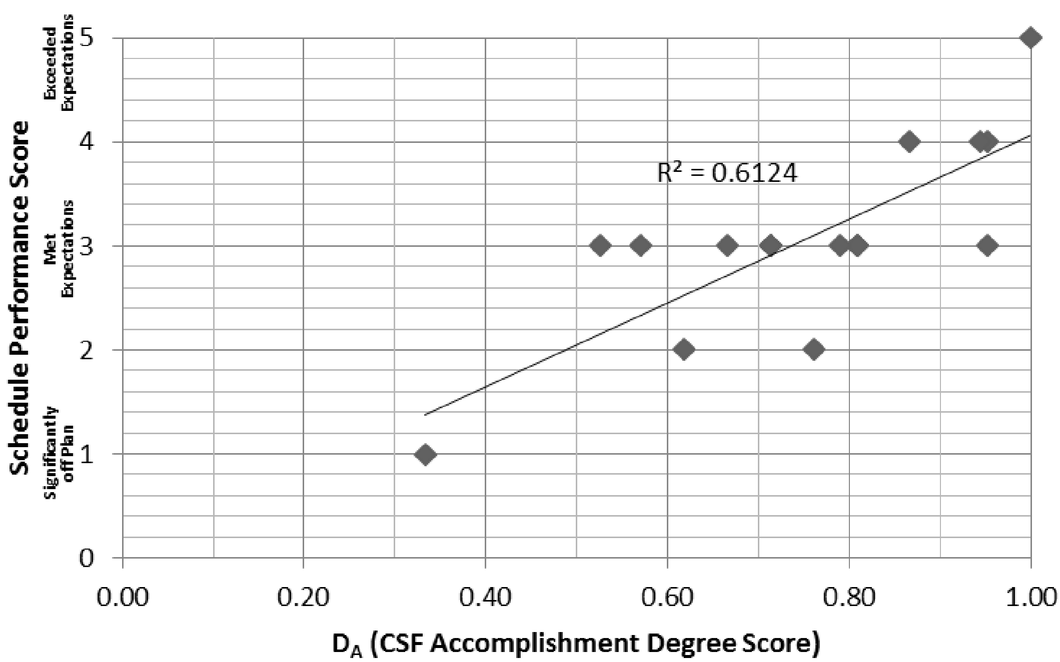


Figure 72. Association between Degree of MOD CSF Accomplishment and Schedule Performance

Association between Degree of MOD CSF Accomplishment and Construction Performance

A statistically significant positive correlation between MOD CSF accomplishment and Construction performance was found: $R^2 = 0.351$, Sig. = 0.033. The positive correlation means that, in general, projects that accomplish more MOD CSFs tend to have better Construction performance and those that do not tend to have worse performance. The effect size of R = .592 is considered large for this area of research. The statistical analysis result of association between degree score of MOD CSF accomplishment and Construction performance is summarized in Table 14.

Table 14 Statistical Analysis Result of Association between Degree of MOD CSF Accomplishment and Construction Performance

N	R	R Square	F	Sig.	Result (<0.10 or not)
13	.592	.351	5.943	.033	**Significant**

There were thirteen sample projects with sufficient data for this analysis: Average $D_A = 0.76$, Average Construction Performance = 3.31. A scatter plot, showing the relationship between degree of MOD CSF accomplishment and Construction performance, is shown in Figure 73.

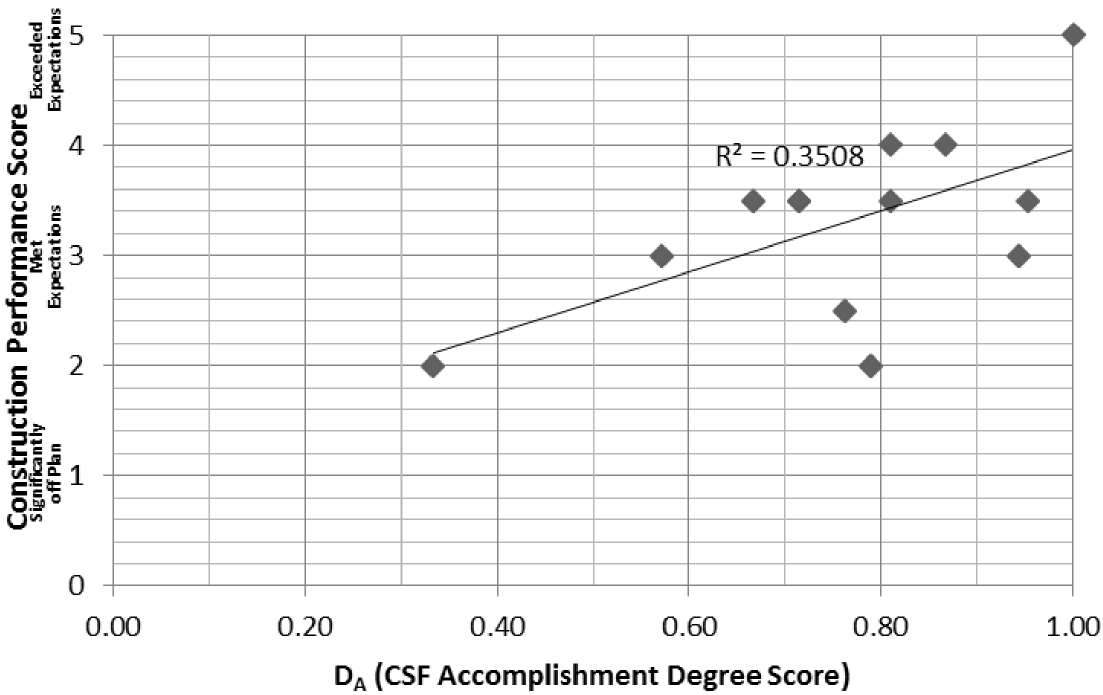


Figure 73. Association between Degree of MOD CSF Accomplishment and Construction Performance

Association between Degree of MOD CSF Accomplishment and Startup Performance

A statistically significant positive correlation between MOD CSF accomplishment and Startup performance was found: $R^2 = 0.387$, Sig. = 0.055. The positive correlation means that, in general, projects that accomplish more MOD CSFs tend to have better Startup performance and those that do not tend to have worse performance. The effect size of R = .622 is considered large for this area of research. The statistical analysis result of association between degree score of MOD CSF accomplishment and Startup performance is summarized in Table 15.

Table 15 Statistical Analysis Result of Association between Degree of MOD CSF Accomplishment and Startup Performance

N	R	R Square	F	Sig.	Result (<0.10 or not)
10	.622	.387	5.051	.055	**Significant**

There were ten sample projects with sufficient data for this analysis: Average D_A = 0.78, Average Startup Performance = 4.00. A scatter plot, showing the relationship between degree of MOD CSF accomplishment and Startup performance, is shown in Figure 74.

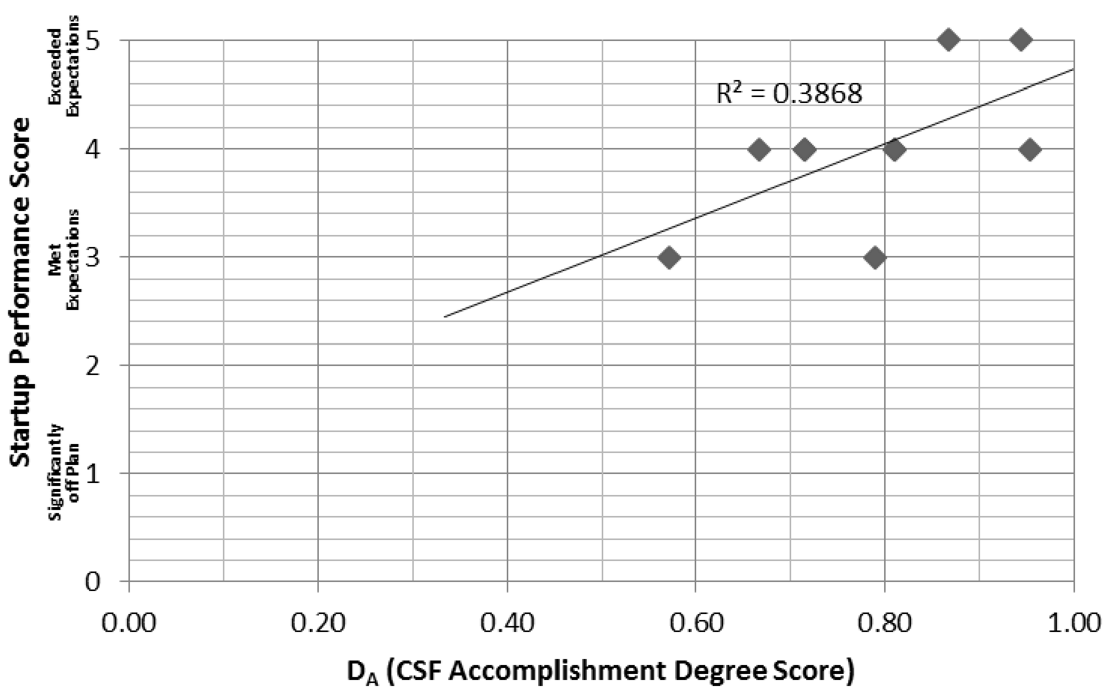


Figure 74. Association between Degree of MOD CSF Accomplishment and Startup Performance

5.5 MOD EXTENT AND MOD CSF ACCOMPLISHMENT

In this study, the researcher tried to answer the following research question.

1. Is there an association between the extent of MOD and MOD CSF accomplishment?

To answer the research question, the following null hypotheses were set.

a. There is no association between the extent of MOD and degree score of MOD CSF accomplishment.
b. There is no association between the extent of MOD and the timing score of MOD CSF accomplishment.

The research (alternative) hypotheses are described below:

a. There is an association between the extent of MOD and degree score of MOD CSF accomplishment.
b. There is an association between the extent of MOD and the timing score of MOD CSF accomplishment.

In the study of testing the first null hypothesis, the researcher failed to reject the null hypothesis R = 0.344, Sig. = 0.176, as the probability was more than the preset alpha level (0.10).

In the study of testing the second null hypothesis, the researcher rejected the null hypothesis R = 0.390, Sig. = 0.089, as the probability was less than the preset alpha level (0.10). However, the R^2 is 0.152 (effect size), which for this area of research is considered quite small. Thus, the utilization of this finding may be limited.

5.6 Individual CSF Accomplishment and Project Performance Metrics (Group by Independent Variable)

In this study, the researcher tried to answer the following research question.

1. Are there project performance differences by the accomplishment of individual CSFs?

To answer these research questions, the following null hypotheses were set.

a. In Cost performance, no differences exist in the accomplishment of individual CSFs.

b. In Schedule performance, no differences exist in the accomplishment of individual CSFs.

c. In Engineering success, no differences exist in the accomplishment of individual CSFs.

d. In Procurement success, no differences exist in the accomplishment of individual CSFs.

e. In Construction success, no differences exist in the accomplishment of individual CSFs.

f. In Startup success, no differences exist in the accomplishment of individual CSFs.

The research (alternative) hypotheses are described below:

a. In Cost performance, differences do exist in the accomplishment of individual CSFs.

b. In Schedule performance, differences do exist in the accomplishment of individual CSFs.

c. In Engineering success, differences do exist in the accomplishment of individual CSFs.

d. In Procurement success, differences do exist in the accomplishment of individual CSFs.
e. In Construction success, differences do exist in the accomplishment of individual CSFs.
f. In Startup success, differences do exist in the accomplishment of individual CSFs.

Independent sample t tests were used with two independent variables. Those two variables were: 1) a group of projects with lower degree of CSF accomplishment (D_A), and 2) a group of projects with higher degree of CSF accomplishment (D_A). As a reminder, the degree of CSF accomplishment was measured at four levels: 1) not accomplished (0%), 2) partially accomplished (30%), 3) mostly accomplished (70%), and 4) fully accomplished (100%).

Thus, a total of 72 (6 × 21) t tests were conducted for this study. The examined t tests are:

1) For each CSF, a difference in cost performance between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A),
2) For each CSF, a difference in schedule performance between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A),
3) For each CSF, a difference in Engineering success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A),

4) For each CSF, a difference in Procurement success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A),
5) For each CSF, a difference in Construction success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A),
6) For each CSF, a difference in Startup success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A).

Due to the small sample size in each group (since most of projects accomplished CSF), among the 21 CSFs, the researcher could not test following: CSF1, CSF6, CSF10, CSF11, CSF13, CSF19, and CSF21. Thus, the readers should understand that the following findings are from only those CSFs that could be analyzed; further research is needed with more sample projects for advanced analysis (multiple regression); identified differences are not the only influencing factors for the dependent variables; and the researcher did not identify the effect size of each CSF for better project performance.

Cost Performance and Individual CSF Accomplishment

There was a statistically significant difference in cost performance between a group of projects with lower degree of CSF accomplishment ($D_{A)}$ and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF2. Alignment on Drivers (t = 2.17, Sig. = 0.047)
- CSF4. Timely Design Freeze (t = 4.02, Sig. = 0.001)
- CSF5. Early Completion Recognition (t = 2.13, Sig. = 0.053)
- CSF8. Cost Savings Recognition (t = 2.86, Sig. = 0.013)
- CSF14. Vendor Involvement (t = 2.13, Sig. = 0.053)

- CSF17. Owner Delay Avoidance (t = 2.3, Sig. = 0.04)

This means that, in general, projects that accomplished these six CSFs tended to score a better cost performance. The statistical analysis results of differences in cost performance between a group of lower accomplishment level projects and a group of higher accomplishment level projects are summarized in Table 16.

Table 16 Statistical Analysis Results of Differences in Cost Performance

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Sample t-Test		
	N	Cost Performance (Mean)	STD	N	Cost Performance (Mean)	STD	t	Sig.	<0.10
CSF2	3	1.67	1.15	13	3.31	1.18	2.17	0.047	Sig.
CSF4	5	1.6	0.89	10	3.5	0.85	4.02	0.001	Sig.
CSF5	5	2	1.41	10	3.3	0.95	2.13	0.053	Sig.
CSF8	10	2.4	0.97	6	4	1.26	2.86	0.013	Sig.
CSF14	5	2	1	10	3.3	1.16	2.13	0.053	Sig.
CSF17	4	1.75	0.96	10	3.1	0.99	2.3	0.04	Sig.

Schedule Performance and Individual CSF Accomplishment

There was a statistically significant difference in schedule performance between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF4. Timely Design Freeze (t = 3.27, Sig. = 0.006)
- CSF8. Cost Savings Recognition (t = 2.28, Sig. = 0.039)
- CSF14. Vendor Involvement (t = 3.27, Sig. = 0.006)
- CSF17. Owner Delay Avoidance (t = 1.93, Sig. = 0.078)

This means that, in general, projects that accomplished these four CSFs tended to score a better schedule performance. Summarized in Table 17 are the statistical analysis results of differences in schedule performance between a group of lower accomplishment level projects and a group of higher accomplishment level projects.

Table 17 Statistical Analysis Results of Differences in Schedule Performance

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Sample t-Test		
	N	Schedule Performance (Mean)	STD	N	Schedule Performance (Mean)	STD	t	Sig.	<0.10
CSF4	5	2.2	0.837	10	3.3	0.48	3.27	0.006	Sig.
CSF8	10	2.7	0.67	6	3.67	1.03	2.28	0.039	Sig.
CSF14	5	2.2	0.84	10	3.3	0.48	3.27	0.006	Sig.
CSF17	4	2.25	0.96	10	3.2	0.79	1.93	0.078	Sig.

Quality Performance and Individual CSF Accomplishment

There was a statistically significant difference in quality performance between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF9. Contractor Leadership ($t = 4.39$, Sig. = 0.001)

This means that, in general, projects that accomplished CSF9 tended to score a better quality performance. The statistical analysis results of differences in quality performance between a group of lower accomplishment level projects and a group of higher accomplishment level projects are summarized in Table 18.

Table 18 Statistical Analysis Results of Differences in Quality Performance

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Samples t-Test		
	N	Quality Performance (Mean)	STD	N	Quality Performance (Mean)	STD	t	Sig.	<0.10
CSF9	4	2	0	8	3.88	8.35	4.39	0.001	Sig.

Engineering Success and Individual CSF Accomplishment

There was a statistically significant difference in Engineering success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF4. Timely Design Freeze (t = 2.67, Sig. = 0.018)

This means that, in general, projects that accomplished CSF4 tended to score a better Engineering success. The statistical analysis results of differences in Engineering success between a group of lower accomplishment projects and a group of higher accomplishment level projects are summarized in Table 19.

Table 19 Statistical Analysis Results of Differences in Engineering Success

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Sample t-Test		
	N	Engineering Success (Mean)	STD	N	Engineering Success (Mean)	STD	t	Sig.	<0.10
CSF4	6	2.58	0.49	10	3.6	0.84	2.67	0.018	Sig.

Procurement Success and Individual CSF Accomplishment

There was a statistically significant difference in Procurement success between a group of projects with lower degree of CSF accomplishment (D_{A}) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF2. Alignment on Drivers (t = 1.91, Sig. = 0.077)
- CSF4. Timely Design Freeze (t = 2.3, Sig. = 0.037)
- CSF12. Investment in Studies (t = 2.95, Sig. = 0.013)
- CSF17. Owner Delay Avoidance (t = 3.21, Sig. = 0.031)
- CSF20. Management of Execution Risks (t = 2.1, Sig. = 0.057)

This means that, in general, projects that accomplished these five CSFs tended to score a better Procurement success. Summarized in Table 20 are the statistical analysis results of differences in Engineering success between a group of lower accomplishment level projects and a group of higher accomplishment level projects.

Table 20 Statistical Analysis Results of Differences in Procurement Success

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Samples t-Test		
	N	Procurement Success (Mean)	STD	N	Procurement Success (Mean)	STD	t	Sig.	<0.10
CSF2	4	2.5	0.58	12	3.3	0.75	1.91	0.077	Sig.
CSF4	6	2.58	0.66	10	3.4	0.7	2.3	0.037	Sig.
CSF12	7	2.57	0.53	6	3.42	0.48	2.95	0.013	Sig.
CSF17	5	2.4	0.55	9	3.17	0.354	3.21	0.031	Sig.
CSF20	3	2.33	0.58	13	3.27	0.73	2.1	0.057	Sig.

Construction Success and Individual CSF Accomplishment

There was a statistically significant difference in Construction success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF2. Alignment on Drivers (t = 2.91, Sig. = 0.013)
- CSF4. Timely Design Freeze (t = 2.23, Sig. = 0.048)
- CSF5. Early Completion Recognition (t = 2.23, Sig. = 0.048)
- CSF7. Owner-furnished/Long Lead Equipment Specification (t = 2.6, Sig. = 0.043)
- CSF8. Cost Savings Recognition (t = 1.91, Sig. = 0.081)

This means that, in general, projects that accomplished these five CSFs tended to score a better Construction success. The statistical analysis results of differences in Construction success between a group of lower accomplishment level projects and a group of higher accomplishment level projects are summarized in Table 21.

Table 21 Statistical Analysis Results of Differences in Construction Success

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Sample t-Test		
	N	Construction Success (Mean)	STD	N	Construction Success (Mean)	STD	t	Sig.	<0.10
CSF2	4	2.5	0.577	10	3.6	0.658	2.91	0.013	Sig.
CSF4	4	2.63	0.48	9	3.39	0.6	2.23	0.048	Sig.
CSF5	4	2.63	0.48	9	3.39	0.6	2.23	0.048	Sig.
CSF7	6	2.75	0.7583	6	3.58	0.2	2.6	0.043	Sig.
CSF8	10	2.05	0.69	4	3.88	0.85	1.91	0.081	Sig.

Startup Success and Individual CSF Accomplishment

There was a statistically significant difference in Startup success between a group of projects with lower degree of CSF accomplishment (D_A) and a group of projects with higher degree of CSF accomplishment (D_A) in the following CSFs:

- CSF8. Cost Savings Recognition (t = 2.7, Sig. = 0.027)

This means that, in general, projects that accomplished CSF8 tended to score better Startup success. The statistical analysis results of differences in Startup success between a group of lower accomplishment projects and a group of higher accomplishment level projects are summarized in Table 22.

Table 22 Statistical Analysis Results of Differences in Startup Success

CSF#	Projects with Lower D_A			Projects with Higher D_A			Independent Samples t-Test		
	N	Startup Success (Mean)	STD	N	Startup Success (Mean)	STD	t	Sig.	<0.10
CSF8	7	3.71	0.49	3	4.67	0.58	2.7	0.027	Sig.

Summary of Analysis Results on Relationships between Individual CSF Accomplishment and Project Performance Metrics

In this study, the researcher tried to answer the following research question: Are there project performance differences by the accomplishments of individual CSF? Due to the small sample size in each group, the researcher could not test, among the 21 CSFs, the following: CSF1, CSF6, CSF10, CSF11, CSF13, CSF19, and CSF21. For all other CSFs, independent sample t-tests were conducted to identify the statistical significant differences between a group of lower accomplishment level projects and a group of higher accomplishment level projects. Summarized in Table 23, are the analysis results of the relationships between individual CSF accomplishment and project performance metrics.

Table 23 Summary: Relationships between Individual CSF Accomplishment and Project Performance Metrics

	STATISTICALLY SIGNIFICANT?						
	PROJECT OBJECTIVE			PROJECT FUNCTION			
#	COST	SCHEDULE	QUALITY	ENGINEERING	PROCUREMENT	CONSTRUCTION	STARTUP
CSF1	NO ANALYSIS (SMALL N)						
CSF2	√				√	√	
CSF3							
CSF4	√	√		√	√	√	
CSF5	√					√	
CSF6	NO ANALYSIS (SMALL N)						
CSF7						√	
CSF8	√	√				√	√
CSF9			√				
CSF10	NO ANALYSIS (SMALL N)						
CSF11	NO ANALYSIS (SMALL N)						
CSF12					√		
CSF13	NO ANALYSIS (SMALL N)						
CSF14	√	√					
CSF15							
CSF16							
CSF17	√	√			√		
CSF18							
CSF19	NO ANALYSIS (SMALL N)						
CSF20					√		
CSF21	NO ANALYSIS (SMALL N)						

Table 23 shows that four CSFs appear to contribute the most to multiple project performance metrics from analysis of relationships between individual CSF accomplishment and project performance metrics:

- CSF2. alignment on drivers
- CSF4. timely design freeze
- CSF8. cost saving recognition
- CSF17. owner delay avoidance

These CSFs may be more important than the others. Thus, the industry should put more effort into accomplishing these CSFs in order to achieve higher levels of project performance.

5.7 Summary of Correlation Findings

The main purpose of this study was to investigate the correlations between MOD CSF accomplishment and project performance.

In the study identifying the differences among MOD business case initiation timing in MOD CSF accomplishment, the researcher could not find significant differences among any of the timing groups in the statistical analysis. This result was mainly due to the small sample size of each group. However, two tendencies were identified from descriptive analysis: 1) projects that initiated MOD business case early accomplished more CSFs at a higher degree and 2) projects that initiated MOD business cases early accomplished CSFs on time more often.

In the study identifying the differences among MOD business case initiation timing in project performance, the researcher also could not find significant differences among any of the timing groups in the statistical analysis. This result was mainly due to the small sample size in each group. The study did, however, identify two tendencies: 1) Projects that initiated MOD business cases during Opportunity Framing achieved better cost performance on average, and 2) projects that initiated MOD business cases at Opportunity Framing achieved better schedule performance on average.

In the study identifying the association between MOD CSF accomplishment and project performance, four statistically significant positive correlations were identified between MOD CSF accomplishment and:

- Cost performance
- Schedule performance
- Construction performance
- Startup performance

The researcher also identified, from the analysis of correlations (identifying significant project performance difference through independent sample t-tests), four CSFs that appear to contribute the most to multiple project performance:

- CSF2. alignment on drivers
- CSF4. timely design freeze
- CSF8. cost saving recognition
- CSF17. owner delay avoidance

Two studies were conducted to identify the CSFs that contribute the most to project performance: 1) significant CSFs accomplishment degree difference analysis between “Best” and “Worst” groups, and 2) significant performance mean difference analysis by each CSF accomplishment through independent sample t-tests. Table 24 summarizes the results. Appearing to contribute to most to multiple project performance metrics are the following CSFs:

- CSF2. Alignment on drivers
- CSF4. Timely design freeze
- CSF5 Early completion recognition
- CSF7 Owner-furnished/long lead equipment specification
- CSF8. Cost Saving recognition
- CSF12 Investment in studies
- CSF14. Vendors involvement
- CSF17. Owner delay avoidance

The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of project performance. It does not mean, however, that the other CSFs are not important or do not contribute to project performance. As Table 24 describes, due to the small sample size in each group or small variance on scores (since most of projects accomplished high D_A), among the 21 CSFs, the researcher could not test following: CSF1, CSF6, CSF10, CSF11, CSF13, CSF19, and CSF21. Thus, the readers should understand that the following findings are from only those CSFs that could be analyzed; further research is needed with more sample projects for advanced analysis (multiple regression); and identified differences are not the only influencing factors for the dependent variables.

Table 24 Summary: CSFs that Contribute the Most to Project Performance Metrics

#	CSF	High D_A	Significant D_A Mean Diff. (Group by Dependent Variable)?				Statistically Significant Performance Mean Diff. (Group by Independent Variable)?						
			Cost	Schedule	Construction	Startup	Cost	Schedule	Quality	Engineering	Procurement	Construction	Startup
CSF1	Module Envelope Limitations	√					NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF2	Alignment On Drivers				√		√				√	√	
CSF3	Owner's Planning Resources & Processes				√								
CSF4	Timely Design Freeze		√		√	√	√	√		√	√	√	
CSF5	Early Completion Recognition				√	√	√					√	
CSF6	Preliminary Module Definition			√	√		NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF7	Owner-furnished/Long Lead Equipment Spec.				√	√						√	
CSF8	Cost Savings Recognition		√	√			√	√				√	√
CSF9	Contractor Leadership								√				
CSF10	Contractor Experience	√					NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF11	Module Fabricator Capability	√					NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF12	Investment In Studies			√		√					√		
CSF13	Heavy Lift/Site Transport Capabilities	√					NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF14	Vendor Involvement		√				√	√					
CSF15	O&M Provisions												
CSF16	Transport Infrastructure												
CSF17	Owner Delay Avoidance		√				√	√			√		
CSF18	Data For Optimization												
CSF19	Continuity Through Project Phases						NO ANALYSIS (SMALL N/SMALL VARIANCE)						
CSF20	Management Of Execution Risks	√									√		
CSF21	Transport Delay Avoidance	√		√			NO ANALYSIS (SMALL N/SMALL VARIANCE)						

Chapter 6: Conclusions and Recommendations

6.1 Introduction

The primary goal of this research has been to better understand the relationships between MOD Critical Success Factors and project performance. The main research hypotheses have been as follows: 1) project performance metrics are associated with degree/timing of MOD CSF accomplishment and MOD business case initiation timing, 2) MOD CSF accomplishment is associated with MOD business case initiation timing, and 3) MOD extent is associated with degree/timing of MOD CSF accomplishment. The secondary goal of the research was to examine actual modular projects' CSFs accomplishment.

This chapter completes this research by discussing conclusions and recommendations. First, it summarizes the findings and second, it reviews the contributions to practice and to the body of knowledge. Finally, this chapter provides ideas for further future research.

6.2 Summary of What was Learned & What is Recommended

From the literature review, the researcher identified that, in the industrial and construction industries, a number of research projects and related publications have laid out the historical development, benefits, challenges, trends, execution plan differences in modularization, standardization strategy, and implications that are associated with the techniques of modularization and related prefabrication, preassembly, modularization, and off-site fabrication (PPMOF).

What the literature is short on, however, is a clarification of the relative significance of CSFs and their associations with the extent of modularization and project performance. The literature was in need of a study that examines correlations between the accomplishment of modularization CSFs and project performance. Also missing was current actual status of previously MOD CSF accomplishment.

Thus, this research was carried out to provide recommendations for better project performance. It has done so by examining actual modular projects' CSFs accomplishment and then identifying correlations between MOD CSF accomplishment and project performance.

In the study examining actual modular projects' CSFs accomplishment, the following items were measured: degree of accomplishment by each CSF, analysis of CSF accomplishment timing by each CSF, actual projects CSFs accomplishment by project phase, and actual projects CSFs accomplishment by project. From the above measurements, the following key items were identified: five lowest CSFs in terms of degree of accomplishment, six highest CSFs in terms of degree of accomplishment, nine timeliest CSFs in terms of accomplishment timing, six most delayed CSFs in terms of accomplishment timing, comparison of CSF accomplishment timing, and comparison of CSFs accomplishment frequency between sample projects and CII RT283. The study also identified the CSFs that appear to contribute the most to 1) "Modular Project Success", 2) Construction success, 3) Startup success, 4) Cost performance, and 5) Schedule performance. It is recommended that the industry strive harder to accomplish more CSFs in terms of accomplishment degree of the CSFs. The industry should pay greater attention to accomplishing those CSFs that got low timing scores earlier and on time.

In the study investigating the correlations between MOD CSF accomplishment and project performance, the study tested the following hypotheses: 1) project performance is associated with MOD CSF accomplishment and MOD business case initiation timing, 2) MOD CSF accomplishment is associated with the timing of the initiation of MOD business cases, and 3) modularization extent is associated with MOD CSF accomplishment.

From this study, descriptive analysis identified four tendencies: 1) projects that initiated MOD business case early accomplished more CSFs at a higher degree; 2) projects that initiated MOD business case early accomplished more CSFs on time; 3) projects that initiated MOD business case during Opportunity Framing achieved better cost performance on average; and 4) projects that initiated MOD business case during Opportunity Framing achieved better schedule performance on average.

In the study identifying the association between MOD CSF accomplishment and project performance, four statistically significant positive correlations were identified between MOD CSF accomplishment and: 1) Cost performance, 2) Schedule performance, 3) Construction performance, and 4) and Startup performance.

The researcher also identified four CSFs that appear to contribute the most to multiple project performance metrics. Those CSFs that appear to contribute the most to multiple project performance metrics are:

- CSF2. Alignment on drivers
- CSF4. Timely design freeze
- CSF5 Early completion recognition
- CSF7 Owner-furnished/long lead equipment specification
- CSF8. Cost Saving recognition
- CSF12 Investment in studies
- CSF14. Vendors involvement
- CSF17. Owner delay avoidance

The industry may put more effort into accomplishing these CSFs in order to achieve higher levels of project performance.

6.3 Contributions

The major contributions of this research can be summarized as follows:

Contributions to Practice

- a better understanding of MOD CSFs and their accomplishment status
- a better understanding of the relationships between MOD CSFs and project performance
- insights for industry on how to achieve higher project performance by accomplishing MOD CSFs

Contributions to the Body of Knowledge

- Development of a theoretical foundation that identifies the relationships between MOD CSFs and project performance.
- Validation of the established MOD CSFs by quantifying the effects of MOD CSFs on project performance

6.4 Recommendations for Future Research

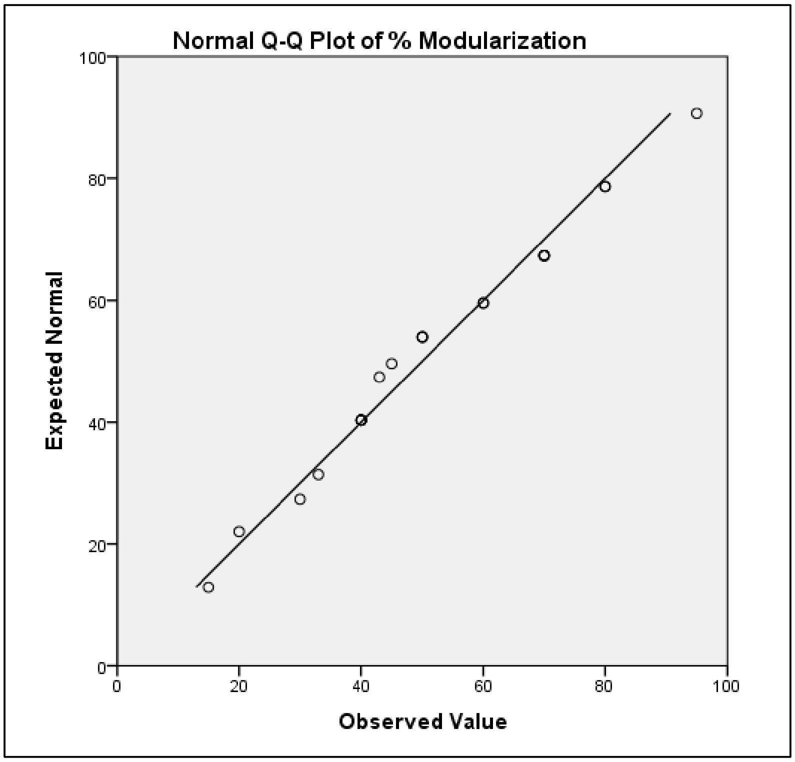
In this section, future studies are suggested beyond the scope of the current research to provide additional opportunities for expanding the current research.

1. Extending the study to other industries
    - What expanded or revised CSFs are needed to better suit the other sectors of the industry, such as commercial building, residential, or infrastructure sectors?
    - Are there different barriers to modularization for different industry sectors? If so, what other special industry efforts are needed by each sector to achieve higher levels of modularization?
2. Examining BIM and IT implementation in modularization

- How can information technologies help in implementing modularization (such as in enhancing information sharing, automating data gathering, communicating and coordinating by project information management system (PIMS), automating document and transmittal management, etc.)?
- How can BIM further enhance implementation of modularization in industrial modularization from the Engineering Phase (COG, weight management, isometric drawing for piping, interface design, design coordination, structural stability analysis, 3D visualization, etc.) to Procurement (material management, long-lead item planning and scheduling, work packaging, equipment procurement, etc.) to Construction (craft and equipment management, site and fab shop parallel scheduling, welding planning, project control, etc.)?

3. Comparing stick-built and modular projects' logistic approaches
    - How, in detail, are the planning of logistics, transportation, and handling in modularization different from that of the stick-built approach?
    - What is the state-of-the-art method or process for planning logistics, transportation, and handling? How can such methods be implemented to maximize modularization?

Appendix A Normal Q-Q Plot of % Modularization



Appendix B Survey Questionnaire

- Project:_______________
- Interviewee:____________
- Company:______________
- ( ) Owner ( ) Contractor ( ) Other:______
- Total Years of Industry Experience:______
- Approx. No. of Modular Projects Worked on during Career: __________
- Date:__________
- Company Address: _______________
- Phone:________________
- Email:_________________

You may complete a Survey in any of the following ways:

1. Manually mark-up the document and return via mail or pdf scan/email to Jin Ouk
2. Use TRACK-CHANGES feature in WORD software and return the file to Jin Ouk

Please Return To Jin Ouk Choi (PhD Candidate At UT Austin):

Via mail: Jin Ouk Choi, CAEE Dept. ECJ.5404, 301 E. Dean Keeton St., Stop C1700, Austin, TX 78712-2100
Via email: jinouk.choi@utexas.edu

Thank you for your prompt participation
and for your time and effort in completing this survey!!!

♦ Information above the line will be sanitized.
♦ Please type/write (X) to select your answer.

Project Characteristics

1. Which of the following best describes the industry group for this project?

( ) *Heavy Industrial:*
( ) Chemical Manufacturing
( ) Electrical (Generating)
( ) Environmental
( ) Metals Refining/Processing
( ) Mining
( ) Tailing
( ) Natural Gas Processing
( ) Oil/Gas Exploration/Production (well-site)
( ) Oil Refining
( ) Oil Sands
( ) Cogeneration
( ) Power
( ) Other Heavy Industrial: ____________

( ) *Light Industrial:*
( ) Automotive Manufacturing
( ) Consumer Products Manufacturing
( ) Foods
( ) Microelectronics Manufacturing
( ) Pharmaceutical
( ) Clean Room (Hi-Tech)
( ) Other Light Industrial: ____________

( ) *Buildings:*
( ) Dormitory/Hotel/Housing/Residential
( ) Low rise Office (≤3 floors)
( ) High rise Office (>3 floors)
( ) Hospital
( ) Laboratory
( ) Parking Garage
( ) Prison
( ) Retail Building
( ) School
( ) Warehouse
( ) Other Buildings: ____________

( ) *Infrastructure:*
( ) Airport
( ) Electrical Distribution
( ) Highway
( ) Process Control
( ) Rail
( ) Water/Wastewater
( ) Telecom
( ) Pipeline
( ) Tank Farms
( ) Gas Distribution
( ) Other: ____________

2. When was the project initiated? (what year)

a. Concept:_______ b. Start of Detailed Engineering:______ c. Construction:_____

3. What is the expected/determined **TIC (Total Installed Cost)** of the project (facilities cost only)? $________ billion
4. What is the determined/expected # **of months for the Project from Start of Site Construction to actual/target Mechanical completion?** _______ months (actual is preferred if available)
5. When did your company first become involved in this project? (month/year) ___________
6. What is the **location of the site**: _______________
7. Did the project use separate fabrication (steel and pipe) and assembly (module) shops?

   ( ) Yes

   a. What is/are the location(s) of the fabrication (steel and pipe) shops: _____________

   b. What is/are the location(s) of the assembly (modules) shops: _____________

   ( ) No

   a. What is/are the location(s) of the common fabrication and assembly shops/yards: __________

8. What is the **current status** of the project?

   a. Phase (check one)

( ) *1.* Opportunity Framing ( ) *3.* Selection (FEL2) ( ) *5.* EPC

( ) *2.* Assessment (FEL1) ( ) *4.* Basic Design (FEL3) ( ) *6.* Startup

Phase	Major Activities
1. Opportunity Framing	• Business opportunities
2. Assessment (FEL1)	• List of alternatives • Prelim assessment of opportunities & risks • Assure alignments with the business case • Initial Module Philosophy
3. Selection (FEL2)	• Final framing of business opportunity • Develop & select best alternative • Technology selection • Develop project philosophies & modularization
4. Basic Design (FEL3)	• Define technical & execution scope (mod.) • Optimal integration of all issues into business plan • Preliminary review of potential execution contractors
5. EPC (Execution)	• Provide assets and deliverables in accordance with business plan • Implement with min. changes • Facility and business systems ready for startup

   b. % Current physical completion:__________%

9. Facility Capacity

   a. **[Industrial projects only]** Indicate the primary product or function of the facility and the unit of measure that best relates the product or function capacity of the facility.

Product or Function	Design Capacity	Unit of Measure

Examples:

Product or Function	Unit of Measure
Chemical Products	Tons/Hour
Consumer Products	Cases/Day

b. **[Building projects only]** Please indicate the size and the unit of measure of the building facility:

Size	Unit of Measure
	Square Feet / Square Meters

10. What types of units/sub-units were modularized on this project? (check all that apply)
*Ref. **Module**: Portion of plant fully fabricated, assembled, and tested away from the final site placement, in so far as is practical*

( ) Process equipment
( ) Utility equipment
( ) Loaded piperacks
( ) Dressed up vessels
( ) Infrastructure components
( ) Power Generation Equipment
( ) Structural modules
( ) Power distribution centers
( ) Remote instrument buildings
( ) Other buildings
( ) Others________________________

11. What is the approximated **percent modularization (% MOD) of the project**? ______%
*Ref. **% Modularization**: Portion of original site-based work hours (excluding site preparation & demolition) exported to fabrication shops*

12. Did the project analyze/identify feasible maximum extent of modularization (MAX MOD)?
*Ref. **MAX MOD**: **technically feasible** maximum modular extent, without considering cost factor.*
( ) Yes- If so what was the estimated maximum modular extent?________%
i. If it varies with selected % MOD (Q11), what was the reason for not pursuing modularization to the maximum extent possible?__________________________
( ) No
( ) Don't Know
In your opinion, what is MAX MOD % for this project?______

13. Did the project analyze/identify optimal (maximum profit) extent of modularization?
( ) Yes - If so what was the estimated optimal (max. profit) modular extent?________%
i. If it varies with selected % MOD (Q11), what was the reason for not pursuing modularization to the optimal extent possible?___________________________
( ) No
( ) Don't Know
In your opinion, what is optimal modular extent for this project? approx. _____%

14. What are the **sizes** of the modules?
c. **Largest** (by dimension) Module: ________H________ L________ W (meter)
d. **Heaviest** Module: _________ton

15. What is the **total number of the modules** for the project? ___________
16. What is the **approximate total tonnage of the modules** for the project? __________
17. When was **modularization** <u>**first assessed**</u> in this project? (check only one)

( ) Opportunity Framing
( ) Assessment
( ) Selection
( ) Early in Detail Engineering
( ) Late in Detail Engineering
( ) Beginning of Construction or later
( ) Don't Know

18. Please select the **primary factor** influencing the execution of this project. Assume safety is a given for all projects.

( ) *Cost* ( ) *Schedule* ( ) *Balanced* ( ) Other:______

19. What were the **Advantages of Modularization Application?** (check all that apply)

( ) Overall lower cost ( ) Improved schedule ( ) Increased productivity
( ) Increased safety ( ) Reduced waste ( ) Better environmental performance
( ) Reduced site-base permits ( ) Others: ______________________________________

20. What were the **Impediments of Modularization Application?** (check all that apply)

( ) Initial cost investment ( ) Coordination ( ) Anti-module oriented design ( ) Heavy lift
( ) Owner capability/tendency ( ) Contractor capability ( ) Fabricator capability ( ) Logistic
( ) Shipping limits ( ) Design freeze ( ) Transport restrictions ( ) Others: ________________

21. What are the **business drivers** for modularization on this project? (check all that apply)

( ) Schedule
( ) Labor cost
( ) Labor productivity
( ) Labor supply
( ) Safety
( ) Quality
( ) Environmental
( ) Regulatory
( ) Legal
( ) Site access
( ) Site attributes
( ) Security/Confidentiality
( ) Sustainability
( ) Predictability/Reliability
( ) Disruption
( ) Other. Specify:_________

22. What are the **project difficulties** recognized thus far (that have led to added cost or delay)? (check all that apply)

( ) Contract terms
( ) Weather (extreme)
( ) Logistics challenges (transportation of modules)
( ) Environmental impact
( ) Organizational change
( ) Scope change
( ) Labor issues
( ) Regulating impact
( ) External stakeholders
( ) Material shortage
( ) Major quality problems
( ) Change in demand for product
( ) Change in project profitability
( ) Change in financing environment
( ) Safety incident
( ) Equipment delivery
( ) Team turnover
( ) Other:____________

23. Availability of **local infrastructure resources** (check all that apply)

( ) Transportation infrastructure (Inland)
( ) Truck (Road/highway)
( ) Rail
( ) Transportation infrastructure (Coastal)
( ) Ship (Deep port)
( ) Barge
( ) Jetty/Port for module
( ) Power
( ) Water
( ) Sewage
( ) Housing

24. How adequate is **site laydown space**?

( ) *Generous* ( ) *Adequate* ( ) *Tight* ( ) *Inadequate*

25. What is the **quantity** of the labor market where the **jobsite** is located?

( ) *Excess supply* ( ) *Adequate supply* ( ) *Inadequate or non-existent supply*

26. What is the **quantity** of the labor market where the **fabrication site(s)** is (are) located?

( ) *Excess supply* ( ) *Adequate supply* ( ) *Inadequate or non-existent supply*

27. What is the **quality** of the labor market where the **jobsite** is located?

( ) *High quality* ( ) *Adequate quality* ( ) *Low quality*

28. What is the quality of the labor market where the **fabrication site(s)** is (are) located?
    ( ) *High quality* ( ) *Adequate quality* ( ) *Low quality*

29. What was the **expected** ***jobsite*** **labor productivity**?
    ( ) *Far better than average* ( ) *Better than average* ( ) *Average (company norms)*

    ( ) *Worse than average* ( ) *Far worse than average* ( ) *Don't know*

30. What was the **expected** ***fabrication site*** **productivity**?
    ( ) *Far better than average* ( ) *Better than average* ( ) *Average (company norms)*

    ( ) *Worse than average* ( ) *Far worse than average* ( ) *Don't know*

31. What was the **actual** ***jobsite*** **labor productivity**?
    ( ) *Far above expectation* ( ) *Above expectation* ( ) *Meets expectation*

    ( ) *Below expectation* ( ) *Far below expectation* ( ) *Don't know*

32. What was the **actual** ***fabrication site*** **labor productivity**?
    ( ) *Far above expectation* ( ) *Above expectation* ( ) *Meets expectation*

    ( ) *Below expectation* ( ) *Far below expectation* ( ) *Don't know*

Standardized Module (Please answer only if the project utilized Standardization)

33. What **types of units/sub-units** were **standardized** on this project? (check all that apply)

( ) Process equipment
( ) Utility equipment
( ) Loaded piperacks
( ) Dressed up vessels
( ) Infrastructure components
( ) Power Generation Equipment
( ) Structural modules
( ) Power distribution centers
( ) Remote instrument buildings
( ) Other buildings:_____________
( ) Others_____________

34. What is the approximated **percent Standardization of the module**? __________%
35. What are the **sizes** of the **Standardized modules**?
   e. **Largest** (by dimension) Standardized Module: ____H_____ L____ W (meter)
   f. **Heaviest** Standardized Module: _________ton

36. What was the **Economic Advantages/ Disadvantages from Standardization Application**?

ECONOMIC IMPACT	**Significance of Impact**		
Type of Advantage	**Low**	**Medium**	**High**
Design Only Once and Reuse Multiple Times			
Design & Procure in Advance / Respond to Schedule Needs			
Accelerated, Parallel Engineering for Site Adaptation			
Learning Curve in *Fabrication*			
Volume Discounts in Procurement			
Construction Materials Management Cost Savings			
Learning Curve in *Module Installation/Site Construction*			
Learning Curve in *Commissioning/Startup (planning & execution)*			
Learning Curve in *Operations & Maintenance*			
O&M Materials Management Cost Savings			
Type of Disadvantage	**Low**	**Medium**	**High**
Cost of Assessing the Market and Establishing Scope			
Cost of Establishing the Design Standard			
Sacrificed Benefits from Conventional Customization			

37. Are there any **other Economic Advantages/Disadvantages from Standardization Application?**

____

____

38. What were the **impediments/challenges for Standardization of modules?**

____

____

Critical Success Factors

39. Assess the **Modularization Critical Success Factors Accomplishment** for this project by **timing**. ***If you are not familiar with CSFs, please read the attached [PDF -21 CSFs] before answering the question***. *This question is the most important one of the research.*
*Note. If the CSF is not applicable to your project, please mark as **Not Accomplished.** (example: no owner involvement because the project is a turnkey project.--> mark C,G, L and, Q, N/A)*

#	Critical Success Factors	NOT Accomp. (0%)	Partially Accomp. (30%)	Mostly Accomp. (70%)	Fully Accomp. (100%)	If Accomplished, When? (ref. Q8)				
						Opportunity Framing	Assessment	Selection	Basic Design	EPC
A	"**Module Envelope Limitations**" prior to Selection									
B	"**Alignment on Drivers**" prior to Selection									
C	"**Owner's Planning Resources & Processes**" prior to Selection									
D	"**Timely Design Freeze**" prior to EPC									
E	"**Early Completion Recognition**" prior to Basic Design									
F	"**Preliminary Module Definition**" prior to Basic Design									
G	"**Owner- Furnished/Long Lead Equipment Specification**" prior to Basic Design									
H	"**Cost Savings Recognition**" prior to Basic Design									
I	"**Contractor Leadership**" prior to Basic Design									
J	"**Contractor Experience**" prior to EPC									
K	"**Module Fabricator Capability**" prior to EPC									
L	"**Investment In Studies**" prior to Basic Design									
M	"**Heavy Lift/Site Transport Capabilities**"									
N	"**Vendor Involvement**" prior to Basic Design									
O	"**O&M Provisions**"									
P	"**Transport Infrastructure**" prior to Basic Design									
Q	"**Owner Delay Avoidance**" prior to EPC									
R	"**Data For Optimization**" prior to Basic Design									
S	"**Continuity Through Project Phases**"									
T	"**Management of Execution Risks**"									
U	"**Transport Delay Avoidance**"									

40. To achieve even higher levels of modularization, what **CSFs would have been required from among those NOT accomplished** for this project? (check all that apply)

( ) A ( ) B ( ) C ( ) D ( ) E ( ) F ( ) G ( ) H ( ) I ( ) J ( ) K ( ) L
( ) M ( ) N ( ) O ( ) P ( ) Q ( ) R ( ) S ( ) T ( ) U

Project Performance

41. How successful was the **project by Function**?

Function	**Success Level**					
	N/A	5	4	3	2	1
Engineering						
Procurement						
Fabrication						
Construction						
Startup						

Success Levels

N/A = Not Applicable/Don't know

5 = Exceeded expectations
4 = Between 3 and 5
3 = Met expectations

2 = Between 1 and 3
1 = Significantly off plan

42. How successful was the **project by project objectives?**

Objectives	**Performance Level**					
	N/A	5	4	3	2	1
Safety						
Quality						
Cost						
Schedule						
Change management						
Field productivity						
Shop productivity						
Environmental						
Sustainability(waste)						

Performance Levels

N/A = Not Applicable/Don't know

5 = Exceeded expectations
4 = Between 3 and 5
3 = Met expectations

2 = Between 1 and 3
1 = Significantly off plan

43. What is the approximated **percent schedule savings compared to stick built**? _______ %

44. What is the approximated **percent cost savings compared to stick built**? _______ %

Thank you for your time and effort in completing this survey!!!

If you have a question, please email Jin Ouk Choi or phone him: 512-XXX-XXX
Or email his supervisor, James T. O'Connor: XXXX@mail.utexas.edu or phone him: 512-XXX-XXXX

Appendix C Survey Questionnaire Revisions by Version

Ver.	Update Date	Contents	Note / Reason
1.0	10/11/2012	DEVELOPED following questionnaire items: 1. Project name; 2. Interviewee name; 3. Company name; 4 Survey completed date; 5. Company address; 6. Phone number; 7. Email address; 8. Industry sector (no industry group with 9 sectors); 9. Project initiated (Concept & Construction); 10. TIC; 11.Total project duration; 12. Site location; 13. Current project status; 14. Types of units; 15. % MOD; 16. Size of modules; 17. First assessed; 18. Business drivers; 19. Project difficulties; 20. Local infrastructure; 21. Stand. Types of units; 22. Stand. %; 23. Stand. Size; 24. Stand. Adv./Dis. impact; 25. Other economic Adv./Dis.; 26. CSF Accomplishment & Timing; and 27. Performance (Phase &	First draft of the survey.

Ver.	Update Date	Contents	Note / Reason
		Others).	
		INCLUDED "Contact instruction" and "Appendix (21 CSFs detail description)"	
1.1	1/15/2013	ADDED "Company type"	To distinguish source of the data Owner / Contractor-"
		ADDED Note "Information above the line will be sanitized"	To inform the respondents
		UPDATED "Industry sector" to "5 Industry Sectors & 5 Sub-Sectors"	Based on MCOP advice
		ADDED "Upstream, Midstream, And Downstream"	Based on MCOP advice
		FIXED FROM "Did not accomplished" TO "Was not accomplish"	Grammar error
		CHANGED success Levels / performance levels order TO descending order	Based on MCOP advice
		FIXED "Success level descriptions": FROM "0 = Not Applicable; 1= Bad (Failed to	To clarify the success level difference Based on Dr. O'Connor's

Ver.	Update Date	Contents	Note / Reason
		meet many expectations); 2 = Between 1 and 3; 3 =Good (Essentially met expectations) ; 4 = Between 3 and 5; 5 = Excellent (Exceeded expectations)" TO "5 = Exceeded expectations; 4 = Between 3 and 5; 3 = Met expectations; 2 = Between 1 and 3;1 = Failed to meet expectations"	advice
1.2	1/31/2013	ADDED " Survey instructions"	To remind the respondents (included in the emails too)
		ALIGNED "Industry Groups and their Subsectors" WITH "CII BENCHMARKING SURVEY" (4 MAJOR INDUSTRY GROUP WITH 38 SUBSECTORS)	NOTE - sectors which unlikely to implement modular technique were excluded from the CII benchmarking industry group/ subsectors
		ADDED "Facility Capacity"	Adapted from the CII benchmarking survey to

Ver.	Update Date	Contents	Note / Reason
			understand the project characteristic better
		ADDED "Total # of modules"	MCOP advice
		ADDED " Primary Project Driver for modularization"	For the characteristic analysis
		ADDED "Advantages of modularization application"	For the characteristic analysis
		ADDED "Impediment of modularization application"	For the characteristic analysis
		ADDED "Site lay down space"	For the characteristic analysis
		ADDED "Quantity of the labor market where the jobsite is located"	For the characteristic analysis
		ADDED "Quantity of the labor market where the Fabshop is located"	For the characteristic analysis
		ADDED "Quality of the labor market where the jobsite is located"	For the characteristic analysis
		ADDED "Quality of the labor market	For the characteristic

Ver.	Update Date	Contents	Note / Reason
		where the Fabshop is located"	analysis
		ADDDED "Expected site labor productivity"	For the characteristic analysis
		ADDED "Actual site labor productivity"	For the characteristic analysis
		COMBINED INTO ONE QUESTION "Other standardization economic advantages and disadvantages"	
		ADDED " Impediment/challenges for standardization of modules"	
		CHANGED "CSFs numbering" from Arabic numeral to alphabet	Not to give impression that lower numbered CSF is more critical
		ADDED "To achieve even higher levels of modularization, what CSFs would have been required from those among NOT accomplished ones for this project?”	
		ADDED "Percent schedule saving compare to stick built"	

Ver.	Update Date	Contents	Note / Reason
		ADDED "Percent cost saving compare to stick built"	
		ADDED "What are the differences between labor in the jobsite and labor in the fab shop? - Labor Cost: Shop-$_______/ hr. Site-$________/hr. (Approximate) - Labor Productivity: Shop-_______% Site-________% (Approximate)"	For the characteristic analysis (business case analysis)
		ADDED "How much EXTRA owner / EPC supervision was added because of modularization (offsite work)? __________ % increase (from stick-built supervision #WH – approximate)"	For the characteristic analysis (business case analysis)
		ADDED "Percent waste decrease compare to stick built"	
		ADDED "Percent accident decrease"	
1.3	2/7/2013	ADDED INSTRUCTION "Type/write"	
		DEVELOPED to be more specific: "Project	For clarity

Ver.	Update Date	Contents	Note / Reason
		month # from Start of Site Construction to actual/target Mechanical completion"	
		ADDED "Appendix B 72 potential factors"	
		ADDED OPTIONS "a. $0.10-$4.99 b. $5.00-$14.99 c. $15.00-$24.99 d. $25.00-$29.99" TO "What are the differences between labor in the jobsite and labor in the fab shop?"	For participant's convenience and alignment. MCOP advised that the respondents will not able to input specific cost due to confidentiality issue and their reluctance
		REMOVED "How much EXTRA owner / EPC supervision was added because of modularization (offsite work)? ___________ % increase (from stick-built supervision #WH – approximate)"	MCOP ADVICE Due to difficulty to gather the information
		REMOVED "Percent waste decrease compare to stick built"	MCOP ADVICE Due to difficulty to gather

Ver.	Update Date	Contents	Note / Reason
			the information
		REMOVED "Percent accident decrease"	MCOP ADVICE Due to difficulty to gather the information
		ADDED "(Optional-Extra Point!! J) To achieve even higher levels of modularization, what CSFs would have been required among 72 potential factors (Appendix B) for this project? (Select all that apply):__ (i.e. AB, BB, and BF)"	To validate RT283 work
		CHANGED Answering Style from box ☐ to brackets ( )	Due to compatibility issue by different Word version
Pilot study to two experts			
1.4	2/21/2013	REORGANIZED Questions order	By related items
		CHANGED FROM "( ) Better than average ( ) Average ( ) Worse than average ( ) Don't know" TO "( ) Far better than average ( ) Better than average ( ) Average (company norms)	"Expected site labor productivity"

Ver.	Update Date	Contents	Note / Reason
		( ) Worse than average ( ) Far worse than average ( ) Don't know "	
		CHANGED FROM "( ) Better than average ( ) Average ( ) Worse than average ( ) Don't know" TO "( ) Far better than average ( ) Better than average ( ) Average (company norms) ( ) Worse than average ( ) Far worse than average ( ) Don't know "	"Actual site labor productivity"
		ADDED "Expected fab productivity"	
		ADDED "Actual fab site labor productivity"	
		ADDED a Note "If the CSF is not applicable to your project, please mark at N/A. (example: no owner involvement because the project is turnkey project.--> mark C,G, L and, Q, N/A)"	CSF QUESTIONNAIRE
		ADDED "N/A = Not Applicable/Don't know"	PROJECT PERFORMANCE

Ver.	Update Date	Contents	Note / Reason
		CHANGED "0" CHANGED TO "N/A"; "1 = Failed to meet expectations" TO "Significantly off plan"	
1.5	2/26/2013	CHANGED FORMAT: Word 2010 (Docx) format to Word 2003 (.Doc) format	for respondents who has only lower version of Word
First distribution of the survey			
1.6	3/5/2013	ADDED "Start of Detailed Engineering"	
		ADDED "Did the project use separate fabrication (steel and pipe) and assembly (module) shops? 1) Yes a. What is/are the location(s) of the fabrication (steel and pipe) shop: ______ b. What is/are the location(s) of the assembly (modules) shops: ____________ 2) No a. What is/are the location(s) of common fabrication and assembly shop/yards:	

Ver.	Update Date	Contents	Note / Reason
		______"	
		CHANGED PROJECT PHASE FROM "( ) Opportunity Framing; ( ) Concept; ( ) Assessment; ( ) Selection; ( ) Basic Design; ( ) Execution; ( ) Startup" TO "( ) 1. Opportunity Framing; ( ) 2. Assessment (FEL1); ( ) 3. Selection (FEL2); ( ) 4. Basic Design (FEL3); ( ) 5. EPC; ( ) 6. Startup"	TO ALIGNED WITH FRONT-END-LOADING (FEL) PHASES A feedback from one participant regarding phase definition confusion
		ADDED "The approximate total tonnage of the modules for the project"	MCOP ADVICE
		ADDED an option "( ) Other:______" in "Primary Project Driver"	Based on feedback
		CHANGED "( ) High supply ( ) Moderate supply ( ) Low supply" TO "( ) Excess supply ( ) Adequate supply ( ) Inadequate or non-existent supply"	Labor quantity at site and fabshop

Ver.	Update Date	Contents	Note / Reason
		CHANGED "( ) Moderate quality" TO "( ) Adequate quality"	Quality at site and fabshop
		ADDED "Note: This question is the most important question for the research."	CSF QUESTIONNAIRE
		REMOVED FROM THE SURVEY "Appendix 21 CSFs detail description" SEPARATED INTO independent document in presentation format with pictures	To support participant's understanding and to increase reliability
1.7	3/6/2013	ADDED "( ) Power" to Heavy Industrial Group	One MCOP member feedback
		ADDED "( ) Power Generation Equipment" IN "Types of units" AND "Stand. Types of units"	One MCOP member feedback
1.8	5/1/2013	MAJOR CHANGE: ADDED "Degree of CSF accomplishment"	To measure degree of CSF accomplishment. While collecting the completed survey,

Ver.	Update Date	Contents	Note / Reason
			realized level differences in CSF accomplishment. Countermeasure to increase reliability
		CHANGED "Accomplished on this Project" TO "If Accomplished, When?"	
		CHANGED FROM "Other project performance?" TO "How successful was the project by project objectives?"	Correct Label
2.0	6/5/2013	ADDED Each phase's major activities (FEL activities)	To help participant's understanding and answer's consistency
		ADDED "Feasible maximum extent of Modularization"	Based on PhD Committee comments on "consider a business case process item" for the analysis of % MOD
		ADDED "Optimal (maximum profit)	Based on PhD Committee

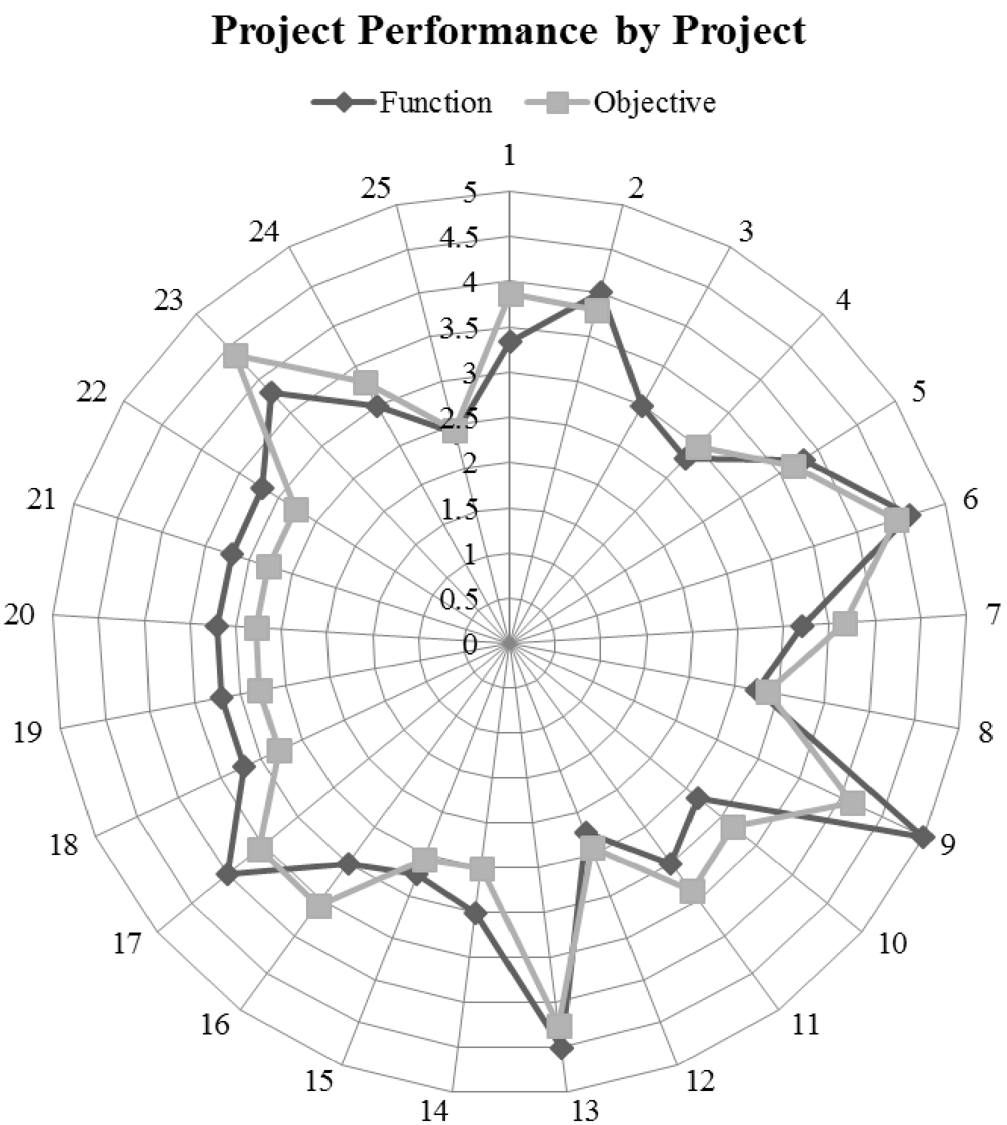
Ver.	Update Date	Contents	Note / Reason
		extent of modularization"	comments on "consider a business case process item" for the analysis of % MOD
		ADDED Percent degrees: "Not accomplished (0%); Partially Accomplished (30%); Mostly Accomplished (70%); and Fully Accomplished (100%)";	For consistency and reliability
		ADDED PHASE REFERENCE in CSF Questionnaire	For consistency and reliability
		CHANGED FROM "How successful was the project by Phase?" TO "the project by Function?"	Correct Label
		REMOVED "Appendix B 72 potential factors"	
2.1	7/15/2013	ADDED "Interviewee's total years of industry experience"	For participant's background analysis and Information credibility

Ver.	Update Date	Contents	Note / Reason
		ADDED "Interviewee's approximate number of modular projects worked on during career"	For participant 's background analysis and Information credibility
		ADDED "First involved"	To check data validity
		ADDED OPTION "( ) Don't Know" at Max MOD & Optimal MOD questions	
		ADDED "In your opinion, what is optimal modular extent?"	To see variance between achieved and opinion
2.2	7/25/2013	FIXED "Approx. No. of Modular Projects Worked in Career" TO "worked on during Career" "only facilities cost" TO "Facilities cost only" "When your company first involved in this project? (month/year) "TO "When do your company first become involved in this project?"	Grammar error
		ADDED "In your opinion, what is MAX MOD % for this project?"	To see variance between achieved and opinion

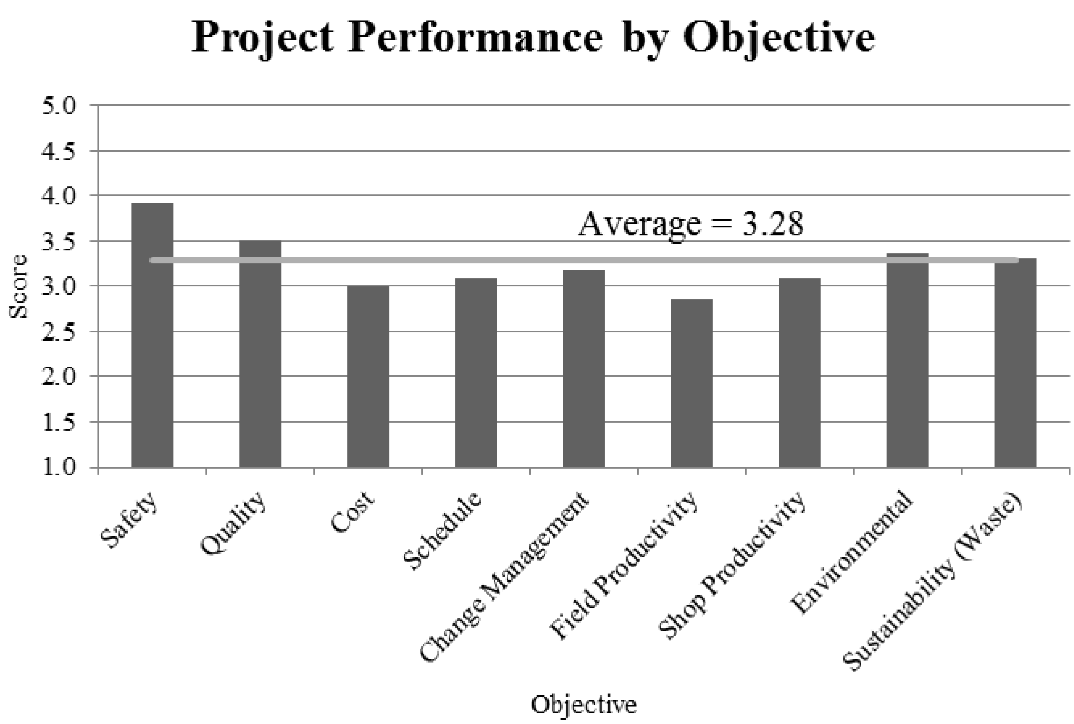
Ver.	Update Date	Contents	Note / Reason
All grammar errors are corrected			
2.3	8/12/2013	FIXED Contact information and ADDED Jin Ouk's supervisors contact information TO "If you have a question, please email Jin Ouk Choi or phone him: XXX-XXX-XXX Or email his supervisor, James T. O'Connor: XXXX@mail.utexas.edu or phone him: XXX-XXX-XXXX"	

Appendix D Project Performance

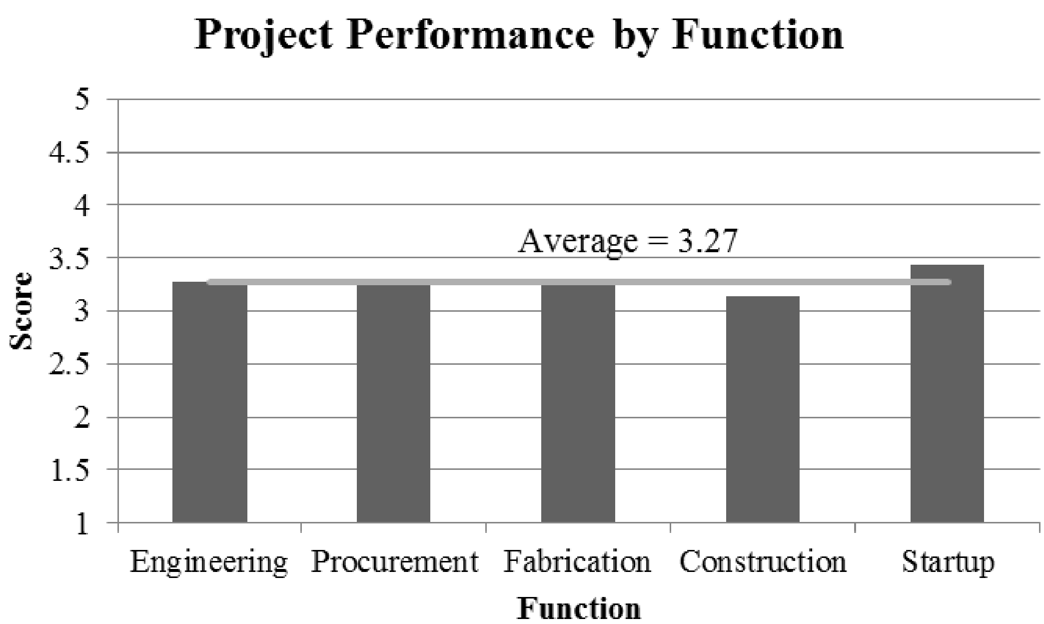
Project Performance by Project



Project Performance by Objective



Project Performance by Function



Appendix E Validation Feedback Form

Reviewer Background: PLEASE COMPLETE AND RETURN

Name		**Company**		**Date of Review**	
Years of Industry Experience		**Current Job Title**		**# of Modular Project in last 5 years**	

How would you weight the components that contribute the most to "Modularization Success"?

	Fabrication Success	Construction Success	Startup Success	Other?______
Modularization Success?	%	%	%	%

∑ = 100%

If you have other idea to define "Modularization Success" please specify________________

____

General Comments

In your review, please consider the following questions:

- ***Is any critical content (link) missing?***
- ***Are any significant corrections needed?***
- ***Is any finding that conflicts with your experience?***
- ***Which findings are most interesting or should be emphasized?(limit to 5 to 10)***

No.	Slide Page	Comments
1		
2		
3		
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No.	Slide Page	Comments
17		
18		
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24		
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26		
27		

Thank you for all your comments!!

Appendix F Validation Feedback Resolution Result

No.	FEEDBACK SOURCE	Slide	Comments	Response	# Responded	# Disagreed with or Neglected	# Already in Place/ No Change Needed
1	Mike Adel	Slide 22 - 27	more reliable data here would be better	Compare by group; remove sample differential cost comparison table; change from bar chart to box plot; better label	√		
2	Greg Welch	Slide 8	This is a very good slide	No response need			√

			demonstrating relationship between phase, impact and CSF.				
3	Michael Kluck	Slide 8	This graph seems to show what? Confusing?	Remove this slide from the literature review	√		
4	Richard Shirley	Slide 37	Slide is too busy	It's just to demonstrate how CSF Accomplishment was analyzed		√	
5	Richard Shirley	Slide 33	change "Fab site" to "Module Fab Site"	Changed	√		
6	Wayne Montgomery	Slide 13	participant	Corrected	√		

7	Ali Aga	All	Bullet texts very informative but need to be summarized more (8 to 10 lines /slide, 5 to 8 words /line)	I understand but in PhD research presentation, some complicated slides are needed.		√	
8	Ali Aga	Slide 4	needs to be updated;	Removed 2013 data	√		
9	Ali Aga	Slide 29	needs to be project wise for both charts	responded	√		
10	James T. O'Connor	Slide 22	highlight: limited access to productivity data	as I stated			√
11	James T. O'Connor	Slide 30	Correct: "Response" to "Respond"	Corrected	√		
12	James T.	Slide	Clarify X scale	Corrected	√		

	O'Connor	48					
13	James T. O'Connor	Slide 49	Flip Axes	Corrected	√		
14	James T. O'Connor	Slide 49	Remove "6" on X axis	Corrected	√		
15	James T. O'Connor	Slide 49	Y axis: (out of 21)	Corrected	√		
16	James T. O'Connor	Slide 49	use "more than xxx" than .7 &1	Corrected	√		
17	James T. O'Connor	Slide 50	Clarify x axis	Corrected	√		
18	James T. O'Connor	Slide 51	Show for each objective	Corrected	√		
19	Roy Chesbro	Slide 7	Maximum? Minimum?	It will make slide busier; Min. and Max. is obvious in this analysis		√	

20	Roy Chesbro	Slide 15	lot heavy weights on fabrication success; some impact from startup success due to pre-commissioning success	agree			√
21	James T. O'Connor	Slide 15	Logistic would be part of Construction; hookup and installation	Explained	√		
22	Steve Whitcomb	Slide 15	modularization success does not have much impact from Startup success	Conflict versus other expert's opinion			√
23	Ali Aga	Slide 15	Engineering is not just a input	agree			√

			factor;				
24	Roy Chesbro	Slide 15	What components contributes to modular success? Biggest contributing factor contributing to modular success is engineering success	adopted	√		
25	James T. O'Connor	Slide 15	You don't know modular success until fabrication and construction	agree			√
26	Roy & James	Slide 15	Engineering deliverables and timeness.	include explanation	√		
27	Roy &	Slide	Include	already in			√

	James	15	Procurement success	place				
28	Patrick Smith	Slide 15	It would have been better to measure modular success directly	agree but this approach is also valid		√		
29	James T. O'Connor	Slide 15	Procurement includes logistic	added explanation	√			
30	Steve Whitcomb	Slide 15	Logistic in Construction	added explanation	√			
31	Roy & James	Slide 15	Engineering was complete/procurement was complete is contributing factor	added explanation	√			
32	Multiple	Slide 15	There is a difference between	added explanation	√			

			onshore and offshore projects in modules (constraint, size, similar to stick-built)				
33	James T. O'Connor	Slide 15	Framing is part of engineering; Transport is part of construction; planning of materials is part of procurement	added explanation	√		
34	Michael Kluck	Slide 22	Productivity is very tough to gather; its internal to company and confidential	added explanation			√

35	Michael Kluck	Slide 22	In general, Chinese and South Asian countries lower productivity but there compensation cost is so much cheaper than US	added explanation	√		
36	Michael Kluck	Slide 22	Contractor usually have good Idea on productivity	agree			√
37	Mike Adel; Greg Welch	Slide 22	It's not apple to apple; It's by project by project	agree			√
38	Peter Van Dvyne	Slide 22	there might be over 200 fabshops and there are so	added explanation	√		

			much diversity				
39	Roy Chesbro	Slide 22	Fluor group is by region	No response need			√
40	Peter Van Dvyne	Slide 22	Consider site productivity and fabshop productivity rate is different in even in same region	added explanation	√		
41	Roy Chesbro	Slide 24	Most of our jobs modularize power distribution centers, dressed up vessels in preassembled; it's very common to the industry	added explanation	√		

42	James T. O'Connor	Slide 25	It's informative; list questions; what if no cost saving? There would be a case that there was a schedule saving and lose cost saving; that's not what industry would expect. It makes me nervous; these numbers kind of surprise me. It's not what I would expect	No response need			√
43	Peter Van Dvyne	Slide 25	It's hard to know unless you built it twice.	No response need			√

44	Patrick Smith	Slide 27	clarify "labor issues"	added explanation	√		
45	James T. O'Connor	Slide 27	make it clear that this is for entire project not limited to modularization; It's project difficulties	added explanation	√		
46	Michael Kluck	Slide 28	It should be "lack of design freeze"	Corrected	√		
47	James T. O'Connor	Slide 28	There are some overlaps with RT283's CSFs	No response need			√
48	James T. O'Connor	Slide 28	"Coordination" is bad label; in next research, should use different label	No response need			√
49	Kim Allen	Slide	It's a lesson	No response			√

		28	learn; We can learn from these projects; It's valuable finding	need			
50	Roy Chesbro	Slide 28	Materials would be one of the impediments	No response need			√
51	James T. O'Connor	Slide 29	compare by high modularization pool vs. low modularization pool	responded	√		
52	Michael Kluck	Slide 29	There is a project done for modular due to schedule but did not meet the schedule	added explanation	√		

53	James T. O'Connor	Slide 29	need to define the numbers; three = meets expectations; It's on different parameters - it should not present it same page	defined	√		
54	James T. O'Connor	Slide 29	It’s about the group thing; how the projects thought schedule was important and how did they do? How the projects thought cost was important and how did they	responded	√		

			do?				
55	Kim Allen	Slide 29	it's driver (what we expected) vs. actual	No response need			√
56	Patrick Smith	Slide 29	it should be interpreted as "Safety was better than we expected"	agree	√		
57	Patrick Smith	Slide 29	Truck-mounted size modules vs. 2000~6000 tone modules	No available due to lack of data		√	
58	Kim Allen	Slide 29	to do that you need to have enough N	agree			√
59	James T. O'Connor	Slide 30	It's third level benefits	agree			√

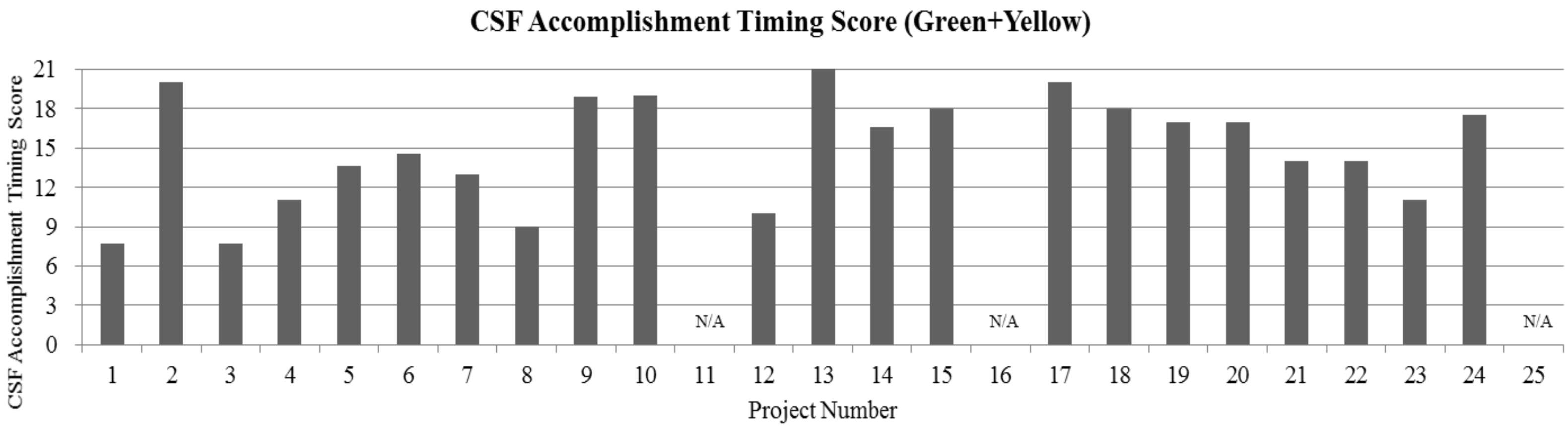
60	James T. O'Connor	Slide 31	what's the percentage said don't know or leave blank	fixed	√		
61	Michael Kluck	Slide 33	Industry is not doing well with estimating at jobsite and fabshop; whatever you guess on labor productivity, you will get lower productivity	agree			√
62	James T. O'Connor; Tim Heffron	Slide 33	It was really close to expectation on fabrication; median value is in-between	agree	√		

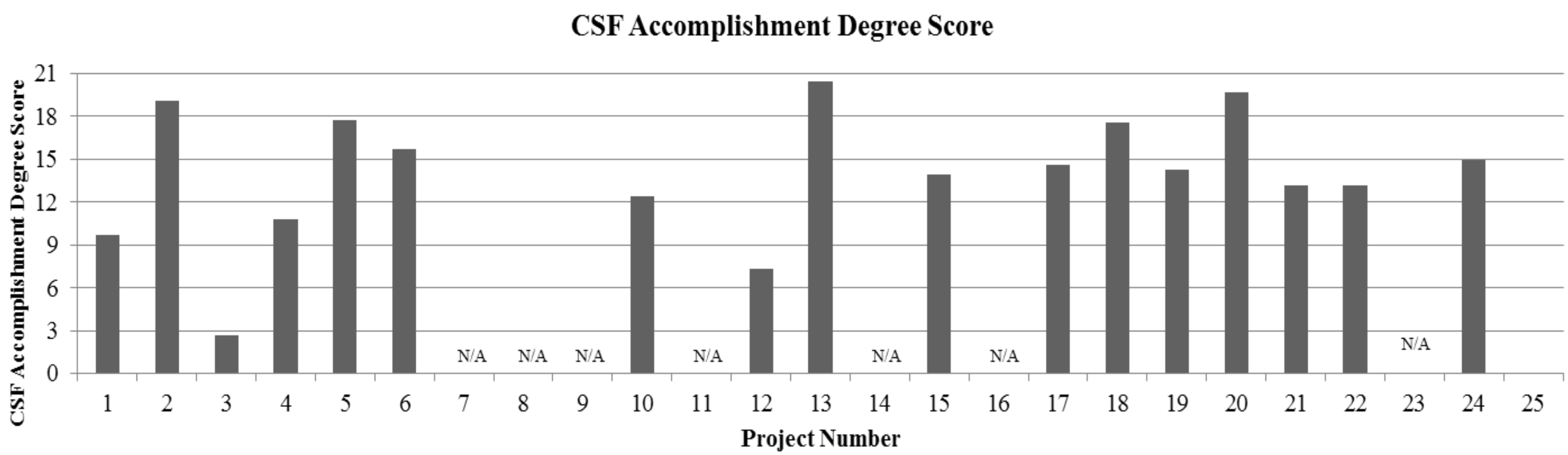
			meets expectation and below expectation; expecting fabshop productivity is better than jobsite				
63	James T. O'Connor; Jin Ouk Choi	Slide 37 &38	re-assessment on timing accomplishment is needed	fixed	√		
64	James T. O'Connor; Patrick Smith	Slide 43	Data collection on different group	responded	√		
65	Michael Kluck	Slide 43	green label vs. red label; experts expected vs.	No response need			√

			actual				
66	James T. O'Connor	Slide 43	one third of CSFs were well expected	No response need			√
67	James T. O'Connor	Slide 49	make it ceiling to 21	fixed	√		
68	Kim Allen	Slide 50	change ">" to "<"	fixed	√		
69	James T. O'Connor	Slide 50	".7&1" should change to "Mostly accomplished or fully accomplished"	fixed	√		
70	James T. O'Connor	Slide 49	what's R squared = amount of variation explained by that variable	No response need			√

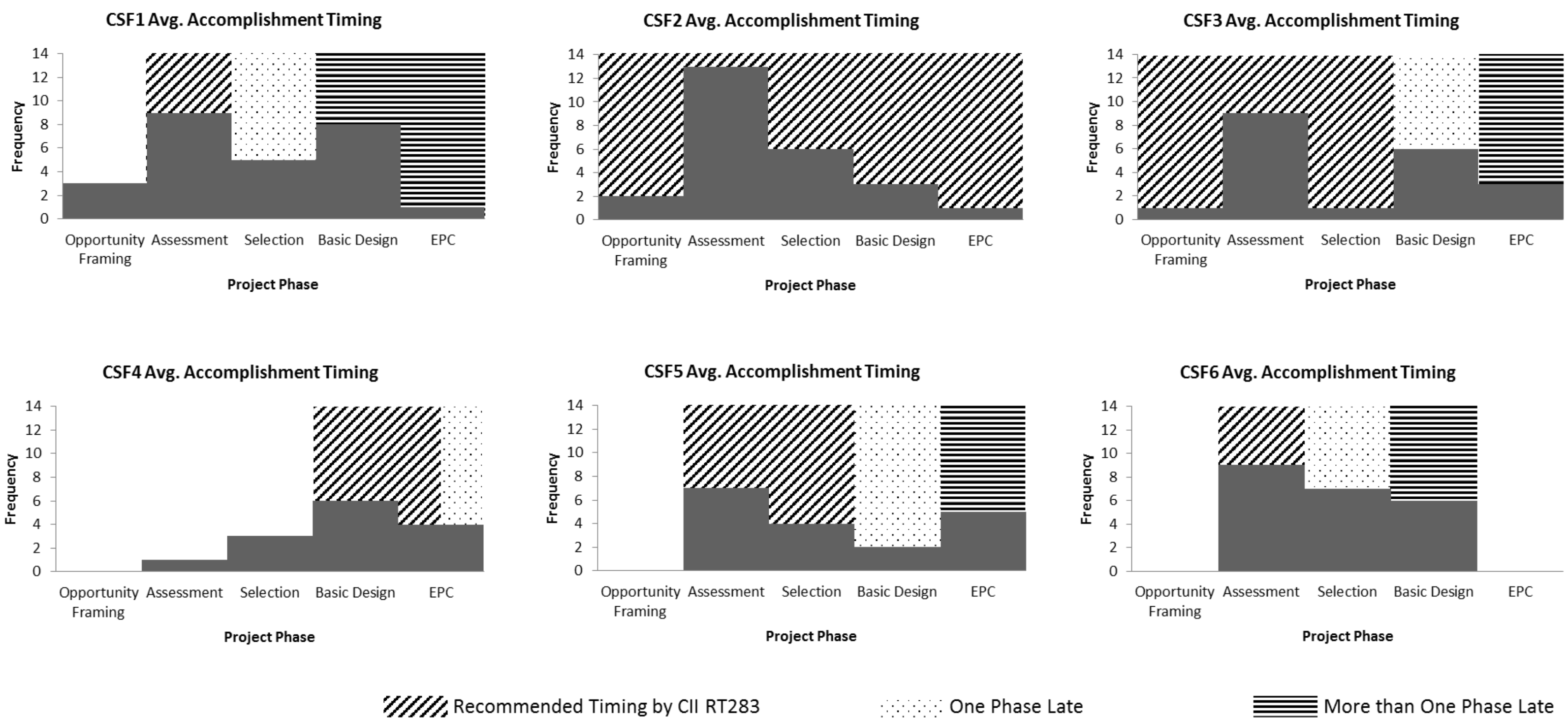
71	James T. O'Connor	Slide 49	amount of variation on cost explained by CSF accomplishment	No response need			√
72	James T. O'Connor	Slide 49	group by the projects with cost successful vs. not successful; projects with schedule successful vs. not successful	responded	√		
			Total Number	72	42	5	25

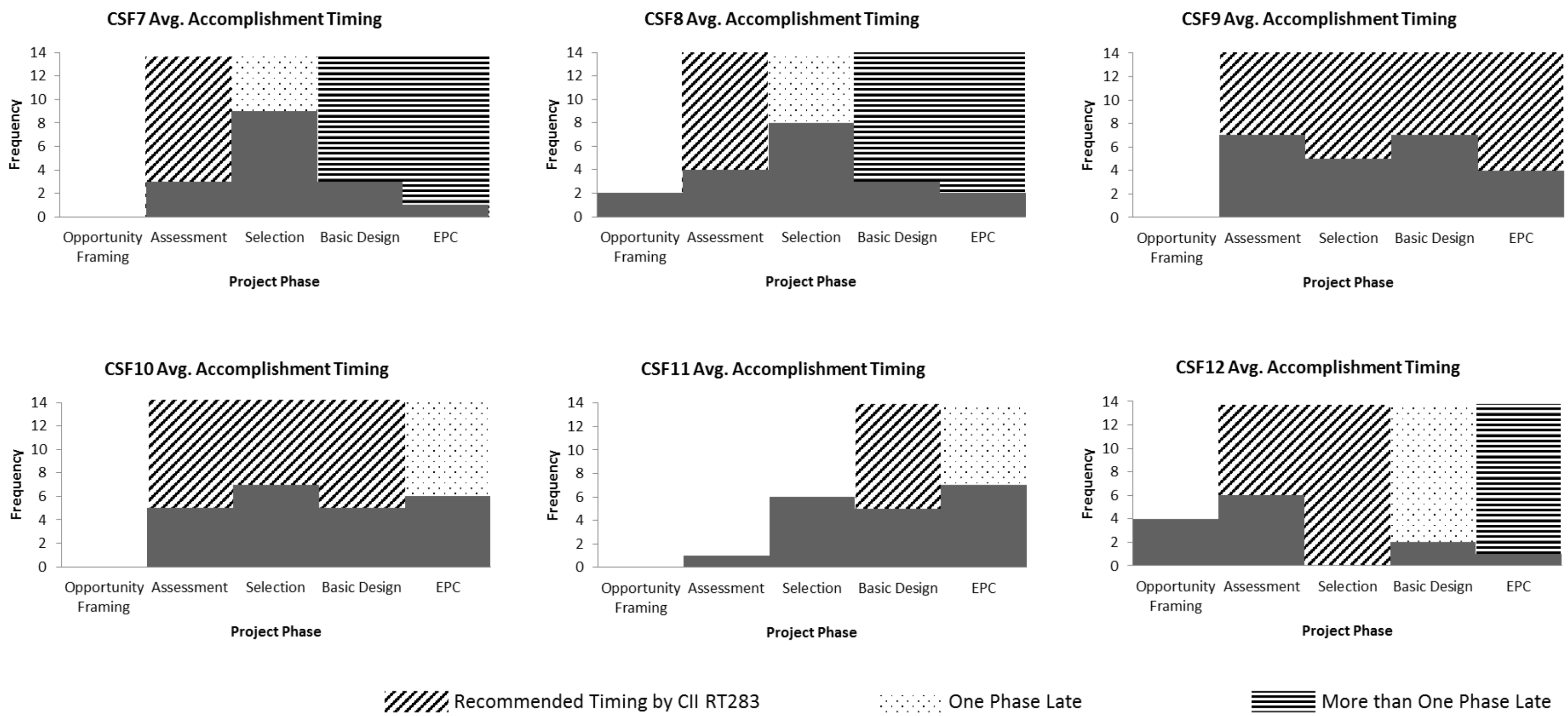
Appendix G CSF Accomplishment by Project

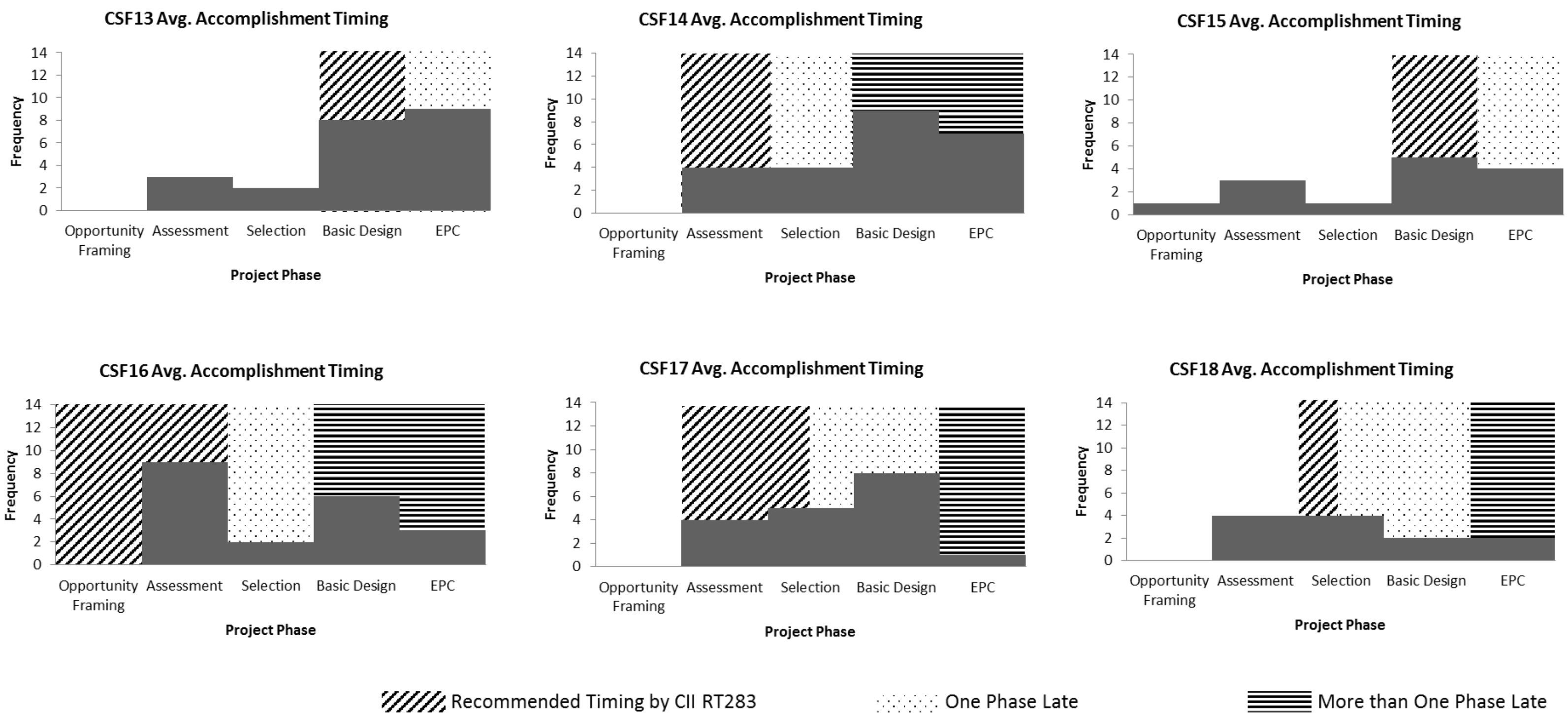


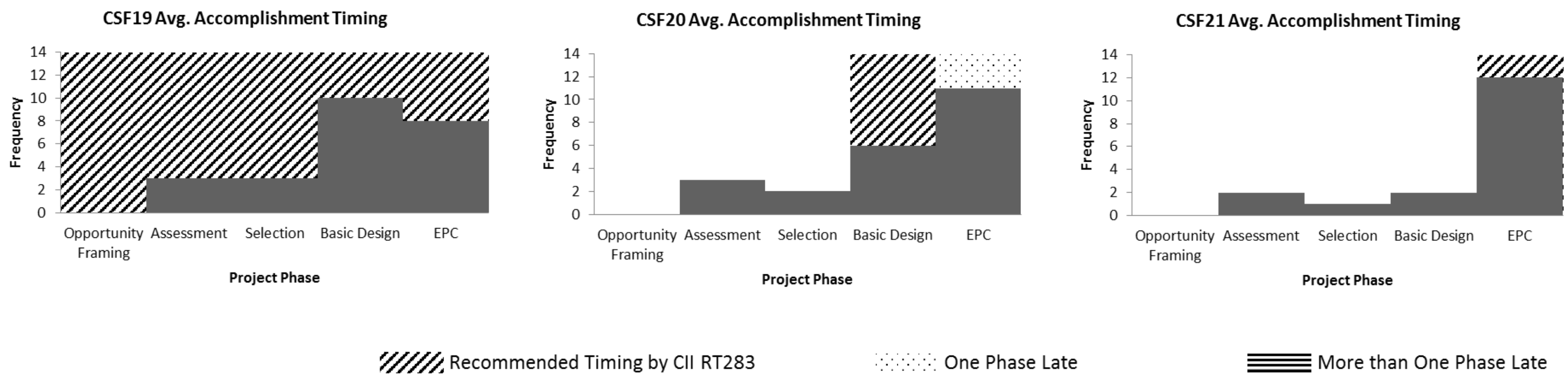


Appendix H CSF Accomplishment Timing by each CSF

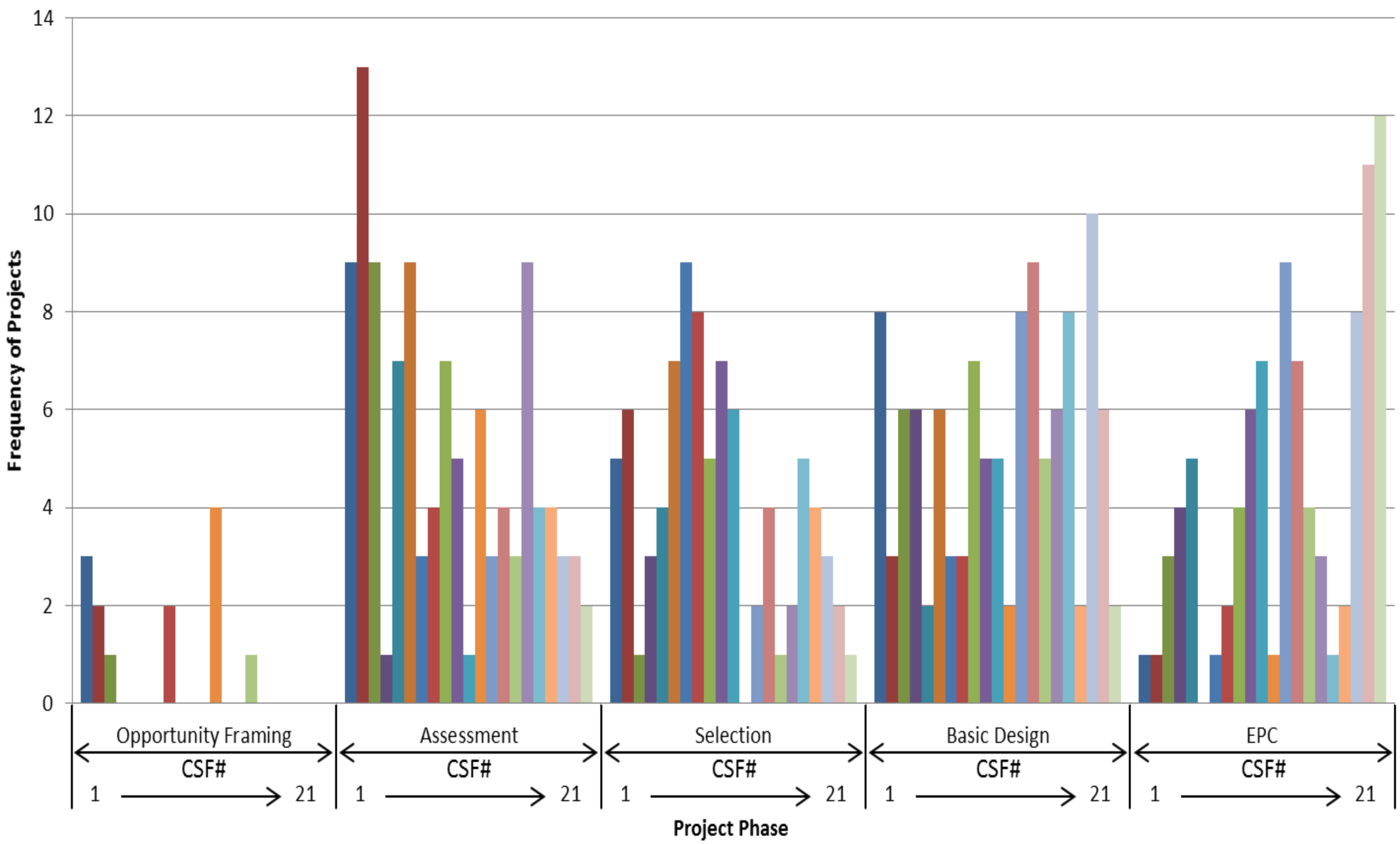



CSF7 Avg. Accomplishment Timing
CSF8 Avg. Accomplishment Timing
CSF9 Avg. Accomplishment Timing
CSF10 Avg. Accomplishment Timing
CSF11 Avg. Accomplishment Timing
CSF12 Avg. Accomplishment Timing
Frequency
0
2
4
6
8
10
12
14
Opportunity Framing
Assessment
Selection
Basic Design
EPC
Project Phase
Recommended Timing by CII RT283
One Phase Late
More than One Phase Late


CSF13 Avg. Accomplishment Timing
CSF14 Avg. Accomplishment Timing
CSF15 Avg. Accomplishment Timing
CSF16 Avg. Accomplishment Timing
CSF17 Avg. Accomplishment Timing
CSF18 Avg. Accomplishment Timing
Frequency
0
2
4
6
8
10
12
14
Opportunity Framing
Assessment
Selection
Basic Design
EPC
Project Phase
Recommended Timing by CII RT283
One Phase Late
More than One Phase Late


CSF19 Avg. Accomplishment Timing
CSF20 Avg. Accomplishment Timing
CSF21 Avg. Accomplishment Timing
Frequency
Project Phase
Opportunity Framing
Assessment
Selection
Basic Design
EPC
Recommended Timing by CII RT283
One Phase Late
More than One Phase Late

Appendix I Distribution of Actual Projects CSF Accomplishment by Project Phase



Appendix J Participants in Validation

Name	Company
Mike Adel	Access Midstream
Greg Welch	Burns & McDonnell
Peter Van Dvyne	CB&I
Roy Chesbro	Fluor
Michael Kluck	KBR
Steve Whitcomb	McDermott
Richard Shirley	Audubon
Wayne Montgomery	Worley Parsons
Ali Aga	Technip
Toby Tschoepe	Kiewit
Patrick Smith	Shell
Tim Heffron	Lauren
James T. O'Connor	The University of Texas at Austin
Kim Allen	Construction Industry Institute

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