Construction Industry Institute®

Industrial Modularization:

How to Optimize; How to Maximize

Research Summary 283-1

Construction Industry Institute

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How to Optimize; How to Maximize

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December 2012

Printed in the United States of America.

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Executive Summary

The industrial sector of the capital projects industry is clearly in need of additional guidance on when and how to exploit the benefits of modularization. While the benefits of applying a modular approach to industrial projects—when compared to those of a conventional stick-built approach—can vary in nature and be very significant, the industry has been slow to achieve high levels of modularization. Some would say that the industry has hit a ceiling in terms of the percentage of stick-built work hours being exported offsite.

CII charged Research Team (RT) 283 with responding to this situation, and the team formulated its essential question in the following way:

> ***What changes or adaptations in traditional project work processes are required to create an optimal environment for broader and more effective use of modularization?***

Focusing on the industrial sector of the capital projects industry, the team sought to compare an idealized all-modular work process with current, largely stick-built work processes, and to identify key high-value practices that are in need of change. The research methodology included a literature review, surveys, case studies, and external validation, among other features.

Findings from this research led to the development of ***five distinct solution elements***:

- a business case process
- execution plan differences
- critical success factors
- a standardization strategy
- modularization maximization enablers.

Because each of these elements is significant in its own way and should play an important role in achieving higher levels of modularization, industry leaders and project managers should be attentive to them.

1. **Business case process**. The modularization business case process should be applied at the earliest opportunity. It should start as early as the Opportunity Framing phase and be analyzed in greater depth during the Assessment phase. For the industry to truly advance, project teams would be better served by making the modular approach the default approach.
2. **Execution plan differences**. The research team identified more than 100 differences between how modular and stick-built projects should be planned and executed. Moreover, the team assigned these different planning and execution processes to their appropriate phases of implementation. Nearly half of them are applicable during the Basic Design phase.
3. **Critical success factors**. The research team identified 21 high-impact critical success factors (CSFs), noting that the industry appears to be having difficulty achieving many of them. Owner responsibilities for CSF achievement during the Assessment and Selection phases are especially significant.
4. **Standardization strategy**. The benefits of combining modularization with design standardization can exceed the additive sum, and therefore deserve special consideration. Two basic approaches exist: 1) the development of standardized modules; and 2) the development of modular standardized plants (MSPs). The business case for standardization should recognize 10 types of economic advantages and three types of economic disadvantages or tradeoffs. The research team developed an eight-step implementation process for the MSP strategy; the team also performed an MSP case study to provide further insight into strategy implementation.
5. **Modularization maximization enablers**. Lastly, industry-wide barriers continue to challenge the broad-based application of modularization. The fifth solution element consists of a listing of 10 counter-measures to these industry-level challenges.

1

Introduction

Modularization entails the large-scale transfer of stick-built construction effort from the jobsite to one or more local or distant fabrication shops/yards in order to exploit one or more strategic advantages. Thus, modularization may be considered a form of project business/execution strategy with unique benefits. Over the last 25 years, modularization has proven to be particularly relevant to the industrial sector of the capital projects industry.

Yet the industrial sector is in need of additional guidance on when and how it can more effectively exploit modularization. While the benefits of modularization vary in nature and can be significant, industry has generally been slow to exploit this approach and, except under extreme conditions, has not implemented higher levels of modularization. Some would say that the industry has hit a ceiling in terms of the percentage of stick-built work hours being exported to fabrication shops and yards.

CII Research Team (RT) 283 was charged with addressing this situation and developed its essential question in the following way:

> ***What changes or adaptations in traditional project work processes are required to create an optimal environment for broader and more effective use of modularization?***

As implied in the essential question, the reader should recognize that this research summary is not focused on promoting or marketing the concept of modularization, but rather on helping project teams better determine whether modularization is the right strategy for a given project—and if so, how to most successfully implement the strategy. Certainly, many different forms of benefit (such as cost or schedule savings) may result from the modular approach, and these should be examined thoroughly through the recommended business case process.

In its effort to identify key high-value project processes that are in need of change, the team sought to compare an idealized all-modular work process with current, largely stick-built work processes. In addition to finding these processes, the team sought to identify and characterize related critical success factors, and to identify and describe industry-level strategies that, together, can help the industry move toward higher levels of modularization.

The study's scope limitations included the following:

- While many findings from this effort may apply to portions of commercial and infrastructure capital projects, the scope of the study primarily covered the industrial sector of the capital projects industry, which includes process and manufacturing facility projects such as offshore facilities, petrochemical plants, power plants, and pharmaceutical plants, among other manufacturing and processing facilities.
- In contrast to the original, narrower charge from the CII Research Committee, the study scope was deliberately broadened to include front end planning-related and equipment manufacturer-related aspects of modularization.
- While plant design standardization is examined in the context of modularization, it is not addressed in any depth for conventional stick-built projects.

To ensure alignment and to establish a foundation for subsequent developments, the team needed an initial clarification of terminology. Two key terms include the following:

- **Module**: a portion of plant fully fabricated, assembled, and tested away from the final site placement, in so far as is practical
- **Percent modularization**: a portion of original site-based work hours (excluding site preparation and demolition) exported to fabrication shops.

This publication is organized as follows:

- a research methodology overview
  - data collection
  - case studies
  - validation
- an overview of five different solution elements
  - business case process
  - execution plan differences
  - critical success factors
  - standardization strategy
  - modularization maximization enablers
- brief descriptions of each of the five solution elements
- conclusions and recommendations.

Readers seeking deeper explanations of the five solution elements are directed to Research Report (RR) 283-11, *Industrial Modularization: How to Optimize; How to Maximize*.

2

Methodology

To illustrates how each of the five solution elements (enumerated and shown in blue) fits into the overall process, Figure 1 provides a graphic overview of the methodology of this research. The process of industrial modularization is well established, and its values and benefits have generally been recognized since it was originally introduced. The literature review conducted in this study investigated the uses of modularization and the benefits it can offer, in terms of increased productivity, lower capital costs, greater quality, reduced waste, and better environmental performance. Beyond its investigation into benefits, the team also documented learnings pertaining to modularization impediments/barriers, comparative pros and cons of modularization, and industry approaches to overcoming the impediments to modularization. The detailed findings of this review may be found in the literature review segment of RR 283-11, *Industrial Modularization: How to Optimize; How to Maximize*.

The broad experience of the research team itself provided the foundation for the development of all five solution elements. The team was composed of extremely well-qualified modularization experts, as evidenced by the team characteristics:

- 17 industry representatives: six owners and 11 contractors
- 450+ years of industry experience
- 170+ modular projects in 13 different countries within the last five years.

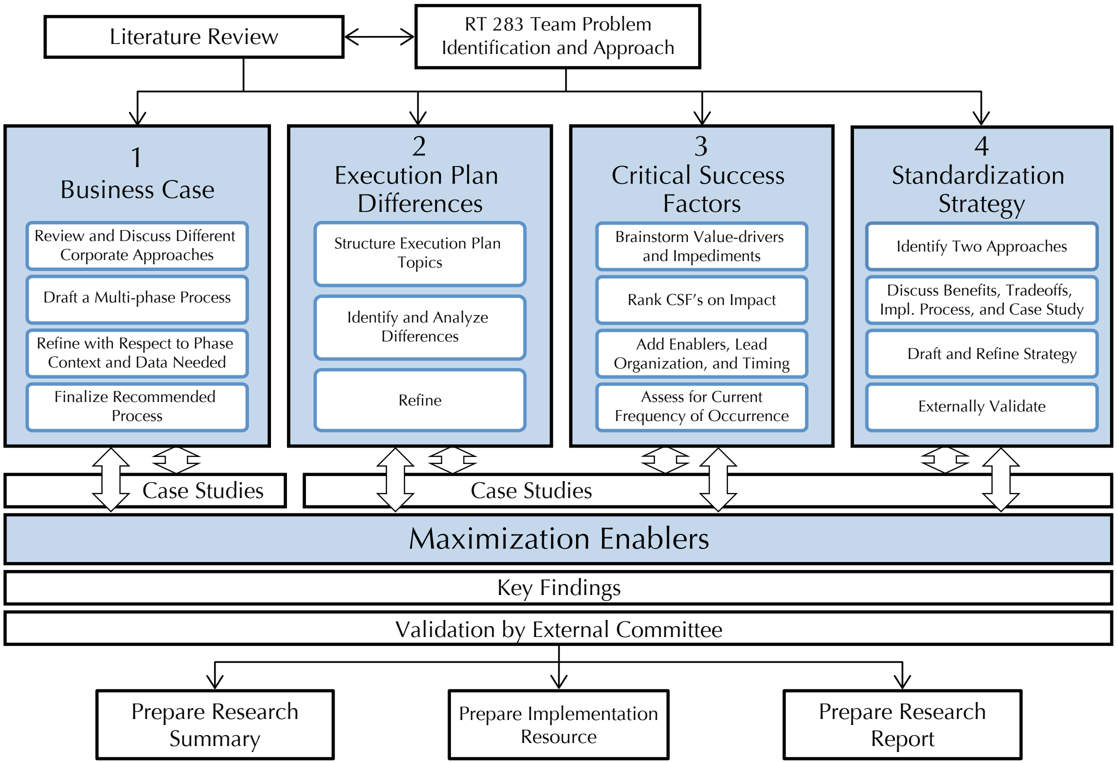

Figure 1. RT 283 Research Methodology

Each of the five solution elements evolved independently from one another and each underwent multiple iterative refinements. For example, the 21 critical success factors emerged from an impact assessment of a longer listing of 72 brainstormed factors, and the research team conducted five review iterations of both the business case process and the execution plan differences. After developing the five solution elements, the team created the flag graphic in Figure 2 to illustrate their interrelationships. (See Chapter 3, page 11.)

To assess the significance of the critical success factors (CSFs) and the frequency of their occurrence or accomplishment, the team surveyed both its own members and external modularization authorities. (Details on the survey instruments may be found in RR 283-11.)

The team further conducted three modularization project case studies, documenting them in detail and extracting key learnings from them. These learnings generally pertained to modularization work scope, barriers to higher levels of modularization, links with project performance, and modularization-related lessons learned. As indicated in Figure 1, case study learnings were used primarily to cross-check or further enhance the descriptions of one or more of the five solution elements. One of the three case studies focused on how the team's standardization strategy works in power plants. This case study is overviewed in Implementation Resource (IR) 283-2, *Industrial Modularization: Five Solution Elements*. (Details of all three case studies may be found in RR 283-11.)

After the team developed all five solution elements, an independent external committee comprising 14 modularization authorities reviewed them for validity. Collectively, the members of this validation committee had over 450 years of industry experience and had worked on over 120 modular projects within the last five years. The research team collected the detailed feedback these independent reviewers provided, and incorporated it into its research products. In general, these comments were helpful for refining, expanding, and/or confirming the various findings and messages contained in the five solution elements. (An overview of reviewer comments, commentary on issues resolution, and details on the background of the external reviewers may be found in RR 283-11.)

3

Findings: Five Solution Elements

This research effort led to the development of five distinct solution elements: 1) business case process, 2) execution plan differences, 3) critical success factors, 4) standardization strategy, and 5) modularization maximization enablers. Each of these elements differs with respect to breadth of intent, phase(s) when applicable, and primary audience, as shown in Table 1.

Table 1. Characteristics of Five Solution Elements

Solution Element	Breadth	Project Phases	Primary Audience
Business Case Process	Project level	Assessment through Basic Design	Project leaders
Execution Plan Differences	Project level	Selection, Basic Design, and EPC	Project managers
Critical Success Factors	Project level	All phases	Project team
Standardization Strategy	Business unit level	Opportunity Framing or earlier	Business strategists
Modularization Maximization Enablers	Industry level	Opportunity Framing or earlier	Industry leaders

Each element, in its own way, plays an important role in the achievement of optimal levels of modularization. The general questions that each element addresses are as follows:

Business Case Process: How can project teams assess all the benefits and costs of the modular approach? What is the optimal level of modularization for the project? When should the business case be assessed? With what information should it be assessed? How does the business case fit within the context of project development?

Execution Plan Differences: How is the implementation of modularization different from that of a stick-built approach? How is this difference reflected in project planning and execution?

Critical Success Factors: What are the CSFs that can drive success with modularization? Who is responsible for these? When are they most critical? How frequently is each achieved—and what special efforts are needed?

Standardization Strategy: How does design standardization relate to modularization? What forms of standardization are most relevant in the modular context? What are the compound benefits—and what are the tradeoffs? How can an owner, contractor, or module manufacturer create or establish a standardized modular plant? What steps are necessary?

Modularization Maximization Enablers: What are the industry-wide barriers to higher levels of modularization? What must the industry do to overcome these impediments?

Figure 2 presents a flag graphic of the five solution elements and their relationships to one another. The project-level process is initiated with the business case, which dovetails with differences in execution planning. Attention to critical success factors reinforces both of these efforts. For some business units, prior to project initiation, the standardization strategy will offer opportunities for leveraged benefits from modularization. Lastly, the maximization of modularization will only happen with an industry-level focus on the 10 maximization enablers identified from this research.

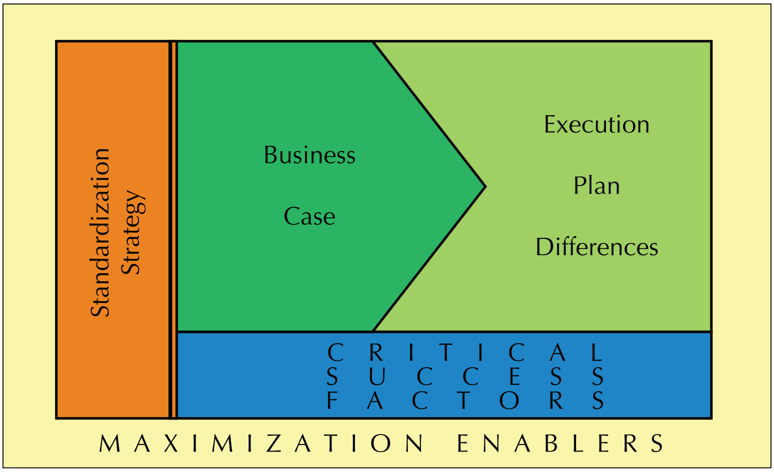

Figure 2. Five Solution Elements Flag

Business Case Process

Modularization can offer many project benefits, and these should be examined in a timely fashion. The modularization business case process is recommended for all projects that are considering the modular approach. The modular approach should be considered the default approach, since it requires little additional investment and since it is more cost-effective to later convert a modular solution to stick-built, if necessary, than vice-versa. Thus, owners should adopt the business case process presented in IR 283-2 as standard procedure.

Analysis should begin as early as practicable, which—for some—may be at the beginning of the Opportunity Framing phase. Detailed analysis should begin in the Assessment phase and be refined iteratively, in conjunction with project stage gates or with the development of each successive project cost estimate. Figure 3 depicts the influence of the modularization decision within the context of typical project phases and associated decision-gate milestones.

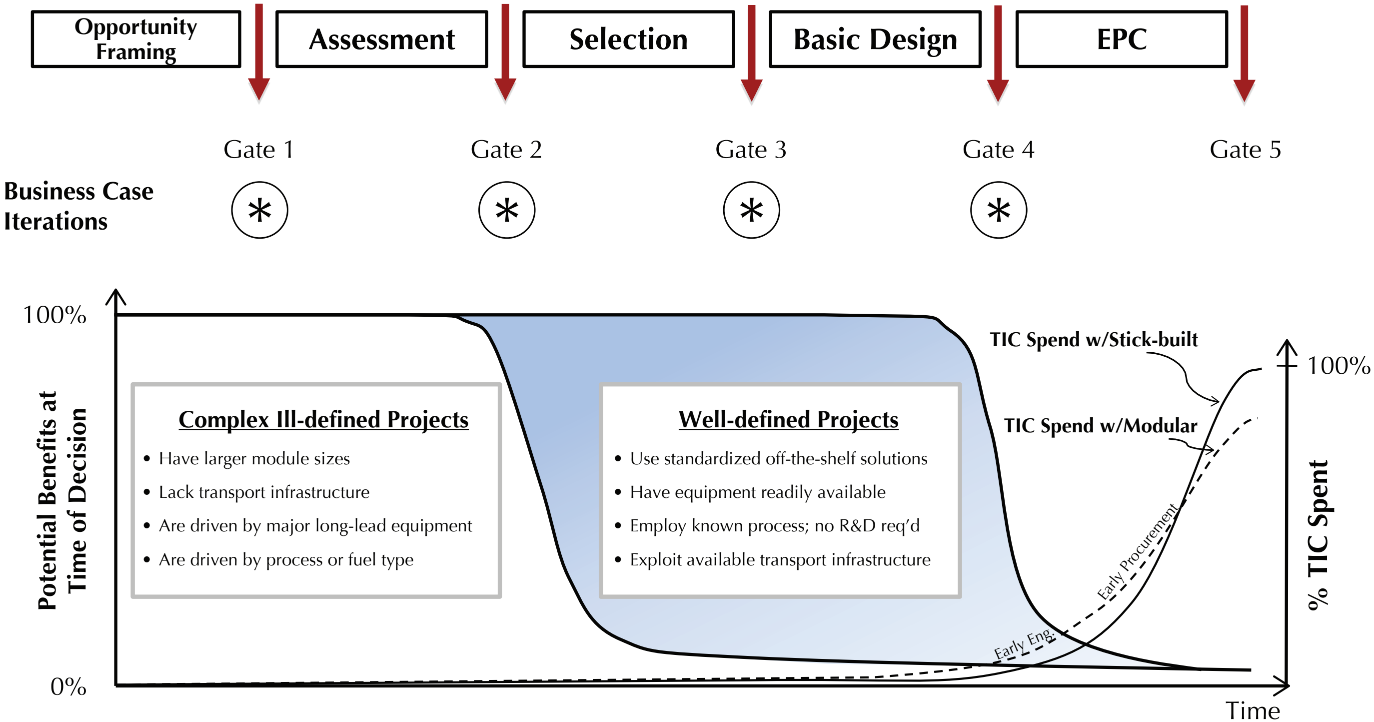

Figure 3. Timing and Iterations of the Modularization Business Case

Optimal modular project execution is achieved by *initiating* detailed module-specific analyses no later than the Assessment phase. Failure to do so at this project phase does not necessarily result in an inability to modularize, it simply limits the opportunity to develop the most cost-effective solution at minimal risk. As a project progresses, the ability to make substantive choices about modularization diminishes. For some projects, it may be possible to delay modularization choices, but the delay may reduce potential benefits. Project-specific factors dictate the optimal timing of adoption.

Analyses at the Opportunity Framing and Assessment phases give the owner the best opportunity to determine an optimal modular execution approach. Detailed analysis is needed to answer the question "What percentage of work hours should be moved offsite through modularization?" As illustrated in Figure 4, the recommended modularization business case process brings rigor to this analysis by plotting net present values against percentage of work hours moved offsite for different modularization scenarios. Net present value is determined by assessing the benefits and costs associated with each individual modularization scenario and computing discounted cash flows. For example, early owner sales revenues resulting from early project completion and reduction in scaffolding expenses are examples of benefits that should be factored into the analysis. As indicated in the figure, the analysis generates "sweet spot" modularization scenarios or approaches.

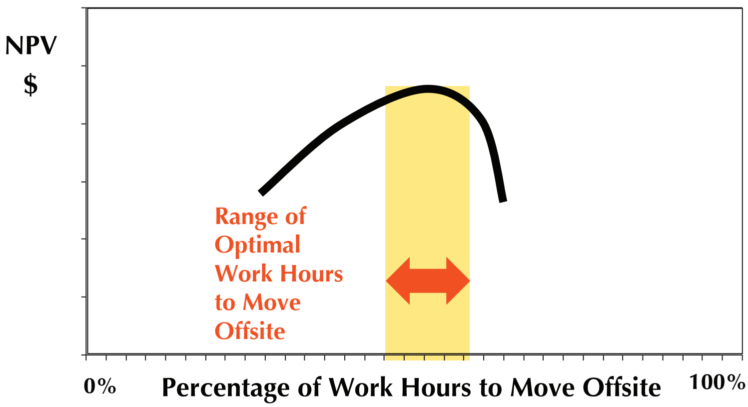

Figure 4. Optimal Percentage of Project Work Hours to Move Offsite

Execution Plan Differences for Modular Implementation

Effective project execution plans are an increasingly critical ingredient for overall project success, whether a project is modular or stick-built. The successful implementation of project modularization requires project execution planning that is significantly different from that of stick-built projects. The research team has identified many of these differences, and they are presented in detail in IR 283-2. The intended audience for these execution plan differences includes all project managers and planners involved in preparing project execution plans.

The team identified more than 100 planning difference items, and organized them according to the following project phase-oriented planning topics:

A. Plans for SELECTION

1. Project Objectives
2. Organization and Staffing
3. HSSE and Social Impacts
4. Craft Labor Relations
5. Contract Strategy

6. Procurement Strategy and Owner-furnished Equipment
7. Planning and Cost Estimating
8. Transport Route Study and Planning
9. Risk Management

B. Plans for BASIC DESIGN

1. Stakeholder Alignment and Reframing
2. Modularization Scoping, Layout Process, and Plot Plan
3. Fabricators, Contractors, and Subcontractors
4. Methods, Heavy Lifts, and Construction Facilities
5. Procurement, Vendor Data, and Expediting
6. Basic Design Standards, Models, and Deliverables
7. Modularization Business Case Validation/Refinement
8. Scope Freeze and Change Management

C. Plans for EPC

1. Project Controls and Site Management
2. Quality Assurance/Quality Control
3. Detailed Design Deliverables
4. System Testing, Commissioning, and Start-up

An example of an execution plan difference, as presented in IR 283-2, is as follows:

A-8 Transport Route Study and Planning

1. ***Ideally, the route study begins during Assessment and continues through Selection. Early estimates of module envelope sizes and weights will be needed as inputs for both the fabrication and transport contracting processes.***

Table 2 presents the distribution of the identified execution plan difference items across the project phases.

Table 2. Distribution of Execution Plan Difference Items by Project Phase

Project Phase	Percentage of Execution Plan Differences
Selection	35%
Basic Design	43%
EPC	22%

78% Prior to EPC

While the plan difference items are well-distributed across all three project phases, it should be noted that they are mostly relevant *prior* to the EPC phase. Furthermore, when examined at the topic level (not shown in the table), nearly 40 percent of the plan differences pertain to just four topics:

- A-7 Planning and cost estimating
- B-2 Modularization scoping, layout process, and plot plan
- B-6 Basic design standards, models, and deliverables
- C-3 Detailed design deliverables.

Thus, differences in execution plans should be addressed as one of the five solution elements needed to successfully achieve higher levels of modularization.

Critical Success Factors

To formally identify critical success factors for modularization, the research team—along with additional external modularization experts—started with a brainstormed listing of 72 potential factors and ranked the factors according to relative typical project impact or significance. As shown in Table 3, a total of 21 high-impact factors surfaced, with impact ratings of 3.0 or more on a 4.0 scale.

Table 3. Critical Success Factors for Modularization

#	Impact (out of 4)	Critical Success Factor
1	3.83	**MODULE ENVELOPE LIMITATIONS**: A preliminary transportation evaluation will give the project team an understanding of module envelope limitations.
2	3.79	**ALIGNMENT ON DRIVERS**: Owner, consultants, and critical stakeholders are aligned on important project drivers as early in the process as possible in order to establish the foundation for a modular approach.
3	3.58	**OWNER'S PLANNING RESOURCES AND PROCESSES**: Owner's front-end planning and decision support systems, work processes, and team resources support early modular feasibility analysis as a potentially viable alternative to conventional stick-building. Owner "comfort zones" are not limited to the stick-built approach.
4	3.58	**TIMELY DESIGN FREEZE**: Owner and contractor are sufficiently disciplined to effectively implement timely, staged design freezes so that modularization can proceed as planned.
5	3.42	**EARLY COMPLETION RECOGNITION**: The modularization business case recognizes and incorporates the economic benefits of the early project completion that results from modularization; it also recognizes the benefits that result from minimal site presence and/or reduction of the risk of schedule overrun.
6	3.42	**PRELIMINARY MODULE DEFINITION**: Front-end planners and designers know how to effectively define the scope of modules in a timely fashion.
7	3.42	**OWNER-FURNISHED/LONG-LEAD EQUIPMENT SPECIFICATION**: Owner-furnished and long-lead equipment (OFE) specifications and delivery lead times support a modular approach.

#	Impact (out of 4)	Critical Success Factor
8	3.42	**COST SAVINGS RECOGNITION**: The modularization business case incorporates all cost savings that can accrue from the modular approach. Project teams avoid the knee-jerk misperception that modularization always has a net cost increase.
9	3.39	**CONTRACTOR LEADERSHIP**: The front-end contractor(s) are proactive—supporting the modular approach on a timely basis and prompting owner support, even when it is not initiated.
10	3.37	**CONTRACTOR EXPERIENCE**: Contractors (supporting all phases) have sufficient previous project experience with the modular approach.
11	3.37	**MODULE FABRICATOR CAPABILITY**: Available, well-equipped module fabricators have adequate craft, skilled in high-quality/tight-tolerance modular fabrication.
12	3.32	**INVESTMENT IN STUDIES**: The owner is willing to invest in early studies into modularization opportunities in order to capture the full benefit of the approach.
13	3.32	**HEAVY LIFT/SITE TRANSPORT CAPABILITIES**: Needed heavy lift/site transport equipment and associated planning/execution skills are available and cost-competitive.
14	3.28	**VENDOR INVOLVEMENT**: OEMs and technology partners are integrated into the modularization solution process in order to maximize related beneficial opportunities.
15	3.26	**O&M PROVISIONS**: Module detailed designs incorporate and maintain established O&M space and access needs.
16	3.22	**TRANSPORT INFRASTRUCTURE**: Needed local transport infrastructure is available or can be upgraded/modified in a timely fashion while remaining cost-competitive.

#	Impact (out of 4)	Critical Success Factor
17	3.16	**OWNER DELAY AVOIDANCE**: The owner has sufficient resources and discipline to be able to prevent delays in commitments on commercial contracts, technical scope, and financial matters.
18	3.05	**DATA FOR OPTIMIZATION**: Owner and Pre-FEED/ FEED contractor(s) have management tools and data to determine the optimal extent of modularization, i.e., maximum NPV (that considers early revenue streams) versus % modularization.
19	3.00	**CONTINUITY THROUGH PROJECT PHASES**: Disconnects in any contractual transitions between Assessment, Selection, Basic Design, and Detailed Design phases are avoided, since their impacts can be amplified with modularization.
20	3.00	**MANAGEMENT OF EXECUTION RISKS**: Project risk managers are prepared to deal with any risks shifted from the field to engineering/procurement functions.
21	3.00	**TRANSPORT DELAY AVOIDANCE**: 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.

After identifying these CSFs, the team subsequently analyzed each one for optimal timing of implementation and for the most appropriate responsible or lead organization. In addition, enablers that can be helpful during implementation were identified for each CSF. An example of these findings is illustrated in Table 4. As it did with the business case process, the team examined implementation timing of the CSFs relative to six project phases: Opportunity Framing, Assessment, Selection, Basic Design, Execution (including detailed design and construction), and Start-up. The pie charts in Figure 5 illustrate the CSF timing and responsibility distribution findings.

Table 4. Example of Critical Success Factor Analysis and Associated Enablers

<table>
<tr><th><u>#</u></th><th colspan="2"><u>Critical Success Factor</u></th><th><u>Enablers</u></th></tr>
<tr><td rowspan="4">1</td><td colspan="2">MODULE ENVELOPE LIMITATIONS</td><td rowspan="4">A. Early logistics and transportation evaluation identifies the costs, critical constraints, and risks of transportation from the proposed fabrication yard locations to the workface.

B. The owner and pre-FEED contractor are familiar with existing plans to upgrade the regional transportation infrastructure.

C. STRETCH: Master plan a new greenfield industrial city (like Jubail) with complete infrastructure to enable high levels of modularization.</td></tr>
<tr><td colspan="2">Preliminary transportation evaluation will give the project team an understanding of module envelope limitations.</td></tr>
<tr><td>Opt. Timing</td><td>Starting in Assessment</td></tr>
<tr><td>Lead Party</td><td>Owner</td></tr>
</table>

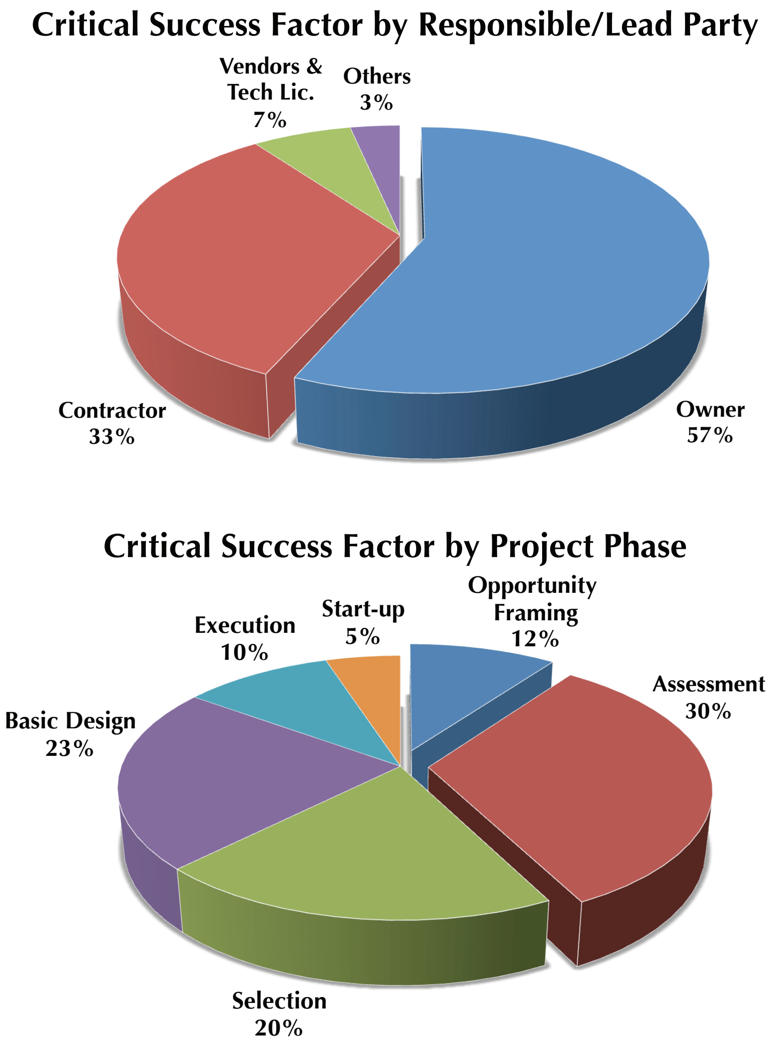

Figure 5. Responsibility and Timing of Critical Success Factors

Most of the 21 success factors are relevant *prior to the EPC* or Execution phase, with the largest share (nearly one-third) occurring during the Assessment phase. 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.*

CSFs were also assessed by modularization authorities for current frequency of implementation. The intent was to determine the factors that are most commonly implemented and those that continue to present difficulties to the industry, companies, and project teams. The findings are presented in the stairway diagram in Figure 6, which indicates how much farther project teams have to climb to be more effective and successful at implementing modularization.

CSFs assessed as occasional, rare, or very rare are in particular need of attention. All organizations involved in projects should be attentive to the CSFs. IR 283-2 provides more descriptive details of these factors, including a listing of all identified CSF enablers.

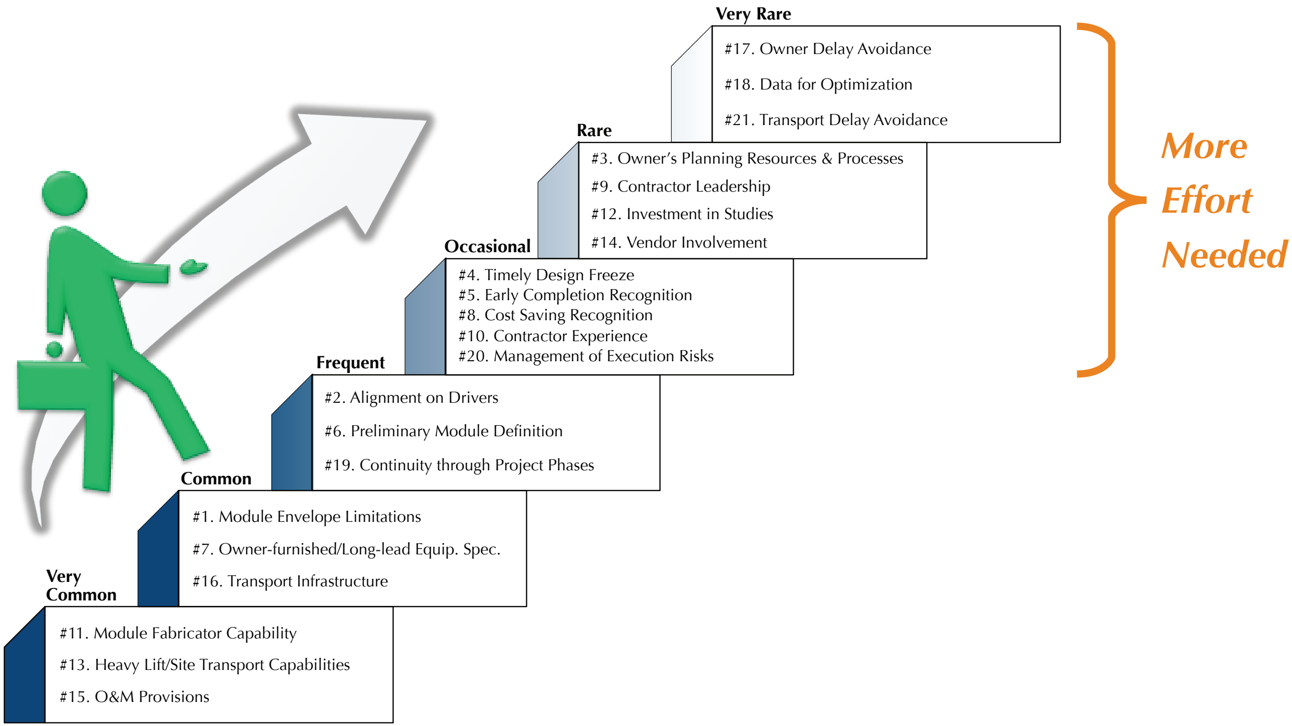

Figure 6. Critical Success Factor Frequency Stairway (#s Indicate CSF Impact Rankings)

Standardization Strategy

Previous CII research on the shipbuilding industry highlighted significant benefits from modular solutions based on standardized designs (CII 2007, 2011). RT 283 compared the extent of modularization with the extent of design standardization in different sectors of the capital projects industry. Figure 7 depicts the current approximate state of the industry, and shows that the long-term trend is toward increasing levels of both modularization and design standardization.

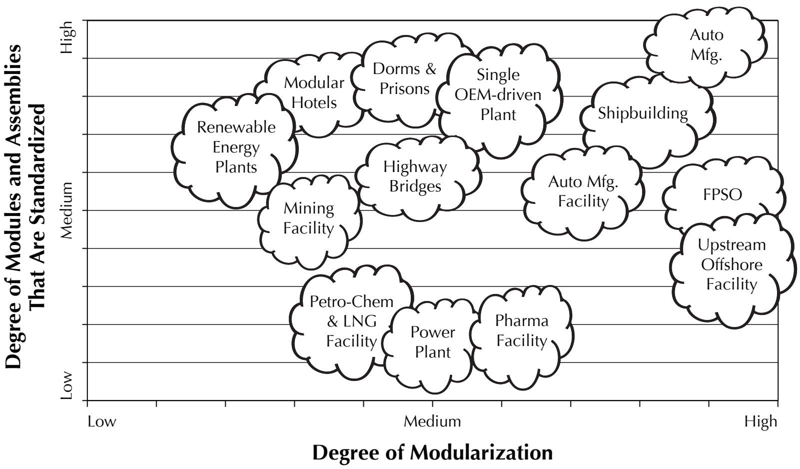

Figure 7. Modularization vs. Standardization: Approximate Current Sector Levels

Further examination indicated that the benefits of modularization can be leveraged with the standardization of facility design, whether at the plant, unit, or module level. Figure 8 illustrates two different approaches to such integration, one leading to standard modules, the other leading to modular standardized plants (MSPs).

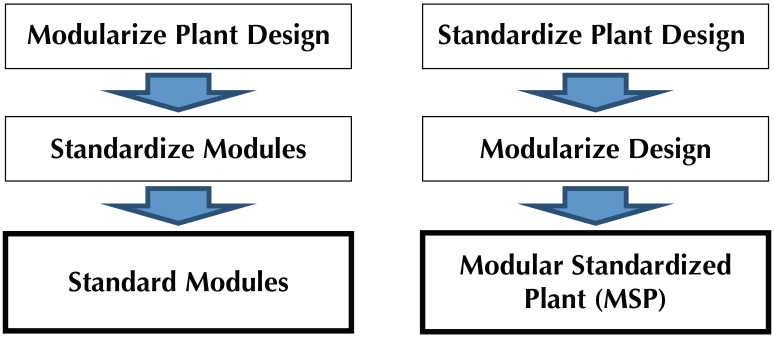

Figure 8. Two Approaches to Integrating Design Standardization with Modularization

Ten types of economic advantages or benefits can result from plant design standardization, and some of these can be further leveraged or amplified when coupled with modularization:

- Design only once and build/fabricate many times.
- Design and procure in advance; respond to schedule needs.
- Implement accelerated, parallel engineering for site adaptation.
- Gain learning curve benefits in *fabrication*.
- Realize procurement discounts from volume and/or early commitment.
- Realize construction materials management cost savings.
- Gain learning curve benefits in *module installation/site construction*.
- Gain learning curve benefits in *commissioning/start-up (planning and execution)*.
- Gain learning curve benefits in *operations and maintenance* (O&M) (given clients with multiple similar plants).
- Realize O&M materials management cost savings.

However, some tradeoffs do exist, and three types of economic disadvantages, or "disbenefits," can result from design standardization:

- costs of assessing the market and establishing scope for the standard design
- costs of establishing the design standard
- sacrificed benefits from conventional customization.

These tradeoffs must be recognized and factored into the MSP business case. And all of the benefits and tradeoffs must be examined in the context of fixed and variable costs. Figure 9 presents the economics of the MSP approach when variable cost reductions (or benefits) exceed the added variable costs from sacrificed customization.

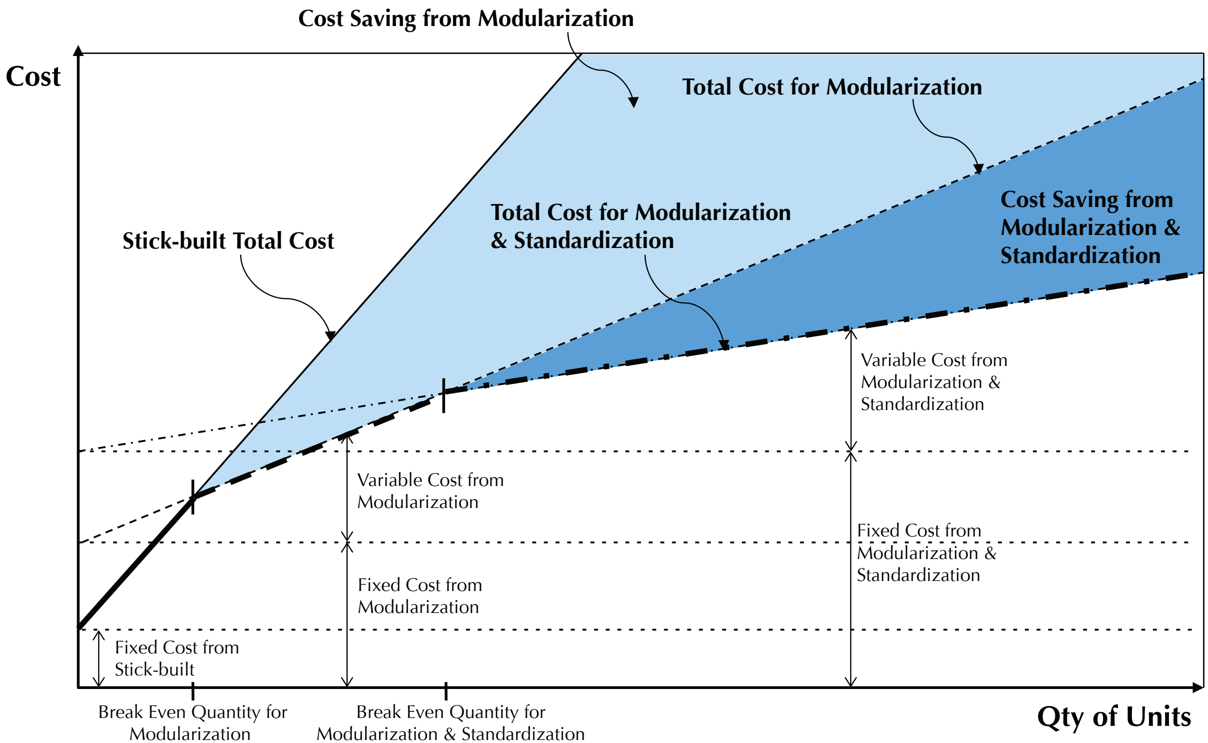

Figure 9. Economic Benefit from Modular Standardized Plant Approach

IR 283-2 presents a process that an owner or manufacturer should follow in order to effectively integrate design standardization with modularization. In brief, it involves the following eight steps:

1. Assess the market and establish objectives and an implementation plan.
2. Create the standard design(s) for the targeted plant type(s).
3. Create the *modular* standard design(s).
4. Repeat Steps 2 and 3, as needed.
5. Firm up agreements with vendor(s)/packager(s) and further involve them in refinements of the modular standard design.
6. Implement execution of the modular standard plant for each client.
7. Assess and benchmark key performance indicators for the effectiveness of the modular standard plant effort.
8. Learn from modular standard plant projects and update/modify the standard design(s) only after thorough analysis and with confident justifications.

The implementation resource also describes an implementation case study in which a major power generation equipment manufacturer/installer applied the eight-step MSP process to establish a new product line of power generation projects. Significant economic benefits resulted from the effort, along with some valuable implementation lessons learned. Thus, companies that seek step-wise advances in capital project performance should examine the opportunities and benefits that accrue from integrating the modular approach with standardized plant designs.

Modularization Maximization Enablers: A Vision for the Industry

The modularization business case, well-prepared execution plans, attention to critical success factors, and use of the standardization strategy should all facilitate higher and more effective use of modularization. However, to truly maximize modularization, leaders must directly confront a variety of industry-wide barriers that can have (and have had) the effect of establishing a ceiling on the levels of modularization achieved. Future levels of modularization will only be fully achievable if industry and project conditions and actions are more compatible with, or supportive of, modular approaches.

Based on its internal discussions and on validation by external modularization authorities, the team identified 10 enablers that will help to buoy or elevate levels of modularization across the industry:

1. Owners, designers, and contractors must expand their modularization "comfort zones," and owners must expand their selection criteria for project service providers. The industry's attitude, understanding, and approach to risk management, when it comes to modularization, need to change.
2. Owners/operators should possess different paradigms of what they need and how to accomplish or deliver projects. These organizations should have sufficient in-house work practices, resources, and expertise to freeze process design, conduct the necessary studies in a timely manner, and effectively exploit modularization opportunities.
3. Early and repetitive collaboration and coordination among project disciplines is the key to success. The optimal planning/design solution requires a multi-disciplinary integrated pro-active approach, involving planning, engineering, procurement, fabrication, construction, commissioning, operations, and project controls disciplines.
4. Engineering schools should establish and promote a new design process paradigm. They should start by teaching the modular approach in addition to the stick-built approach. They should also seek to make the integrated modular approach routine in the design of capital projects.
5. Owners and contractors must capture and exploit data to support modularization optimization studies. This data should address all aspects of modularization cost and schedule savings, along with all other benefits.

6. Modules must be denser (in terms of fabrication work hours per cubic foot) and more complete (in terms of number of systems and functional components incorporated). Of course, safety, operations, and maintenance requirements must be preserved, and related asset loss prevention tactics must be considered. Designers must learn how to accomplish these objectives.
7. The industry needs a different approach to scoping and configuring equipment to make it more modularization-friendly. This can only happen as a result of much more collaboration between manufacturers, owners, process engineers, designers, contractors, and economic analysts.
8. The industry should offer more off-the-shelf modular components, as well as assemblies that possess compatible interfaces. Package units should be compatible as sub-modules within a larger module. Component-to-component physical interface standard protocols should be expanded.
9. Transportation infrastructure must be improved. Better ports, broader roadway and bridge clearances, and other improvements should be considered for capital investment projects. This will likely require collaboration among local parties and may involve some master planning by regional authorities.
10. The industry should develop advanced technologies that facilitate fabrication, transport, and installation/connection. For example, there is a need for stronger, lighter materials, easier connections, and site connection methods that are fully compatible with fabrication tolerances.

These maximization enablers represent a vision for how the industry can achieve step-wise advancement in its application of modularization. Implementation plans are now needed to provide further guidance on how industry organizations can address or respond to these maximization enablers.

4

Conclusions and Recommendations

In order to achieve higher, more successful levels of modularization, industry and project leaders should be attentive to five different elements of the solution:

Business Case: The modularization business case process should be applied at the earliest opportunity, starting as early as Opportunity Framing and proceeding in-depth during subsequent phases. All forms of benefits should be factored into the analysis. For the industry to truly advance, project teams should consider the modular approach the *default* approach, disproven only with thorough justification.

Execution Plan Differences: In contrast to stick-built projects, modular projects require different planning steps; the research team identified over 100 differences in how modular projects should be planned, and organized them by appropriate phase of implementation. Nearly half of these are applicable during the Basic Design phase, and nearly 40 percent of the plan differences pertain to four topics: 1) planning and cost estimating; 2) modularization scoping, layout process, and plot plan; 3) basic design standards, models, and deliverables; and 4) detailed design deliverables.

Critical Success Factors: The team identified 21 high-impact CSFs and found that owner responsibilities for CSF achievement during the Assessment and Selection phases are especially significant. The industry appears to be having difficulty achieving CSFs that pertain to the following:

- owners' planning resources and processes
- timely design freeze
- early completion recognition
- cost savings recognition
- contractor leadership

– investment in studies
– vendor involvement
– owner delay avoidance
– data for optimization
– transport delay avoidance.

Standardization Strategy: The benefits of combining modularization with design standardization can exceed the additive sum; therefore, these benefits deserve special consideration. The research team discerned two basic approaches: standard modules and the modular standardized plant. These two strategies are presented in detail in IR 283-2. The business case for the modular standardized plant should recognize 10 forms of economic advantages and three forms of economic disadvantages or tradeoffs. An eight-step process has been documented for the implementation of the standardization strategy, and a documented case study provides further insight into strategy implementation, benefits, and lessons learned.

Modularization Maximization Enablers: Industry-wide barriers continue to challenge broad-based achievement of high levels of modularization. The team identified 10 maximization enablers and proposes them as counter-measures to these challenges. In some cases, concerted, broad-based industry efforts will be needed for full advancement of modularization.

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